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Disertační práce

Doktorský studijní program: Kineziologie a rehabilitace

Přístrojové dynamické vyšetřovací metody v rehabilitaci

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Souhlasím s trvalým uložením elektronické verze mé práce v databázi systému meziuniverzitního projektu Theses.cz za účelem soustavné kontroly podobnosti kvalifikačních prací.

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Jakub Jačisko

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Abstrakt

Úvod: Předmětem této dizertační práce byly dvě dynamické přístrojové vyšetřovací metody, pohybového aparátu: ultrazvukové vyšetření pohybového systému a dynamická přístrojová objektivizace posturálních funkcí (měření tlaku, který vytváří břišní stěna).

Metody a cíle: Na základě rešerše literatury a konsenzu mezinárodních expertů vytvořit ucelené dynamické vyšetřovací protokoly kloubů, které zatím v literatuře nejsou dostupné. Dalším cílem bylo vytvoření rešeršních článků popisujících nejčastější intervence pod UZ kontrolou a následné vytvoření originálních vzdělávacích materiálů pro začátečníky v muskuloskeletální ultrasonografii. Dalším cílem bylo ověřit, jestli klinické testy posturální stabilizace korelují s objektivně měřeným tlakem, který vytváří břišní stěna. Korelace byla nejprve testována na zdravých probandech, následně na probandech s bolestmi zad. Další část páce si kladla za cíl ověřit, zda existuje korelace mezi tlakem vytvořeným břišní stěnou a nitrobřišním tlakem měřeným anorektální sondou. V poslední části projektu byl porovnáván tlak vytvořený břišní stěnou u pacientů s bolestmi zad před a po šestitýdenní fyzioterapii.

Výsledky: Na základě konsenzu mezinárodních odborníků byly vytvořeny dynamické vyšetřovací protokoly a edukační materiály formou videogalerií. Dále byly publikovány tři rešeršní články zaměřující se na intervenční procedury v oblasti lokte a zápěstí. V další části byla prokázána signifikantní korelace hodnot tlaku, který vytváří břišní stěna a palpačního hodnocení u čtyř z pěti analyzovaných posturálních testů. U zdravých probandů byla zjištěna nejsilnější korelace mezi objektivním hodnocením tlaku tvořeným břišní stěnou a subjektivním hodnocením dvěma examinátory u bráničního testu ($r = 0{,}661$ a $0{,}75$). U probandů s LBP byla prokázána signifikantní středně silná korelace ($r=0{,}479$) u bráničního testu. Signifikantní silná korelace mezi hodnotmi tlaku břišní stěny a anorektální manometrií byla identifikována u všech měřených testů, tj. Klidové dýchání ($r = 0.735$), Valsalvův manévr ($r = 0.836$), Müllerův manévr ($r = 0.651$), instruované dýchání ($r = 0.708$) a dýchání držením břemene ($r = 0.921$).

Souhrn: V rámci této doktorské práce byly publikovány dynamické vyšetřovací protokoly a mnemotechnické pomůcky pro výuku v muskuloskeletální ultrasonografii. Dále byly publikovány rešeršní práce na téma nejčastějších intervencí v oblasti lokte a zápěstí. V rámci výzkumu problematiky objektivizace posturálních funkcí byl vyvinut přístroj DNS Brace, který umožňuje snímat tlak, který vytvoří břišní stěna proti senzorům umístěných na jejím povrchu. V rámci této doktorské práce se podařilo prokázat, že nitrobřišní tlak koreluje s tlakem tvořeným břišní stěnou měřeným pomocí DNS Brace. Dále se podařila prokázat korelace mezi tlakem tvořeným břišní stěnou a klinickým hodnocením posturálních testů u tří posturálních testů u zdravých probandů a u jednoho posturálního testu u probandů s LBP.

Klíčová slova: muskuloskeletální ultrasonografie, objektivizace posturálních funkcí

Abstract

Introduction: The subject of this thesis were two dynamic diagnostic methods of the musculoskeletal system: dynamic ultrasound examination and instrumental objectification of postural functions (measurement of the pressure produced by abdominal).

Methods and objectives: Based on literature review and consensus of international experts, the aim was to create comprehensive dynamic diagnostic protocols for joints that are currently not available in the literature. Another objective was to create research articles describing the most common interventions under ultrasound guidance and also original educational materials for beginners in musculoskeletal ultrasound. Another objective was to verify whether clinical tests of postural stability correlate with objectively measured pressure produced by abdominal wall in healthy subjects and then on subjects with low back pain. Another part of the study aimed to verify if there is a correlation between the pressure produced by abdominal wall and intrabdominal pressure measured by anorectal probe. The last part of the project compared the pressure produced by abdominal cavity in patients with low back pain before and after several weeks of physiotherapy.

Results: Dynamic diagnostic protocols and educational materials in the form of video galleries were created. Additionally, three research articles focusing on intervention procedures in the elbow and wrist area have been published. Further, a significant correlation between abdominal wall pressure values and palpation assessment was demonstrated in four out of five postural tests. In healthy subjects, the diaphragmatic test showed the strongest correlation ($r = 0.661$ and 0.75). In subjects with LBP, a significant moderate correlation ($r = 0.479$) was demonstrated in the diaphragmatic test. Significant strong correlation between abdominal wall pressure values and anorectal manometry was established in all measured tests. Resting breathing ($r = 0.735$), Valsalva maneuver ($r = 0.836$), Müller maneuver ($r = 0.651$), instructed breathing ($r = 0.708$), and breathing while holding a load ($r = 0.921$).

Summary: Within this doctoral thesis, dynamic diagnostic protocols and mnemonics aids for learning musculoskeletal ultrasound have been published. Reviews about the most common interventions in the elbow and wrist were also published. As part of the research on the objectification of postural functions, the DNS Brace device was developed, capable of measuring the pressure created by the abdominal wall against sensors placed on its surface. This thesis successfully demonstrated that intrabdominal pressure correlates with pressure produced by abdominal wall measured using the DNS Brace. Furthermore, correlations were demonstrated between abdominal wall pressure and clinical assessment of postural tests in three postural tests in healthy subjects and one postural test in subjects with LBP.

Keywords: musculoskeletal ultrasound, objectification of postural functions

Seznam zkratek

atd. - a tak dále

AI - artificial inteligence

BMI - body mass index

BPI-PS - Pain severity subscale of Brief Pain Inventory

CD - Color Doppler

cm - centimetr

CT - počítačová tomografie

DNS - Dynamická neuromuskulární stabilizace

EMG - elektromyografie

EURO-MUSCULUS - European Musculoskeletal Ultrasound Study Group

IAP - nitrobřišní tlaka

ICC - interclass correltaion coefficients

ISPRM - International Society of Physical and Rehabilitation Medicine

MDT - Mechanické diagnostiky a terapie

ML - machine learning, strojové učení

MRI - vyšetření magnetickou rezonancí

např. - například např.

NRS - numerická hodnotící škála

ODI - Oswestry disability index

OT - OhmTrak

PD - Power Doppler

RTG - rentgenové vyšetření

SD - směrodatná odchylka

USPRM - Ultrasound Study Group of International Society of Physical and Rehabilitation Medicine

VAS - vizuální analogová škála

OBSAH

1. ÚVOD

1.1. Rehabilitace

Rehabilitace (Rehabilitační a fyzikální medicína, anglicky Physical Medicine and Rehabilitation nebo Physiatry) je lékařský obor, který si klade za cíl zlepšit či obnovit funkční schopnosti a kvalitu života u pacientů s tělesným postižením nebo onemocněním postihujícím pohybový systém (svaly a jejich nervy, šlachy, vazy a kosti).

Na rozdíl od jiných lékařských specializací, smyslem rehabilitačního lékařství není pouze vyléčit nemoc pacienta, ale také maximalizovat pacientovu samostatnost v aktivitách běžného života a zlepšit kvalitu jeho života.

1.2. Vyšetřovací metody v rehabilitaci

Aby byl proces rehabilitace úspěšný, je nejprve třeba správně stanovit diagnózu. Často se jedná o diagnostiku pohybového systému, který svojí funkcí zprostředkovává jednu ze základních činností živých organizmů – pohyb. Z tohoto důvodu je při jakémkoliv vyšetření pohybového systému nutné reflektovat nejenom jeho strukturu (statické vyšetření), ale i vlastní funkci – pohyb (dynamické vyšetření).

Dynamické vyšetřovací metody se dají rozdělit na klinické a přístrojové. Mezi klinická dynamická vyšetření patří zejména ta, která hodnotí vyšetřující subjektivně, např. testy kloubní stability, testy rozsahu pohybu v kloubech, odporové testy a další. Pro potřebu lepší objektivizace, možnosti porovnání a statictického zpracování a archivace se zavádějí taktéž různé škály, hodnotící například trupovou stabilitu souborem testů nebo aktivit (např. Trunk impairment scale, Brunel balance assessment, Berg balance scale) (Cabanas-Valdés et al. 2021). Do skupiny přístrojových vyšetřovacích metod patří například zobrazovací metody, které umožňují vyšetřit pohybový systém v čase (například dynamické rentgenové vyšetření, vyšetření funkční magnetickou rezonancí a vyšetření ultrasonografické). Kromě zobrazovacích metod do této skupiny také patří další diagnostické metody, například elektromyografie (EMG) či rozličné senzory snímající různé fyzikální veličiny (např. tlak, sílu nebo povrchové napětí) v čase, a tím pomáhají k hodnocení funkce pohybového systému (Cabanas-Valdés et al. 2021).

Předmětem této dizertační práce jsou dvě dynamické přístrojové vyšetřovací metody, které napomáhají přesnějšímu stanovení diagnózy a objektivizaci funkce pohybového systému: ultrazvukové vyšetření pohybového systému a dynamická přístrojová objektivizace posturálních funkcí (měření aktivity břišní stěny a expanze břišní dutiny).

1.3. Posturální stabilizace

1.3.1. Postura

Postura je definována jako poloha těla v prostoru. Existuje řada definicí optimální postury. Ideální postura může být např. definována jako jakákoliv poloha těla, která umožňuje udržování rovnováhy s maximální stabilitou, minimální spotřebou energie a minimálním zatížením anatomických struktur (Carini et al. 2017). Udržování postury je řízeno centrálním nervovým systémem, koordinováno vestibulárním, vizuálním a senzitivním systémem a zprostředkováno pohybovým systémem. Postura je ovlivněna neurofyziologickými, biomechanickými a psychoemotivními faktory.

Hlavními anatomicko-funkčními strukturami, které koordinují udržování posturální rovnováhy, je vestibulární, vizuální a senzitivní (proprioceptivní - svalová a šlachová vřeténka nebo receptory umístěné v kloubním pouzdře; a exteroceptitvní – hmatové a tlakové receptory) systém, dále mozeček, mozková kůra a retikulární formace. Postura je udržována kontrakcí svalů.

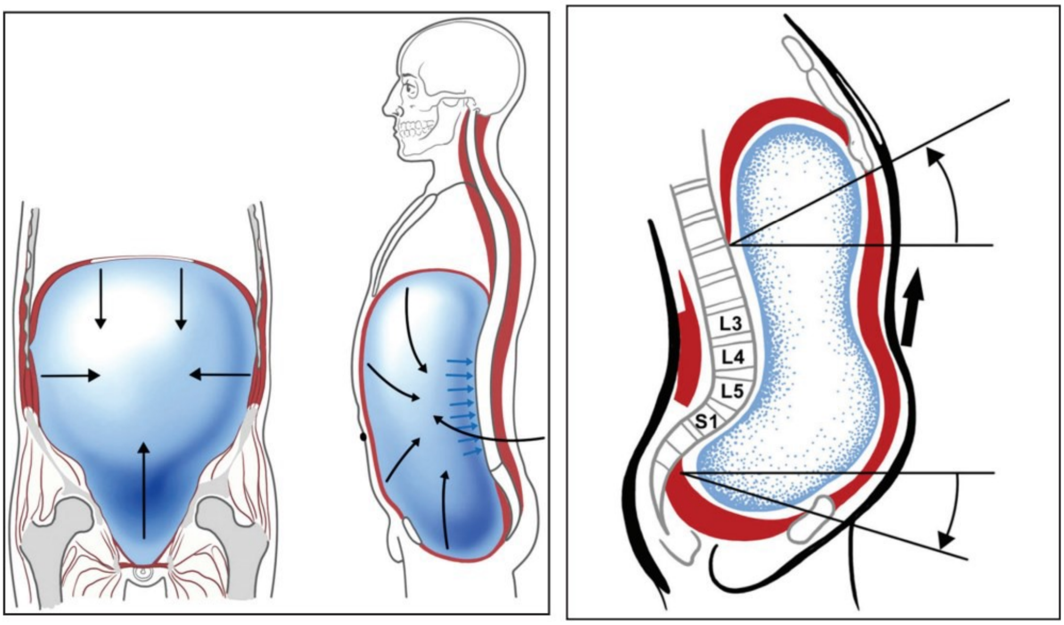
Udržování postury je dynamický, podvědomý proces, který reaguje na změnu působení vnějších sil na tělo člověka. Hlavní vnější síla, která na lidské tělo působí, je síla gravitační. Při změně polohy těla, při níž se mění těžiště (působiště gravitační síly), se musí postura na tuto změnu automaticky adaptovat. (Carini et al. 2017).

1.3.2. Nitrobřišní tlak a jeho význam v posturální stabilizaci

Nitrobřišní tlak (Intra-abdominal pressure, IAP) je hydraulický tlak v břišní dutině. Jeho hodnota je určena svalovou prací bránice, svalů břišní stěny a svalů pánevního dna. Za normálních okolností se velikost IAP u zdravých jedinců pohybuje mezi 0–7 mm Hg (De Keulenaer et al. 2009). IAP se fyziologicky mění během dechového cyklu. Při nádechu se bránice pohybuje kaudálně a tlačí obsah břišní dutiny dolů. Tento pohyb společně s excentrickou kontrakcí svalů břišní stěny mají za následek zvýšení nitrobřišního tlaku. Na rozdíl od klidového výdechu (při němž dochází ke snížení IAP) při usilovném výdechu dochází v souvislosti s koncentrickou kontrakci svalů břišní stěny ke zvýšení IAP (Hodges a Gandevia 2000b). Ke kolísání IAP nedochází pouze v dechovém cyklu, ale také při dalších činnostech, kdy se IAP obvykle zvyšuje, jako např. při kašli, nebo v posturálně náročnějších pozicích jako je stání, skákání, či bicepsový zdvih (Cobb et al. 2005).

Vliv IAP na posturální stabilitu prokázali Hodges et al., kteří ve svých experimentech potvrdili, že zvýšení IAP vede ke zvýšení stability bederní páteře (W Hodges et al. 2005). V publikaci McGilla et al. je vliv nárůstu IAP na stabilitu bederní páteře obhajován eliminací rotace a translačního pohybu mezi obratli (McGill a Norman 1987). Podle biomechanického modelu dle Arshada et al. IAP redukuje kompresivní síly v oblasti páteře a snižuje nutnost zapojení okolního svalstva (Arshad et al. 2016). Také Stokes et al. došli na biomechanickém modelu k závěru, že správná aktivace IAP má schopnost odlehčit bederní páteř (Stokes et al. 2010).

Regulace IAP ovlivňující kvalitu trupové stabilizace má v rehabilitaci významný vliv. Nesprávná souhra posturálního svalstva a nedokonalá stabilizační funkce je považována za jeden z etilogických faktorů u patologií páteře spojených s bolestmi zad jako například spondylartroza, herniace disku nebo spondylolisthéza. (Hodges 1999; Cresswell et al. 1994) Nesprávná trupová stabilizace je spojena s vyšším výskytem bolesti dolních zad, ale také s vyšším rizikem pádů a strachu z pádu u pacientů. To může mít vliv na snížení nezávislosti v aktivitách běžného života a vést ke snížení kvality života (Cabanas-Valdés et al. 2021). Obezřetnost s nadměrným zvyšováním IAP je na místě u pacientů s prolapsem pánevního dna, pacientů po břišních operacích, s kýlou nebo inkontinencí (Da Silva Borin et al. 2013). Cílem terapie by nemělo být absolutní zvýšení hodnot IAP, ale spíše optimalizace jeho regulace a distribuce (Novák J, 2022) viz obrázek 1.



Obrázek 1. Vlevo optimální schéma regulace IAP, vpravo dysfuknční schéma regulace, které vede k chronickému přetěžování bederní páteře. (Frank et al. 2013)

2. DYNAMICKÉ ZOBRAZOVACÍ METODY POHYBOVÉHO SYSTÉMU

Porozumění normální a abnormální funkci pohybového systému je klíčem ke správné diagnostice jeho patologií. Přesné a spolehlivé in vivo vyšetření biomechaniky pohybového systému je nezbytné pro porozumění funkci kloubů a měkkých tkání u asymptomatických jedinců, ale slouží i k detekci patologií pohybového systému (například detekce kloubní instability nebo impingementu měkkých tkání) a v neposlední řadě k určení odpovídající léčby, cíleným intervencím a monitoraci účinku léčby (Borotikar et al. 2017).

2.1. Rentgenové vyšetření

Fluoroskopie je dynamické vyšetření pohybového systému využívající rentgenové záření a poskytující pohyblivý obraz v reálném čase. Nevýhodou tohoto vyšetření je radiační zátěž jak pacienta, tak personálu, který vyšetření provádí. Další nevýhodou je skutečnost, že využití fluoroskopie v hodnocení morfologie a funkce měkkých tkání lze použít pouze limitovaně a nepřímo. V rehabilitační praxi se provádí například flouroskopické vyšetření polykacího aktu (Giraldo-Cadavid et al. 2017), dále se fluoroskopie využívá při navigované aplikaci intraartikulárních injekcí (například křížokyčelního kloubu). Rentgenového záření využívá i počítačová tomografie (CT) např. při periradikulární terapii (PRT). CT jako taková není dynamická vyšetřovací metoda, využívá se ale pro zhodnocení aktuální situace k orientaci a ověřování správného zavedení instrumentace při semiinvazivních metodách terapie (obstřiky) nebo při ortopedických nebo traumatologických operačních výkonech (Schmidt et al. 2018).

K posouzení sagitální stability obratlů se využívají dynamické snímky páteře. Při této metodě se porovnává posun obratlů v předklonu a záklonu a tak je možné objektivizovat nestabilní listézu obratlů (D'Andrea et al. 2005).

2.2. Vyšetření magnetickou rezonancí

V současné době se vyšetření magnetickou rezonancí (MRI) využívá zejména ke statickému vyšetření měkkotkáňových a kostních struktur, nicméně statické zobrazení kloubu neumožňuje komplexní analýzu funkce pohybového systému. To může mít za následek neadekvátnost konzervativní nebo dokonce chybné indikace chirurgické léčby.

Dynamické techniky MRI byly původně využívány pro zhodnocení funkce srdečních chlopní kvantifikací toku krve (Borotikar et al. 2017). V 90. letech minulého století se dynamická MRI začala využívat ke zhodnocení funkčního pohybu v kloubech. Dynamické MRI vyšetření se dnes využívá k hodnocení biomechaniky hlavně kolenního, hlezenního a čelistního kloubu, dále také ramenního, kyčelního a zápěstního kloubu (Borotikar et al. 2017). Rovněž se využívá k analýze mechaniky kosterního svalstva. Výhodou této metody je přesné zobrazení intraartikulárních i periartikulárních měkkotkáňových struktur. Nevýhodou tohoto vyšetření je jeho vysoká cena, limitovaná dostupnost a nedostatečná standardizace vyšetřovacích a diagnostických postupů. Limitací je také postproceduální komplexita zpracování dat, časová náročnost a nemožnost vyšetření pacienta v zátěžových polohách, jako například při běhu, nebo při zdvihání břemen (Borotikar et al. 2017).

2.3. Ultrazvukové vyšetření

Role ultrazvukového vyšetření (UZ) pohybového systému (muskuloskeletálního ultrazvuku) v posledních letech nabývá na významu nejen v klinické, ale také ve vědecké praxi. Ultrazvukové vyšetření umožňuje vyšetření v reálném čase, je levné, neinvazivní, opakovatelné a nevystavuje pacienta ani lékaře ionizujícímu záření. Mezi další výhody patří možnost okamžité stranové komparace a dynamického vyšetření. Struktura a funkce různých anatomických jednotek může být hodnocena při aktivním, pasivním či rezistovaném pohybu. Dalšími možnostmi dynamického ultrazvukového vyšetření je sonopalpace a vyšetření speciálních diagnostických manévrů. Výhodou ultrazvukového vyšetření je také možnost přesné navigace diagnostických a terapeutických intervencí. Do moderních funkcí, které dokážou kvantifikovat krevní tok, patří Power Doppler (PD) a Color Doppler (CD) a nově také nedopplerovské metody. Další recentně diskutovanou metodou je elastografie, která hodnotí elastické vlastnosti měkkých tkání, a dokáže tak kvantifikovat tuhost těchto tkání. Jako poměrně nové rozšíření standardního ultrazvukového vyšetření se nyní v diagnostice testuje umělá inteligence, od které se očekává zpřesnění diagnostiky.

Hlavní nevýhodou ultrazvuku je závislost kvality vyšetření na vyšetřujícím a dlouhá učební křivka vyšetřujícího. Z tohoto důvodu je jedním z cílů této doktorské práce vytvoření vzdělávacích materiálů a vyšetřovacích protokolů, které urychlují učební křivku. Další limitací ultrazvukového vyšetření je skutečnost, že ultrazvukové vlny nedokážou proniknout hutnou vrstvou kosti či strukturami obsahujícími vzduch a nelze tak zobrazit struktury, které jsou v akustickém stínu kostí nebo dutých orgánů (Özçakar et al. 2012).

2.3.1. Dynamické ultrazvukové vyšetření měkkých tkání

Dynamické ultrazvukové vyšetření měkkých tkání umožňuje objektivizaci jejich morfologie jak v klidu, tak při aktivních, pasivních či rezistovaných pohybech. V těchto pohybech lze odhalit strukturální a funkční patologie, například mechanický konflikt (impingement) měkkotkáňových struktur, instabilitu (snapping) šlachy, výhřez (herniaci) menisku nebo natržení (rupturu) svalu (Özçakar et al. 2012). V dynamickém hodnocení šlacho-svalové funkce lze in vivo vyšetřovat například rychlost kontrakce či hodnotit tzv pennation angle (úhel mezi hlubokou aponeurózou svalu a jednotlivými svalovými vlákny), který není konstantní a mění se v průběhu pohybu (Sikdar et al. 2014).

2.3.2. Sonopalpace

Sonopalpace je způsob dynamického ultrazvukového vyšetření, při němž vyšetřující aplikuje tlak sondou proti tělu pacienta. Pokud vyvolá tento tlak bolest, může se jednat o jeden z příznaků potvrzující klinickou relevanci abnormálního nálezu. V některých případech může pacient umožnit přesnou lokalizaci místa patologie tím, že sám umístí ultrazvukovou sondu na bolestivé či jinak subjektivně problematické místo (Özçakar et al. 2018).

2.3.3. Speciální dynamické manévry

Ultrazvukového vyšetření může být použito při specifických klinických testech, například při testu stability loketního nervu v sulcus nervi ulnaris humeri. Bylo prokázáno, že UZ je spolehlivá metoda k hodnocení stability loketního nervu (Rutter et al. 2019). Dalším příkladem objektivizace dynamického manévru může být Mulderův hmat při diagnostice Mortonova neurinomu (Padua et al. 2020), či hodnocení tzv. testu přední zásuvky při ruptuře předního zkříženého vazu kolenního kloubu. Ucelené dynamické vyšetřovací protokoly kloubů nejsou v dostupné literatuře přítomny, proto je jedním z cílů této doktorské práce jejich vytvoření.

2.3.4. Intervence pod ultrazvukovou kontrolou

Ultrazvukové zobrazení může být využito také jako navigační metoda při rozličných intervenčních výkonech, např. na kloubech a periferních nervech, při aspiraci tekutinové kolekce nebo při biopsii. Výhodou UZ kontrolované intervence je kontrola jehly v reálném čase po celou dobu intervence a jistota správného cílení či možnost identifikace anatomických struktur, které nemají být při intervenci poškozeny (tepny, žíly, nervy, duté orgány atd.) (Özçakar et al. 2012).

2.3.5. Color Doppler a Power Doppler

Tyto dvě technologie jsou založeny na principu Dopplerova jevu, založeném na změně frekvence mechanických vln při pohybu zdroje, či přijímače zvukového vlnění. Color Doppler a PD dovolují současné zobrazení ultrazvukového obrazu v B-módu (brightness) a superponovaného dopplerovského signálu, který znázorňuje tok krve a umožňuje tak jeho přesnou anatomickou lokalizaci. Color Doppler umožňuje zobrazení směru a rychlosti toku krve. Power Doppler je senzitivnější při hodnocení pomalých krevních toků a je tedy klinicky používán pro objektivizaci patologické hypervaskularizace. V klinické praxi se metody barevného mapování standardně používají ke zhodnocení některých patologických nálezů, například synovitidy, entezitidy nebo abnormální vaskularizace např. měkkotkáňového tumoru. Power Doppler je senzitivní a spolehlivá metoda pro sledování aktivity onemocnění u pacientů s chronickou artritidou (Iagnocco et al. 2008).

2.3.6. Elastografie

Elastografie je metoda, která dokáže hodnotit viskoelastické vlastnosti vyšetřované tkáně. Umožňuje odhalení subklinicky poškozených svalů a šlach hodnocením jejich mechanických vlastností. Lze ji využít jak v časné diagnostice, tak při monitoraci léčby pohybového systému (Shin et al. 2021). V současné době se využívají zejména metody kompresní elastografie a elastrografie střižných vln. V praxi je elastografie využívána k hodnocení elastických vlastností fascií, periferních nervů, měkkotkáňových expanzivních procesů, svalů, šlach a vazů. Jedná se o metodu relativně novou, která musí být dále podrobena kritické analýze a studována na větším počtu pacientů, aby bylo možno definovat klinickou relevanci vyšetření a jeho skutečný přínos pro klinickou praxi (Snoj et al. 2020).

2.3.7. Umělá inteligence

Umělá inteligence je vědecký obor, který se zabývá vytvořením inteligentních strojů, které jsou schopny interpretovat a učit se z externích dat. Podoborem artificial inteligence (AI) je strojové učení (machine learning; ML), jež se zabývá algoritmy umožňujícími počítačovému systému učit se. Tohoto se využívá například v rozpoznávání obrazů. V současnosti probíhají studie zkoumající možnosti využití AI v hodnocení svalových onemocnění (Duchennova svalová dystrofie), diagnostice kyčelní dysplázie, hodnocení synovitidy nebo stavu chrupavky, či lokalizace periferních nervů. Současné poznatky ve výzkumu AI naznačují, že by se mohla stát diagnostickým pomocníkem při vyšetření svalů, šlach, kloubů, kostí a vazů (Shin et al. 2021).

Kromě výše popsaných existují i další dynamické vyšetřovací metody, které se využívají v evaluaci pohybového aparátu. Jedná se například o 3D Kinematickou analýzu, stabilometrii, polyEMG, Moire, Pedoscan a další. Tyto metody nebyly předmětem této disertační práci, proto zde nebudou popisovány.

3. PŘÍSTROJOVÁ OBJEKTIVIZACE POSTURÁLNÍCH FUNKCÍ

3.1. Objektivizace posturálních funkcí

V klinické praxi i ve vědeckých studiích je potřeba vyšetřit, ohodnotit a zaznamenat informace z klinického vyšetření které hodnotí posturu, což je pojem sám o sobě obtížně definovatelný a tím obtížněj i objektivně hodnotitelný. Za tímto účelem vznikla řada diagnostických testů, metod, archů a škál nebo přístrojových vyšetřovacích metod, které si kladou za cíl hodnotit nebo srovnávat aktuální posturální stabilizaci pacienta nebo efektivitu různých typů tréninku či intervencí na posturu. V klinické praxi se posturální funkce nebo následky její dysfunkce hodnotí nejčastěji klinickými testy, hodnocením bolesti a dotazníkovými metodami, ve výzkumu se pro objektivizaci trupové stabilizace a nitrobřišního tlaku využívají také přístrojové měřící metody.

3.1.1. Klinické testy

Zlatým standardem hodnocení pohybového systému je klinické vyšetření (Elgueta-Cancino et al. 2014). Spočívá v pohmatovém (palpačním) hodnocení tuhosti měkkých tkání, provádění specifických testů, které vyvolávají bolest či jiné nepříjemné pocity, pohmatu pohyblivosti v jednotlivých kloubech, hodnocení svalového tonu a vizuálním hodnocení struktur, základních pohybů a postury lidského těla (Kobesova et al. 2020; Shamsi et al. 2015). Příklady klinických testů hodnotící trupovou stabilizaci, které se využívají v klinické praxi, jsou Trunk impairment scale (TIS), což je soubor testů, který hodnotí hybnost trupu u pacientů po cévní mozkové příhodě a Berg balance scale, což je soubor testů, které mají za cíl určit, zda je pacient schopen udržet statickou a dynamickou rovnováhu (Yoon et al. 2020).

Rozličné rehabilitační koncepty využívají funkční diagnostiku ke zhodnocení pacientovy postury a hybných vzorů jako základ pro následnou terapeutickou intervenci. Koncept Mechanické diagnostiky a terapie (MDT) využívá vlastní formuláře k posturálnímu vyšetření. Tento koncept zaznamenal přijatelnou inter-rater reliabilitu (Garcia et al. 2018). Dalším přístupem je vyšetření dle Jandy, které představuje algoritmy k systematickému vyšetření postury, rovnováhy a chůze, pohybových vzorců a svalové délky (Page et al. 2010). Tento koncept však neposkytuje standardizovaný skórovací systém, který by sloužil k archivaci a sledování změn v jednotlivých doménách. Tato metoda nemá stanovenou inter a intra-rater reliabilitu. Functional Movement Screen hodnotí základní pohybové stereotypy jak kvalitativně, tak kvantitativně pomocí skórovacích archů. Tato metoda má přijatelnou interrater reliabilitu pro klasifikaci pacientů s bolestmi zad do hlavních dvou subkategorií, pokud hodnotící terapeut složil zkoušku v hodnocení dle metodiky Functional Moevment Screen. V případě, že hodnocení provádí terapeut bez příslušné zkoušky v dané metodě, reliabilita není dostatečná (Garcia et al. 2018). Dle výsledného skóre mohou být identifikování rizikoví jedinci a následně určen další tréninkový program k zlepšení jejich výkonu. Dynamická neuromuskulární stabilizace je diagnosticko-terapeutický koncept založený na principech vývojové kineziologie. Kobesová et al. publikovali vyšetřující protokol s hodnotícím archem v jedenácti vývojových polohách, které vysvětlují požadovanou kvalitu posturálně-lokomočního vzorce z perspektivy vývojové kineziologie (Kobesova et al. 2020). Každá metoda sloužící k analýze kvality posturální stability by měla využívat testování ve funkčních pozicích. Pokud je například sval využíván hlavně v uzavřeném kinematickém řetězci, měl by být testován v polohách a pohybech využívajících uzavřený řetězec. Pokud je sval používán hlavně excentricky, měl by být vyšetřován testem, ve kterém je sval tímto způsobem zapojený. Při testování trupové stabilizace je potřeba hodnotit práci více svalů či svalových skupin jako komplexního celku. Toho lze hodnotit evaluací specifických pohybových vzorců a hodnocením kvality pohybu. Tento způsob analýzy je velice těžko kvantifikovatelný, ale více odpovídá funkci trupové stabilizace v trojrozměrném prostoru. Příklady těchto testů jsou stoj či dřep na jedné noze (Kibler et al. 2006).

3.1.2. Hodnocení bolesti

Další součástí vyšetření je hodnocení bolesti, které neanalyzuje přímo vlastní posturální funkce, ale spíše následek nedostatečných posturálních funkcí, což vede k rozvoji bolesti, která je předmětem hodnocení. Do této skupiny patří například vizuální analogová škála (VAS), numerická hodnotící škála (NRS), Pain severity subscale of Brief Pain Inventory (BPI-PS) nebo McGillův dotazník bolesti. Numerická škála, VAS a BPI-PS jsou užitečné metody jak pro vědecké, tak pro klinické potřeby hodnocení bolesti. Tyto metody nepřinášejí skoro žádnou zátěž ani zdravotnickým pracovníkům ani pacientům (Chiarotto et al. 2019), neinformují ale žádým způsobem o kvalitě postury ani o tom, zda je abnromální postura příčinou či následkem bolesti. Lze je tedy považovat za doplňková vyšetření, nikoliv však za způsob hodnocení postury.

3.1.2.1. Vizuální analogová škála

Vizuálně analogová škála (VAS) je samohodnotící škála, která se skládá ze sto milimetrové horizontální úsečky, která je ohraničena při krajních bodech dvěma verbálními deskriptory bolesti (například: žádná bolest a nejhorší bolest, jakou jste kdy zažili). Pacient má na úsečce označit místo, které nejlépe vystihuje jeho bolest (Chiarotto et al. 2019).

3.1.2.2. Numerická hodnotící škála

Numerická hodnotící škála je numerická obdoba VAS, na níž pacient má vybrat jedno číslo (nejčastěji jedenáctibodová škála od 0 do 10), které nejlépe vystihuje pacientovu bolest (Chiarotto et al. 2019). Oproti výše zmíněné škále je její využití s výhodou využíváno při telefonických konzultacích s pacientem.

3.1.2.3. Pain severity subscale of Brief Pain Inventory

BPI-PS se skládá ze čtyř jedenáctibodových NRS. Dvě NRS se dotazují na pacientovu nejintenzivnější a nejméně intenzivní bolest za posledních 24 hodin. Další dvě NRS hodnotí pocit vnímané bolesti v daný okamžik a bolest "právě teď" (Chiarotto et al. 2019).

3.1.3. Dotazníkové hodnotící metody

Třetím typem nepřímého hodnocení postury jsou dotazníkové metody, například Oswestry disability questionaire, které se používají k hodnocení omezení fyzických funkcí pacienta ve vztahu k bolestem v křížové krajině. Podobně jako u předchozí skupiny, u níž se hodnotila bolest, také zde se nejedná o přímé hodnocení posturálních funkcí, ale spíše o měření následku jejich špatné funkce – disability. Tento dotazník je samohodnotící pomůckou, jejíž výsledek je subjektivní procentuální skóre, které ukazuje na schopnost pacienta zvládat aktivity běžného života (Fairbank a Pynsent 2000).

3.1.4. Přístrojové hodnocení

Čtvrtou možností je hodnocení kvality trupové stabilizace pomocí přístrojů, například pomocí povrchové polyelektromyografie, pomocí přístroje Pressure biofeedback unit nebo ultrazvukem, který dokážou hodnotit jak pohyb bránice, tak objektivně měřit tloušťku vyšetřovaných svalů. Z výsledků systematického přehledu vyplývá, že ultrasonografie je efektivnější než samohodnotící škály bolesti v identifikaci statistických rozdílů mezi experimentální a kontrolní skupinou u pacientů s bolestmi dolní části zad (Chang et al. 2015).

3.1.4.1. Evaluace nitrobřisního tlaku

Nitrobřišní tlak je hydraulický tlak v břišní dutině, který ovlivňuje posturální stabilizaci (W Hodges et al. 2005). Metody stanovení nitrobřišního tlaku se v běžné rehabilitační praxi pro jejich invazivitu nepoužívají, využití nacházejí spíše v intenzivní medicíně při diagnostice a monitoraci nitrobřišní hypertenze.

Možnosti měření IAP jsou:

3.1.4.1.1. Transperitoneální měření nitrobřišního tlaku

Tato přímá metoda měření IAP spočívá v laparoskopickém zavedení tlakového čidla přímo do břišní dutiny. Jedná se o nejpřesnější metodu, ale zároveň o nejinvazivnější. V praxi se využívá pro zhodnocení nitrobřišní hypertenze v intenzivní medicíně (Correa-Martín et al. 2013).

3.1.4.1.2. Intrakavální měření nitrobřišního tlaku

Další přímá metoda spočívající v zavedení tlakového katetru do dolní duté žíly. Tato metoda umožňuje kontinuální monitoraci IAP, jejími nevýhodami jsou riziko infekce, krvácení a trombózy. Pro invazivitu této metody se využívá pouze v intenzivní medicíně (Malbrain et al. 2013).

3.1.4.1.3. Intravezikální měření nitrobřišního tlaku

Tato metoda spočívá v zavedení čidla do močového měchýře, na který je převáděn IAP. Tato metoda je nepřímá a je zlatým standardem při monitorování nitrobřišního kompartment syndromu a pro diagnostiku nitrobřišní hypertenze (Malbrain et al. 2013). Pro možné komplikace jako je zavlečení infekce či poranění močové trubice se ale v rehabilitační praxi také nepoužívá.

3.1.4.1.4. Intravaginální měření nitrobřišního tlaku

Při této metodě je tlakové čidlo zavedeno do pochvy. Při využití bezdrátových senzorů mohou být touto metodou měřeny každodenní aktivity. Nevýhodou této metody je možnost využití pouze u žen (Shaw et al. 2014).

3.1.4.1.5. Intrarektální měření nitrobřišního tlaku

Dalším možností nepřímé registrace IAP je zavedením tlakové sondy do konečníku. Kontraindikace k tomuto vyšetření jsou krvácení z dolní části trávicího ústrojí a průjem. Nevýhodou této metody je to, že pro pacienty není příjemná (Malbrain 2006).

3.1.4.1.6. Intragastrické měření nitrobřišního tlaku

Poslední formou nepřímé detekce IAP je intragastrické měření. Sonda je zaveden buďto nazo/orogastrickou sondou nebo cestou gastrostomie do žaludku. Tento způsob měření se v běžné praxi nepoužívá z několika důvodů: pacienti shledávají tento způsob měření jako velice nepříjemný, je dražší v porovnání s intravezikálním měřením a je ovlivněn žaludečními stahy, které se objevují každých 90 minut a trvají asi 2 minuty (Sugrue et al. 1994).

3.1.4.2. Evaluace aktivity trupového svalstva

Hodnocení aktivity svalů lze provádět buď přímo měřením jejich aktivity pomocí EMG nebo změnou jejich tloušťky pomocí UZ, nebo nepřímo pomocí registrace změny fyzikálních veličin (povrchového napětí, síly nebo tlaku) na povrchu břišní stěny.

3.1.4.2.1. Elektromyografie

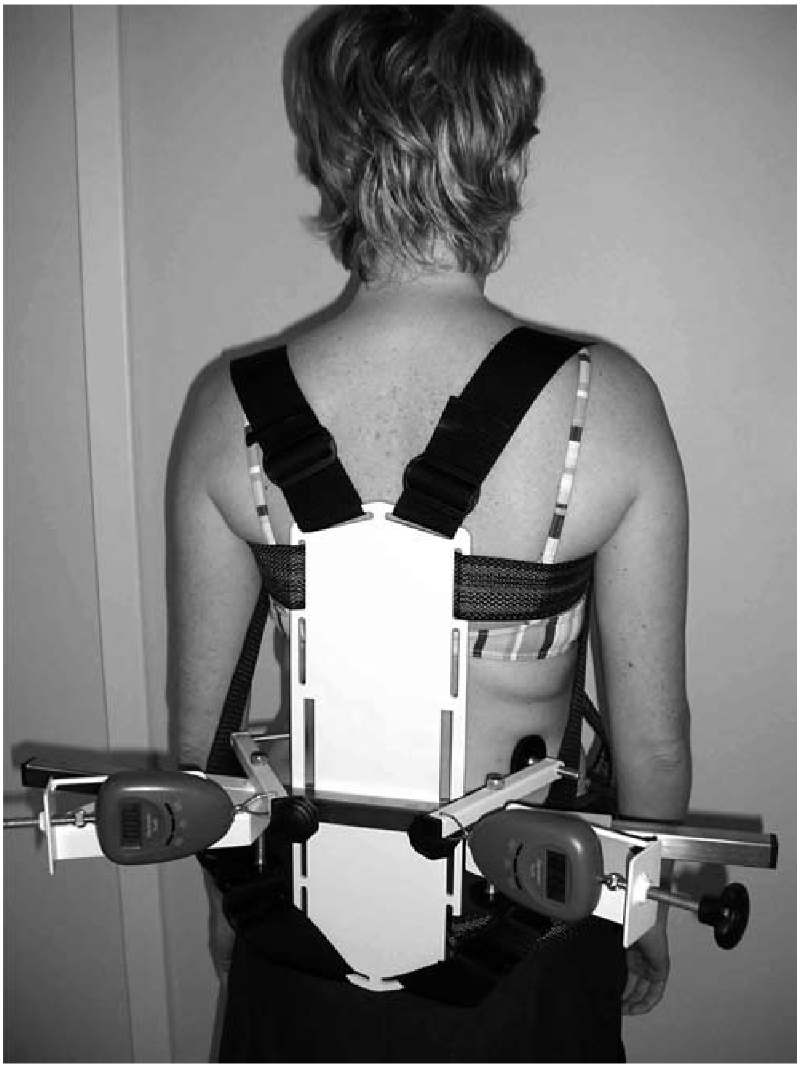
Elektromyografie (EMG) je metoda, která se používá k hodnocení aktivity svalů. Lze využít buď povrchovou EMG (neinvazivní) nebo jehlovou EMG (invazivní). Nevýhodou této metody je, že hodnotí aktivitu svalů pouze lokálně a nezohledňuje celkovou koordinaci trupových svalů. Využití EMG za účelem hodnocení aktivity trupových svalů je spíše využíváno ve vědecké než v klinické praxi (De Luca et al. 2006).

3.1.4.2.2. Ultrasonografie

Ultrasonograficky je možné hodnotit svalovou aktivitu měřením tloušťky svalu. Tato metoda je levná, neinvazivní, ale její spolehlivost závisí na zkušenostech vyšetřujícího. Ultrasonografické zobrazení využívající M-módu se využívá k měření pohybu bránice při dýchání. Vyšetření B-módem se využívá k měření šířky musculus transversus abdominis, musculus obliqus internus abdominis a musculus obliquus externus abdominis (Yoon et al. 2020). Nevýhodou ultrasonografického hodnocení aktivity břišních svalů je skutečnost, že hodnocení svalové aktivity je podobně jako u EMG spíše lokální a že je obtížné vyšetření provádět v běžných denních činnostech. Provádí se nejčastěji v polohách, v nichž pacient leží na vyšetřovacím lehátku, popř. v jiných nenáročných posturálních situacích (Hodges et al. 2003).

3.1.4.2.3. Dynamometrie

Dynamometrie představuje další neinvazivní metodu, která měří sílu břišní stěny vytvořenou trupovými svaly. Senzory jsou k břišní stěně probanda připevněny nastavitelnými popruhy. Měření lze provést jak během statické, tak během dynamické aktivity. Výhodou této metody je to, že hodnotí aktivitu trupového svalstva jako celku, ne pouze jednotlivých svalů (Malátová et al. 2007). Nevýhodou této metody je omezená dostupnost přístroje, který není sériově vyráběný, a pro svoji robustnost obtížněji využitelný v klinické praxi viz obrázek 2.



Obrázek 2. Dynamometr (Malátová et al. 2007) a jeho upevnění na trup.

3.1.4.2.4. Tenzometrie

Tenzometrie je další neinvazivní metodou měření aktivace trupových svalů. Měří povrchové napětí břišní stěny, které se mění při změně nitrobřišního tlaku (van Ramshorst et al. 2011).

3.1.4.2.5. Pressure biofeedback unit

Pressure biofeedback unit je přístroj, který obsahuje tlakový snímač a dokáže měřit změnu tlaku. Nevýhodou této metody je to, že dokáže registrovat tlak pouze v určitých pozicích (vleže na břiše nebo na zádech), nedá se tedy využít při testování běžných denních činností či ve svislé pozici, například ve stoji a při chůzi, při níž je zatížení páteře jiné než vleže (Cha et al. 2017).

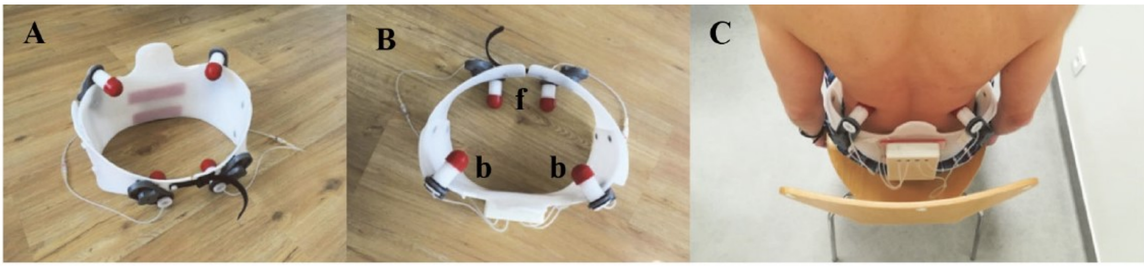
3.1.4.2.6. OhmTrak sensor (obrázek 3)

OhmTrak sensor je pomůcka skládající se z jednoho nebo dvou kapacitních senzorů měřících tlak. Senzory jsou připevněny na břišní stěnu pomocí pásků a mohou registrovat sílu při dýchání i v posturálně náročnějších pozicích (Novak et al. 2022).

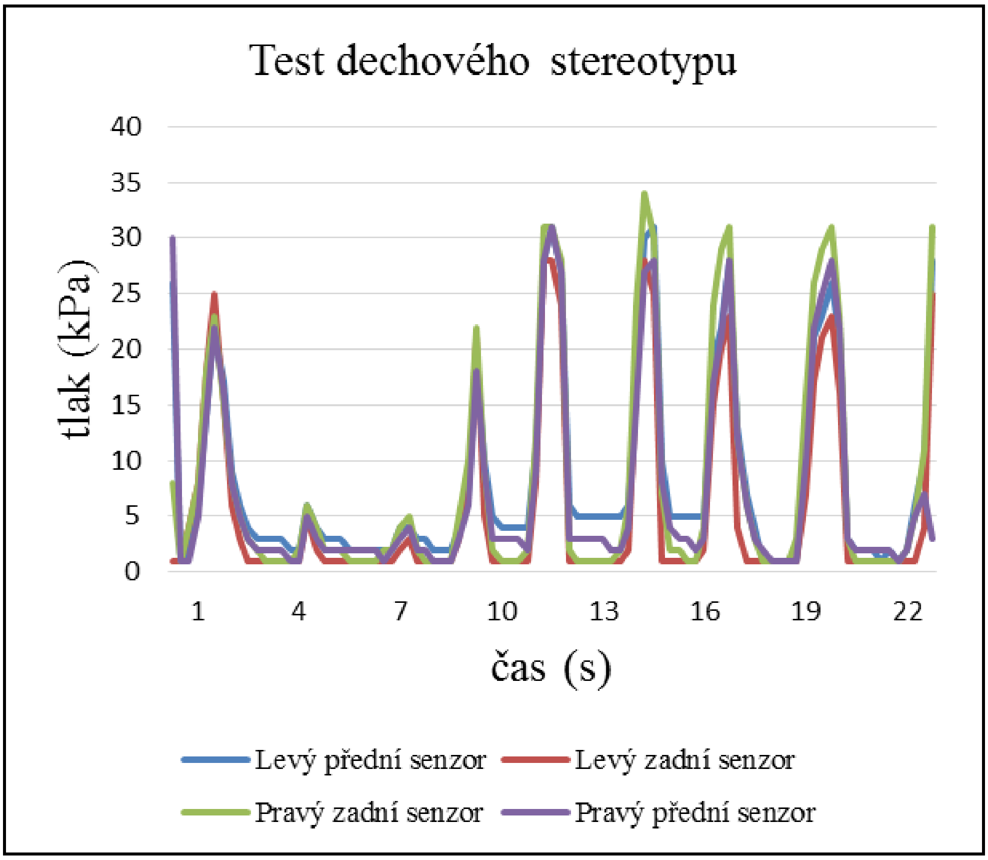
Obrázek 3. OhmTrak (dříve nazývaný OhmBelt) senuzor (vlevo) a jeho umístění na trupu (vpravo) (Tyburcová M, 2022)

3.1.4.2.7. DNS Brace

DNS Brace je trupová ortéza se čtyřmi tlakovými senzory, které pracují na mechanicko-pneumaticko-elektronickém principu viz obrázek 4. Senzory jsou umístěny oboustranně nad tříselným vazem a oboustranně v trigonum lumbale inferius. Senzory se skládají ze vzduchové komory, která registruje změnu v tlaku při deformaci senzoru, který je způsobený vnějším tlakem břišní stěny. Komora je spojena silikonovou hadičkou s digitálním tlakovým senzorem. Digitální tlakový senzor měří změnu tlaku v kilopaskalech a přenáší ji přes Bluetooth do mobilního telefonu nebo počítače (Jacisko et al. 2021). Z daných hodnot lze následně v progrmu Excel vytvořit graf tlaku, který vytváří břišní stěna v čase viz obrázek 5.



Obrázek 4. DNS Brace: A. Pohled na ortézu zepředu; B. Pohled na ortézu zezhora, f - dva přední senzory, b - dva zadní senzory; C. Umístění ortézy na pacienta. (Jacisko et al. 2021)



Obrázek 5. výsledný graf testu dechového stereotypu v programu Excel z naměřených hodnot pomocí DNS Brace. (Stříbrný M, 2020)

4. EXPERIMENTÁLNÍ ČÁST

V rámci výzkumné práci je prezentováno 12 článků publikovaných v recenzovaných vědeckých časopisech (viz přílohy 1 - 12). Dále jsou zde prezentovány výsledky, které byly publikovány jako obsah diplomových prací, které vedl či oponoval autor této disertační práce. V následujících kapitolách jsou stručně uvedeny cíle, hypotézy, metodika, výsledky a diskuse souhrnně pro všechny články, které jsou podkladem této disertační práce. Detailní popis metodiky, výsledků a podrobná diskuze k jednotlivým konkrétním studiím jsou uvedeny v přílohách disertační práce formou kopií publikovaných prací. U studií, které byly publikovány jako obsah diplomových prací je popis metodiky a výsledků rozsáhlejší, protože diplomové práce nejsou součástí příloh této disertační práce.

4.1 Úvod

Na základě literární rešerše se disertační práce zaměřuje na následující výzkumné cíle.

4.1.1. Dynamické vyšetření pohybového systému pomocí ultrasonografie

Vzhledem k tomu, že při rešerši této doktorské práce nebyly nalezeny jednotné vyšetřovací postupy k ultrazvukovému dynamickému vyšetření kloubů lidského těla, bylo cílem této práce vytvořit ucelené dynamické vyšetřovací protokoly kloubů jak horní, tak dolní končetiny, které zatím v literatuře nejsou dostupné. Dalším cílem bylo vytvoření rešeršních článků popisujících nejčastější intervence pod UZ kontrolou a následné vytvoření originálních vzdělávacích materiálů pro začátečníky v muskuloskeletální ultrasonografii s cílem zkrátit výukovou křivku, a umožnit tak rozšíření muskuloskeletální ultrasonografie do rutinní praxe rehabilitačních pracovníků.

4.1.2. Objektivizace posturálních funkcí

V současné literatuře není zmínka o korelaci klinického hodnocení testů posturální stability s objektivně měřenou trupovou stabilizací. Hlavním cílem experimentální části této doktorské práce bylo ověřit, jestli klinické testy posturální stabilizace korelují s objektivně měřeným tlakem, kterým břišní stěna působí na tlakové senzory. Korelace byla nejprve testována na zdravých probandech. V tomto kroku bylo hodnoceno pět klinických testů. Dalším cílem práce bylo stanovení inter-rater reliability klinického hodnocení jednotlivých testů. Testy s nejsilnější korelací byly následně použity ke korelaci mezi klinickým hodnocením aktivace břišní stěny zkušenými terapeuty a objektivním přístrojovým vyšetřením schopnosti vytvořit tlak břišní stěnou proti tlakovým senzorům u pacientů s bolestí dolní části zad (low back pain). U těchto pacientů byl dále testován vztah mezi schopností vytvoření tlaku břišní stěnou a Oswestry disability index (ODI) skóre. V následující části projektu byla porovnávána schopnost břišní stěny vytvořit tlak u pacientů s LBP před a po šestitýdenní fyzioterapii. Další část výzkumného projektu si kladla za cíl ověřit, zda existuje korelace mezi tlakem tvořeným břišní stěnou a nitrobřišním tlakem měřeným anorektální sondou.

4.2. Cíle a hypotézy

4.2.1. Dynamické vyšetření pohybového systému pomocí ultrasonografie

1. Dynamické vyšetřovací protokoly (podrobněji viz příloha 7,8 a 11).

Cílem bylo podílet se na revizi a tvorbě dynamických vyšetřovacích protokolů velkých kloubů formou článků charakteru videogalerie ve spolupráci s odborníky mezinárodní pracovní skupiny „EURO-MUSCULUS: European Musculoskeletal Ultrasound Study Group a USPRM: Ultrasound Study Group of ISPRM (International Society of Physical and Rehabilitation Medicine)“.

2. Intervence pod ultrazvukovou kontrolou (podrobněji viz příloha 3 a 5).

Cílem bylo vypracovat literární review týkající se častých intervencích v muskuloskeletální ultrasonografii. Konkrétně se jedná o intervence v oblasti lokte (tenisový loket, golfový loket, distální šlacha musculus biceps brachii, patologie ulnárního nervu atd.) a zápěstí (morbus de Quervin, lupavý prst, syndrom karpálního tunelu, atd.).

3. Edukační materiály pro začátečníky pracující s muskuloskeletálním ultrazvukem (podrobněji viz příloha 9 a 10).

Cílem bylo vypracovat edukační materiály formou článku charakteru videogalerie skládající se z originálních audiovizuálních materiálů pro začátečníky v muskuloskelátlní ultrasonografii. Jednou z nevýhod ultrazvukového vyšetření je poměrně dlouhá učební křivka. Na tento nedostatek se zaměřuje cíl této práce ve snaze urychlit učební křivku.

4. Cílem bylo formou kazuistiky či dopisu redakci publikovat edukativní případy, kde UZ představoval zásadní roli při diagnostickém procesu a následné terapeutické rozvaze. Dále

upozornit na nepřesnosti v publikované literatuře formou dopisu editorovi (podrobněji viz příloha 1 a 4).

4.2.2. Objektivizace posturálních funkcí

1. Korelace klinického hodnocení testů posturální stabilizace s objektivně monitorovaným tlakem, který vytváří břišní stěna u zdravých probandů (podrobněji viz příloha 2).

Hypotéza: klinické hodnocení testů posturální stabilizace koreluje s tlakem, který vytváří břišní stěna u zdravých probandů. Tato práce si také klade za cíl zhodnotit inter-rater reliabilitu při hodnocení klinických posturálních testů.

2. Korelace IAP s tlakem břišní stěny (podrobněji viz příloha 6).

Tato studie si kladla za cíl ověřit, zda existuje vztah mezi nitrobřišním tlakem měřeným anorektální sondou a objektivně měřeným tlakem, který vytváří břišní stěna.

Hypotéza: nitrobřišní tlak měřený anorektální sondou koreluje s tlakem, který vytváří břišní stěna.

3. Korelace klinického hodnocení testů posturální stabilizace s tlakem, který vytváří břišní stěna u pacientů s LBP.

Cílem této práce bylo navázat na studii 4.2.2.1 a ověřit korelaci u pacientů s LBP. Dalším cílem bylo zjistit, zda subjektivní symptomy pociťované pacientem (hodnoceny pomocí dotazníku) korelují se schopností expanze břišní stěny hodnocené pomocí DNS Brace a funkčních posturálních testů.

Hypotéza 1: klinické hodnocení testů posturální stabilizace koreluje s tlakem, který produkuje břišní stěna u pacientů s LBP (podrobněji viz Krausová E, 2023).

Hypotéza 2: bude zjištěna korelace mezi schopností expanze břišní stěny a mírnou obtíží pacientů hodnocených pomocí dotazníků. Čím výraznější má pacient obtíže, tím menší má schopnost expandovat břišní stěnu.

4. Změna schopnosti expanze břišní stěny před a po terapii

Následující projekt si kladl za cíl porovnat schopnost expanze břišní stěny u pacientů s LBP před a po šestitýdenní fyzioterapii. Polovina probandů cvičila v domácí autoterapii s biofeedback přístrojem OhmTrak (OT), druhá polovina bez této pomůcky. Cílem bylo zjistit, zda probandi cvičící s OT dosáhnou signifikantně vyšších hodnot expanze břišní stěny měřenou pomocí přístroje DNS Brace při testu bráničního dýchání.

Hypotéza: schopnost expanze břišní stěny bude signifikantně vyšší u skupiny pacientů, kteří v autoterapii cvičí s biofeedback přístrojem OT. ODI skore se po terapii sníží (podrobněji viz Tyburcová M, 2022).

5. Posledním cílem bylo formou rešeršní práce zmapovat možné způsoby objektivizace posturálních funkcí a trupové stabilizace.

Společným cílem všech prací bylo popsat diagnosticko-terapeutické využití dynamických vyšetřovacích metod u pacientů s patologiemi pohybového aparátu (Podrobněji viz příloha 12).

4.3. Metodika

4.3.1. Dynamické vyšetření pohybového systému pomocí ultrasonografie

1. Byla provedena revize a aktualizace stávajících vyšetřovacích protokolů velkých kloubů se zaměřením na relevantní problematiku patologií vyskytujících se v ordinacích lékaře rehabilitační a fyzikální medicíny. Protokoly vznikaly jako konsenzus mezinárodních expertů z pracovní skupiny EURO-MUSCULUS: European Musculoskeletal Ultrasound Study Group a USPRM: Ultrasound Study Group of ISPRM (International Society of Physical and Rehabilitation Medicine) (podrobněji viz příloha 7,8 a 11).

2. V rámci rešeršní části práce došlo k revizi dostupné literatury, revize anatomických poměrů a diskusi existujících možností a evidence jednotlivých intervenčních zákroků. (Podrobněji viz příloha 3 a 5).

3. Byla provedena rešerše literatury a na základě konsenzu odborníků sestavena videogalerie mnemotechnických pomůcek (podrobněji viz příloha 9 a 10).

4. Formou kazuistického sdělení byl demonstrován přínos UZ vyšetření v klinické prxi. Formou dopisu redakci upozornit na přítomnost nepřesností v literatuře (podrobněji viz příloha 1 a 4).

4.3.2. Objektivizace posturálních funkcí

1. Celkem pět posturálních testů bylo hodnoceno subjektivně dvěma zkušenými terapeuty, tyto hodnoty byly korelovány s objektivně měřeným tlakem, který dutina břišní dokáže vytvořit proti tlakovým senzorům umístěným na trupové ortéze DNS Brace. Celkem bylo hodnoceno 25 zdravých probandů. Interrater reliabilita byla vypočítána za užití interclass correltaion coefficients (ICC). Pro hodnocení korelace byl použit Spearmanův koeficient (podrobněji viz příloha 2).

2. V této observační studii bylo hodnoceno 31 symptomatických probandů. Probandi podstoupili simultánní hodnocení nitrobřišního tlaku pomocí anorektální manometrie a měření tlaku břišní stěny pomocí DNS Brace. Probandi byli hodnocení v pěti odlišných pozicích - klidové dýchání, Valsalvův manévr, Müllerův manévr, instruované dýchání, dýchání při držení břemene (podrobněji viz příloha 6).

3. Celkem 37 probandů podstoupilo měření aktivace břišní stěny pomocí přístroje DNS Brace a subjektivní hodnocení testů posturální stabilizace fyzioterapeutem. Jeden proband musel být ze souboru vyřazen pro příliš malý obvod pasu, pro který nešel změřit tlak břišní stěny pomocí DNS Brace. Výsledný soubor zahrnoval 14 mužů a 22 žen ve věkovém rozmezí 23-75 let (průměr 41,2 let, SD±16,9), další demografické údaje: výška 173 cm (SD±8,2), váha 73,7 kg (SD±12,7) a BMI 24,4 (SD±3,2). Klinické hodnocení prováděl certifikovaný terapeut Dynamické neuromuskulární stabilizace (DNS), který vyšetřoval 3 testy posturální stabilizace dle DNS protokolu (Kobesova et al. 2020) v tomto pořadí: brániční dýchání, brániční test a test flexe v kyčelním kloubu. Do hodnocení byla zahrnuta jak kvalita, tak kvantita provedení daného testu. Výsledky každého testu byly zaznamenány do vizuálně-analogové škály na úsečce o délce 10 cm, kdy 0 označovala žádnou aktivaci a 10 zcela optimální aktivaci. Polovina probandů byla nejprve vyšetřena přístrojem DNS Brace a následně fyzioterapeutem, u druhé poloviny probandů tomu bylo naopak. Provedení jednotlivých testů bylo stejné jako ve studii 1. (podrobněji viz Krausová E, 2023).

4. Jednalo se o prospektivní klinickou studii, do které bylo zařazeno 20 pacientů s chronic low back pain. Probandi (n=20) podstoupili šestitýdenní ambulantní rehabilitaci 1x týdně pod vedením fyzioterapeuta. Probandi byli náhodně rozděleni do 2 skupin. Deset pacientů

zařazených do experimentální skupiny absolvovalo šestitýdenní ambulantní rehabilitaaci 1x týdně pod vedením fyzioterapeuta a byli edukováni k autoterapii s přístrojem OT, kterou prováděli alespoň 5x týdně 15 minut. Kontrolní skupina prováděla autoterapii bez přístroje OT. Probandi byli změřeni před začátkem a na konci terapie. Schopnost expanze břišní stěny byla hodnocena pomocí přístroje DNS Brace, dále byla provedena autoevaluace subjektivních obtíží pomocí dotazníku Oswestry Disability Index (ODI) (podrobněji viz Tyburcová M, 2022).

5. V rámci rešeršní práce došlo k revizi dostupné literatury, diskusi existujících možností a evidence jednotlivých metod objektivizace trupové stabilizace (podrobněji viz příloha 12).

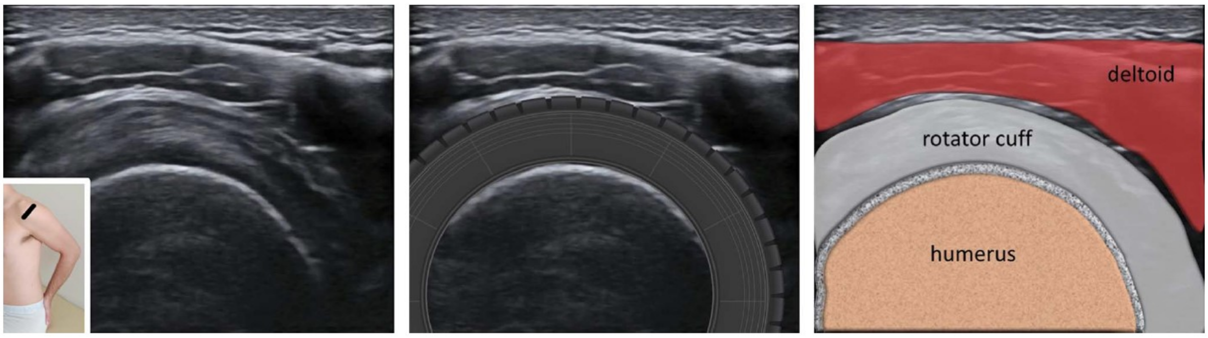
4.4. Výsledky

4.4.1. Dynamické vyšetření pohybového systému pomocí ultrasonografie

1. Byly vytvořeny vyšetřovací protokoly, spolu s doprovodnou videogalerií vyšetřovacích postupů pro lepší porozumění vyšetřovacím technikám a možným patologiím. Videogalerie je volně dostupná z webového rozhraní časopisu (https://journals.lww.com/ajpmr/Fulltext/2022/09000/EURO_MUSCULUS_USPRM_Dynamic_Ultrasound_Protocols.12.aspx) American Journal of Physical Medicine and Rehabilitation (Mezian et al. 2022b; 2022a; Pirri et al. 2023) (podrobněji viz příloha 7,8 a 11).

2. Byly publikovány dva rešeršní články zaměřující se na intervenční procedury v oblasti lokte a zápěstí (Mezian et al. 2021b; 2021a) (podrobněji viz příloha 3 a 5).

3. Byly publikovány dva články, první se zaměřuje na mnemotechnické pomůcky při vyšetřování fyziologických funkcí pohybovéo systému. Druhý se zaměřuje na diagnostiku patologických stavů. Tyto videogalerie mnemotechnických pomůcek viz obrázek 6 potencují zapamatování struktur na podkladě multisenzorického vstupu do paměti (vizuální, audio, emoční paměť a priming) (Jačisko et al. 2022; 2023) (Podrobněji viz příloha 9 a 10).



Obrázek 6. Příklad mnemotechnické pomůcky - rotátorvá manžeta připodobněna k pneumatice (Jačisko et al. 2022)

4. Byl publikován článek formou kazuistiky komentující důležitost UZ vyšetření při syndromu kubitálního kanálu. Déle byl publikován článek upozorňující na možnou záměnu předního zkříženého vazu za ligamentum mucosum formou dopisu redakci (Jačisko et al. 2020; Jačiško et al. 2021) (podrobněji viz říloha 1 a 4).

4.4.2. Objektivizace posturálních funkcí

1. Korelace hodnot tlaku břišní stěny a palpačního hodnocení obou DNS instruktorů byla u čtyř z pěti posturálních testů identifikována jako statisticky významná (p < 0,24). Pearsonovy korelační koeficienty značí silnou korelaci u bráničního testu u obou DNS instruktorů (r = 0,661 a 0,75) a testu nitrobřišního tlaku u DNS instruktora č. 2 (r = 0,672). Střední korelace se u palpace vyskytovala ve všech ostatních posturálních testech (r = 0,415 až 0,567). Nejlepší reliabilita mezi DNS instruktory byla zaznamenán u testu nitrobřišního tlaku (Jacisko et al. 2021, Stříbrný 2020) (kompletní výsledky viz příloha 2).

2. Silná korelace mezi expanzí břišní stěny měřené pomocí DNS Brace a nitrobřišním tlakem měřeným pomocí anorektální manometrie byla zjištěna u všech hodnocených testů. Klidové dýchání (r = 0.735, r2 = 0.541, p < 0.001), Valsalvův manévr (r = 0.836, r2 = 0.699, p < 0.001), Müllerův manévr (r = 0.651, r2 = 0.423, p < 0.001), instruované dýchání (r = 0.708, r2 = 0.501, p < 0.001) a dýchání držením břemene (r = 0.921, r2 = 0.848, p < 0.001) (Novak et al. 2021) (kompletní výsledky viz příloha 6).

3. Byla prokázána signifikantní středně silná až silná korelace (r=0,479) mezi klinickým hodnocením a hodnotami DNS Brace u bráničního testu. Naopak u testu dechového stereotypu a testu flexe v kyčelním kloubu se hodnoty r blíží k nule (r=0,027, r=0,091) - korelace je tedy velmi slabá až nulová, navíc není ani statisticky významná. Nebyla prokázána signifikantní korelace mezi hodnotami ODI a DNS Brace, ani mezi hodnocením DNS instruktora a ODI v žádném ze tří testů (Krausová E, 2023). Kompletní výsledky v tabulce číslo 1.

Correlation Matrix

		test 1	test 2	test 3	VAS 1	VAS 2	VAS 3
test 1	Spearman's rho	—					
	p-value	—					
test 2	Spearman's rho	0.233	—				
	p-value	0.171	—				
test 3	Spearman's rho	0.278	0.176	—			
	p-value	0.101	0.306	—			
VAS 1	Spearman's rho	0.027	0.279	0.144	—		
	p-value	0.876	0.100	0.404	—		
VAS 2	Spearman's rho	0.071	0.479 **	0.174	0.752 ***	—	
	p-value	0.679	0.003	0.309	< .001	—	
VAS 3	Spearman's rho	0.045	0.353 *	0.091	0.624 ***	0.808 ***	—
	p-value	0.795	0.035	0.598	< .001	< .001	—

Poznámka. * p < .05, ** p < .01, *** p < .001

Tabulka 1. Korelace mezi měřením DNS Brace a DNS instruktora (The jamovi project (2022), R Core Team (2021)) (Krausová E, 2023) test 1: test dechového stereotypu, test 2: brániční test, test 3: test flexe v kyčelním kloubu. VAS 1: hodnocení terapeutem test dechového stereotypu, VAS 2: hodnocení terapeutem brániční test, VAS 3 hodnocení terapeutem testu flexe v kyčelním kloubu

4. Ačkoliv došlo ke zlepšení expanze břišní stěny u obou skupin probandů s LBP, tato změna nebyla identifikována jako statisticky signifikantní. Taktéž nebylo zaznamenáno signifikantní zlepšení u experimentální skupiny v porovnání se skupinou kontrolní. U skupiny experimentální došlo ke statisticky významnému snížení bolesti hodnocené pomocí ODI, u skupiny kontrolní bylo zlepšení na hranici statistické významnosti (Tyburcová M, 2022). Kompletní výsledky v tabulce 2.

Tabulka 4. *Výsledky ANOVA pro porovnání v rámci skupin, [Průměrná hodnota (Směrodatná odchylka)] zprůměrovaných hodnot ze senzorů*

	Před 1. terapií *M* (*SD*)	**Po 6 týdnech autoterapie** *M* (*SD*)	**Rozdíl průměrů**	*95 % CI*	*P*-**hodnota**
Všechny senzory					
Kontrolní	22,75 (10,97)	30,38 (14,69)	-7,63	(-20,62; 5,35)	,233
Experimentální	16,75 (11,20)	23,35 (14,64)	-6,60	(-19,58; 6,38)	,300
Přední senzory					
Kontrolní	17,17 (10,80)	19,18 (9,50)	-2,01	(-9,00; 4,98)	,553
Experimentální	11,10 (7,30)	10,81 (4,65)	,285	(-6,71; 7,28)	,933
Zadní senzory					
Kontrolní	28,33 (18,63)	41,59 (29,15)	-13,26	(-34,63; 8,12)	,209
Experimentální	22,39 (16,22)	35,88 (29,31)	-13,48	(-7,90; 34,86)	,202

Poznámky: Celkový počet probandů *N* = 20, kontrolní skupina *n* = 10, skupina s OhmTrakem *n* = 10, M průměrná hodnota, SD směrodatná odchylka

Tabulka 2. Hodnoty DNS Brace před a po terapií. (Tyburcová M, 2022)

5. Byl publikován rešeršní článek monitorující možné a v současné době využívané způsoby monitorace nitrobřišního tlaku (Novak et al. 2022).

4.5. Diskuze

Ultrazvukové vyšetření pohybového aparátu se v posledních letech stává nedílnou součástí klinické i vědecké praxe rehabilitačního lékaře. Muskuloskeletální ultrazvuk dokáže hodnotit širokou škálu patologií pohybového aparátu jako například zánětlivá onemocnění, degenerativní onemocnění a sportovní poranění měkkých tkání (Kara et al. 2020). Ultrazvukové vyšetření má mnoho výhod: je neinvazivní, neztěžuje pacienta radiací, nemá kontraindikace - vyšetřovaný pacient může mít v těle kovový materiál nebo kardiostimulátor, může být využit k vyšetření dítěte i těhotné ženy, zařízení pro UZ vyšetření je přenosné, umožňuje stranovou komparaci, možnost sonopalpace/sonotinelu (komprese sondou nad postiženým nervem), i detekci vaskularizace, vyšetření není časově náročné (Özçakar et al. 2015). Bylo prokázáno, že ultrazvukové vyšetření v rehabilitačním lékařství snižuje čekací dobu pacientů na zobrazovací metody, snižuje radiační zátěž a šetří náklady (Özçakar et al. 2010). Ultrazvukové vyšetření také zlepšuje palpační schopnosti zdravotníků (Woods et al. 2018) a je jedním z důležitých motivátorů, proč si studenti medicíny v USA vybírají obor rehabilitace (Raja et al. 2022). Ultrazvuk také poskytuje navigaci pro cílené intervence. V rehabilitačním lékařství se tato navigace využívá například k aplikaci botulotoxinu v léčbě spasticity a nebo k intervencím do kloubu, nebo měkotkáňových struktur (Kaymak et al. 2018). Tato disertační práce umožnila vytvoření přehledových článků týkajících se intervencí v oblasti zápěstí, lokte a ulnárního nervu, které nabízí čtenáři orientaci v problematice ultrazvukem cílených obstřiků a intervencí. Ve výčtu výhod je také třeba uvést, že ultrazvuk umožňuje dynamické vyšetření, tedy hodnotí nejen strukturální stav, ale také aktuální funkci vyšetřované struktury, což je v rehabilitačním lékařství velice důležité (Özçakar et al. 2015). Ačkoliv se dynamické vyšetření ultrazvukem v praxi běžně používá a existují i publikace o jeho využití při diagnostice takových stavů, jako jsou lupavé kyčle, svalová kýla, či patologie perineálních šlach atd. (Caldwell et al. 2023) doposud nebyly popsány jednotné vyšetřovací protokoly pro jednotlivé klouby (Ricci et al. 2022). Protokoly byly vytvořeny v rámci této disertační práce (viz přílohy 7, 8 a 11). Unikátní vlastností publikovaných těchto protokolů je to, že pro lepší názornost nabízejí online videozáznamy vyšetřovacích a intervenčních technik. Tyto materiály jsou volně dostupné na webových stránkách odborného časopisu (https://journals.lww.com/ajpmr/pages/default.aspx).

Ultrazvukové vyšetření má také své nevýhody a těmi jsou hlavně limitované zobrazení kostí a struktur ležící v kostním stínu. Dále jde o závislost na vyšetřujícím a dlouhá učební křivka. Tyto dva limity se snaží redukovat dva publikované originální články (viz příloha 9 a 10) prezentujících mnemotechnické pomůcky usnadňující rychlejší získání znalostí a dovedností při diagnostickém využívání muskuloskeletálním ultrazvuku. Mnemotechnické pomůcky zlepšují zapamatování a porozumnění problematice, což zefektivňuje studijní proces (Singhal a Rogers 2002; Dhawan a Gupta 2012). Tato unikátní audio-vizuální výuková videogalerie je volně dostupná na webových stránkách odborného časopisu (https://journals.lww.com/ajpmr/pages/default.aspx).

Kromě statického a dynamického vyšetření, které poskytuje B-mode se v rehabilitačním lékařství dá využít také M-mode, který dokáže hodnotit pohyb anatomických struktur. Šembera et al využili M-mode ultrazvukové vyšetření bránice k hodnocení její posturálně-respirační funkce. V této studii autoři verifikovali, že posturální funkce bránice je nezávislá na její dechové funkci (Sembera et al. 2022). Bránice jakožto hlavní dýchací sval zajišťuje ventilaci a kromě toho plní také funkci dolního jícnového svěrače, a hraje klíčovou roli ve stabilizaci páteře (Hodges a Gandevia 2000a). Jelikož lze obsah dutiny břišní víceméně považovat za nestlačitelný, dojde při kontrakci bránice ke zvýšení IAP a rozepnutí anterolaterální části břišní stěny (Mead a Loring 1982). Šembera et al dokázali, že při zvýšeném posturálním zatížení dochází k vyšší exkurzi bránice kaudálně a zároveň ke zvýšení tlaku břišní stěny měřeným pomocí DNS Brace (Sembera et al. 2022). Tyto výsledky jsou v souladu s našim měřením, ve kterém jsme prokázali, že zvýšení IAP vede ke zvýšení tlaku, kterým působí břišní stěna oproti senzorům umístěným v ortéze DNS Brace. Jinými slovy, míra IAP koreluje s expanzí břišní stěny. Naše měření jsou teké v souladu s prací Ramshorsta, který provedl studii na kadaverech kdy insufloval břišní dutinu vzduchem a měřil tenzi břišní stěny, výsledkem této studie bylo zjištění statisticky významné korelace mezi mírou nitrobřišního tlaku a tenzí břišní stěny (van Ramshorst et al. 2011).

Ačkoliv existuje mnoho možností přímého i nepřímého měření IAP, v klinické praxi se tyto postupy nevyužívají pro svoji invazivitu, časovou a odbornou náročnost atd. (Novak et al. 2021). Nevýhodou intravezikálního měření IAP je, že přesnost měření pomocí sondy zavedené do močového měchýře je nejvyšší v supinační poloze. Při posturálně náročnějších polohách přesnost tohoto způsobu měření klesá (Al-Abassi et al. 2018). Měření IAP vaginální sondou je na poloze nezávislé, protože sonda je bezdrátová, a lze tak měřit i v posturálně složitějších pozicích. Tento způsob měření však nelze využít pro muže a podobně jako vyšetření anorektální sondou se jedná o vyšetření, které působí pacientům dyskomfort. (Shaw et al. 2014). Co se týče přístrojového měření aktivace svalů břišní stěny, jsou v literatuře popsány měření pomocí

Pressure Biofeedback unit (Lima et al. 2011), tenzometrů (van Ramshorst et al. 2011), dynamometru (Malátová et al. 2013), elektromyografie (Marshall a Murphy 2010), nebo pomocí ultrazvuku (Amerijckx et al. 2020). Tyto metody však hodnotí aktivitu břišních svalů pouze lokálně, na rozdíl od v této studii využívané originální ortézy DNS Brace, která pomocí 4 senzorů (dva na přední straně, dva na zadní trupu) hodnotí expanzi trupu komplexněji (Novak et al. 2021). V klinické praxi se nejvíce využívá palpace břišní stěny s předpokladem, že tlak břišní stěny se zvyšuje při zvýšení IAP (van Ramshorst et al. 2011). Palpace je prováděna nad tříselnými vazy a v trigonum lumbale (Kobesova et al. 2020). V těchto místech leží mezi dutinou břišní a senzory pouze ploché trupové svaly a měření expanze trupu je snadno realizovatelné (Grevious et al. 2006). Chabá schopnost aktivace břišní stěny v těchto oblastech je velmi často asociovaná s LBP (Frank et al. 2013).

Ve studii, která je součástí této disertační práce (viz příloha 2) se podařilo prokázat korelaci mezi subjektivním klinickým hodnocením testů posturální stabilizace a objektivně měřenou expanzí břišní stěny u zdravých probandů (Jacisko et al. 2021). Subjektivní hodnocení prováděli zkušení terapeuti s více než pětiletou klinickou praxí, protože přesnost vyšetření palpací je závislá hlavně na zkušenostech vyšetřujícího (Malátová et al. 2007). Naše měření jsou ve shodě s Malátovou et al., která taktéž popisuje minimální statistický rozdíl, mezi hodnotami naměřené dynamometrem MD01 a palpací (Malátová et al. 2007). V průběhu měření v naší studii prováděl proband všechny testované aktivity třikrát s variací pořadí stanovišť. Stejný postup popsali autoři při objektivizaci aktivity posturálních svalů během pronačního testu, kterou měřili pomocí Pressure Biofeedback Unit a palpací. Smyslem variace stanovišť byla minimalizace vlivu pořadí jednotlivých měření (Von Garnier et al. 2009). Mezi jednotlivými měřeními probandi nesměli zkoušet testované pozice (Von Garnier et al. 2009). Probandi před studií nebyli obeznámeni s průběhem testování, instruktáž obdrželi až při samotném testování. Toto je v rozporu s postupem ve studii Cha et al, ve které před vlastním testováním kvalitu trupové stabilizace probandi trénovali v rámci deseti instruktážních lekcí, ve kterých nacvičovali následně vyšetřované pozice (Cha et al. 2017). Tato studie porovnávala reliabilitu dvou posturálních testů a zjistila, že DNS heel sliding test je spolehlivý test pro hodnocení trupové stability. Posturální testy dle konceptu DNS (Kobesova et al. 2020) hodnotí trupovou stabilizaci ve vývojových pozicích, kde je aktivace trupové stabilizace zajištěna podvědomě. To je velký rozdíl oproti hodnocení testů v jiných studiích, které hodnotí aktivaci posturálních svalů pouze při volně kontrolované aktivaci, jako například při "Prone test" nebo "Bilateral straight leg lowering test" (Cha et al. 2017). Volní hybnost je řízena z kortikálních center na rozdíl od posturální aktivity, která je řízena ze subkortikálních center (Kolář 2009; Kim et al. 2018). Testy, které hodnotí volní aktivaci, tedy nemusí odrážet aktivitu posturálního svalstva při jeho nevědomé aktivaci při běžných denních činnostech.

V další studii se podařilo prokázat korelaci mezi subjektivním klinickým hodnocením testů posturální stabilizace a objektivně měřenou expanzí břišní stěny u pacientů s LBP u testu bráničního dýchání. LBP je jednou z nejčastějších lidských obtíží a její etiologie je značně variabilní. Příčina vzniku LBP je často multifaktoriální. Na pacienta by se mělo nahlížet pomocí biopsychosociálního modelu a terapie by měla být vedena multioborovým týmem (Vlaeyen et al. 2018). Na hodnocení pacientů s LBP lze nahlížet z mnoha úhlů pohledu: zobrazovací metody objektivizují strukturální patologie, klinické hodnocení vyšetřujícím subjektivně hodnotí kvalitu trupové stabilizace, DNS Brace dokáže změřit expanzi břišní stěny, vizuálně-analogová škála kvantifikuje bolest a dotazníky hodnotí disabilitu pacienta. V současné době se diskutuje vztah mezi klinickým stavem pacienta a nálezem na zobrazovacích metodách. Chou et al prokazuje cestou systematického přehledu signifikantní asociaci mezi degenerativními změnami páteře a LBP (Chou et al. 2011). Jiná studie však popisuje pouze malou korelaci mezi nálezem na MRI a subjektivním stavem pacienta (Gunnar Svanbergsson et al. 2017). Jednou z příčin LBP může být i nedokonalá postura. Dle In et al existuje korelace mezi patologickou křivkou hrudní kyfózy, bederní lordozy, Oswestry disbility indexem a VAS (In et al. 2021). Mimo to však příčina vzniku LBP může být psychická, může být dána způsobem života, kouřením a mnoha dalšími faktory. (Bento et al. 2020). Fakt, že na vznik LBP má vliv řada faktorů může být příčinou toho, proč v naší práci (Krausová E, 2023) nebyla zjištěna korelace mezi hodnotami DNS Bracea hodnotami ODI skóre, a to v žádném z vyšetřovaných testů. Funkčí testy posturální stabilizace hodnotí schopnost posturální stabilizace jak kvalitativně tak kvantitativně (Kobesova et al. 2020). Trupová ortéza DNS Brace hodnotí pouze kvantitu expanze břišní stěny. Toto může být důvodem, proč byla nalezena korelace pouze u bráničního testu, kde je expanze břišní stěny a tedy i její tlak proti senzorům (kvantitativní složka) nejvíce vyjádřený.

V poslední studii (Tyburcová M, 2022) nebyla prokázána signifikantní změna ve schopnosti expandovat břišní stěnu proti tlakovým senzorům před a po šestitýdenní terapii u pacientů s LBP. Zlepšení stabilizace trupu se využívá v terapii pacientů s LBP ke snížení bolesti, snížení funkčního postižení a zlepšení kvality života (Ghavipanje et al. 2022; Salik Sengul et al. 2021). Z biomechanických studií je znám kladný vliv IAP na spinální dekompresi. Stokes et al ve své práci uvádí, že když se zvětší IAP z 5 na 10 kPa, dojde ke snížení zatížení páteře v průměru o 25 % (Stokes et al. 2010). Liu et al uvádí, že při absenci adekvátního IAP dochází k výrznému zatížení meziobratlového disku a malému zapojení ligament páteře. Po aktivaci IAP naopak pozorujeme odlehčení ploténky (Liu et al. 2019). Další studie uvádí, že stabilizační trupová cvičení jsou účinnější v reducki bolesti než odpočinek či minimální aktivita (Paungmali et al. 2017). V klinické praxi existuje velké množství rehabilitačních postupů, které se zaměřují na terapii LBP. Metaanalýza z roku 2022 porovnávala efekt Pilates cvičení, posilování, cvičení zaměřená na "core aktivaci", protahování, metody McKenzie a aerobiku. Z výsledků vyplývá, že všechny druhy terapie měly kladný vliv na disabilitu a intenzitu bolesti, krome McKenzie (zjištěn byl signifikantní efekt pouze na disabilitu) a protahování (mělo signifikantní vliv pouze na bolest). Nejlepší výsledky dosáhlo cvičení Pilates (Fernández-Rodríguez et al. 2022). Některé studie poukazují na zlepšení v dotazníku ODI po stabilizačním cvičení (Coulombe et al. 2017; Frizziero et al. 2021) což potvrzuje i naše studie. Jelikož test nitrobřišního tlaku vycházel z předchozích studií (viz příloha 2) jako nejlépe měřitelný pomocí DNS Brace byl tento test použit i ve studii, která hodnotila vliv stabiizačního cvičení podle metody DNS na obtíže pacientů s LBP (Tyburcová N, 2022). Polovina pacientů absolvovala fyzioterapii s autoterapií, druhá polovina absolvovala stejnou fyzioterapii s autoterpií, při které ale používali pacienti biofeedback v podobě pásu se senzorem (pomůcku Ohmtrack = OT), který napomáhal pacientům v cílené aktivaci břišní stěny během cvičení. Biofeedback může zvyšovat neuroplasticitu zapojením pomocných senzorických vstupů a tím zvýšit efektivitu cvičení. Předpokládali jsme, že změna schopnopsti expanze břišní stěny při bráničním testu bude signifikantně vyšší u probandů cvičících s biofeedback pomůckou OT. Ačkoliv se schopnost expanze břišní stěny zvětšila u obou skupin (v porovnání před a po terapii) nebyl nalezen signifikantní rozdíl mezi jednotlivými skupinami a toto zvýšení nebylo signifikantní ani v rámci jednotlivých skupin při porovnání aktivace před terapií a po 6 týdenní teapii. Důvodem může být to, že účinek biofeedbacku má dřívější nástup než 6 týdnů a probandi, kteří využívali OT, mohli výsledků dosáhnout rychleji, než probadni kteří cvičili bez OT. Ale v období ž týdnů se už schopnost aktivovat břišní stěnu mezi skupinami vyrovnala. Jinými slovy naučili se to už cvičením i probandi bez pomůcky. Dalším důvodem může být malý počet probandů zařazených do studie. V dalších studiích by proto bylo dobré změřit probandy častěji než pouze před a po terapii a hodnotit více probandů a ve více, posturálně různě náročných situacích.

4.5.1. Limity práce

Vzhledem k různé obtížnosti hodnocení jednotlivých anatomických struktur a oblastí nelze jednoznačně definovat minimální dobu potřebnou pro získání potřebných zkušeností při ultrazvukovém vyšetření (Garcia-Santibanez et al. 2018).

Limitem vyšetření DNS Brace jednoznačně představuje nemožnost vyšetření příliš subtilních nebo naopak příliš obézních pacientů. Z našich zkušeností vyplývá, že nynější model DNS Brace lze adaptovat pouze na jedince, kteří mají obvod pasu v rozmezí od 65 do 120 centrimetrů.

Dalším limitem je nízký počet probandů v jednolitých studiích, který může mít za následek to, že výsledky nejsou statisticky významné.

Detaily k metodikám, výsledkům a podrobné diskuze jsou uvedeny v přílohách ve formě kopií publikovaných prací.

4.6. Závěr

Tato práce se zaměřila na dynamické vyšetřovací metody v rehabilitaci. Ultrasonografie pohybového aparátu se čím dál tím více stává běžnou součástí práce rehabilitačního lékaře. Ačkoliv má ultrazvukové vyšetření četné výhody, stále se objevuje kritika, že je to modalita závislá na vyšetřujícím a má dlouhou učební křivku. Proto byly v rámci této doktorské práce publikovány dynamické vyšetřovací protokoly a navrženy mnemotechnické pomůcky pro výuku v muskuloskeletální ultrasonografii. Dále byly publikovány rešeršní práce na téma nejčastějších intervencí v oblasti lokte a zápěstí. V klinické praxi, zejména u pacientů s LBP je velice důležité hodnocení trupové stabilizace. Jednou z měřitelných proměnných je nitrobřišní tlak, který úzce souvisí s kvalitou posturální stabilizace. V běžné klinické praxi je však nitrobřišní tlak obtížně vyšetřovatelný pro invazivitu měření. V rámci výzkumu této problematiky byl vyvinut přístroj DNS Brace, který umožnuje snímat tlak, kterým působí břišní stěna proti senzorům umístěných na trupové ortéze. V rámci této doktorské práce se podařilo prokázat, že nitrobřišní tlak koreluje s tlakem břišní stěny měřeným pomocí DNS Brace. Dále se podařila prokázat korelace mezi tlakem břišní stěny a klinickým hodnocením posturálních testů u tří posturálních testů u zdravých probandů a u jednoho posturálního testu u probandů s LBP.

5. SOUHRN

5.1. Dynamické vyšetření pohybového systému pomocí ultrasonografie

5.1.1. Dynamické vyšetřovací protokoly

1. Mezian K, Ricci V, Güvener O, **Jačisko J**, Novotný T, Kara M, Ata AM, Wu WT, Chang KV, Stecco C, Pirri C, Leblebicioğlu G, Özçakar L. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Wrist and Hand. Am J Phys Med Rehabil. 2022 Apr 20. doi: 10.1097/PHM.0000000000002005. Epub ahead of print. PMID: 35440527. **IF_{2021}=3,412**

V tomto vyšetřovacím protokolu byly popsány různé dynamické manévry a postupy k vyšetření zápěstí a ruky. Jednotlivé vyšetřovací postupy byly zdokumentovány na videozáznamu, který slouží jako návod k vyšetření a ukázka možných patologií zároveň. Tento vyšetřovací protokol vznikl jako mezinárodní konsenzus odborníků a klade si za cíl ulehčit a sjednotit vyšetřovací postupy v praxi rehabilitačního lékaře.

2. Mezian K, Ricci V, Güvener O, **Jačisko J**, Novotný T, Kara M, Chang KV, Naňka O, Pirri C, Stecco C, Dughbaj M, Jain NB, Özçakar L. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for (Adult) Hip. Am J Phys Med Rehabil. 2022 Jun 9. doi: 10.1097/PHM.0000000000002061. Epub ahead of print. PMID: 35687784. **IF_{2021}=3,412**

V tomto vyšetřovacím protokolu byly popsány různé dynamické manévry a postupy k vyšetření kyčelního kloubu. Jednotlivé vyšetřovací postupy byly zdokumentovány na videozáznamu, který slouží jako návod k vyšetření a ukázka možných patologií zároveň. Tento vyšetřovací protokol vznikl jako mezinárodní konsenzus odborníků a klade si za cíl ulehčit a sjednotit vyšetřovací postupy v praxi rehbilitačního lékaře.

3. Pirri, Carmelo; Stecco, Carla; Güvener, Orhan; Mezian, Kamal; Ricci, Vincenzo; **Jačisko, Jakub**; Novotný, Tomáš; Kara, Murat; Chang, Ke-Vin; Dughbaj, Muhammad; Jain, Nitin B.; Özçakar, Levent. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Knee. American Journal of Physical Medicine & Rehabilitation ():10.1097/PHM.0000000000002173, December 22, 2022. | DOI: 10.1097/PHM.0000000000002173 **IF_{2021}=3,412**

V tomto vyšetřovacím protokolu byly popsány různé dynamické manévry a postupy k vyšetření kolenního kloubu. Jednotlivé vyšetřovací postupy byly zdokumentovány na videozáznamu, který slouží jako návod k vyšetření a ukázka možných patologií zároveň. Tento vyšetřovací protokol vznikl jako mezinárodní konsenzus odborníků a klade si za cíl ulehčit a sjednotit vyšetřovací postupy v praxi rehbilitačního lékaře.

5.1.2. Intervence pod ultrazvukovou kontrolou

1. Mezian K, **Jačisko J**, Kaiser R, Machač S, Steyerová P, Sobotová K, Angerová Y, Naňka O. Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment. Front Neurol. 2021 May 14;12:661441. doi: 10.3389/fneur.2021.661441. PMID: 34054704; PMCID: PMC8160369. **IF_{2021}=4,086**

V tomto review byla diskutována diagnostika, etiologie a možnosti terapie neuropatie ulnárního nervu v oblasti lokte.

2. Mezian K, Ricci V, **Jačisko J**, Sobotová K, Angerová Y, Naňka O, Özçakar L. Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies. Am J Phys Med Rehabil. 2021 Jun 1;100(6):599-609. doi: 10.1097/PHM.0000000000001683. PMID: 33443851. **IF_{2021}=3,412**

V tomto review byly diskutovány nejčastější typy ultrazvukem navigovaných intervencí při terapii patologií v oblasti zápěstí a ruky.

5.1.3. Edukační materiály pro začátečníky s muskuloskeletálním ultrazvukem

1. **Jačisko J**, Mezian K, Güvener O, Ricci V, Kobesová A, Özçakar L. Mnemonics and Metaphorical Videos for Teaching/Learning Musculoskeletal Sonoanatomy. Am J Phys Med Rehabil. 2022 Aug 9. doi: 10.1097/PHM.0000000000002084. Epub ahead of print. PMID: 35944076. **IF_{2021}=3,412**

V tomto článku byly prezentovány mnemotechnické pomůcky pro zapamatování fyziologických nálezů při vyšetření pohybového aparátu pomocí ultrazvuku.

2. **Jačisko J**, Ricci V, Mezian K, Güvener O, Chang KV, Kara M, Kobesová A, Özçakar L. Mnemonics and Metaphorical Videos for Detecting/Diagnosing Musculoskeletal Sonopathologies. Am J Phys Med Rehabil. 2022 Oct 11. doi: 10.1097/PHM.0000000000002119. Epub ahead of print. PMID: 36228196. **IF_{2021}=3,412**

V tomto článku byly prezentovány mnemotechnické pomůcky pro zapamatování patologických nálezů při vyšetření pohybového aparátu pomocí ultrazvuku.

5.1.4. Kazuistika a dopis redakci

1. **Jačisko J**, Sobotová K, Mezian K. The utility of ultrasound examination in cubital tunnel syndrome caused by heterotopic ossification. Med Ultrason. 2020 Mar 1;22(1):117-118. doi: 10.11152/mu-2419. PMID: 32096802. **IF_{2020}=1,611**

Toto kazuistické sdělení prezentovalo pacienta s ulnární neuropatií v oblasti lokte způsobenou heterotopickou osifikací, a zdůrazňuje důležitost ultrazvukového vyšetření a cílení terapie.

2. **Jačisko J**, Mezian K, Naňka O. Sonography of the anterior cruciate ligament revisited. J Clin Ultrasound. 2021 Mar;49(3):248-249. doi: 10.1002/jcu.22978. Epub 2021 Feb 1. PMID: 33527383. **IF_{2021}=0,869**

Tento "letter to the editor" upozornil na možnost záměny předního zkříženého vazu a ligamentum mucosum při ultrazvukovém vyšetření.

5.2. Objektivizace posturálních funkcí

5.2.1. Korelace klinického hodnocení testů posturální stabilizace s tlakem břišní stěny u zdravých probandů

Jacisko J, Stribrny M, Novak J, Busch A, Cerny P, Kobesova A. Correlation Between Palpatory Assessment and Pressure Sensors in Response to Postural Trunk Tests. Isokinetics and Exercise Science 1 Jan. 2021 DOI: 10.3233/IES-205238 **IF_{2021}=0,729**

Na podkladě zjištěné inter-rater reliability a korelace objektivního a subjektivního měření lze předpokládat, že testy nitrobřišního tlaku, brániční test a test flexe v kyčelním kloubu, mohou být užitečné při hodnocení kvality posturální stabilizace asymptomatických jedinců. Ke zhodnocení splehlivosti testů při vyšetření symptomatických pacientů je potřeba další výzkum.

5.2.2 Korelace nitrobřišního tlaku s tlakem břišní stěny

Novak J, **Jacisko J**, Busch A, Cerny P, Stribrny M, Kovari M, Podskalska P, Kolar P, Kobesova A. Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests. Clin Biomech 2021 Aug;88:105426. doi: 10.1016/j.clinbiomech.2021.105426. Epub 2021 Jul 14. **IF$_{2021}$=2,034**

Nitrobřišní tlak silně koreloval s expanzí břišní stěny nad inguinálním ligmentem a nad trigonum lumbale. Tato originální studie prezentovala novou možnost nepřímého hodnocení nitrobřišního tlaku, resp, posturální stabilizace v běžné klinické paxi.

5.2.3 Přehledová práce možných způsobů objektivizace posturálních funkcí/trupové stabilizace

NOVAK, Jakub, **JACISKO, Jakub**, STVERAKOVA, Tereza, JUEHRING, David D., SEMBERA, Martin, KOLAR, Pavel and KOBESOVA, Alena, 2022. The signifikance of intra-abdominal pressure on postural stabilization: a low back pain case report. Slovak Journal of Sport Science. 17 January 2022. Vol. 7, no. 2, pp. 3–18. DOI 10.24040/sjss.2021.7.2.3-18.

Tato práce revidovala existující literaturu na téma objektivizace posturálních funkcí a také představuje kazuistiku pacaienta s LBP.

6. SUMMARY

6.1. Dynamic ultrasound examination of the musculoskeletal system

6.1.1. Dynamic examination protocols

1. Mezian K, Ricci V, Güvener O, **Jačisko J**, Novotný T, Kara M, Ata AM, Wu WT, Chang KV, Stecco C, Pirri C, Leblebicioğlu G, Özçakar L. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Wrist and Hand. Am J Phys Med Rehabil. 2022 Apr 20. doi: 10.1097/PHM.0000000000002005. Epub ahead of print. PMID: 35440527. $\mathbf{IF_{2021}=3,412}$

In this examination protocol there were described various dynamic maneuvers and approach to wrist examination. Individual examinations are documented in videos that were part of the article. These videos serves as guide for examination and presentation of some exemplary pathologies. This examination protocols is based on consensus of international authors and aimed to facilitate the role of musculoskeletal ultrasound in clinical praxis of physical medicine and rehabilitation.

2. Mezian K, Ricci V, Güvener O, **Jačisko J**, Novotný T, Kara M, Chang KV, Naňka O, Pirri C, Stecco C, Dughbaj M, Jain NB, Özçakar L. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for (Adult) Hip. Am J Phys Med Rehabil. 2022 Jun 9. doi: 10.1097/PHM.0000000000002061. Epub ahead of print. PMID: 35687784. $\mathbf{IF_{2021}=3,412}$

In this examination protocol there were described various dynamic maneuvers and approach to adult hip examination. Individual examinations are documented in videos that were part of the article. These videos serves as guide for examination and presentation of some exemplary pathologies. This examination protocols is based on consensus of international authors and aimed to facilitate the role of musculoskeletal ultrasound in clinical praxis of physical medicine and rehabilitation.

3. Pirri, Carmelo; Stecco, Carla; Güvener, Orhan; Mezian, Kamal; Ricci, Vincenzo; **Jačisko, Jakub**; Novotný, Tomáš; Kara, Murat; Chang, Ke-Vin; Dughbaj, Muhammad; Jain, Nitin B.; Özçakar, Levent. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Knee. American Journal of Physical Medicine & Rehabilitation ():10.1097/PHM.0000000000002173, December 22, 2022. | DOI: 10.1097/PHM.0000000000002173 $\mathbf{IF_{2021}=3,412}$

In this examination protocol there were described various dynamic maneuvers and approach to knee examination. Individual examinations were documented in videos that are part of the article. These videos serveed as guide for examination and presentation of some exemplary pathologies. This examination protocols is based on consensus of international authors and aimed to facilitate the role of musculoskeletal ultrasound in clinical praxis of physical medicine and rehabilitation.

6.1.2. Interventions under ultrasound guidance

1. Mezian K, **Jačisko J**, Kaiser R, Machač S, Steyerová P, Sobotová K, Angerová Y, Naňka O. Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment. Front Neurol. 2021 May 14;12:661441. doi: 10.3389/fneur.2021.661441. PMID: 34054704; PMCID: PMC8160369. **IF_{2021}=4,086**

In this review the ultrasound diagnostics, and ultrasound guided therapy options were discussed in ulnar nerve neuropathy at the elbow.

2. Mezian K, Ricci V, **Jačisko J**, Sobotová K, Angerová Y, Naňka O, Özçakar L. Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies. Am J Phys Med Rehabil. 2021 Jun 1;100(6):599-609. doi: 10.1097/PHM.0000000000001683. PMID: 33443851. **IF_{2021}=3,412**

In this review were discussed the most common US guided interventions in wrist pathologies.

6.1.3. Education materials for musculoskeletal ultrasound beginners

1. **Jačisko J**, Mezian K, Güvener O, Ricci V, Kobesová A, Özçakar L. Mnemonics and Metaphorical Videos for Teaching/Learning Musculoskeletal Sonoanatomy. Am J Phys Med Rehabil. 2022 Aug 9. doi: 10.1097/PHM.0000000000002084. Epub ahead of print. PMID: 35944076. **IF_{2021}=3,412**

In this article a videoglallery of mnemonics signs of physiologic findings were presented.

2. **Jačisko J**, Ricci V, Mezian K, Güvener O, Chang KV, Kara M, Kobesová A, Özçakar L. Mnemonics and Metaphorical Videos for Detecting/Diagnosing Musculoskeletal Sonopathologies. Am J Phys Med Rehabil. 2022 Oct 11. doi: 10.1097/PHM.0000000000002119. Epub ahead of print. PMID: 36228196. **IF_{2021}=3,412**

In this article a videoglallery of mnemonics signs of pathologic findings were presented.

6.1.4. Case report and letter to the editor

1. **Jačisko J**, Sobotová K, Mezian K. The utility of ultrasound examination in cubital tunnel syndrome caused by heterotopic ossification. Med Ultrason. 2020 Mar 1;22(1):117-118. doi: 10.11152/mu-2419. PMID: 32096802. **IF_{2020}=1,611**

This case report presented patient with ulnar neuropathy at the elbow caused by heterotopic ossification and emphesise the role of ultrasound examination and therapy guidance.

2. **Jačisko J**, Mezian K, Naňka O. Sonography of the anterior cruciate ligament revisited. J Clin Ultrasound. 2021 Mar;49(3):248-249. doi: 10.1002/jcu.22978. Epub 2021 Feb 1. PMID: 33527383. **IF_{2021}=0,869**

This letter to the editor reported possible mistaking anterior cruciate ligament with mucose ligament during ultrasound examination.

6.2. Objectivization of the trunk functions

6.2.1. Correlation between palpatory assessment and pressure sensors in response to postural trunk tests.

Jacisko J, Stribrny M, Novak J, Busch A, Cerny P, Kobesova A. Correlation Between Palpatory Assessment and Pressure Sensors in Response to Postural Trunk Tests. Isokinetics and Exercise Science 1 Jan. 2021 DOI: 10.3233/IES-205238 **IF_{2021}=0,729**

Based on inter-rater reliability and correlation of the objective and subjective measurements it can be assumed, that intraabdominal test, diapragm test and hip flexion test can be usefull in evaluation of the quality of postural stabilization in asymptomatic individuls.

6.2.2 Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests

Novak J, **Jacisko J**, Busch A, Cerny P, Stribrny M, Kovari M, Podskalska P, Kolar P, Kobesova A. Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests. Clin Biomech 2021 Aug;88:105426. doi: 10.1016/j.clinbiomech.2021.105426. Epub 2021 Jul 14. **IF$_{2021}$=2,034**

Intra-abdominal pressure correlated with tension produced by abdominal wall measured over inguinal ligmaent and trigonum lumbale in postural tasks. This study presented a new option of indirect objectivization of IAP/postural stabilization in clinical practice.

6.2.3 The significance of intra-abdominal pressure on postural stabilization: A low back pain case report

NOVAK, Jakub, **JACISKO, Jakub**, STVERAKOVA, Tereza, JUEHRING, David D., SEMBERA, Martin, KOLAR, Pavel and KOBESOVA, Alena, 2022. The signifikance of intra-abdominal pressure on postural stabilization: a low back pain case report. Slovak Journal of Sport Science. 17 January 2022. Vol. 7, no. 2, pp. 3–18. DOI 10.24040/sjss.2021.7.2.3-18.

This study reviewed current options of objectivization of the postural functions. It also presented a case report of a patient with LBP.

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8. SEZNAM PUBLIKACÍ

Původní vědecké práce, které jsou podkladem této disertační práce

1. **Jačisko J**, Sobotová K, Mezian K. The utility of ultrasound examination in cubital tunnel syndrome caused by heterotopic ossification. *Med Ultrason*. 2020 Mar 1;22(1):117-118. doi: 10.11152/mu-2419. PMID: 32096802. **IF_{2020}=1,611**

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11. Pirri, Carmelo; Stecco, Carla; Güvener, Orhan; Mezian, Kamal; Ricci, Vincenzo; **Jačisko, Jakub**; Novotný, Tomáš; Kara, Murat; Chang, Ke-Vin; Dughbaj, Muhammad; Jain, Nitin B.; Özçakar, Levent. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Knee. American Journal of Physical Medicine & Rehabilitation ():10.1097/PHM.0000000000002173, December 22, 2022. | DOI: 10.1097/PHM.0000000000002173 **IF$_{2021}$=3,412**

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9. PŘÍLOHY

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Příloha 2: Publikace

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Příloha 4: Publikace

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Příloha 5: Publikace

Mezian K, **Jačisko J**, Kaiser R, Machač S, Steyerová P, Sobotová K, Angerová Y, Naňka O. Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment. *Front Neurol.* 2021 May 14;12:661441. doi: 10.3389/fneur.2021.661441. PMID: 34054704; PMCID: PMC8160369. **IF_{2021}=4,086**

Příloha 6: Publikace

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Příloha 7: Publikace

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Příloha 8: Publikace

Mezian K, Ricci V, Güvener O, **Jačisko J**, Novotný T, Kara M, Chang KV, Naňka O, Pirri C, Stecco C, Dughbaj M, Jain NB, Özçakar L. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for (Adult) Hip. *Am J Phys Med Rehabil*. 2022 Jun 9. doi: 10.1097/PHM.0000000000002061. Epub ahead of print. PMID: 35687784. **IF_{2021}=3,412**

Příloha 9: Publikace

Jačisko J, Mezian K, Güvener O, Ricci V, Kobesová A, Özçakar L. Mnemonics and Metaphorical Videos for Teaching/Learning Musculoskeletal Sonoanatomy. *Am J Phys Med Rehabil*. 2022 Aug 9. doi: 10.1097/PHM.0000000000002084. Epub ahead of print. PMID: 35944076. **IF_{2021}=3,412**

Příloha 10: Publikace

Jačisko J, Ricci V, Mezian K, Güvener O, Chang KV, Kara M, Kobesová A, Özçakar L. Mnemonics and Metaphorical Videos for Detecting/Diagnosing Musculoskeletal Sonopathologies. Am J Phys Med Rehabil. 2022 Oct 11. doi: 10.1097/PHM.0000000000002119. Epub ahead of print. PMID: 36228196. **IF_{2021}=3,412**

Příloha 11: Publikace

Pirri, Carmelo; Stecco, Carla; Güvener, Orhan; Mezian, Kamal; Ricci, Vincenzo; **Jačisko, Jakub**; Novotný, Tomáš; Kara, Murat; Chang, Ke-Vin; Dughbaj, Muhammad; Jain, Nitin B.; Özçakar, Levent. EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Knee. American Journal of Physical Medicine & Rehabilitation ():10.1097/PHM.0000000000002173, December 22, 2022. | DOI: 10.1097/PHM.0000000000002173 **IF_{2021}=3,412**

Příloha 12: Publikace

NOVAK, Jakub, **JACISKO, Jakub**, STVERAKOVA, Tereza, JUEHRING, David D., SEMBERA, Martin, KOLAR, Pavel and KOBESOVA, Alena, 2022. The signifikance of

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Příloha 1

normal side (fig 1). In light of the US findings, the patient was diagnosed with a healing strain of the lateral head of the gastrocnemius muscle.

Calf pain is a common complaint among patients of all ages but is most frequent in young and active people (especially runners). Often , calf strains or ruptures are seen in the medial gastrocnemius muscle (i.e. 'tennis leg') but other components of the posterior leg including the lateral gastrocnemius, soleus and plantaris may also harbor the underlying cause/lesion [1]. These injuries usually occur during physical activities whereby forced dorsiflexion of the ankle and simultaneous extension of the knee are inevitable. Patients commonly report a sudden tear or 'pop' in their posterior leg after which they start suffering acute pain and tenderness [2]. According to the imaging studies, involvement of the medial gastrocnemius occurs in 58 to 65% of all cases; the lateral gastrocnemius in 8 to 38% and other muscles are less frequent [2,3].

Presenting this (rare) case of ours, firstly, we emphasise that medical history and physical examination might sometimes be insufficient for an exact diagnosis. Secondly, sono-palpation is definitely helpful for demonstrating and the prompt understanding of the lesion (for the physician and for the patient alike) [4]. Last but not least, especially when an intervention is to be planned, the aforementioned 'sonographic understanding' will turn into 'precise targeting' also [5].

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The utility of ultrasound examination in cubital tunnel syndrome caused by heterotopic ossification

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To the Editor,

A 65-year-old man presented with a one-year history of bilateral paresthesia of the ulnar side of the forearm and 4[th] to 5[th] finger, accompanied by numbness and weakness of the mentioned area. The patient also reported sleep disturbance due to tingling sensations in his hand and fingers, resulting in awakening 3-4 times per night. His history involved 30 years working with a vibrating sander.

Clinical examination revealed hypotrophy of the interosseous muscles. Tinel's test was positive only over the ulnar nerve in the right ulnar sulcus area. Electromyography and nerve conduction studies revealed bilateral cubital tunnel syndrome, more severe on the right side. Ultrasound (US) examination of both elbows showed a hyperechoic mass causing acoustic shadowing, in close contact with the ulnar nerve on the right side. The ulnar nerve was swollen bilaterally (right side, cross-sectional area 15 mm^2; left side 11 mm^2). Radiographs of the

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Fig 1. ***Left side:*** Ultrasound revealed a hyperechoic mass causing acoustic shadowing bilaterally, with close contact to a swollen ulnar nerve on the right side. D, distal; P, proximal; JG, joint gap; ME, medial epicondyle; white arrow, swollen ulnar nerve; asterisk, heterotopic ossification. ***Right side:*** Anteroposterior radiographs of both elbow joints. White arrows, heterotopic ossifications; L, left; R, right.

elbows showed multiple ossifications of the soft tissue around the medial and lateral humeral epicondyles bilaterally (fig 1). The patient was informed of the treatment options (corticosteroid injection/consideration of surgery) and opted for corticosteroid injection. The ulnar nerve on the right side was injected under US guidance with a mixture of 40 mg (1 ml) methylprednisolone and 1 ml 1% trimecaine. The injection provided satisfactory pain relief at the 2-week and 3-month follow-up.

The utility of US examination is found not only in diagnostic, but also in providing accurate therapy and follow-up. US examination can provide information about ulnar nerve morphology and surrounding structures that can be the cause of compression [1]. Therapeutic injection under US control is more precise and targeted. During follow-up, US examination can be a very useful tool for evaluating therapeutic effect - in this particular case, a reduction in the cross-sectional area of the swollen nerve.

Heterotopic ossification (HO) is a pathologic formation of bone within soft tissues. The main risk factors for HO are orthopedic surgery, trauma, brain or spinal cord injury and severe burns. Repetitive mechanical stress or microtrauma is generally thought to be present among the rest of the patients [2]. The long history of working with a vibrating sander in our patient was, probably, the risk factor for HO. More studies about HO in patients exposed to occupational vibration are needed.

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Extensor digitorum brevis manus is uncommon but can easily be misinterpreted during wrist ultrasound examination

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To the Editor

A 37-year-old female complained of a distended sensation over her right wrist for the last six months. She reported occasional swelling at its dorsal aspect, accompanied by only soreness but no pain after 30 minutes of continuous computer use. The medical history was otherwise unremarkable.

Příloha 2

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IOS Press

Correlation between palpatory assessment and pressure sensors in response to postural trunk tests

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Abstract.
BACKGROUND: The evaluation of postural trunk muscle function is a critical component of clinical assessment in patients with musculoskeletal pain and dysfunction. Postural activation of the trunk muscles has been evaluated by various methods. This study evaluates the correlation between subjective assessment of postural trunk muscle function with an objective measurement of abdominal wall expansion.
METHODS: Twenty-five healthy participants (16 women, 9 men, age 22.4 years) were assessed. The subjective assessment was performed by two experienced Dynamic Neuromuscular Stabilization (DNS) clinicians evaluating the quality of trunk stabilization using five postural stability tests through palpation and observation. Interrater reliability was determined using an intraclass correlation coefficients (ICC). Objective measurement was performed using a new device (DNS Brace) which externally measures abdominal wall pressure. Spearman rank correlations were calculated for both palpation and observation measures with DNS Brace data.
RESULTS: The interrater reliability (ICC2,k) estimates demonstrated moderate reliability in palpation measures for three DNS tests: Hip flexion test, Diaphragm test, & Intra-abdominal pressure regulation test (IAPRT) (ICC = 0.645–0.707). For observation measures, good reliability was found in IAPRT (ICC = 0.835), and three tests demonstrated moderate reliability: Hip flexion test, Diaphragm test, & Breathing Stereotype (ICC = 0.577–0.695). Correlation analysis demonstrated several moderate to strong correlations between palpation and DNS brace values (Assessor 1): IAPRT, $r_s = 0.580$, $p = 0.002$, Diaphragm test, $r_s = 0.543$, $p = 0.005$, (Assessor 2): IAPRT, $r_s = 0.776$, $p < 0.001$, Breathing Stereotype, $r_s = 0.625$, $p = 0.001$, Diaphragm test, $r_s = 0.519$, $p = 0.008$, Hip Flexion test, $r_s = 0.536$, $p = 0.006$, and Arm Elevation test, $r_s = 0.460$, $p = 0.021$. For observation, several moderate correlations were demonstrated with DNS brace values (Assessor 1): Arm Elevation test, $r_s = 0.472$, $p = 0.017$, (Assessor 2) Diaphragm test, $r_s = 0.540$, $p = 0.005$, IAPRT $r_s = 0.475$, $p = 0.016$, Hip Flexion test, $r_s = 0.485$, $p = 0.014$, and Arm Elevation, $r_s = 0.451$, $p = 0.024$.
CONCLUSION: Based on inter-rater reliability and DNS brace correlations with trained DNS professionals, the IAPRT, Diaphragm test, and Hip Flexion test may prove useful when assessing asymptomatic individuals. More research is needed in order to establish the utility of DNS brace and clinical testing both in asymptomatic and back pain populations. DNS tests must be supplemented by further examinations for definitive clinical decision making.

Keywords: Postural stabilization, breathing, abdominal muscles, intra-abdominal pressure, Dynamic Neuromuscular Stabilization

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1. Introduction

Evaluation of postural trunk muscle function is a critical component of clinical assessment in patients with musculoskeletal pain and dysfunction. Activation of the postural trunk muscles is essential for maintaining IAP (Intra-Abdominal Pressure) [1,2]. Appropriate IAP regulation secures stability of the lumbar spine [3,4]. Altered function of trunk muscles is associated with low back pain (LBP) [5,6] which is a major public health problem worldwide causing significant personal and financial burden [7]. Numerous studies suggest that trunk and lumbar spine stabilization exercises may help in LBP treatment and contribute to LBP prevention [8].

Postural activation of the trunk muscles has been evaluated by various methods such as ultrasonography [9], electromyography [9], pressure biofeedback unit [10], dynamometry [11] or direct IAP measurement [3,4]. Although some of these methods can measure the core activity or even IAP quite accurately, most of them serve for research purpose rather than clinical practice because the procedures may be uncomfortable for the patient, invasive, time consuming and often difficult to interpret the results. In routine clinical practice subjective assessment via various clinical tests is the most common way to evaluate postural function of the trunk muscles [12,13].

One concept offering a complete set of clinical tests to evaluate closely inter-related postural-respiratory functions [14] is Dynamic Neuromuscular Stabilization (DNS) [13]. DNS is a functional diagnostic and therapeutic approach based on human ontogenesis applying principles of movement and posture development during the first years of a healthy individual's life [15,16]. The complete set of DNS testing [13] captures the stereotype of postural stabilization and movement [17], respiratory pattern [14,18], functional joint centration [15] and segmental movement [19], while offering a functional treatment plan for musculoskeletal [20,21] or neurological patients [22]. Still, there is a need for more objective data to demonstrate the reliability of DNS procedures and to monitor the progress or improvements based on DNS principles.

Therefore, this study presents a new, non-invasive device called DNS Brace which objectively measures the expansion of the abdominal wall, a function which purportedly correlates with IAP changes and breathing [1]. Expansion of the abdominal wall related to IAP regulation is an important mechanism of trunk and spinal stabilization [14]. Additionally, this study examines the correlation between a clinician's subjective postural function assessment and objective measurement of the abdominal wall expansion using the DNS Brace.

2. Methods

2.1. Participants

The study was approved by the local ethics committee (Protocol number 17954, 8.1. 2020, Ethics committee of the Second Faculty of Medicine, Charles University and University Hospital Motol, Prague, Czech Republic). Participants were addressed via social media. Exclusion criteria were any symptomatic neurologic, orthopedic, respiratory or musculoskeletal disorder, spine or abdominal surgery, severe trauma during the last year, pregnancy, and undergoing DNS therapy in the past. In total 25 participants, 16 women and 9 men were involved in the study. Before the assessment, every participant received the same detailed information about the testing procedure. Every participant signed the informed consent. Basic descriptive data including gender, age, anthropometric data were recorded for each participant. Table 1 shows general characteristics for the whole group.

2.2. Instrumentation

The DNS Brace (Produced by Ortotika, FN Motol V Úvalu 84, Praha, (Fig. 1) which is mechanically configured as a trunk orthosis is equipped with four sensors working on a mechanical-pneumatic-electronic principle. For assessment, the brace fits tightly to bony structures allowing the expansion of soft tissues. The sensors are fixed on the inner wall of the brace. Two sensors are located on the brace parts adhering to laterodorsal sections (trigonum lumbale) of the abdominal wall and two are placed above the groin. The position of the sensors can be easily adjusted to fit each individual. The sensor heads are hemispheric in shape, allowing them to adhere to soft tissues in the monitored locations. Each sensor head contains an inner-air chamber and is made from silicone, which provides stable mechanical quality in a wide range of temperatures. The inner-air chamber is connected to a digital pressure sensor via a capillary tube. When recording measurements, each sensor's silicone head is deformed by the applied pressure, which causes a reduction of volume in the inner-air chamber, thus increasing pneumatic pressure in the inner capillary system. Pneumatic pressure is registered via an

Table 1
Participant's anthropometric characteristics. $n = 25$, 9 males, 16 females

	Age (year)	Height (m)	Weight (kg)	BMI (kg/m^2)	Waist (cm)
Mean	22.4	172.68	68.88	23.02	77.16
SD	1.76	7.26	8.66	1.58	5.98
Min	20	161	58	19.82	67
Max	25	190	85	25.85	90

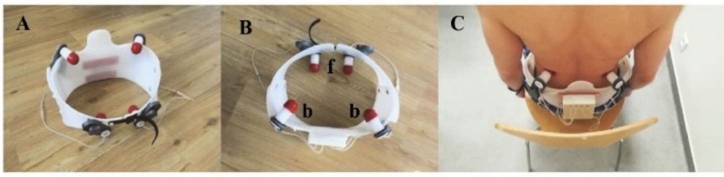

Fig. 1. DNS brace A. Front view; B. Top view, f – two sensors in the front, b – two sensors in the back; C. Back view, Brace on a man.

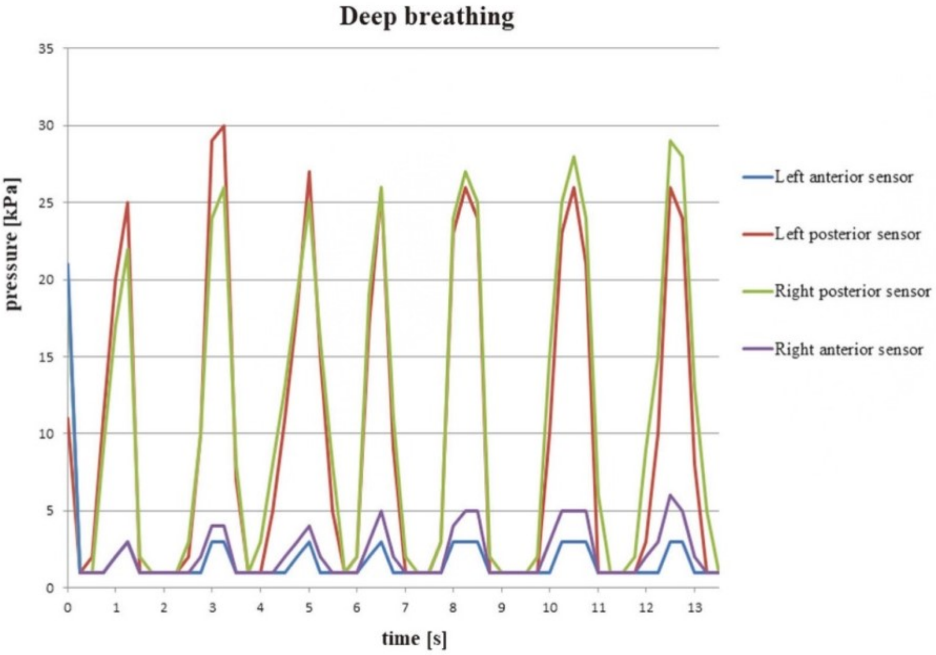

Fig. 2. Data from DNS Brace measuring deep breathing displayed in a graph.

auxiliary electric device (digital pressure sensor) on the orthosis. The sensors register the pressure exerted by the abdominal wall. The values recorded in kilopascals (kPa) are transferred via Bluetooth, stored and graphically displayed in a smart-phone device (Fig. 2). The sampling rate is 240 Hz.

2.3. Procedure

Participants ($n = 25$) were randomly assigned to two groups. Participants from group 1 ($n = 13$, female 8, male 5) were first assessed by the two DNS assessors in a random order (some participants were first assessed by assessor #1 and then by assessor #2 or vice versa), and subsequently by DNS Brace which was applied by another clinician. Participants from group 2 ($n = 12$, female 8, male 4) were first assessed by DNS Brace, and subsequently by the two DNS assessors in random order. The measurements were always performed under the same environmental conditions.

DNS assessors evaluated the five postural tests according to DNS (as described below) consecutively in

Fig. 3. Visual-analogue scale for subjective assessment of postural tests (the assessors made two lines on VAS – one for aspection, one for palpation).

the same order on each participant. Every participant was given exactly the same instructions before each test. After assessing all 5 tests by the first DNS assessor, the participant was assessed by the other DNS assessor, who gave the same instructions to evaluate each test. There was no time limit for the evaluation. Both assessors assessed each participant first by palpation and then visually using VAS (visual analogue scale) from 0 (no activation) to 100 (ideal activation) [23] (Fig. 3). Palpation by DNS assessors was performed at the same body regions where the DNS Brace sensors were placed, i.e. in trigonum lumbale bilaterally and above the groin bilaterally. DNS tests were reported as reliable assessment methods in other research projects previously [24].

2.4. *Subjective assessment*

Five DNS postural tests were performed by each participant and evaluated by two experienced assessors (certified DNS instructors) by palpation and inspection using VAS from 0 to 100 points where 0 represents absolute inability to perform required activity and 100 represents ideal activation (Fig. 3).

During all five tests the participants were seated, their hips and knees flexed in 90° angle, feet touching the ground while keeping spine upright and shoulders relaxed. With each participant the tests were evaluated in the following order:

1. Breathing stereotype test. (Fig. 4) The participant was instructed to take five deep breaths. The assessor first palpated the activation in the lower intercostal spaces and below the lower ribs bilaterally and then above the groin. Then, the assessor performed visual observation focusing on lower ribs and shoulder movement.
2. Intra-abdominal pressure regulation test. (Fig. 5) The assessor palpated bilaterally the lower abdominal sections above the groin. The participant was instructed to activate the IAP by pushing against assessor's fingers. Amount and symmetry of activation is assessed by palpation. Then, visual observation of abdominal contour, umbilicus and shoulder movement was performed.
3. The diaphragm test. (Fig. 6) The assessor was positioned behind the participant palpating bilaterally below participant's lower ribs. The participant was instructed to take a deep breath and push towards assessor's fingers to activate the abdominal wall. The assessor evaluated the amount and symmetry of activation of the abdominal wall. Then, the assessor visually observed lateral movement of the lower ribs while monitoring the spine (upright and stable) and the presence of shoulder movement or pathological synkinesis (Fig. 6).

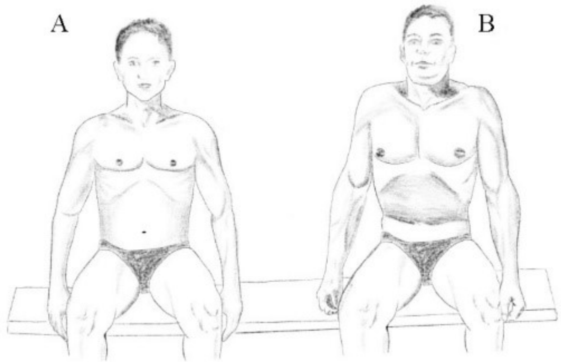

Fig. 4. Breathing stereotype test. A. Optimal pattern. Spine upright, trunk in neutral position, relaxed auxiliary breathing muscles, proportional expansion of abdominal wall occurs with inhalation. B. Pathological stereotype. The chest moves superiorly, shoulders moves superiorly and into protraction during inhalation, insufficient or no expansion of the abdominal wall.

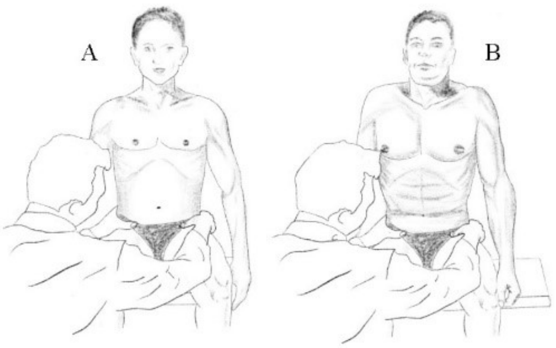

Fig. 5. Intra-abdominal pressure regulation test. A. Optimal pattern. Proportional tensing of abdominal wall in all sections. B. Pathological stereotype. Inability to expand lower abdominal wall, asymmetrical activation, overactivity of upper rectus abdominis muscle, ribcage elevation.

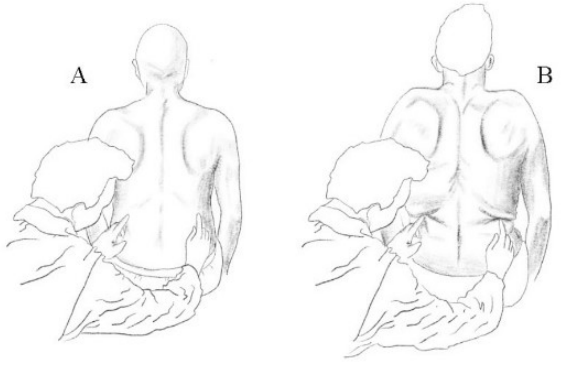

Fig. 6. Diaphragm test. A. Optimal pattern. Abdominal wall eccentric expansion, upright spine, without shoulder movements cranially. B. Pathological stereotype. Inability to expand latero-dorsal parts of the abdominal wall, asymmetrical activation, rib cage or shoulder elevation, substitutive mechanism with spinal kyphosis compensating for lack of eccentric abdominal wall activation.

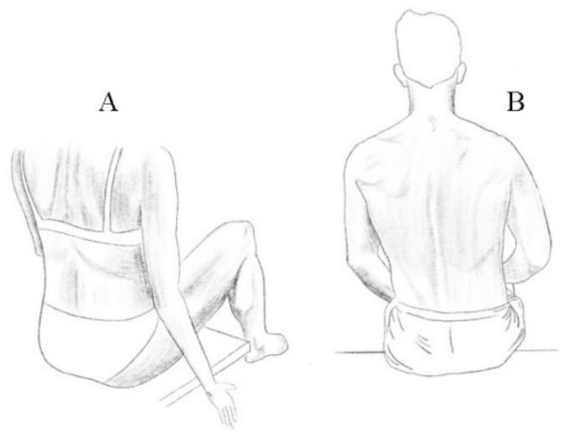

Fig. 7. Hip flexion test. A. Optimal pattern. Chest and pelvis in neutral position, spine upright. B. Pathological stereotype. Inability to keep the spine upright and pelvis stable, lateral shift of the trunk.

4. Hip flexion test. (Fig. 7) The assessor instructed the participant to slowly lift up right leg (approximately 10 to 20 cm) above the ground. Participant breathed naturally while maintaining this position. The activity of the latero-dorsal sections of abdominal wall was assessed bilaterally by palpation (as in diaphragm test). Then, any spinal and pelvic movements were assessed by visual inspection.
5. Arm lifting test. (Fig. 8) The participant lifted a dumbbell that corresponded to 20% of the body weight. Elbows were flexed to 90° and participant breathed naturally in this position. The assessor palpated bilaterally the abdominal wall activation first in trigonum lumbale, then above the groin.

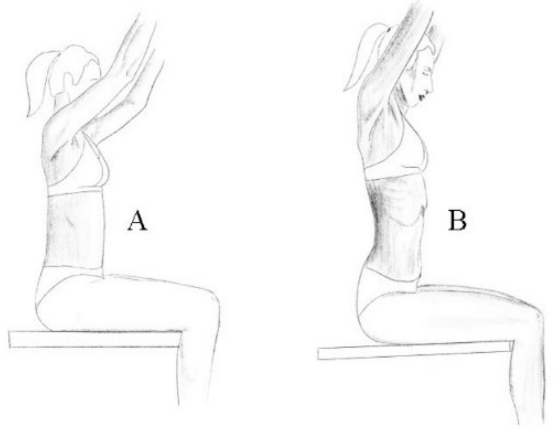

Fig. 8. Arm lifting test. A. Optimal pattern. Ribcage in neutral position, thoracolumbar junction stable, symmetrical expansion of abdominal wall. B. Pathological stereotype. Chest elevation, thoracolumbar instability, hyperlordosis of the lumbar spine.

Spinal or pelvic movements were assessed visually.)

All DNS tests were performed according to the detailed procedures described by Kobesova et al. 2020, which include all signs of optimal and abnormal presentations [13].

2.5. DNS Brace measurements

The DNS Brace was applied by another clinician and was attached around the participant's trunk. The activity of the abdominal wall was monitored during the same five DNS tests and in the same order as with the subjective assessment. The same instructions were given for DNS Brace measurement as for the subjective testing. The sensors were always calibrated to 0 kPa in resting exhalation position prior to each measurement. Afterwards the participants were instructed to take two natural breaths and then the test was performed and the abdominal wall activity recorded. A total of 3 to 7 breathing cycles were recorded (recording time was between 6 to 20 seconds depending on individual breathing speed). Afterwards, the average pressure against all four sensors was calculated and used for correlation with the subjective clinical assessment. The assessors were not allowed to view results received from the DNS Brace measurements nor were they allowed to consult each other during testing.

2.6. Statistical analysis

Descriptive data were calculated, including means

Table 2
Interrater reliability of different DNS tests using palpation and observation ($ICC_{2,k}$)

DNS test	Palpation			Observation		
	ICC	95% CI	Sig	ICC	95% CI	Sig
1-Breathing stereotype	0.446	(−0.258, 0.756)	0.078	0.695*	(0.308, 0.866)	0.003
2-IAPRT	0.707*	(0.334, 0.871)	0.002	0.835**	(0.626, 0.927)	0.000
3-Diaphragm test	0.646*	(0.197, 0.844)	0.007	0.668*	(0.246, 0.854)	0.005
4-Hip flexion test	0.645*	(0.194, 0.843)	0.007	0.577*	(0.04, 0.814)	0.020
5-Arm elevation	0.308	(−0.570, 0.695)	0.187	0.464	(−0.217, 0.764)	0.067

Note: DNS = Dynamic neuromuscular stabilization; ICC = Intraclass correlation coefficient; IAP = Intra abdominal pressure regulation test; Both examiners were trained DNS professionals. *Denotes: Moderate reliability. **Denotes: Good reliability.

Table 3
Correlations of DNS instructor values with average DNS brace values in five DNS tests (mean [standard deviation])

DNS test	DNS brace average values	Palpation			Observation		
		Score	Spearman r_s	Sig	Score	Spearman r_s	Sig
DNS Assessor 1							
1-Breathing stereotype	4.89 (3.18)	70.28 (19.43)	0.443	0.026	65.56 (20.85)	0.290	0.159
2-IAPRT	12.19 (8.47)	84.12 (14.27)	0.580	0.002*	76.88 (16.25)	0.380	0.061
3-Diaphragm test	11.73 (9.11)	76.16 (17.06)	0.543	0.005*	71.32 (16.86)	−0.105	0.616
4-Hip flexion test	6.28 (5.52)	65.44 (19.53)	0.338	0.009*	70.20 (17.34)	−0.039	0.852
5-Arm elevation	9.44 (8.80)	77.12 (14.12)	0.303	0.142	75.80 (10.91)	0.472	0.017*
DNS Assessor 2							
1-Breathing stereotype	4.89 (3.18)	43.60 (13.32)	0.625	0.001*	41.68 (15.87)	0.342	0.094
2-IAPRT	12.19 (8.47)	53.40 (20.58)	0.776	< 0.001*	47.60 (19.35)	0.475	0.016*
3-Diaphragm test	11.73 (9.11)	52.40 (16.83)	0.519	0.008*	49.64 (21.75)	0.540	0.005*
4-Hip flexion test	6.28 (5.52)	47.20 (13.00)	0.536	0.006*	45.68 (15.23)	0.485	0.014*
5-Arm elevation	9.44 (8.80)	46.08 (15.79)	0.460	0.021*	45.68 (20.43)	0.451	0.024*

Note: DNS = Dynamic neuromuscular stabilization; IAPRT = Intra-abdominal pressure regulation test; Both examiners were trained DNS professionals. *Statistically significant correlation (Bonferroni Correction $P < 0.025$).

and standard deviations (SD) for each DNS assessor's palpation and observation using the VAS, and the DNS brace values. Interrater reliability was determined using intraclass correlation coefficients ($ICC_{2,k}$) and their 95% confidence intervals (CI) between the two DNS assessors' measures of either palpation or observation for all five DNS tests based on a mean-rating ($k = 2$), consistency, 2-way random model. Reliability was defined as poor (ICC < 0.50), moderate (ICC 0.50–0.75), or good (ICC > 0.75). Spearman's rank order correlations were used to analyze the relationship between different DNS assessors measures with the average DNS Brace values. The strength of correlations were interpreted as weak (< 0.3), moderate (0.4–0.6), or strong (> 0.7), as reported by Akoglu [25]. The alpha level used for significance, with Bonferroni corrections, was set a priori at $p < 0.025$. All data was analyzed using SPSS statistical package v26 (SPSS Inc, Chicago, IL).

3. Results

Descriptive data for all participants are presented in Table 1. Not all variables were normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$). Interrater reliability ICC estimates are shown in Table 2. For palpation, moderate reliability was demonstrated duirng three DNS tests: Hip flexion test, Diaphragm test, & IAPRT (ICC = 0.645–0.707). For observation, moderate reliability was again demonstrated in three tests: Hip flexion test, Diaphragm test, & Breathing Stereotype (ICC = 0.577–0.695) while a good reliability was found in IAPRT (ICC = 0.835).

All correlational data with 95 % confidence intervals are presented in Table 3. For DNS Assessor 1, palpation demonstrated moderate correlations between the DNS brace values with IAPRT, r_s (23) = 0.580, p = 0.002 and the Diaphragm test, r_s (23) = 0.543, p = 0.005 while observation demonstrated a lower correlation with the Arm Elevation test, r_s (23) = 0.472, p = 0.017. For DNS instructor 2, palpation demonstrated a strong correlation for for IAPRT, r_s (23) = 0.776, $p < 0.001$ and modetate correlations for the Breathing Stereotype, r_s (23) = 0.625, p = 0.001, Diaphragm test, r_s (23) = 0.519, p = 0.008, and Hip Flexion test, r_s (23) = 0.536, p = 0.006. A lower correlation was demonstrated with the Arm Elevation test, r_s (23) = 0.460, p = 0.021. Observation for DNS Assessor 2 demonstrated moderate correlations in the Diaphragm test, r_s (23) = 0.540, p = 0.005, IAPRT r_s (23) = 0.475, p = 0.016, Hip Flexion test, r_s (23) = 0.485, p = 0.014, and Arm Elevation, r_s (23) = 0.451, p = 0.024.

4. Discussion

Trunk stabilization analysis is critical part of clinical assessment. Postural function is closely related to movement and locomotion; mobility and stability form a functional unit that is under the constant control of central nervous system [26]. Another function closely related to trunk stabilization is respiration. The respiratory stereotype affects trunk muscle coordination and modifies the movement [27] therefore specific breathing instructions form a critical part of many stabilization exercise protocols [28,29]. Some studies indicate, that impaired postural control is associated with chronic low back pain [30]. Trunk stabilization training is often applied to treat and prevent back pain and other musculoskeletal problems and injuries [31].

The first step to analyze the influence of postural stabilization training on movement performance and musculoskeletal pain is to define the optimal pattern of postural stabilization. Due to extreme postural variability the exact definition of optimal posture is still ambiguous with each author defining the ideal posture differently [32–34]. One concept that aims to define optimal postural stabilization is Dynamic Neuromuscular Stabilization [35]. This DNS concept derives an ideal stabilization stereotype from genetically predetermined developmental patterns observed during normal early human ontogenesis. DNS offers a set of a functional diagnostic tests and evaluation to monitor a patient's posture [13]. However, the reliability of DNS clinical tests has not been demonstrated yet. This study correlates subjective assessment via five DNS tests performed by two experienced DNS clinicians with objective measurement of abdominal wall activity using new device called DNS Brace. The correlation between the subjective DNS assessments and objective measurement of abdominal wall expansion may help to determine the reliability of clinical DNS tests. At the same time this study reports interrater reliability for the five DNS tests. Additionally, this study introduces a new, simple and non-invasive device to measure the activity of the abdominal wall.

For both palpation (ICC = 0.707) and observation (ICC = 0.835) assessments, the IAPRT test demonstrated the best reliability between assessors. We identified moderate interrater reliability for both palpation and observation for the Diaphragm and the Hip Flexion test. Considering the complexity of DNS assessment, which emphasizes much detail and nuance both in palpation and observation assessment, the findings of moderate-good ICC's for 3/5 DNS tests was encourraging. These findings are similar to other well established systems, such as Mechanical Diagnosis and Therapy (MDT), where reported inter-rater reliability ranges from 0.11 to 1.00 [36]. Much more reasearch is needed to establish the relevance of DNS testing both in normal cohorts and in populations with various musculoskeletal problems.

The results of this study confirmed a positive correlation between objectively measured expansion of the abdominal wall and subjective palpatory assessment of postural trunk muscle function according to the DNS approach. For assessor 1, statistically significant correlation was identified for three DNS tests (IAPRT, Diaphragm and Hip Flexion test) and for assessor 2, palpation significantly correlated with all 5 DNS tests Brace measurements. The increase in pressure against the sensors was the highest in the situations when the measured participant was instructed to activate the IAP, i.e. when he or she had to push specifically against the sensors above the groin (IAPRT; average pressure = 12.19 kPa) or against the sensors placed in trigonum lumbale (diaphragm test; average pressure = 11.73 kPa). The third highest value was recorded during the arm elevation test holding the weight (average pressure = 9.44 kPa). The hip flexion test required 6.28 kPa average pressure increase only, yet such change was appropriately recognized by palpating assessors. During all these tests positive correlation between subjective and objective assessment was confirmed. The only exception was the breathing stereotype test where significant correlation between objective DNS Brace testing and subjective palpatory assessment was reached in one assessor only (see Table 2). During the breathing stereotype test the lowest average pressure increase (4.89 kPa) was measured by DNS Brace. It can be assumed that the smaller the change in the activation, the more difficult it is to estimate the amount of change by mere palpation.

Based on these results, instructed activation tests such as IAPRT or the Diaphragm test appear potentially useful in evaluating trunk stabilization function in clinical practice. Still, such tests need to be supplemented by further examinations for definitive clinical decision making. Surprisingly, lifting the weight corresponding to 20% of the participant's body weight evoked less postural stabilization activity than an instructed increase in IAPRT. Apparently, in healthy individuals such weight does not require much activity of the abdominal wall. This result further supports the study published by Essendrop et al. who report IAP increase from 0 to 40% when holding a load of 15% body weight [4].

The DNS Brace measures both voluntarily controlled and automatic subconscious postural activation. We can either instruct the individual to activate their abdominal wall pushing against the sensors, thus the brace can also be used for feedback training or we can monitor spontaneous level of activation during various movements. Both situations may be convenient in clinical practice and in research. Advantages of using the DNS Brace lie in it's fixed position of all 4 sensors that maintains contact with the trunk allowing the assessment in various positions and when moving. Such modifications may not be available when using other devices designed to measure and train abdominal muscles and lumbopelvic stability such as a Pressure Biofeedback Unit [37] or ultrasound which analyze mainly local activation of the abdominal muscles. The information from the four DNS Brace sensors is a more global monitoring of abdominal muscle co-activation. Also, it is very easy to apply the DNS Brace and to record and analyze results. Unlike electromyography, ultrasound or direct IAP measurement techniques, there is no need for special personnel training.

The entire assessment took approximately 8 minutes with each assessor, i.e. 24 minutes all together (2 subjective assessments + DNS brace assessments). The measurement order between assessor 1, 2 and DNS Brace was random to exclude the influence of any motor learning. The participants considered the examination to be both physically and mentally easy. The DNS Brace measurement starts from a fully relaxed state that does not require any pre-tensioning. In a study using a Pressure Biofeedback Unit, participants were instructed to maintain the target pressure range (40 ± 10 mmHg) [38]. This may exclude some individuals who are unable to reach such starting pressure. The DNS brace does not require any minimum prerequisite pressure to start the measurement, making the procedure simple, convenient and clinically useful. The DNS Brace measurement range is 0 to 500 kPa. The values measured by the brace are absolute thus comparable in time or among raters.

Correlation and statistical significance for palpation was in most cases better than that for observation. Palpation is an integral skill forming the vital component of many hands-on clinical examinations [39] including DNS concept. The results of this study support the use of the DNS tests described above when performed by skilled DNS clinicians. In this study the tests were evaluated by experienced DNS clinicians with more than five years clinical experience. This is an important aspect to consider since the palpation accuracy is closely related to examiner's experience and training [40]. To our knowledge this is the first study correlating subjective assessment of postural function of the trunk muscles with objective measurement of the abdominal wall expansion. The inspection should rather be complementary to palpation.

Future studies should investigate the correlation between abdominal wall expansion and direct IAP measurement to find out if DNS brace can actually replace invasive and uncomfortable techniques of direct IAP monitoring such as intravesical, anal or vaginal pressure measurements. Also, inter- and intra-rater reliability for DNS Brace needs to be established. Finally, the relationship between LBP and abdominal wall expansion needs to be explored as well as the effect of abdominal wall training. In the future DNS Brace may become a useful clinical and research tool.

There are some limitations to this study. First, this study was done in asymptomatic individuals. It is unknown if such DNS tests would show similar results in LBP patients or in individuals with other musculoskeletal disorders. Future studies in patients with LBP are warranted. Second, the average pressure against all four sensors was calculated and used for statistical analysis and the symmetry of the abdominal wall expansion was not considered. The brace could not be properly used in one extremely slim individual who had to be excluded from the study. In the future, smaller versions of DNS Braces will be constructed. Finally, DNS tests were assessed by DNS professionals (DNS instructors) with more than 5 years DNS experience. Future research could compare novice pracitioners with experienced, to learn differences.

5. Conclusion

Based on interrater reliability and DNS brace correlations with trained DNS professionals, the IAPRT, Diaphragm test, and Hip Flexion test may be useful for clinicians when assessing normal individuals. More research is needed in order to establish the utility of DNS brace and DNS clinical testing both in normal and back pain populations.

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Ethical considerations

The study was approved by the local ethics committee (Protocol number 17954, 8.1. 2020, Ethics committee of the Second Faculty of Medicine, Charles University and University Hospital Motol, Prague, Czech Republic). Before the assessment, every participant received the same detailed information about the testing procedure. Every participant signed the informed consent.

Conflict of interest

The authors have no conflict of interest to declare.

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Příloha 3

Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies

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Abstract: Wrist/hand pain is a prevalent musculoskeletal condition with a great spectrum of etiologies (varying from overuse injuries to soft tissue tumors). Although most of the anatomical structures are quite superficial and easily evaluated during physical examination, for several reasons, the use of ultrasound imaging and guidance has gained an intriguing and paramount concern in the prompt management of relevant patients. In this aspect, the present review aims to illustrate detailed cadaveric wrist/hand anatomy to shed light into better understanding the corresponding ultrasonographic examinations/interventions in carpal tunnel syndrome, trigger finger, de Quervain tenosynovitis, rhizarthrosis, and the radiocarpal joint arthritis. In addition, evidence from the literature supporting the rationale why ultrasound guidance is henceforth unconditional in musculoskeletal practice is also exemplified.

Key Words: Carpal Tunnel, Trigger Finger, de Quervain, Rhizarthrosis, Ultrasonography, Steroid, Injection

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The prevalence of disabling wrist/hand pain among the working population reaches up to 36.2%.[1] The spectrum of chronic wrist/hand pain is quite broad, ranging from overuse injuries to soft tissue tumors.[2] Aside from several conservative alternatives (rest, physical therapy etc.); various interventional treatments (e.g., corticosteroid, local anesthetic, or regenerative injections) are frequently applied to treat these painful conditions affecting the hand and wrist. Herein, it is noteworthy that—in contrast to previous blind approaches—the role of ultrasound (US) imaging and guidance has essentially been established in recent years.[3] Of note, US guides these procedures initially by providing prompt clinical decision making —for the diagnosis and optimal/technical planning of the intervention alike.[4,5] Needless to say, it also provides precise targeting during the intervention (avoiding collateral damage) as well as convenient/close follow-up thereafter.[6]

In this aspect, this article aims to describe the anatomy, US imaging/guidance, and the literature evidence pertaining to the most commonplace interventional procedures in daily clinical practice, that is, carpal tunnel syndrome, trigger finger (TF), de Quervain tenosynovitis, rhizarthrosis, and radiocarpal joint arthritis.

CARPAL TUNNEL SYNDROME

Carpal tunnel syndrome (CTS) is the most common peripheral nerve entrapment syndrome worldwide, resulting from compression of the median nerve at the wrist. Its diagnosis is based on clinical evaluation, nerve conduction studies, and US examination.

Anatomy

The carpal tunnel is a fibro-osseous space situated between the carpal bones' concave arch from the dorsal and the flexor retinaculum from the volar side. The bony landmarks for the carpal tunnel are the scaphoid and the pisiform proximally and the hook of hamate and the trapezium distally. Structures that pass through the carpal tunnel comprise the median nerve, four flexor digitorum superficialis and four flexor digitorum profundus tendons, and the flexor pollicis longus tendon inside their synovial sheaths. Distal to the retinaculum, the median nerve usually divides into five or six branches, showing a miscellaneous anatomic variability. Understanding variations of the median nerve's recurrent motor branch is essential[7] because its inadvertent resection during surgery would be associated with thenar function loss. The recurrent branch arises from the nerve's lateral side with a slight recurrent curve and continues superficial to or traverses the flexor pollicis brevis muscle, which is usually supplied by this nerve (Fig. 1A).[8] Notably, the median nerve also shows variations within the carpal tunnel, for example, bifid median nerve and persistent median artery.[9–11] Furthermore, space-occupying lesions/structures such as ganglion cysts, flexor tenosynovitis, and accessory muscles may also be present.[12] To this end, it is paramount to use a convenient imaging modality (e.g., US) to understand the pertinent anatomy before the injection.

US Imaging and Guided Injection Technique

Patients are usually seated facing the sonographer with their affected wrist in slight dorsiflexion resting on a rolled towel in a palm-up position, the forearm supinated, and elbow semiflexed at 90 degrees. As most of the wrist and hand structures are superficially localized, a high-frequency (8–18 MHz or higher) linear or hockey-stick probe would be preferred[13] during all the below-described procedures. The transducer is

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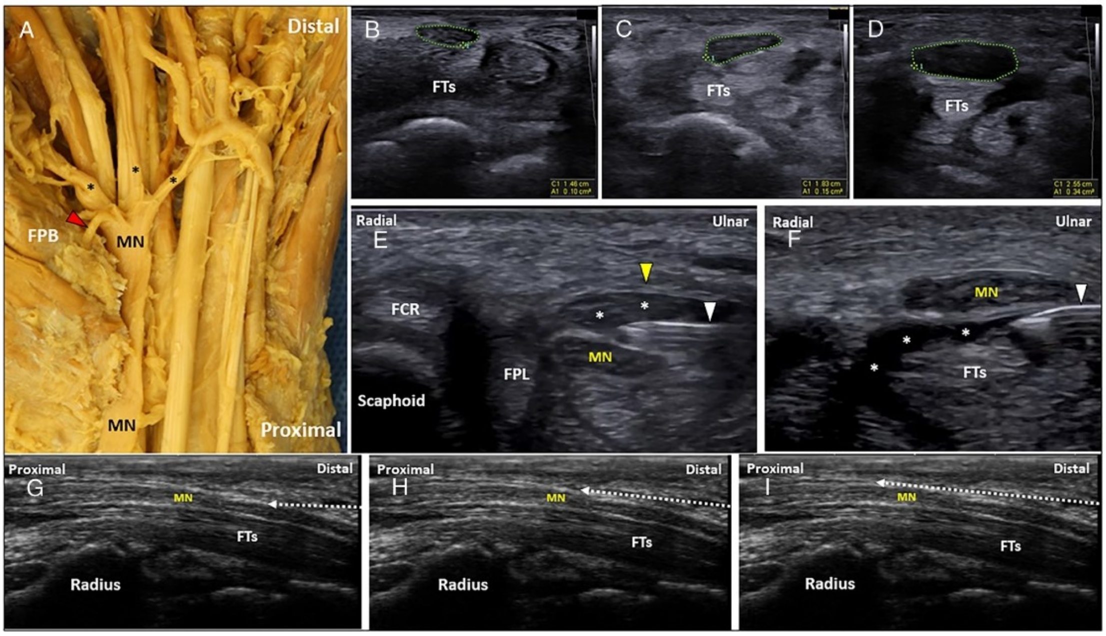

FIGURE 1. The cadaveric specimen shows the recurrent branch (red arrowhead) of the median nerve (MN) piercing the flexor pollicis brevis (FPB) muscle and the terminal branches–common digital palmar nerves (black asterisks) coursing distally (A). The short-axis sonogram promptly allows a detailed measurement of the cross-sectional area of the median nerve to evaluate the pathology/entrapment at mild (B), moderate (C), and severe (D) stages. US-guided hydrodissection (in-plane, ulnar to radial approach) guarantees a dual-target intervention releasing the median nerve–flexor retinaculum (yellow arrowhead) interface (E) and the median nerve–flexor tendon (FT) interface (F) during the same procedure. Although the longitudinal acoustic window allows an extensive hydrodissection (of the MN–flexor retinaculum interface) as the needle (white dotted arrow) is advanced from distal to proximal, it is not suitable if the nerve-FT interface is planned to be injected (G, H, I). White asterisks: mixture of the injectate; white arrowhead: needle. FCR indicates flexor carpis radialis tendon; FPL, flexor pollicis longus tendon.

placed along the short-axis of the wrist, slightly proximal to the scaphoid-pisiform level. The median nerve can be visualized as a honeycomb-appearing oval structure just beneath the flexor retinaculum. In CTS, the nerve typically shows flattening (at the entrapment site), loss of its normal fascicular pattern, and swelling (usually proximal to the entrapment site). Using US-measured cross-sectional nerve area, the severity can be classified as mild (<11.64 mm^2) (Fig. 1B), moderate (>13.74 mm^2) (Fig. 1C), and severe (>16.80 mm^2) (Fig. 1D).[14] In 2008, Hobson-Webb et al.[15] proposed a novel parameter for CTS's ultrasonographic diagnosis, named the wrist-to-forearm ratio, which was obtained 12 cm proximal in the forearm, measured from the distal wrist crease. In their preliminary results, the authors reported 100% sensitivity using a wrist-to-forearm ratio of greater than 1.4 to diagnose CTS. To increase the diagnostic specificity, apart from the carpal tunnel inlet, the median nerve cross-sectional area (CSA) can also be measured at the level of the proximal third of the pronator quadratus muscle to obtain the "ΔCSA" (CSA-inlet—CSA–pronator quadratus muscle). Klauser et al.[16] obtained the best diagnostic discrimination by using a ΔCSA threshold of 2 mm^2. According to a meta-analysis by Chen et al.,[17] the wrist-level CSA can also be used in diabetic patients, with a possible nonsignificant preexisting enlargement of the median nerve. Because the median nerve is considered stiffer in CTS patients, US elastography can also increase the diagnostic accuracy.[18] Furthermore, radial and ulnar arteries must be accurately identified/avoided during the procedure and color/power Doppler imaging can readily be used in this sense. A proximal-to-distal and distal-to-proximal sonotracking of the region should also be performed to rule out space-occupying lesions or to evaluate likely anatomical variants.

According to the aseptic technique, the skin should be disinfected, and to minimize the risk of infection, the probe should be covered with a sterile cover and sterile gel should be used as well. A freehand ulnar side in-plane approach visualizing the median nerve in the short-axis is usually performed. Under direct US visualization, a thin (e.g., 25-gauge, 25-mm) needle is advanced subcutaneously, slightly obliquely, superficial to the ulnar nerve and artery. The needle tip can be advanced next to the median nerve with subsequent slow administration of the injectate either between the median nerve and the superficial flexor tendons (Video 1, Supplemental Digital Content 1, http://links.lww.com/PHM/B224) or between the flexor tendons away from the median nerve.[19] A hydrodissection technique can also be used (especially in "failed-carpal tunnel release" patients) whereby a circumferential fluid plane should be formed around the epineurium of the median nerve, that is, in the median nerve–flexor retinaculum (Video 2, Supplemental Digital Content 2, http://links.lww.com/PHM/B225) and median nerve–flexor tendon interfaces (Fig. 1E–I). Delivering the injectate both deep and superficial to the median nerve allows separation of the nerve from the (potentially constricting) surrounding connective tissues, restoring the normal nerve mobility.[20] After the procedure, repetitive wrist flexion/extension is recommended to enhance the injectate delivery along the carpal tunnel.

Exemplary Evidence

Among conservative treatment options, US-guided corticosteroid injections have been proven effective (and superior to those landmark-guided) for symptom severity improvement in CTS patients.[21] Apart from corticosteroids and local anesthetics, different substances such as platelet-rich plasma, hyalase, local ozone (O_2-O_3), and 5% dextrose have been used in the literature as well.[22–24] Moreover, several studies comparing different injection sites have also been reported. Babaei-Ghazani et al.[25] compared US-guided corticosteroid injections "above" *vs.* "below" the median nerve in patients with mild to moderate CTS and found that both techniques effectively reduced the symptoms and improved function as well as the US and electrodiagnostic findings. Nair et al.[26] published a double-blind noninferiority trial comparing corticosteroid injections 2 cm proximal and 2–3 cm distal to the wrist crease whereby patient-reported outcomes were found to be similar. Hsu et al.[27] reported greater symptom relief and patient satisfaction for intraepineurial (*vs.* extraepineurial) corticosteroid injections. In the same study, patient-reported outcomes and nerve conduction studies at the 12-wk follow-up were similar between subjects injected with 40 *vs.* 10 mg of triamcinolone acetonide.

A relatively novel technique that is currently studied in the management of nerve entrapment syndromes is described as "nerve hydrodissection."[28] This method usually involves delivering the injectate (e.g., local anesthetic, saline, dextrose, corticosteroids) to separate the nerve from the surrounding tissues. Some authors believe that hydrodissection, coupled with mechanical disruption of the adhesions around the nerve, may restore normal nerve mobility.[29] Wu et al.[30] conducted a placebo-controlled study where hydrodissection of the median nerve (in contrast to subcutaneous 5 mL saline injection) yielded symptom improvement 6 mos after the procedure. On the other hand, Schrier et al.[31] reported comparable results of US-guided injections applied by either hydrodissection or single delivery medial to the median nerve.

Another option for CTS treatment is US-guided release of the transverse carpal ligament. This mini-invasive percutaneous technique has been shown as a safe, quick, effective, and reproducible procedure to transect the transverse carpal ligament on cadavers.[32,33] Compared with open surgery, US-guided release has shown better outcomes in scar tenderness, grip strength, superficial pain, and return to daily activities.[34] Further investigation of this method is certainly warranted.

TRIGGER FINGER

TF, also known as stenosing tenovaginitis, results from inflammation of the finger flexor tendons and/or their synovial sheaths. The conflict at the intersection of the tendon with its pulley is most commonly related to the thickening of the first annular pulley (A1). However, other pulleys can also be affected, and therefore, clinical findings without imaging can indeed cause misdiagnosis. In such clinical scenarios, the use of static/dynamic US examination would be crucial for detecting the triggering and the possible underlying mechanism.

Anatomy

The digital flexor fibrous sheath-pulley system keeps the tendons adjacent to the bone when bending the fingers. In other words, these fibro-osseous bands (most importantly A2 and A4) prevent bowstringing of the flexor tendons during finger flexion.[35] Those pulleys are five annular (A1–A5) and three cruciform (C1–C3) ligaments for the second to fifth digits and

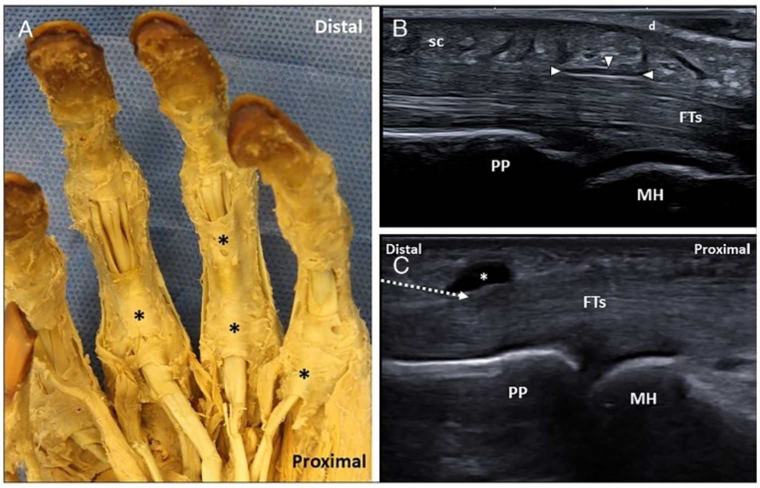

FIGURE 2. The cadaveric specimen shows the pulleys of fibrous sheaths (black asterisks) stabilizing the flexor tendons of the fingers (A). Using a high-frequency linear probe, a normal pulley (white arrowheads) may be visualized as a thin and hypoechoic structure located between the subcutaneous tissue and the flexor tendons (FTs) (B). In some patients, a focal collection (white asterisk) of fluid in proximity of the flexor tendons (FTs) —related to pathological changes of the pulley and/or synovial cyst of the tendon sheath—can be targeted using an in-plane (distal to proximal) approach while advancing the needle (white dotted arrow) until the intrasheath compartment (C). MH indicates metacarpal head; PP, proximal phalanx; d, dermis.

two annular (A1–A2) and one oblique pulley for the thumb. A1 pulley is located anterior to the metacarpal head. The A2 overlies the middle third of the proximal phalanx but may extend more proximal or distal. It is the strongest pulley and arises from the longitudinal ridges on the phalanx's palmar aspect (Fig. 2A).[8] A3 is a narrow pulley lying palmar to the proximal interphalangeal joint, and A4 and A5 overlie the middle phalanx and the distal interphalangeal joint, respectively. Variations occur frequently, though. A1, A3, and A5 pulleys insert onto the volar plate, whereas A2 and A4 insert directly on the bone.[36] Histologically, the pulley system consists of a deep synovial component and a superficial retinacular component. Flexors digitorum superficialis and profundus and flexor pollicis longus tendons are enveloped in two synovial sheaths at the flexor retinaculum level and distally reach about halfway along the metacarpal bones, where they end as blind diverticula. In the little finger and the thumb, the sheaths are usually more extended.[8]

US Imaging and Guided Injection Technique

The patient is seated face to face to the examiner with the affected hand in a palm-up position. The transducer is placed along the finger's long-axis to visualize the flexor tendons as a hyperechoic fibrillar structure superficial to the metacarpals/phalanges. Annular pulleys are seen as hypoechoic thickening of the volar aspect of the tendon sheath (Fig. 2B). Subsequently, transverse scanning should also be performed to rule out other pathologies potentially mimicking TF (Video 3, Supplemental Digital Content 3, http://links.lww.com/PHM/B226). After static imaging, (passive) dynamic examination during flexion/extension of the finger should be performed (Videos 4 and 5, Supplemental Digital Content 4 and 5, http://links.lww.com/PHM/B227, http://links.lww.com/PHM/B228) to complete the functional assessment. In TF, pulley swelling/thickening or effusion inside the synovial sheath may be present. In addition, tendon thickening and abnormal tendon motion associated with friction patterns are typical US findings.[37]

Various injection techniques have been reported in the literature. Owing to the highly innervated and sensitive palmar skin, some authors even recommend using the interdigital web skin for the needle entry point as a less painful alternative.[38] While planning for the intervention, power Doppler imaging would again provide clear identification of the neurovascular bundle (proper digital nerves and vessels) to be avoided. During the injection, a thin (e.g., 27-gauge, 19-mm) needle is preferred to reduce the procedure-related pain. With the transducer placed in a longitudinal, oblique plane on the palmar side, the needle can be inserted via the interdigital wing skin (Fig. 2C). The

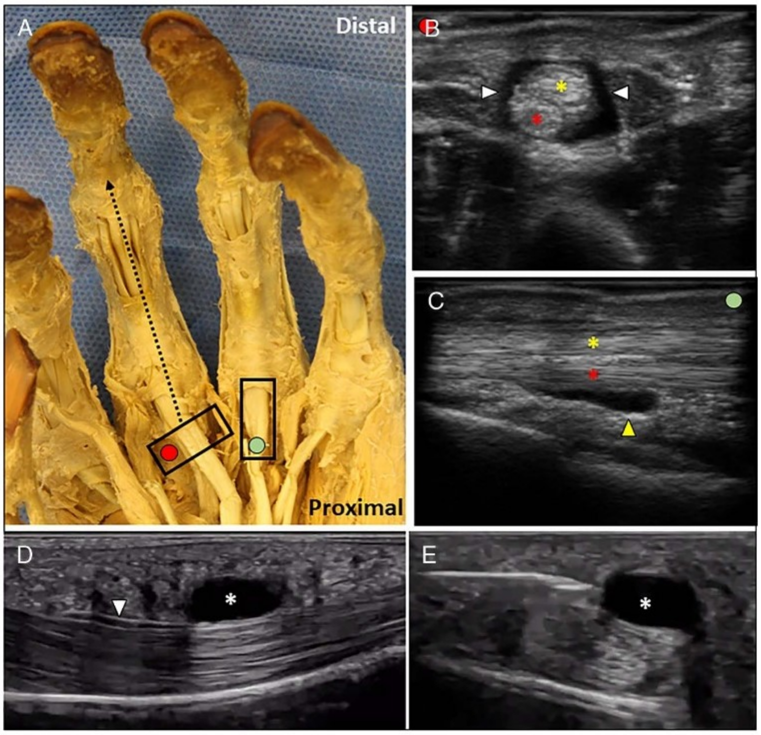

FIGURE 3. After the US-guided intervention for the trigger finger, a postprocedure check is recommended in two orthogonal planes and using the elevator technique (black dotted arrow) (A). A circumferential, anechoic ring (white arrowheads) surrounding the superficial (yellow asterisk) and deep (red asterisk) flexor tendons in short-axis view (B) and a cul-de-sac collection (yellow arrowhead) below the deep (red asterisk) flexor tendons in long-axis view (C) are usually considered to be confirmatory for a correct intrasheath injection. For sure, the US-guided procedure for a trigger finger must be planned in relation to the specific clinical and ultrasonographic findings for each and every patient. In this particular case, a cyst-like lesion (white asterisk) originating from the pulley (white arrowhead) (D) has been approached using an in-plane technique in short-axis view to better perform needling of the mass (E). Black rectangle: probe.

injection may be performed using a direct in-plane technique, and the injectate is delivered into the intrasheath space underneath the affected pulley (Fig. 3A–E).

Exemplary Evidence

Corticosteroid injections improve TF by reducing flexor tendon and A1 pulley inflammation, with the documented response rates being between 45% and 80%.[39] A meta-analysis on treatment success showed better short-term effects of corticosteroid injections combined with lidocaine than lidocaine alone.[40] Shultz et al.[41] reported better success of corticosteroid injections (1 mo after the procedure) in patients with mild triggering than those with severe findings. Furthermore, the success rate was lower in cases with multiple digit involvement. The outcome was reported to be poorer in patients with coexisting diabetes and inflammatory conditions.[42] The long-term effectiveness of corticosteroid injections is possibly not as favorable as surgery; however, 37%–56% symptom relief has been reported in patients presenting with TF for as long as 10 yrs.[43,44]

In a study that included 124 trigger digits (119 patients), Rozental et al.[45] found a symptom recurrence rate of 56% at a median of 5.6 mos after the injection as well as higher rate of treatment failure in diabetic patients. According to one study, US guidance showed an accuracy of 70% with regard to intrasheath placement of steroids when compared with the rate of 15% for landmark-guided injections.[37] Concerning the corticosteroid preparation, Roberts et al.[46] reported a higher need for additional injections when triamcinolone was administered in contrast to dexamethasone or methylprednisolone. US-guided A1 pulley release is another procedure that can be performed. Significant pain reduction and functional improvement were reported in 98% of patients, with no recurrence of catching/locking in the first year of follow-up.[47] Compared with open surgery, US-guided treatment resulted in shorter sick leave and better cosmetic results, without any major complications.[48]

DE QUERVAIN TENOSYNOVITIS

de Quervain disease (DQD) was first described in 1895 by Fritz de Quervain (1868–1940) as a common cause of radial-sided wrist pain.[8] It is an inflammation of the abductor policis longus (APL) and/or extensor policis brevis (EPB) tendons, and their tendon sheaths confined within the first dorsal compartment at the level of the radial styloid. Several anatomic variations (e.g., subcompartmentalization or accessory abductor pollicis longus) are commonly seen in this extensor compartment (Fig. 4C). As such, (US) imaging is necessary to understand the local anatomy/relevance of the findings and to plan the likely intervention accordingly.

Anatomy

In general, the normal anatomy of the first extensor compartment describes the APL and EPB as a single tendon enveloped in a common extensor sheath running through a single fibro-osseous tunnel deep to the extensor retinaculum. However, this compartment shows a high anatomic variability with significant implications for DQD and the pertinent injections. One possible variation to be considered before the injection would be the presence of multiple compartments divided by septae, which was actually reported to be more prevalent in patients with DQD when compared with healthy individuals.[49] The septum usually creates a separate narrow compartment for the EPB tendon.[50] Regarding the tendinous anatomy, EPB is usually described as a single tendon inserting on the thumb's proximal phalanx. However, multiple EPB tendon slips with

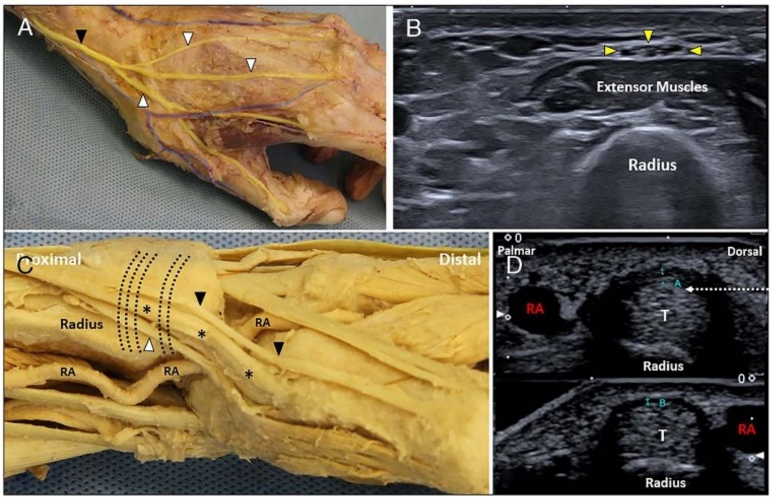

FIGURE 4. The cadaveric specimen shows the superficial branch (black arrowhead) of the radial nerve and its terminal branches (white arrowheads) coursing superficial to the fascia (A). Before any intervention at the level of the radial side of the forearm, sonotracking of the sensory components of the radial nerve (yellow arrowheads) should be performed for a safer planning of the procedure avoiding iatrogenic injuries (B). The extensor pollicis brevis (black arrowheads), abductor pollicis longus (black asterisks), and, in some patients, the accessory abductor pollicis longus (white arrowhead) tendons course proximally between the cortical surface of the radius and the retinaculum (black dotted lines), whereas, distally, they cross over the radial artery (RA) to reach the insertional sites (C). Comparative scanning may promptly identify pathological thickening of the first extensor retinaculum, and if clinically indicated, a US-guided injection, using an in-plane technique (dorsal to palmar approach) may be performed releasing the mixture at the retinaculum-tendon (T) interface (D). White dotted arrow: needle.

several different attachment points have also been described.[51] Moreover, EPB tendon was reported to be absent or replaced by an accessory tendon of APL in 6.2% of the cases, and EPB was also considered to be the most variable muscle in the forearm.[52] At least one slip of the APL is inserted on the first metacarpal base in almost all cases. However, the presence of multiple distal tendinous slips is ubiquitous, and they might insert into the trapezium or the carpometacarpal joint or can be merged with adjacent tendons.

US Imaging and Guided Injection Technique

The patient sits face to face with the physician, with a table in between. US imaging starts with the elbow flexed and the forearm in pronated position lying on the table/examination bed. The probe is placed axially over the Lister tubercle (at the distal radius), which can also/easily be palpated. However, forming a boundary between the second and third compartments, it serves as an anatomical landmark. Thereafter, the probe can be moved further radial to depict the first extensor compartment in the short-axis. Common sonographic findings of DQD comprise hypoechoic thickening of the extensor retinaculum and/or thickening of the first extensor compartment tendons (Fig. 4D; Video 6, Supplemental Digital Content 6, http://links.lww.com/PHM/B229). When performing dynamic scanning, gliding of the tendon(s) beneath the retinaculum can be compromised. Enhanced intratendinous vascular flow on power Doppler and a variable volume of inflammatory fluid in the synovial sheath can also be present. In general, a thin needle (e.g., 27 gauge, 19 mm) is inserted from either side of the probe using an in-plane approach to reach the tendon sheath (Video 7, Supplemental Digital Content 7, http://links.lww.com/PHM/B230). According to the US and clinical findings, DQD injections can be performed proximally at the common tendon sheath or distally after their division in the individual compartments. However, as the distal separate tendon sheaths are tighter, injection at this level may be more painful. Alternatively, an out-of-plane approach can be used as well. In case of aforementioned aberrations, the affected tendon sheath or subcompartment needs to be selectively injected under real-time guidance (Fig. 5A–E). Caution should be taken to avoid the radial artery (running on the volar side) and the superficial radial nerve, which courses from volar to dorsal just proximal to the radial styloid—with variable branching pattern (Fig. 4A, B; Video 8, Supplemental Digital Content 8, http://links.lww.com/PHM/B231).[53]

Exemplary Evidence

Corticosteroid injection into the first dorsal compartment sheath is a commonly used treatment approach for DQD patients. A systematic review and meta-analysis investigating the effectiveness of corticosteroid injection in DQD reported a significant increase in the resolution of symptoms, pain relief, and increased function. In the analyzed studies, the most commonly used steroids were methylprednisolone, dexamethasone, and triamcinolone.[54] In 2007, Sawaizumi et al.[55] compared a landmark-guided single injection (above the tender induration) and two-point injection (over the EPB and APL tendons), and the latter technique provided better outcomes—with the efficacy reaching 89%. In 2017, another systematic review proposed that if a single injection technique is to be administered, a proximal (rather than distal) injection should be preferred because it would be more likely to infiltrate multiple compartments in case of septations.[49] Importantly, with the use of US guidance, new techniques are being widely reported in the recent literature.[56] McDermott et al.[57] reported at least partial

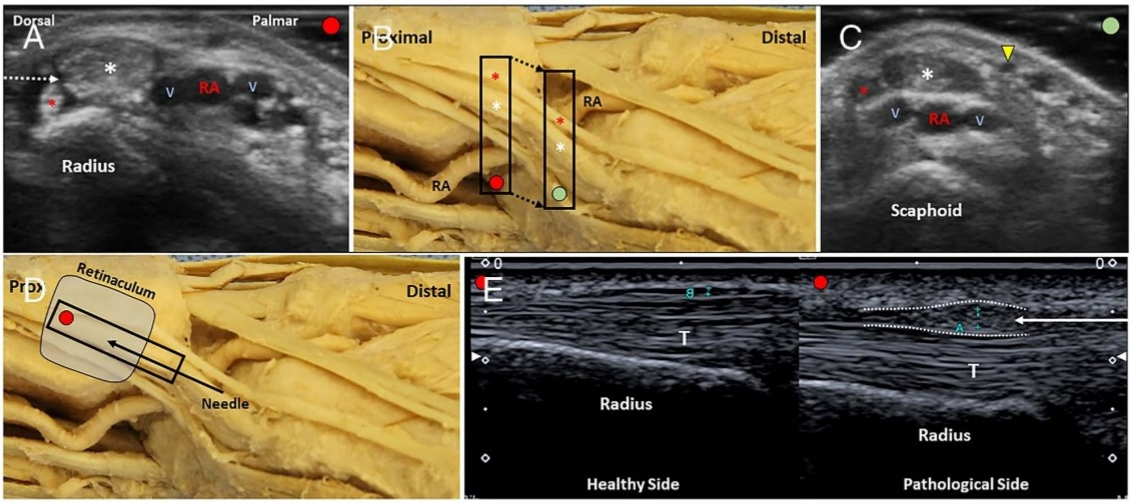

FIGURE 5. In selective pathologies of the extensor pollicis brevis tendon (red asterisk), a US-guided injection targeting its synovial sheath may be performed. Avoiding the abductor pollicis longus tendon (white asterisk) is possible with the use of an in-plane (dorsal to palmar approach) at the distal end of the radius (A). Of note, shifting the probe (black rectangle) more distally (B), the injection may be more challenging because of the "criss-cross" between the tendons, the radial artery (RA), and the distal branch (yellow arrowhead) of the sensory component of the radial nerve (C). If clinically indicated, a US-guided needling/release of the first extensor retinaculum can also be performed using an oblique longitudinal acoustic window (D). Targeting the thickened retinaculum (white dotted lines) and avoiding the underlying tendons (T) are possible with back-and-forward movements of the needle (white arrow) (E). White dotted arrow: needle. V indicates vein.

resolution of symptoms in 97% of the patients 6 wks after the US-guided injection. In their retrospective study, Hajder et al.[58] reported good long-term (7.3 mos) results in 91% of patients who received two US-guided corticosteroid injections. US was shown to be important in the visualization of an intercompartmental septum, and US-guided injections were proven to be accurate—providing good outcomes.[59] In short, the efficacy and safety of corticosteroid injections are linked to prompt imaging and guidance.[60–63] Although studied in a small group of cadavers/patients, US-guided release in patients with DQD has been reported as a safe and reliable procedure, without any specific morbidity.[64]

RHIZARTHROSIS

The first carpometacarpal (CMC) or the trapeziometacarpal joint is the second most commonly affected site by primary idiopathic arthritis in the hand, only after the distal interphalangeal joints.[65] *Rhizarthrosis* and *thumb CMC osteoarthritis* are commonly used terms to describe morphologic alterations due to degenerative process of the CMC joint. The thumb is the key contributor to hand function. As such, symptomatic rhizarthrosis can interfere with work and normal daily activities, potentially resulting in significant functional disability coupled with decreased quality of life. Moreover, pain in the thumb and the radial side of the wrist is associated with rhizarthrosis.[66] It is more prevalent in postmenopausal women and in elderly patients.[67] Its diagnosis is based on clinical evaluation, radiographic, and US examination.

Anatomy

The first CMC joint is a biconcave saddle-type joint between the first metacarpal base and the trapezium bone. Its shape with extensive articular surfaces allows motion in three planes, providing wide mobility and active opposition.[68] The great range of motion is associated with a need for stability, which is provided by a system of ligamentous structures that stabilize the joint while performing a pinch movement. Lateral, anterior, and posterior ligaments, together with a fibrous capsule, bind the first metacarpal and trapezium bones together (Fig. 6A). The joint's stability is important because clinical studies have correlated joint laxity with the development of CMC osteoarthritis. The forces affecting the first CMC are great. Biomechanic studies have shown that while performing grasp and pinch, the forces increase exponentially from the tip to the CMC joint.[68] Some muscles (e.g., APL and extensor pollicis brevis) and arteries (e.g., radial artery) are situated in the proximity of the first CMC.

US Imaging and Guided Injection Technique

The patient is seated face to face with the physician. The arm is flexed to 90% in the elbow, and the hand is resting on a table or bed with the thumb facing upward.[66] The probe is attached to the radial side of the first metacarpal and translated proximally until the base of the first metacarpal and trapezium bones is identified (Fig. 6B). If the joint is not clearly visible, passive thumb motion can reveal the joint margins.[69] Identification of APL and EPB tendons crossing the joint, as well as the radial artery, is important to avoid collateral damage (Fig. 6C).[66]

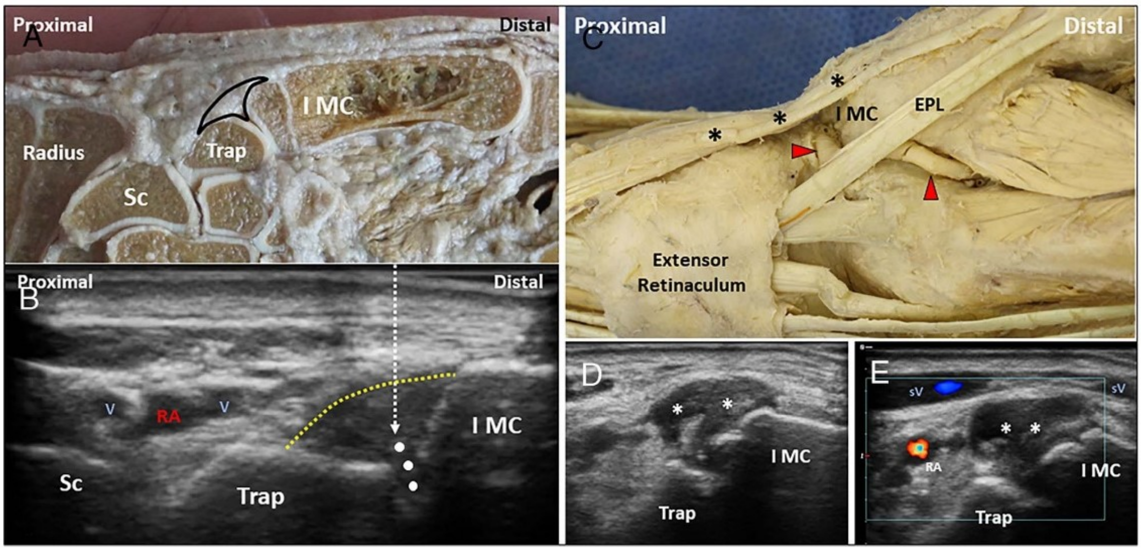

FIGURE 6. The cadaveric specimen—with an internal view—shows the triangular-shaped joint (black line) between the trapezium (Trap) and the proximal end of the first metacarpal bone (I MC) (A). Using an out-of-plane (radial to ulnar) approach, the needle tip (white dotted arrow) can be clearly visualized passing the capsule (yellow dotted line) and releasing the mixture (white dots) into the joint cavity avoiding the radial artery (RA) and veins (V) (B). The cadaveric specimen—with an external view—shows the tendons of the first extensor compartment (black asterisks) and the radial artery (red arrowheads) partially "covering" the trapezium–I MC joint (C). The US-guided injection should be modified in relation to the anatomical variability of each and every patient. In this particular case, detailed planning of the procedure was necessary to target the articular ganglion (white asterisks) originating from the trapezium (Trap)–I MC joint (D). Color Doppler imaging clearly shows the radial artery (RA) and superficial vein (sV) surrounding the mass (E). Sc indicates scaphoid bone; EPL, extensor pollicis longus tendon.

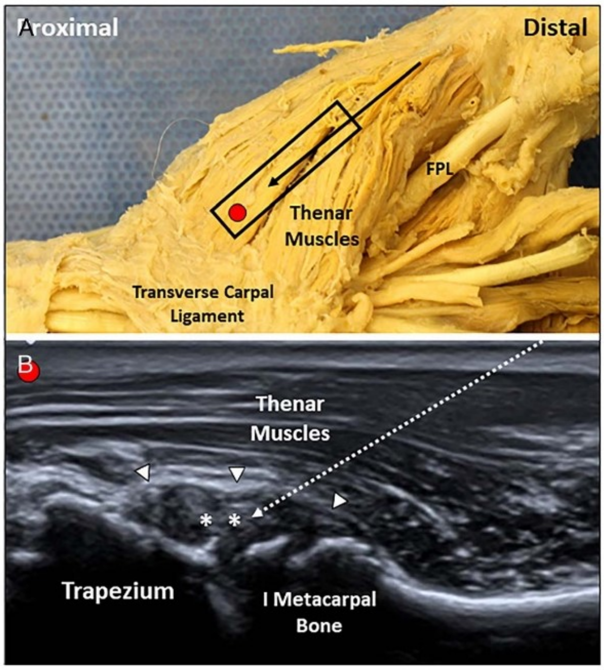

FIGURE 7. In selected cases, an in-plane (distal to proximal) approach may be used to target the trapezium–first metacarpal joint from the palmar side (A). Of note, using this technique, the needle (white dotted arrow) is advanced through the thenar muscles to pass the capsule (white arrowheads) and target the synovial cavity (white asterisks) (B). As such, a palmar approach may be more painful compared with the dorsal one. Black rectangle: probe; black arrow: needle. FPL indicates flexor pollicis longus tendon.

Findings that might be present in patients with rhizarthrosis include joint effusion, articular space narrowing, cortical irregularities, and osteophyte formation (Fig. 6D, E). The injection is performed with a short 25- to 27-G needle. There are several techniques to perform the injection: in-plane or out-of-plane, lateral to medial, proximal to distal, or distal to proximal (Fig. 7A, B; Video 9, Supplemental Digital Content 9, http://links.lww.com/PHM/B232). The selection of the technique should be adapted to the individual anatomical variability and the physician's expertise.[69] Of note, because the joint space is very small, only a small amount of volume (max. 0.5 to 1 ml) should be injected to avoid pain caused by overdistension of the joint capsule.[66,70]

Exemplary Evidence

Despite the fact that rhizarthrosis is quite common, there are only poor-quality studies with inconsistent results in the literature.[71] Corticosteroid and hyaluronic acid injections are commonly used in the conservative treatment of rhizarthrosis. In a recent meta-analysis, hyaluronic acid was reported to be efficient on the function and corticosteroids on pain control in the long-term.[72] Herewith, the limitation in that meta-analysis was that there was high heterogeneity between studies with regard to different dosages/types of the drugs used. With regard to thumb OA, Riley et al.,[73] in their meta-analysis, stated that there is a lack of evidence on which injection-based therapy is the most effective. According to the RCT of Monfort et al.[74] with 88 patients using hyaluronic acid and betamethasone, both were effective in the management of rhizarthrosis, whereas the effectivity of HA was higher over time. The accuracy of US-guided CMC injections was found to be better than injections without US guidance.[75]

RADIOCARPAL JOINT ARTHRITIS

Because of inflammatory or noninflammatory causes (with a common eventuality of radiocarpal joint degeneration), patients usually present with pain and limited motion. The history should be focused on flagging previous injuries (e.g., distal radius/scaphoid fracture, scapholunate ligament injury) as well as an existing/early inflammatory condition (e.g., rheumatoid arthritis).[66,76] US examination of the radiocarpal joint can reveal pathologic findings such as joint effusion, synovial thickening, cortical irregularities, or formation of osteophytes.[69] Conservative treatment is usually initiated with anti-inflammatory medications and rest (e.g., wrist splints). Corticosteroid injection would perhaps be the next option to preserve function and to control pain. Aside from its therapeutic effect, the injection might diagnostically serve to distinguish between intra-articular pathologies, tendinopathies, or compressive neuropathies.[76] In patients who are not responsive to conservative alternatives, surgical treatment might be considered.

Anatomy

The radiocarpal joint is a biaxial and ellipsoid-type synovial joint, comprising the articulation of distal radius and triangular fibrocartilage with the scaphoid, lunate, and triquetrum bones (Fig. 8A). Together with the ligaments, triangular fibrocartilage (2–5 mm thick disc), composes a part of the triangular fibrocartilaginous complex. Triangular fibrocartilaginous

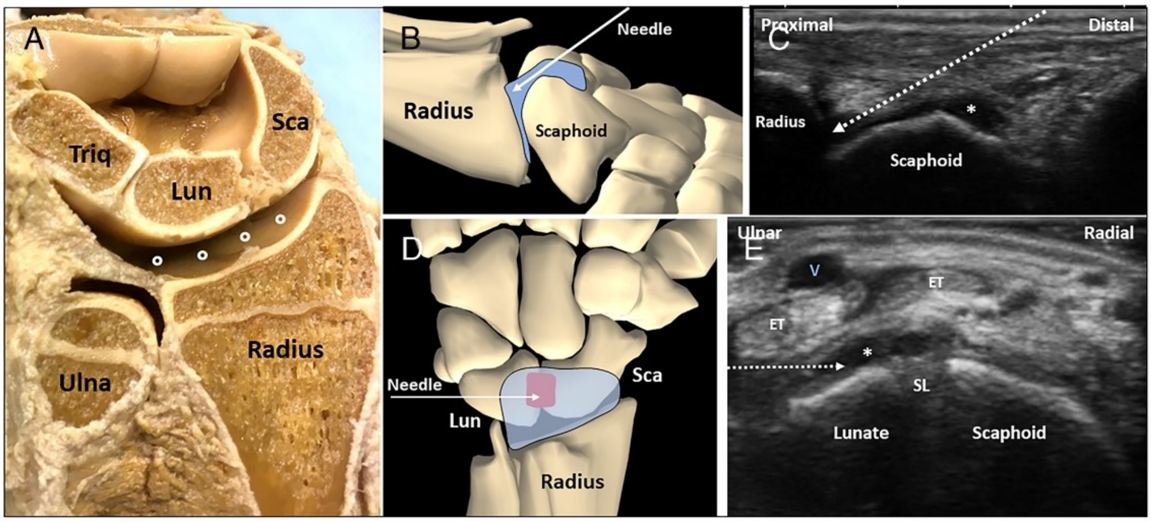

FIGURE 8. The cadaveric specimen—with an internal view—shows the radiocarpal joint (white dots) between the distal end of the radius and the scaphoid (Sca), lunate (Lun), and triquetrum (Triq) bones (A). Using an in-plane (distal to proximal) approach, the needle (white dotted arrow) can be advanced inside the dorsal, radioscaphoid recess (white asterisk) to perform a radiocarpal injection (B, C). Likewise, using an in-plane (ulnar to radial) approach, the dorsal recess of the radiocarpal joint (white asterisk), which is located between the dorsal scapholunate ligament (SL) and the extensor tendons (ET), may be easily targeted, keeping the needle more parallel to the US beam and optimizing its visualization (D, E). Blue: articular cavity; red: dorsal scapholunate ligament. V indicates vein.

complex suspends the ulnar carpus and distal radius from distal ulna. The fibrous capsule of the joint is lined by synovial membrane and is strengthened by palmar and dorsal radiocarpal, palmar ulnocarpal, and radial and ulnar collateral ligaments. When the wrist is in neutral position, only scaphoid and lunate are in contact with radius and the triangular fibrocartilaginous complex. Triquetrum comes to contact only when the wrist is fully adducted. Radiocarpal movements are evaluated together with the intercarpal bones, since they are both involved in wrist movements whereby same muscles perform the action. Active wrist joint movements are flexion, extension, abduction (radial deviation), adduction (ulnar deviation), and circumduction (all four movements together).

US Imaging and Intervention Technique

The patient can either be sitting in front of the examiner or lying supine. The supine position is more comfortable for the patient, lowering the risk of vasovagal syncope.[69] The forearm of the patient is in maximal pronation. A small towel is put under the wrist, which is in slight flexion, and the radiocarpal joint opens on the dorsal side.[77] For injection, radioscaphoid joint is a preferred place because it is easily accessible and there are no overlying tendinous or vascular structures.[69] The injection into the tendon sheath or the small vessels can easily be prevented with US guidance.[77] For localizing the radioscaphoid joint, the transducer is initially/axially put over the radial styloid and wrist. After visualizing the Lister's tubercle in the middle of the image, the probe is rotated 90 degrees to the sagittal plane, so the probe becomes longitudinal across the radioscaphoid joint. Pathologic US findings would be joint effusion, thickening of the synovium, articular space narrowing, bony irregularities, and osteophyte formation.[66,69] A 25-G needle loaded with 2–3 ml of injectate (e.g., corticosteroids, viscosupplementation, and platelet-rich plasma) volume is typically used.[66,78] The needle is inserted using the in-plane technique following a distal to proximal trajectory (Fig. 8B, C). Another possibility can be the out-of-plane approach following a radial-to-ulnar or ulnar-to-radial trajectory.[69] When the injection is correctly administered into the joint, no resistance should be encountered.[66] An alternative would be the in-plane technique and ulnar to radial approach, releasing the drug over the dorsal scapholunate ligament inside the dorsal radiocarpal recess (Fig. 8D, E).

Exemplary Evidence

According to a recent meta-analysis, US examination is a valid and reproducible technique for detecting synovitis in the wrist and it may be considered as a part of the standard diagnostic algorithm in RA.[79] Intraarticular injections are commonly used to treat (non)inflammatory conditions in the radiocarpal joint.[80] These injections have been traditionally given blindly, using palpation for landmarks to identify the joint. US-guided injections have better accuracy[78] and clinical efficacy.[80] Likewise, another RCT reported that US guidance improved the performance, cost-effectiveness, and clinical outcomes of intraarticular wrist injections in rheumatoid arthritis.[81] Concerning the comparison of operative *vs.* nonoperative treatments of wrist osteoarthritis, one recent meta-analysis has reported the paucity of prospective studies on the topic.[82]

CONCLUSION

As most of the wrist/hand structures are superficial, US imaging/guidance would be noteworthy for the management of pertinent disorders in the daily practice of musculoskeletal physicians. Accordingly, in this article, the authors tried to exemplify certain anatomical and technical issues that—they believe—excel such diagnostic and therapeutic procedures performed by using US. Last but not least, it is necessary to keep in mind that US is an invaluable tool to guide the holistic clinical approach to patients.

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Příloha 4

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LETTER TO THE EDITOR

WILEY

Sonography of the anterior cruciate ligament revisited

Dear Editor,

We have read with interest the article entitled "Ultrasound (US)-guided aspiration of anterior cruciate ligament mucinous cysts in the posterior intercondylar notch: Technique and short-term outcomes".[1] We would like to congratulate the authors for their work in describing the nonoperative management of mucinous cysts associated with theanterior cruciate ligament (ACL). This excellent article also draws attention to the ultrasound examination of the ACL. However, the authors reported that only one out of 13 patients had an US examination prior to MRI of the knee. We would like to emphasize the role of an initial US evaluation, which is less expensive than magnetic resonance imaging (MRI), more accessible and allows for dynamic testing. In addition, US evaluation has shown a high diagnostic performance to detect ACL injuries as reported in the recent systematic review with meta-analysis.[2]

We would also like to mention a common pitfall in the US evaluation of ACL. Anatomically, the ACL descends anterolaterally, twisting itself toward its attachment onto the tibia's anterior intercondylar area. The distal part of the ACL is usually separated in two bundles named according to their tibial attachments as anteromedial and posterolateral (Figure 1A). Of note, the two bundles have different biomechanical properties in terms of tension patterns. The ACL is covered anteriorly by a fat pad which occupies the infrapatellar space deep to the patellar ligament (Figure 1B). The Hoffa's fat pad consists of a framework of vessels and fibrous tissue resulting in a complex echotexture as commonly seen on US images. An important structure to note anterior to the ACL is the ligamentum mucosum (infrapatellar plica), which extends from the distal femur distally and anteriorly through Hoffa's fat pad to be attached to its central body. In a cadaveric study, the infrapatellar plica was reported to be present in 65% of specimens.[3]

The evaluation of ACL may be challenging, especially for inexperienced physicians.[4] For the US evaluation of the ACL, the patient is placed in the supine position, with maximal flexion of the knee. The probe is first placed along the patellar tendon and then slightly rotated along the course of ACL (30° clockwise for the left knee and 30° counterclockwise for the right knee). The ACL can be visualized as a hyper to hypoechoic (depending on the level of anisotropy) band-like structure beneath the Hoffa's fat pad (Figure 2A). Sometimes it is difficult to distinguish between the ACL and fibrous tissue septa or the infrapatellar plica within Hoffa's pad (Figure 2B).

We support the utilization of US for screening ACL disorders, provided the proper scanning technique as described above is used. A limitation of the US evaluation of the ACL is that only the mid and distal portions can be readily visualized. Another limitation is that not all patients presenting with knee pain are capable of the knee flexion that is necessary to obtain adequate images.

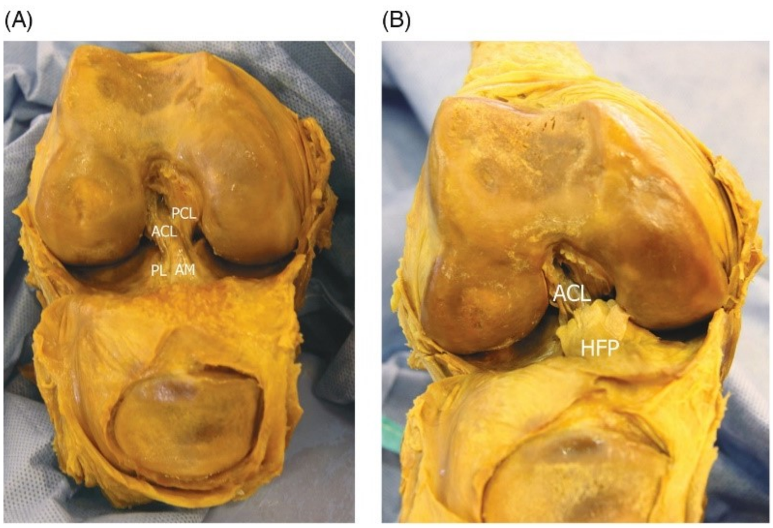

FIGURE 1 Cadaveric specimens of the knee showing normal anatomy. A, ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; AM, anteromedial part of ACL; PL, posterolateral part of ACL. B, HFP, Hoffa's fat pad; ACL, anterior cruciate ligament posterior to Hoffa's fat pad

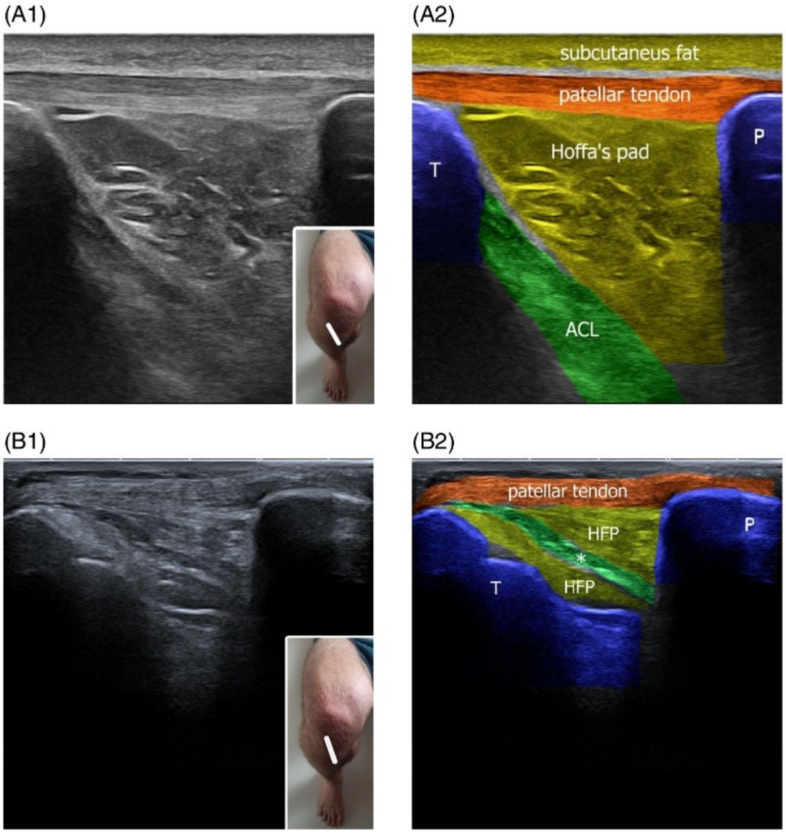

FIGURE 2 Sonograms of the knee joint. A, Longitudinal sonogram of ACL with colored diagram. The position of the probe is shown in inset. P, patella; T, tibia; ACL, anterior cruciate ligament. B, Longitudinal sonogram of Hoffa's pad with colored diagram. The position of the probe is shown in inset. P, patella; T, tibia, asterisk, ligamentum mucosum mimicking the anterior cruciate ligament

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Příloha 5

frontiers in Neurology

REVIEW
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Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment

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Ulnar neuropathy at the elbow (UNE) is commonly encountered in clinical practice. It results from either static or dynamic compression of the ulnar nerve. While the retroepicondylar groove and its surrounding structures are quite superficial, the use of ultrasound (US) imaging is associated with the following advantages: (1) an excellent spatial resolution allows a detailed morphological assessment of the ulnar nerve and adjacent structures, (2) dynamic imaging represents the gold standard for assessing the ulnar nerve stability in the retroepicondylar groove during flexion/extension, and (3) US guidance bears the capability of increasing the accuracy and safety of injections. This review aims to illustrate the ulnar nerve's detailed anatomy at the elbow using cadaveric images to understand better both static and dynamic imaging of the ulnar nerve around the elbow. Pathologies covering ulnar nerve instability, idiopathic cubital tunnel syndrome, space-occupying lesions (e.g., ganglion, heterotopic ossification, aberrant veins, and anconeus epitrochlearis muscle) are presented. Additionally, the authors also exemplify the scientific evidence from the literature supporting the proposition that US guidance is beneficial in injection therapy of UNE. The non-surgical management description covers activity modifications, splinting, neuromobilization/gliding exercise, and physical agents. In the operative treatment description, an emphasis is put on two commonly used approaches—*in situ* decompression and anterior transpositions.

Keywords: ulnar nerve (MeSH), ultrasound, musculoskeletal, US-guidance, entrapment neuropathy, cubital tunnel syndrome, peripheral nerve, elbow

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INTRODUCTION

Ulnar neuropathy at the elbow (UNE) represents the second most common entrapment neuropathy in the upper extremity encountered in clinical practice. The features suggesting a lesion of the ulnar nerve (UN) are based upon knowledge of the UN and its sensory and motor branch distribution. However, due to anatomic variations, a broad spectrum of differential diagnoses, and miscellaneous clinical presentations, the clinical diagnosis is often far from straightforward. If not treated timely and adequately, UNE can progress to persistent impairment of sensation, pareses, and joint contracture (1). Ultrasound (US) imaging might provide better insight into the UN morphology, mainly if the diagnosis is in doubt. The UN can be depicted using high-end

US equipment with a high resolution in its course from the axilla to palm level (2). US imaging is an emerging tool in physicians' clinical practice across different specialties (3), as it allows an immediate correlation between imaging and clinical findings. It also provides a sort of "US-assisted physical examination," e.g., "sono-Tinel" and "sono-palpation" (4). A better understanding of the relevant (sono)anatomy might help optimize clinical reasoning in patients presenting with UNE symptoms (5).

ANATOMY

In practice, there are mainly two locations where the UN can be compressed: the retroepicondylar groove and under the humeroulnar aponeurotic arcade (HUA). However, the UN can be entrapped at various sites across the elbow: the medial intermuscular septum (MIS) of the arm, the thickened proximal edge of the arcade of Struthers and the entire arcade of Struthers, cubital tunnel, connective tissue between the flexor carpi ulnaris (FCU), and flexor digitorum superficialis (FDS) muscles (**Figure 1**). The UN is the terminal branch of the brachial plexus's medial cord and originates mainly from C8 and T1 and sometimes also receives fibers from C7 roots. At the arm level, the UN descends toward the medial bicipital sulcus along with the MIS. Approximately 10 cm above the elbow (6), the UN penetrates the MIS from the arm's anterior to the posterior compartment (**Figure 2**) (7). Struthers' arcade is a non-constant, morphologically variable tendinous or muscular tissue situated 6–10 cm proximal to the medial epicondyle (ME), between the medial head of the triceps brachii muscle and MIS (1). Mizia et al. (8) estimated its prevalence as 53%. Tubbs et al. (9) described three types of Struthers' arcade. Type I was described as the most common, where thickening of the brachial fascia formed the arcade. In type II, the arcade is related to the internal brachial ligament (aponeurotic continuation of the brachialis muscle), and type III arcade is due to thickened MIS (9).

In some cases, the arcade can be formed by the superficial muscle fibers of the medial head of the triceps brachii muscle as they attach the MIS (10).

Then they pass through the retroepicondylar groove (RTC, groove for the UN in formal anatomical terminology), which a floor is formed by the posterior bundle of the medial collateral ligament, and the roof is represented by a superficial fascia or non-constant retroepicondylar retinaculum. In the relaxed condition (when the elbow is extended), the retinaculum is shorter, whereas it stretches during the elbow flexion. This retinaculum was described as a structure under which UN entrapment may occur (11). O'Driscoll et al. (12) divided the retinaculum into four groups, considering its morphology and function. In type 0, the retinaculum was absent. In type Ia, the retinaculum was lax in extension and taut in full flexion not compressing the UN. Type Ib stands for the retinaculum that tights at 90–120° of flexion, with evidence of UN compression. In type II, the ligament was replaced by the anconeus epitrochlearis muscle (12).

Abbreviations: CSA, cross-sectional area; FCU, flexor carpi ulnaris; ME, medial epicondyle of the humerus; MIS, medial intermuscular septum; RCT, randomized controlled trial; UN, ulnar nerve; US, ultrasound.

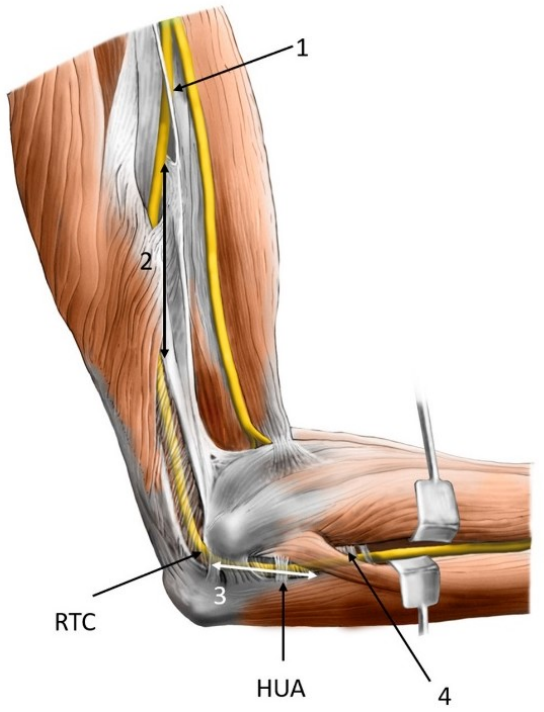

FIGURE 1 | Possible sites of compression of the ulnar nerve at and around the elbow: (1) the medial intermuscular septum of the arm, (2) arcade of Struthers, (3) cubital tunnel, and (4) connective tissue between flexor carpi ulnaris and flexor digitorum superficialis muscles. RTC, retroepicondylar groove; HUA, humeroulnar aponeurotic arcade.

The nerve continues distally behind (ME) the elbow. It enters the forearm through the true cubital tunnel (**Figure 3**), a space between the ulna and the ulnar and humeral heads of FCU, and a thickened fascial tissue connecting the two heads of FCU, known as the HUA (**Figure 4**) (13). HUA represents a thickened fascial tissue layer derived from the fusion of the antebrachial fascia and the deep fascia of the FCU (14).

After exiting the cubital tunnel, the nerve runs inside the FCU muscle and distally between the FCU and the flexor digitorum profundus (FDP) muscle. In the proximal forearm, the nerve runs at a certain distance from the ulnar artery, while more distally, the ulnar artery and nerve become adjacent. Won et al. (15) described the aponeurosis of flexor muscles of the forearm, such as intermuscular aponeuroses between the FCU and flexor digitorum superficialis, and between the FCU and the FDP as a potential site of entrapment of the UN (15).

EPIDEMIOLOGY AND RISK FACTORS

The prevalence of UNE reaches up to 5.9% in the general population (16). An increased risk for developing UNE has been reported in association with smoking (17). Another retrospective study identified increasing age and male sex as risk factors

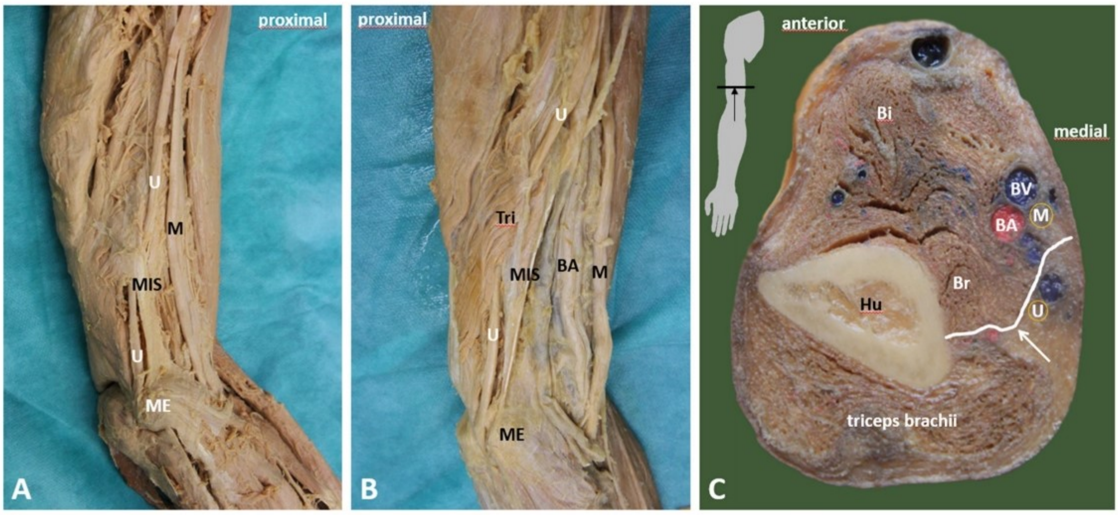

FIGURE 2 | Course of the ulnar nerve in the arm. **(A)** Relationship of the ulnar nerve (*U*) and the medial septum (*MIS*). Ulnar nerve penetrates the medial septum—the penetration is demarcated by a ligamentous thickening (Struther's arcade). **(B)** Penetration of the septum and further course of the ulnar nerve is covered by muscular fibers of medial head of triceps brachii muscle, which begins on the medial intermuscular septum. **(C)** Transverse section of midarm depicting the relationship between ulnar nerve (*U*) and medial intermuscular septum (white arrow). BA, brachial artery; Bi, biceps brachii muscle; Br, brachialis muscle; BV, brachial vein; Hu, humerus; M, median nerve; ME, medial epicondyle; MIS, medial intermuscular septum; U, ulnar nerve; white arrow, medial intermuscular septum.

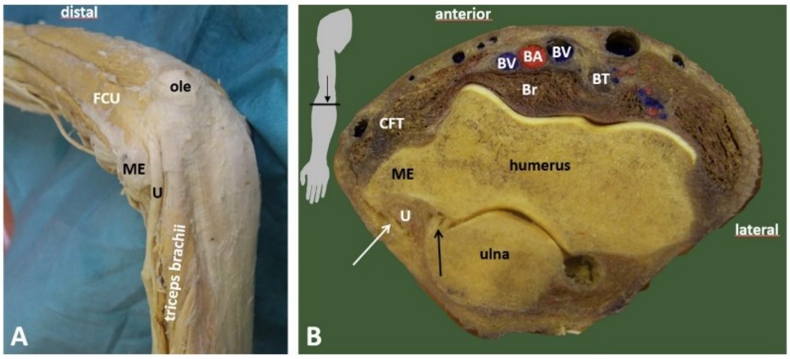

FIGURE 3 | Retroepicondylar groove and the entrance to the cubital tunnel. **(A)** Entrance of the ulnar nerve to the cubital tunnel. **(B)** Demarcation of the cubital tunnel. BA, brachial artery; Br, brachialis muscle; BT, biceps brachii muscle tendon; BV, brachial vein; CFT, common flexor tendon; FCU, flexor carpi ulnaris muscle; ME, medial epicondyle; ole, olecranon; U, ulnar nerve; black arrow, medial collateral ligament, posterior bundle; white arrow, retroepicondylar retinaculum.

for UNE development (18). UNE development is also possible in relation to occupational hand-arm-vibration exposure (19). Interestingly, UNE was reported on the left side more frequently than on the right, regardless of the patient's handedness (20). Although recurrent subluxation or dislocation of the UN and its contribution to UNE is widely debated, some authors consider the UN instability as one of the risk factors for UNE (21). The reported prevalence of UN instability varies depending on the method of measurement. In asymptomatic arms, Van Den Berg et al. (22) reported the occurrence of UN subluxation and dislocation as 5.7 and 5.7%, respectively. According to Omejec and Podnar, the incidence rate of UN subluxation and dislocation may reach up to 27 and 20%, respectively. According to their data, the UN dislocation may cause mild damage to the UN (23).

PATHOPHYSIOLOGY AND CAUSES

The UN at the elbow level can be harmed statically in entrapment neuropathies (usually below the HUA). UNE at the HUA level was reported to be associated with hard manual labor. By contrast, episodic damage to the UN may occur during specific

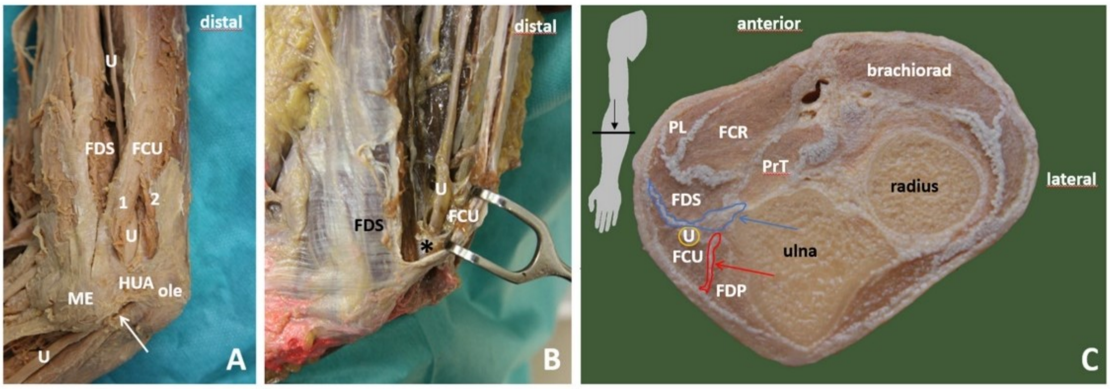

FIGURE 4 | Cubital tunnel. **(A)** View on proximal part of the cubital tunnel with humeroulnar aponeurotic arcade (*HUA*) and ulnar nerve (*U*) going between humeral (1) and ulnar (2) head of flexor carpi ulnaris muscle (*FCU*). The course of ulnar nerve between FCU and flexor digitorum superficialis muscle (*FDS*). Humeral head is moved away, and the retroepicondylar retinaculum is transsected (*white arrow*). **(B)** Ulnar nerve exiting the cubital tunnel to forearm. The nerve is in close relationship to intermuscular connective tissue between FCU and FDS (*black asterisk*). **(C)** Cross section of the forearm depicting the relationship between the ulnar nerve and surrounding muscles and connective tissues (*red and blue arrows*). (1) flexor carpi ulnaris muscle, humeral head; (2) flexor carpi ulnaris muscle, ulnar head; HUA, humeroulnar aponeurotic arcade; Brachiorad, brachioradialis muscle; FCU, flexor carpi ulnaris muscle; FDP, flexor digitorum profundus muscle; FDS, flexor digitorum superficialis muscle; ole, olecranon; PrT, pronator teres; U, ulnar nerve; blue arrow, intermuscular connective tissue between FCU and FDS, deep flexor pronator aponeurosis; red arrow, intermuscular connective tissue between FCU and FDP.

movements (typically elbow flexion) or external compression around the retroepicondylar groove, e.g., when the forearm is lying pronated on the desk during working on the computer (a possible explanation of the more common occurrence of UNE on the left) (23). The pathophysiology of dynamic UN compression is not yet fully understood. Nevertheless, some factors associated with elbow flexion seem to play a crucial role, e.g., tightening of the retroepicondylar groove retinaculum. Furthermore, a decrease in the canal's volume, increase of intracanal pressure, and the strain of the UN accompanied by its flattening were also documented during the elbow flexion (24, 25). A congenital absence of the retroepicondylar groove retinaculum forming its roof is one of the possible explanations for the increased mobility of the UN outside the retroepicondylar groove during elbow flexion (11). Another factor possibly contributing to the UN instability would be a shallow bony retroepicondylar groove (26). However, as UN instability was reported to be common in asymptomatic volunteers, the causative relationship between symptoms and UN instability remains unclear (27). Although asymptomatic in most cases, UN instability is considered as a possible cause of pain syndrome due to friction and increased pressure applied to the UN across the ME.

Furthermore, as the hypermobile UN becomes more vulnerable during flexion, a direct trauma or pressure forces might contribute to its damage. According to Bordes et al. (28) review, the UN instability can also contribute to frictional and tractional neuritis. The concept of "frictional neuritis" assumes the subluxating/dislocating UN being irritated during the movement against bony irregularities around an arthritic or post-traumatic joint. Interestingly, Leis et al. (29) proposed complete UN dislocation as a protective factor toward the nerve strain. In entrapment neuropathy, an impaired intraneural blood flow and axoplasmic transport inside the nerve might trigger swelling. If the flow inside the nerve remains impaired, long-term intra- and extraneural fibrotic alternation with irreversible nerve damage may occur (30).

In contrast, Omejec and Podnar reported the nerve constriction as typical for UN entrapment distal to the ME by using US imaging. Simultaneously, lesions at or proximal to the ME did not show the UN's characteristic hourglass appearance, indicating its swelling in the longitudinal view (31). Other underlying causes of UNE at the elbow would comprise nerve tumors or space-occupying lesions (ganglia, accessory muscles, bony irregularities/osteophytes, or traumatic bone abruption) (32). Regarding the accessory anconeus epitrochlearis muscle, its causative role in UNE development is controversial. Wilson et al. (33) reported the occurrence of accessory anconeus epitrochlearis muscle significantly lower in patients with cubital tunnel syndrome than in asymptomatic controls. They hypothesized that anconeus epitrochlearis might be a protective factor against UNE development (33).

DIAGNOSIS AND ULTRASOUND SCANNING TECHNIQUES

Diagnosis is based on history, physical examination, electrophysiological assessment, and US examination. Symptoms suggesting the UNE at the elbow are medial elbow pain, tingling, and numbness in the UN supplied area (usually the fourth and fifth digits). These symptoms are commonly aggravated with elbow flexion, e.g., when talking on the phone or leaning on the elbow at the table, or sleeping with the elbow bent more than 90°. Due to neuropathic pain, sleep disturbance is common

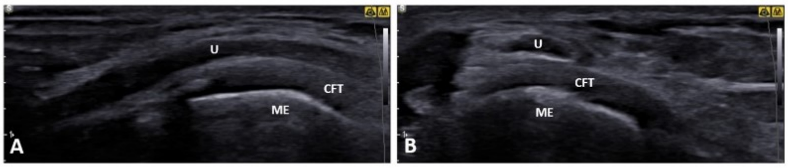

FIGURE 5 | Ultrasound (*US*) imaging of the ulnar nerve (*U*) at the level of the medial epicondyle (*ME*) in a patient with symptomatic ulnar nerve dislocation. Both longitudinal **(A)** and short-axis **(B)** views clearly demonstrate a close contact between the ulnar nerve and common flexor tendon origin. U, ulnar nerve; CFT, common flexor tendon; ME, medial epicondyle.

in patients presenting with cubital tunnel syndrome (34, 35). Patients sometimes describe having difficulties with typing on a keyboard, buttoning buttons, and opening bottles. However, more contributory (motor) findings suggesting UN damage are often absent initially (e.g., atrophy and weakness of the intrinsic hand muscles). The broad differential diagnosis even mounts diagnostic challenges, covering Guyon canal syndrome, carpal tunnel syndrome, C7 or C8 radiculopathy (sometimes coexisting with UNE), brachial plexopathy, or Pancoast's tumor invading its medial cord, generalized polyneuropathy, and tendinopathy (36). The UNE is often misdiagnosed as a golfer's elbow due to an intimate relationship between UN and the common flexor tendon (CFT) origin. Notably, in a case of UN instability, the nerve can be directly overlying the CFT during elbow flexion (**Figure 5**). In more severe cases, weakness and the UN's innervated muscle wasting can be apparent (the first dorsal interosseous muscle in particular).

Further characteristic findings of severe UNE are clawing of the ring and small fingers (also known as Duchenne's sign), Wartenberg's sign (involuntary abduction of the little finger), and a positive Froment's sign (weakening of the pinch grip between the thumb and index finger). Several diagnostic provocative tests aid in diagnosing UNE, e.g., the Tinel test at the retroepicondylar groove and the elbow flexion test with wrist extension. Additional shoulder internal rotation has been reported to increase sensitivity and specificity (24). Furthermore, impairment of two-point discrimination of the ring/small fingers can also be present. For assessing of the dislocating UN, sometimes, the nerve snapping beneath the fingertips anterior to the ME during elbow flexion can be perceived. The clinical severity is widely evaluated using McGowan's classification: Grade 1, intermittent subjective symptoms with or without mild hypoesthesia; Grade 2, remarkable sensory loss and measurable motor weakness of ulnar intrinsic hand muscles (both lumbrical and interosseous muscles); and Grade 3, persistent severe sensorimotor deficits with muscle wasting (37).

Electrodiagnosis represents a useful tool for diagnosing UNE, determining the site of entrapment and disease severity (from mild to demyelinating or axonal), aiding in prognosis, and ruling out alternative diagnoses (e.g., carpal tunnel syndrome or radiculopathy) (38). The following techniques can be used: motor nerve conduction studies (MNCSs), short segment motor studies (SSMSs), sensory nerve conduction studies (SNCSs), and needle examination. UN MNCS is a commonly performed method. As the length of the standard MNCS measured segment is 10 cm, a small lesion typical for UNE can be missed because of the dilution of the short abnormal segment in a much longer unaffected measured segment. Therefore, another method called SSMS (inching) technique is used to reveal the UN's focal damage more precisely. The elbow should be flexed to 90°, to prevent slack of the UN, which occurs when the elbow is fully extended and leads to an apparent slow conduction velocity across the elbow (39). The inching method evaluates short segments (most often 2 cm blocks) of the UN from under the elbow to above the elbow. This method's advantage is the precise localization of the nerve damage, which is important because it can influence decision making on whether conservative or surgical treatment is more beneficial (40). On the other hand, this method is technically more difficult, and despite the higher sensitivity, this method is rarely used in clinical practice. Some studies presented normative and reference values for SSMS UN evaluation (31, 41). As sensory nerves are more sensitive to compression than motor nerves, SNCS reveals pathology earlier than MNCS, but it has low significance in the diagnostic process because of its low specificity. Needle examination is important for ruling out other nerve damage sites such as wrist, brachial plexus lesion, or C8 radiculopathy. However, electrodiagnostic studies are not contributory in assessing the morphology of the UN and its surrounding tissues. A secondary cause of UN compression (e.g., ganglion and heterotopic ossification) can be missed if an imaging examination is not carried out.

Additionally, the clinical (and electrophysiological) examination can lead to an erroneous diagnosis if an anomalous innervation is present, e.g., Martin–Gruber or Marinacci anastomosis (42, 43). These forearm interconnections between the motor branches of the ulnar and median nerves account for a prevalence of up to 39% of healthy individuals (44) and can be sometimes identified with US imaging (45). To this end, US or magnetic resonance imaging should be considered, mainly if the diagnosis is in doubt. Conventional radiographs can be beneficial in assessing for the cubitus valgus, bony deformities, and space-occupying lesions (e.g., heterotopic ossification).

ULTRASOUND SCANNING TECHNIQUES

Device Settings and Patient Positioning

The images and videos in this section (except for the images of exemplary pathology) were obtained using the Samsung UGEO HM70A machine (Samsung, Seoul, South Korea) with a 3–16 MHz linear transducer. Settings for the depth, gain, and frequency were adjusted by the examiner to obtain the optimal image of the UN. The focus was positioned at the same depth or just below the UN. For the comfortable UN visualization in the retroepicondylar groove, the patient is positioned supine on the examination bed. The patient's arm is resting on the examination bed with the forearm hanging over the edge of the bed, so the examiner can comfortably reach the retroepicondylar groove. The described position is comfortable for both the patient and the examiner (46). The UN evaluation and dynamic dislocation test can be easily performed, while the examination bed provides excellent probe stability. For the UN assessment at the elbow, both static and dynamic scans need to be performed (47).

Static Evaluation

First, the transducer is positioned between the olecranon and the medial humeral epicondyle. The UN can be seen adjacent to the ME's bony surface as a uni- or multifascicular hypoechoic, round, oval, or triangle-like structure surrounded by a hyperechoic rim (**Figure 6A**). Due to the arching course, the UN appears hypoechoic at the retroepicondylar groove as a result of anisotropy (48). A hypoechoic band extended from the medial humeral condyle to the olecranon represents the retroepicondylar retinaculum. Rotation of US transducer 90° will change the short-axis view into a long-axis view of the UN (**Figure 6B**). In the authors' opinion, this is a convenient site from which the UN can be easily tracked either proximally or distally. For the proximal tracking, the UN is followed from the retroepicondylar groove further proximally. It ascends along the anterior aspect of the medial head of the triceps brachii muscle, posterior to the MIS (**Figure 7A**). Further proximally, at the midarm level, it inclines laterally while piercing the MIS to reach the anterior compartment, where it accompanies on the posteromedial side the proximal part of the brachial artery and brachial veins (**Figure 7B**). More proximally, the UN runs beside the axillary artery. For the UN distal tracking from the retroepicondylar groove level, the examiner follows the UN while entering the cubital tunnel between the humeral and ulnar heads of the FCU (**Figure 7C**). More distally, the UN runs inside the FCU and further between the FCU and FDP muscles (**Figure 7D**). In the proximal mid-forearm, the UN starts to be accompanied by the ulnar artery (**Figures 4**, **7E**). At the wrist, the UN enters its cross-sectional triangular-shaped Guyon canal, which is superficially bounded by the palmar carpal ligament. The transverse carpal ligament forms the floor, and the pisiform represents the medial border (**Figure 7F**).

In general, characteristic US findings suggest nerve function impairment and swelling (usually) proximal to the compression site, loss of the normal nerve fascicular pattern, and reduced nerve mobility (47). In addition, the Doppler sonography can reveal hypervascularity to evaluate the severity of UNE (49).

An essential method to evaluate the UN statically is the measurement of its cross-sectional area (CSA) along the inner hypoechoic border (**Figure 8**). At the same time, the examiner can use digital tracing methods to obtain its numeric values. According to Chang et al. (50) meta-analysis, UN CSA's upper cutoff value of 10 mm^2 at the ME level should be considered for diagnosing UNE. Mean values of 18.3 mm^2 in CSA were reported in severe cases with axonal loss (51). As an alternative, a swelling ratio of the UN $CSA_{ME}/CSA_{forearm}$ has also been proven as a good indicator to diagnose UNE, particularly in patients with polyneuropathy (52, 53). Besides, a focal change of the UN diameter or hourglass-shaped appearance suggests of the location of the nerve lesion in case of mechanical compression or torsion (54).

Dynamic Evaluation

While the hand of the examiner is supported on the examination bed, the patient's supine position for the UN dynamic assessment provides excellent probe stability during passive movement from extension to full flexion (usually 135°) of the elbow. Notably, the examiner should avoid too much pressure on the transducer, as this may cause deformation of the UN and prevent its dislocation. Dynamic US evaluation of the UN allows real-time visualization of the UN in high resolution throughout elbow flexion and extension. Thus, it is considered the gold standard method to assess its stability within the retroepicondylar groove. In a part of the population, the UN moves anteromedially, out of the retroepicondylar groove upon elbow flexion either onto the tip (**Supplementary Video 1**) or snapping entirely anterior to the ME (**Supplementary Video 2**). At the same time, it relocates back to its groove during extension (22). For increased mobility of the UN, Childress, in 1975, proposed a classification to type A (incomplete dislocation) and type B (complete dislocation) during elbow flexion (55). The UN hypermobility was identified in 37% and of those bilaterally in 30% as reported by Calfee et al. (56). Besides increased mobility, the UN during elbow flexion also shows a change in its shape in terms of flattening (25).

Exemplary Pathologies

Theoretically, the UN can be compressed at any site along its course in the upper extremity (32). Besides idiopathic entrapment neuropathy, other relevant causes of UNE are space-occupying lesions, e.g., ganglion (**Figure 9A**), heterotopic ossification (**Figure 9B**), anconeus epitrochlearis accessory muscle (**Figure 9C**), peripheral nerve tumors, elbow fractures associated with cubitus valgus or post-traumatic degenerative joint disease (**Figure 9D**), the nerve compression from scar tissue (**Figure 9E**), aberrant veins (**Figure 9F**) (57), and systemic diseases, e.g., diabetes or leprosy. Importantly, dynamic nerve irritation associated with repeated subluxation/dislocation outside the retroepicondylar groove during flexion of the elbow is also possible (**Supplementary Videos 1, 2**) (58).

NON-SURGICAL TREATMENT

Conservative treatment of UNE region mainly consists of approaches based on empirical experience more than on a significant level of quantified evidence. A key component of the treatment is to instruct the patient concerning risky arm positions, along with situations and movements that should be avoided. Furthermore, non-operative treatment often includes anti-inflammatory medications, manual therapy, splinting,

FIGURE 6 | Normal ultrasound images of the ulnar nerve. **(A)** Short axis. **(B)** Long axis. U, ulnar nerve; ME, medial epicondyle; arrowheads, retroepicondylar retinaculum.

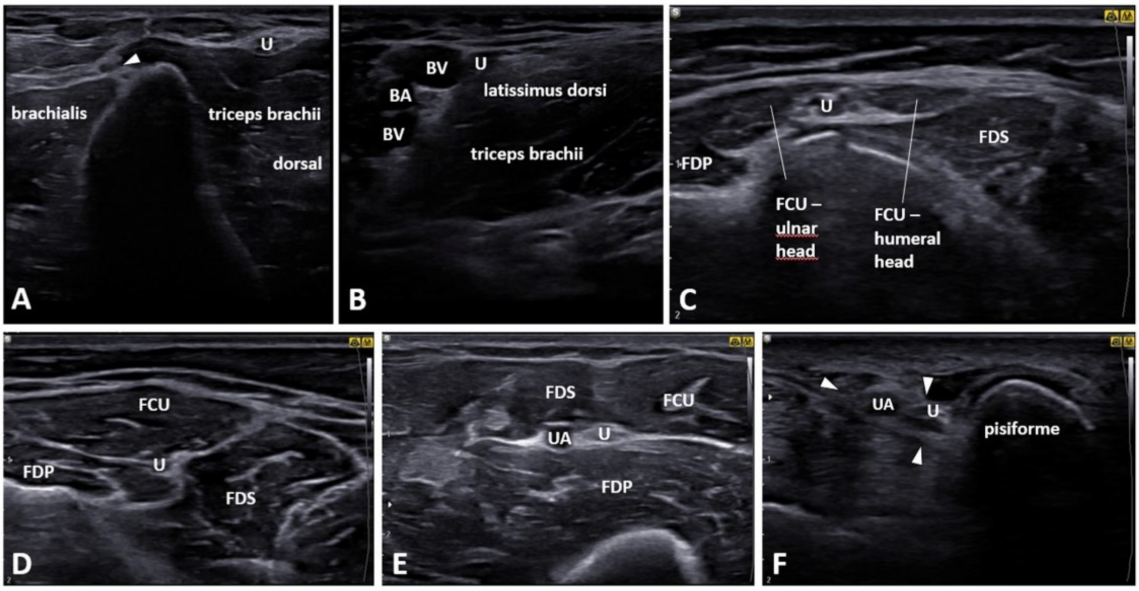

FIGURE 7 | Proximal and distal tracking of the ulnar nerve starting from the retroepicondylar groove. **(A)** Midarm, arrowhead: medial intermuscular septum. **(B)** Proximal midarm. **(C)** Flexor carpi ulnaris muscle (FCU) level. **(D)** Proximal forearm. **(E)** Proximal mid-forearm, the ulnar nerve accompanied by the ulnar artery. **(F)** Ulnar nerve in Guyon canal (*arrowheads*). FDP, flexor digitorum profundus muscle; FDS, flexor digitorum superficialis muscle; U, ulnar nerve; BA, brachial artery; BV, brachial vein.

kinesiotaping, exercise and neurodynamic mobilization, electrotherapy, shock wave therapy, dry needling, and injections. In general, the non-surgical treatment seems to be less suitable for patients with persistent post-traumatic cubital tunnel symptoms (59). Omejec and Podnar reported a study on 96 patients where the treatment was tailored based on the presumed mechanism of the UN's compression. The patients with external compression were instructed to avoid risky positioning, and those with entrapment under the HUA were offered surgical release. They reported an improvement in 83% of HUA and 84% of RTC patients. In line with this strategy, another 11 patients who were treated contrary to their recommendations showed less favorable outcomes (60).

The majority of studies on conservative treatment of UNE consists of case reports or case series with a low number of patients. Nearly all studies demonstrated clinical improvement in patient symptoms over time. However, the absence of adequate controls made it difficult to distinguish the natural amelioration of cubital tunnel syndrome from the effects of therapy (61).

The latest Cochrane review on the treatment of UNE identified only two studies on the treatment of UNE using conservative approaches (62). Besides, it was not very clear when to treat a person with this condition conservatively or surgically (62). Another recent systematic review confirms the paucity of literature and high-quality studies regarding the conservative management of cubital tunnel syndrome. The following treatment modalities were identified: education and activity modification, splinting, steroid/lidocaine injection, nerve mobilization/gliding, pulsed US, laser therapy, non-steroidal anti-inflammatory drugs, and physiotherapy. Kooner et al. (61) systematic review suggested that activity modification/education and splinting may be effective for mild or moderate disease.

Svernlöv et al. (63) published one of the few clinical trials evaluating the conservative treatment of cubital tunnel

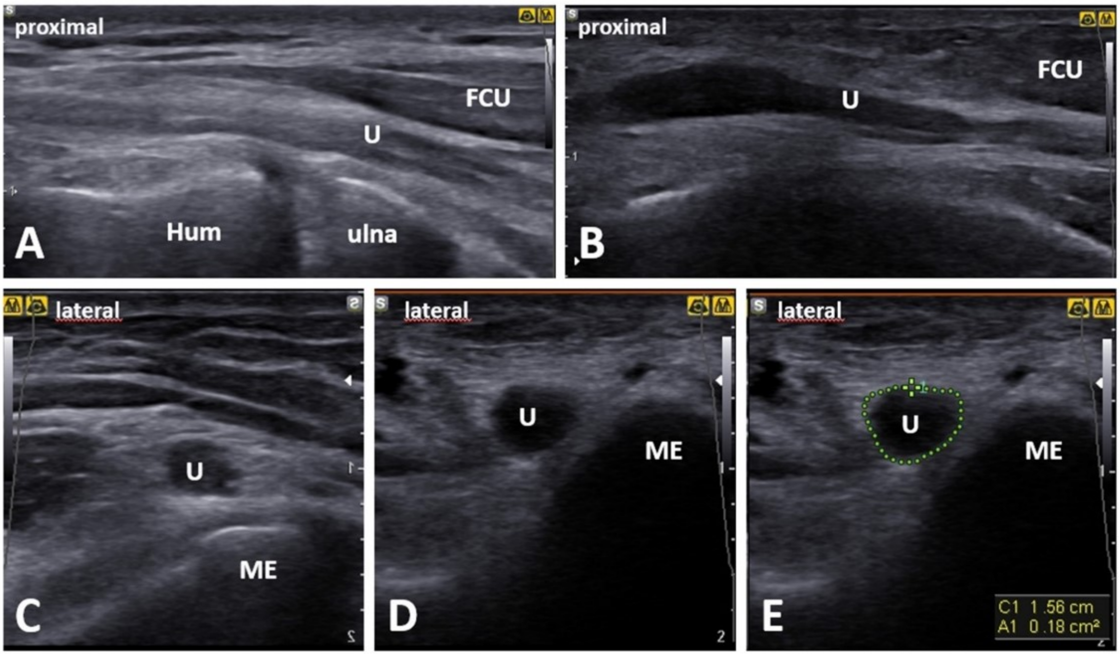

FIGURE 8 | Comparative ultrasound (*US*) imaging of the ulnar nerve (*U*) at the level of the medial epicondyle (*ME*) in a patient with cubital tunnel syndrome. When compared with the normal side. **(A)** The asymptomatic side in a long axis of the ulnar nerve. **(B)** The symptomatic side ulnar nerve shows swelling ("bottle neck appearance") proximal to the cubital tunnel inlet in long-axis. **(D,E)** In short axis, compared with the normal side **(C)**, the ulnar nerve on the symptomatic side shows enlargement in its cross-sectional area of 18 mm^2 outlined using the direct US tracing method (*green dotted line*). Hum, humerus; FCU, flexor carpi ulnaris muscle.

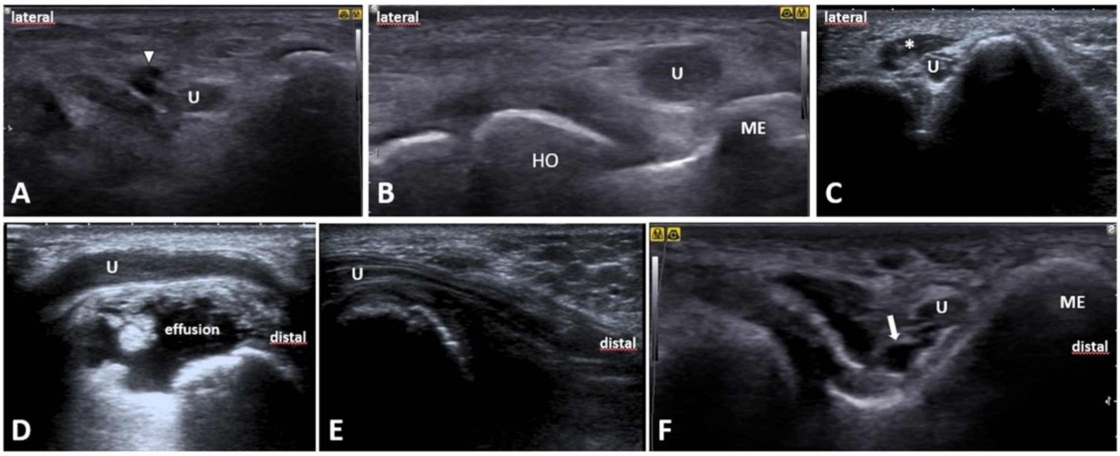

FIGURE 9 | Ultrasound images of the ulnar nerve exemplary pathologies. **(A)** Short-axis image at the level of the humeral medial epicondyle (*ME*) shows the ulnar nerve (*U*) in an intimate contact with a ganglion (*white arrowhead*), likely derived from the triceps tendon. **(B)** A short-axis US image of the ulnar nerve situated just next to the heterotopic ossification (*HO*). **(C)** The ulnar nerve short-axis image shows an accessory anconeus epitrochlearis muscle (*asterisk*). **(D)** A longitudinal US image of the post-traumatic degenerative joint disease with effusion compressing the ulnar nerve. **(E)** A longitudinal image of the ulnar nerve depicts the nerve compression from scar tissue after olecranon surgery. **(F)** A short-axis view at the ulnar nerve (*U*) shows an aberrant vein (*white arrow*) next to it. ME, medial epicondyle of humerus; U, ulnar nerve.

syndrome. This study of 3 months' duration enrolled 70 subjects with mild-to-moderate discomfort, while 51 subjects completed the study. All patients were employed as manual laborers. The subjects were randomly divided into three groups. One group was instructed to use a prefabricated elbow brace each night for 3 months. The brace prevented flexion of more than 45°. The second group was instructed to perform nerve gliding exercises. The third group did not perform exercises or apply any night braces. All three groups received the same written information on the anatomy of the UN, an explanation of the probable pathomechanics, and a regimen regarding the avoidance of movements and positions provoking the symptoms. Surprisingly, after 6 months, there was no significant difference in hand function, pain, strength, and neurophysiological examination. Ninety percent of patients with mild-to-moderate cubital tunnel symptoms (most patients had normal electrodiagnostic testing) improved with non-surgical treatment. In that study, 10% of patients had proceeded to surgical intervention at 6 months. Information on the causes of the condition and how to avoid provocation appeared sufficient, while night splints and nerve gliding exercises did not add favorably in this patient group (63).

Instructions to the Patients

It is supposed that traction is one of the key mechanisms causing harm to the UN, while an elevated level of strain is strongly associated with elbow flexion. Furthermore, the duration of abnormal postures or repetitive motion probably plays a significant role in the UNE development. The strain in UN is particularly increased when nerve gliding is limited. As Vinitpairot et al. (64) described on a cadaveric model, the strain on the UN can increase if nerve gliding is restricted by 154% while working on a computer. The long-term static activity of the FCU muscle, e.g., when using a cell phone or working on a computer, or in relation to some occupations (e.g., glassmakers), probably also plays an important role. If repetitive external pressure and traction occur, often concerning activities that provoke pain and paresthesia, these symptom-causing activities should be avoided or modified. The importance of modification of movement regime was demonstrated in the above-mentioned study by Svernlöv et al. (63), where night splints and nerve gliding exercises did not add any benefit in addition to the simple instruction to avoid provocative moments (63). Arm position control may be difficult during sleep when the arm may move into a sharp flexion of the elbow beyond conscious control; hence, the use of a night brace may be appropriate in some cases.

Splinting

The main principle of splinting is the reduction of compressive and tensile pressure on the UN by limiting elbow flexion (65). A nightly fixation of the elbow with a splint made of plastic material with good padding from the middle of the upper arm all way to the hand (30–35° flexion of the elbow, forearm at 10–20° pronation, and the wrist in a neutral position) for 6 months led to a significant amelioration of symptoms (66, 67). Nocturnal splinting can be shorter in clinical practice than the 6 months mentioned above, depending on symptom relief. Other splint options range from rolled towels placed in the antecubital fossa and secured with an elastic bandage using a neoprene brace with aluminum reinforcement to rigid thermoplastic custom-fit orthoses.

Neuromobilization/Gliding Exercise

Therapeutic approaches based on neurodynamics have become a popular model for manual therapeutic techniques in peripheral nerve neuropathy. In particular, Butler's description of these techniques has become the norm (68). A fundamental premise of this concept is that intraneural swelling at the affected peripheral nerve site restricts intraneural blood flow (69). Simultaneously, correctly applied dynamic changes in intraneural pressure can act in a "pumping action" or "milking effect" and thus reduce this intraneural swelling together with a reduction of the symptoms (70, 71). Another assumption is that neurodynamic techniques may limit fibroblastic activity and minimize scar formation via normal and early use of mesoneurial gliding tissues (72).

The basis of this therapeutic concept is two different techniques—a sliding technique and a tensioning technique. Generally speaking, sliding is achieved by increasing the tension on the peripheral nerve by correctly applying changes in joint position at one end and releasing the tension of the nerve at its opposite end—in the UN, this is elbow flexion and simultaneous shoulder abduction or vice versa. Tensioning is achieved by increasing the tension of the nerve at both ends at one time. Indeed, in cadavers, it has been shown that a typical UN sliding technique does cause nerve movements of 8.3 mm proximal to the elbow with almost no impact on the nerve strain while tensioning causes a nerve displacement of only 3.8 mm and stretches the nerve by 9.8%. From these data, it seems that the sliding technique is less aggressive and may be more appropriate for acute injury, postoperative management, and situations leading to nerve irritation and entrapment such as bleeding and inflammation around the nerve (73). However, while in the case of carpal tunnel syndrome, neural mobilization showed some positive neurophysiological effects (e.g., reduced intraneural edema), the effect on cubital tunnel syndrome remains uncertain (74). However, it should be emphasized that the successful use of neurodynamic techniques depends, of course, on the experience and skills of the physiotherapist or physician and their ability to correctly implement these techniques in patients and to combine these approaches with manual soft tissue release (fascias in particular), forearm muscle relaxation (especially FCU muscle), and other manual techniques.

Electrotherapy, Shock Wave Therapy, and Laser Therapy

As in the case of electrotherapy, shock wave therapy, or laser therapy in the treatment of UNE, there is insufficient evidence for a clear choice of an effective approach. Bilgin Badur et al. (75) published one of the few double-blind, randomized controlled clinical trials. In this study, the authors evaluated the therapeutic effect of shortwave diathermy in the treatment of UNE. Sixty-one patients completed the study, while approximately half of them ($n = 31$), randomly selected, were treated using shortwave diathermy 10 times over 2 weeks. The control group was given a placebo shortwave diathermy. Both groups were given elbow splints and instructed to avoid activities likely to provoke symptoms. Three months after the intervention, there was no significant difference between the groups regarding health status as measured by SF-36 (short form) questionnaires, pain, or hand function (75).

In clinical practice, the use of shock waves is widespread across the world in patients with different diagnoses. The presumed effect of the shock wave on the peripheral nerves is based on animal studies using a rat model (76, 77). The shock wave's effectiveness in patients with other types of entrapment syndromes, especially carpal tunnel syndrome, has previously been studied. Compared with the application of therapeutic US, patients with carpal tunnel syndrome who received extracorporeal shock wave therapy showed a more significant improvement in pain and hand function parameters at 12-week follow-up (78). In another randomized clinical trial, Raissi et al. (79) showed a comparable clinical outcome in patients with carpal tunnel syndrome treated with (1) wrist splints alone and (2) wrist splints + extracorporeal shock wave therapy. However, in the group with added shock wave therapy, a more favorable effect was demonstrated in median nerve distal sensory latency in nerve conduction studies (79). These results were in line with a recently published study by Gesselbauer et al., (80) who found promising clinical and electromyography (EMG) improvement after three sessions of focused extracorporeal shock wave therapy in patients with mild-to-moderate carpal tunnel syndrome and no improvement in the control group. Notably, a pilot study evaluating the effect of extracorporeal shock wave therapy for cubital tunnel syndrome has also been presented (81). Seven patients (10 elbows) received three radial extracorporeal shock wave sessions (2.000 shots, 4 bar, 5 Hz) in a total period of 3 weeks. As assessed by the Quick DASH questionnaire, the upper limb function showed significant improvement at all follow-up points evaluated within 12 weeks after therapy. According to the visual analog scale (VAS), the pain assessed was also significantly reduced (mean decrease from 4.7 ± 0.3 to 2.2 ± 0.2). The most significant improvement was in the first month after treatment. No placebo group was included in this pilot study. Nevertheless, the mean symptom duration in this study was 27.9 months, and spontaneous remission of symptoms in this patient group was not very likely. Other potential treatment options for UNE include low-laser therapy. Ozkan et al. (82) showed promising results of this therapy on functional, clinical, and electrophysiological outcomes. All beneficial effects lasted, in contrast to the US-treated group, until the third month of follow-up. Nevertheless, there was no control group in this study (82).

Priessnitz's Wrap

To the best of our knowledge, there is no study evaluating the effect of Priessnitz's wrap on the effectiveness of UNE therapy. However, our clinical experience with this treatment is favorable. Priessnitz's wrap consists of applying two layers to the elbow area: (1) a wet squeezed cloth is applied directly to the skin, and (2) the second layer is a dry cloth serving as thermal isolation. In approximately the first 15 min, application of this wrap causes tissue cooling, followed by local hyperemia. The duration of the described wrap can range from several dozens of minutes to several hours. The assumed effect is mainly against swelling along with anti-inflammatory action. The CSA of the UN, as measured sonographically, is expected to be reduced after several applications. However, there is no published evidence for this assumption at this time, and this is only an expert opinion of the authors of this paper.

Dry Needling

Anandkumar and Manivasagam reported three cases of patients with confirmed cubital tunnel syndrome. All patients had previously undergone unsuccessful treatments, including medication, massage, exercise therapy, US therapy, neurodynamic mobilization, and taping. The patients were treated four times over 2 weeks with dry needling, targeting the FCU muscle in two patients. In one patient, the needle was superficially inserted between the ME and the olecranon process. At discharge at 6-month follow-up, all three patients were pain-free and fully functional (83). Of note, to minimize possible adverse effects of nerve damage during the dry needling procedure, sonographic monitoring is advantageous.

Ultrasound-Guided Injection Techniques and Exemplary Evidence

The patient's position is either lying supine with the elbow flexed and hand over the head (**Figures 10C,D**) or lying prone with the elbow bent and hand hanging over the examination bed (**Figures 10A,B**). As the UN at the elbow is close to the skin surface, a high-frequency linear transducer can be effectively used. Vascular structures and local abnormalities should be clarified in advance when planning the needle trajectory (84). Rules of the standard aseptic technique should be followed. Before the injection itself, a basic evaluation of the nerve and surrounding structures should be performed. A thin, e.g., 25-gauge, needle is usually preferred. The injected volume varies from 2 to 5 ml. A combination of steroids and a local anesthetic is commonly administered (85).

The UN should be visualized in the short axis, while the in-plane approach can be used. This technique allows constant visualization of the nerve's margins and the needle tip during the procedure. This technique showed a lower risk of intraneural application of the injectate (86). According to Kim and Choi, the needle should be inserted into the cubital tunnel at the ME level penetrating the retroepicondylar retinaculum (87, 88). The needle tip should be placed tightly adjacent to the nerve between the ME and the UN. To prevent compartment syndrome with persistent paresthesia, the UN injection may be performed proximal to the retroepicondylar groove (**Supplementary Video 3**). To confirm the needle tip's epineural position, a test injection with lidocaine can be performed to see the injectant's epineural flow. To provide total coverage of the injectate around the nerve, it is sometimes necessary to reposition the needle to the other side of the nerve. This hydrodissection separating the UN from the ME end might be followed by US during the injection (85). According to a recent randomized controlled trial (RCT), the effect of dextrose injection was superior to that of steroid injection (89). vanVeen et al. (90) in their study used visualization in the long axis, which,

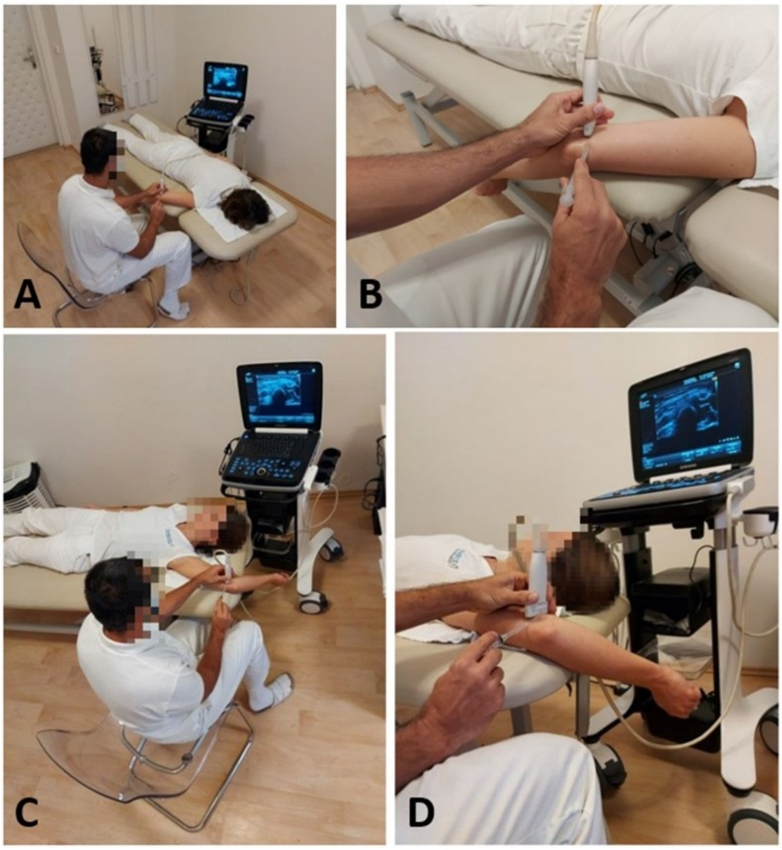

FIGURE 10 | **(A)** Prone position for the ultrasound-guided ulnar nerve in-plane injection with the elbow flexed and hanging over the examination bed. **(B)** The same procedure as described before in detail. **(C)** Supine position for the ultrasound-guided ulnar nerve in-plane injection; the patient is positioned on the examination bed with the elbow flexed and hand over the head. **(D)** The same procedure as described before in details.

according to other authors, is less convenient because the nerve can be confused with other structures (91). In a case report, Stoddard suggested that hydrodissection with a higher injected volume might also be beneficial (92).

A recent systematic review evaluating conservative treatment of cubital tunnel syndrome proposed that steroid injection decreased nerve CSA. The review's limitation was the paucity and heterogeneity of the studies concerning steroid or local anesthetic injection (61). Hong et al. (66) compared two conservative treatment approaches—splinting vs. splinting plus injection with corticosteroids and local anesthetic. A total of 10 patients (12 nerves) were assessed. Clinical evaluation and nerve conduction studies were performed 1 and 6 months after the intervention. Their results showed significant improvement in both groups' symptoms, and there were no significant differences between the two intervention groups. Therefore, splinting alone was concluded to be sufficient with no need for an additional steroid injection. However, the injections in this study were landmark-guided (66). vanVeen et al. (90) conducted a randomized, double-blinded trial to compare the effect of steroid injection with that of placebo injection. In total, 55 patients were involved in this study. The primary outcome was a subjective change in symptoms after 3 months from intervention. Secondary outcomes were CSA of the nerve and electrodiagnostic studies. The results showed that 30% of steroid group participants reported a favorable outcome, compared with 28% in the placebo control group. There was a significant decrease of CSA in the steroid injection group and no significant improvement in electrodiagnostic studies. The study concluded that the positive effect of US-guided steroid injection compared with placebo was not demonstrated (90). Rampen et al. (93) published a case series of seven patients with UNE, treated with steroid injection. Four out of seven patients reported clinical improvement (in terms of symptom relief and neurologic improvement) and CSA reduction 6 weeks following the intervention. Symptoms were unchanged in two of the patients and worsened in one patient. This study, however, lacked a control group, and the patients opted for injection because they disapproved of surgical treatment after initial conservative therapy failed (93). Alblas et al. (94) conducted a feasibility study with eight patients (nine UNEs) regarding US-guided steroid injection. During 3 months of follow-up, five patients reported improved symptoms, whereas three patients had no change in symptoms, and one patient reported worsening of the symptoms. The study concluded that US-guided steroid injection was as safe and easy (94).

Another feasibility study was conducted by Choi et al., (88) who assessed the in-plane approach of US-guided steroid injection for cubital tunnel syndrome in 10 patients. Their results showed a statistically significant decrease in the severity of the symptoms as evaluated by the VAS and CSA decrease in the first and fourth week of follow-up. No side effects were reported (88). A recent RCT by Chen compared the effect of steroid injection with that of dextrose injection in patients with UNE. In total, 33 patients completed the study. The primary outcome was digital pain/paresthesia evaluated with VAS. Secondary outcomes were disability questionnaires, nerve conduction studies, and CSA of the UN. There was a more considerable decrease in symptom severity in the dextrose group from the third month of follow-up and onward. The study concluded dextrose to be more suitable for perineural injection in patients with UNE (89).

SURGICAL TREATMENT

In 1957, Osborne described the first series of surgically treated patients with spontaneous UNE (95). Surgical treatment of cubital tunnel syndrome remains controversial. Although many techniques may be used for decompressing the UN, there are no clear consensus for one approach over another. This uncertainty was not resolved even by several systematic reviews published during the last decade. Therefore, the choice of approach is often based on personal experience and subjective preference for specific clinical findings. Almost 90% of surgeons use more than one procedure in the treatment of cubital tunnel syndrome (96). However, up to 30% of the patients do not improve after surgery and require revision procedures, which is even more controversial and rarely curative (97, 98).

In situ Decompression

Simple decompression is a basic and probably the most commonly used technique, particularly beneficial when nerve entrapment is the underlying cause of UNE. It is easy to perform and generally free of complications. It is performed from a small incision above the ME parallel to the course of the UN. Care must be taken to protect the posterior branches of the medial antebrachial cutaneous nerve. The surgery aims to release the nerve by cutting the superficial fascia of the FCU muscle, retroepicondylar groove retinaculum, and the HUA. However, it is always necessary to explore the nerve proximally toward the MIS of the arm to check for any compression by the arcade of Struthers or by the septum itself. Similarly, the nerve is explored distally to the proximal forearm to release possible compression within the FCU by the thicker parts of the intermuscular connective tissue (**Figure 11A**). After sufficient decompression of the nerve, flexion and extension of the elbow are examined to rule out subluxation over the ME (99).

In such cases, the decompression can be facilitated by the medial epicondylectomy, which allows a mini-anterior transposition without excessive dissection and devascularization of the nerve. It is recommended to remove less than 4 mm of the ME's width in the coronal plane to prevent damage of the anterior part of the medial collateral ligament, which may result in elbow instability or medial elbow pain (100). Some authors, however, prefer to perform an anterior transposition of the nerve to preclude chronic injury to the nerve by its repetitive subluxation (101).

Anterior Transposition

Transpositional surgical treatment may be performed by subcutaneous, intramuscular, and submuscular techniques. The transposition aims to reduce the tension on the nerve and prevent further compression in the cubital tunnel by bony spurs, synovial swelling, or chronic subluxation (102).

All other techniques than *in situ* decompression require a longer incision (~6 cm). The nerve is transposed anteriorly under the skin flap (or intra or under the forearm flexors' common head) after its wide release from the original bed. The easiest and most commonly performed technique is subcutaneous transposition (**Figure 11B**). Submuscular or intramuscular transpositions are much more invasive and, therefore, carried out less frequently, especially in patients with minimal amounts of subcutaneous fat or in some revision cases. The argument for higher invasiveness is to create a healthy vascular bed protected by soft tissue. Nevertheless, Liu et al. (101) found in their meta-analysis that subcutaneous and submuscular transpositions are equally effective.

Said et al. (103) demonstrated in their meta-analysis no difference in outcome or revision rate between simple decompression and anterior transpositions in primary cubital tunnel syndrome. Similarly, Chen et al. (102) found the same effect of both methods and a significantly lower incidence of complications in cases operated by simple decompression. Anterior transposition is often used in revision release after failed primary decompression. Moreover, some authors recommend submuscular transposition after failed subcutaneous transposition (104). However, there is no robust evidence supporting the need for anterior transposition in recurrent cubital tunnel syndrome (105).

Moreover, an excessive release of the nerve before its transposition is associated with decreased regional blood flow to the nerve for at least 3 days. Those mentioned above may increase the complication rate after surgery (102).

Endoscopic Decompression

The endoscopic technique was introduced as a minimally invasive alternative for open decompression, aiming to minimize

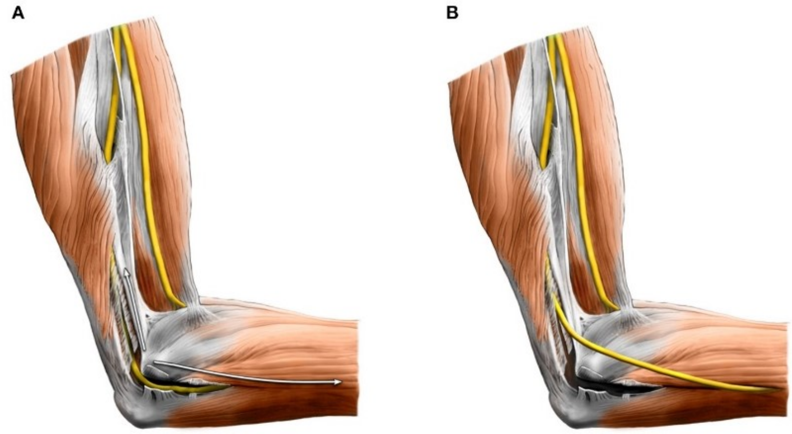

FIGURE 11 | (A) *In situ* decompression of the ulnar nerve in the cubital tunnel. **(B)** Anterior subcutaneous transposition—after wide decompression, the ulnar nerve is transposed anteriorly under the cutaneous flap.

trauma to the tissues and improve postoperative recovery. Its theoretical advantages are the patient's faster recovery, decreased invasiveness, minimal adverse events, and less scar discomfort. However, it should be applied only in selected cases without evidence of nerve subluxation, traumatic etiology of cubital tunnel syndrome, or significant structural pathology (106).

Schmidt et al. (107) and Krejčí et al. (99) performed RCTs comparing open and endoscopic decompression. In both studies, the authors failed to show any additional benefit of the endoscopic technique, and they concluded that both techniques are equally effective. These results were in line with several systematic reviews and meta-analyses (106, 108, 109).

However, it has been proven that endoscopic technique is associated with a lower incidence of scar tenderness or elbow pain (106). Moreover, it is performed with a smaller skin incision (1.5–2 cm) compared with open decompression (∼4 cm). On the other hand, it is significantly longer than open surgery. Although the difference in the median duration of decompression (i.e., incision to suture time) was only 6 min in a study of Krejčí et al. (99) (30 min for open and 36 min for endoscopic techniques, respectively), the setup time was almost three times longer in the endoscopic procedure (6 and 18 min, respectively). Another disadvantage is that it is necessary to have an assistant holding the arm in place and changing the flexion degree as needed (99).

Summary of the Techniques

Wade et al., (98) in 2020, performed a comprehensive review and meta-analysis of all possible open or endoscopic methods for treating cubital tunnel syndrome. They found that open *in situ* decompression (with or without medial epicondylectomy) appears to be the safest and most effective method for primary cubital tunnel syndrome patients. It was associated with the greatest response to treatment and the lowest risk of complications, reoperation, and recurrence. They also showed that *in situ* decompression (open, minimally invasive, or endoscopic) was associated with a lower risk of complications than any form of transposition. Moreover, the addition of epicondylectomy led to a higher success rate without increasing the risk of complications. Another advantage of *in situ* decompression is the reduced operative time and its simplicity. Of note also is that it is 18–55% cheaper than the transposition procedure (98). Therefore, open *in situ* decompression should be considered a first choice in treating patients with primary cubital tunnel syndrome. In recurrent cases, the surgeon should consider the extent of primary decompression, previous elbow trauma, and possible chronic subluxation to decide whether to perform more extensive decompression only or an anterior transposition. To this end, one should plan the surgery concerning local anatomy (e.g., anatomic variations and space-occupying lesions), where US can provide valuable information preceding the surgery, e.g., aberrant vein (**Figure 9F**).

CONCLUSIONS AND FUTURE DIRECTIONS

Cubital tunnel syndrome is commonly encountered in daily clinical practice. If correctly diagnosed, the treatment outcome can be promising. In the light of the broad differential diagnosis, a convenient imaging tool may be necessary in some cases. Hence, high-resolution US can be an inexpensive, safe, and accessible modality for visualizing and guiding the treatment of UN neuropathy around the elbow. US imaging in such indications can be expected to increase its awareness among physicians worldwide in the near future.

AUTHOR CONTRIBUTIONS

KM devised the project and the main conceptual ideas. ON supervised this work. Five authors wrote the first drafts of the manuscript sections (KM—introduction and US assessment. JJ—US-guided procedures and anatomy. RK—surgical techniques. SM—non-operative treatment. ON—anatomy). JJ formatted the figures and their legends. ON and KM dissected the cadaveric specimen and obtained the corresponding photographs. PS provided exemplary US images together with figure legends. KS, YA, and PS (together with other co-authors) provided critical feedback, helped shape the manuscript, and obtained figures and videos. All authors approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fneur.2021.661441/full#supplementary-material

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Original Articles

Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests

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ABSTRACT

Background: The abdominal muscles play an important respiratory and stabilization role, and in coordination with other muscles regulate the intra-abdominal pressure stabilizing the spine. The evaluation of postural trunk muscle function is critical in clinical assessments of patients with musculoskeletal pain and dysfunction. This study evaluates the relationship between intra-abdominal pressure measured as anorectal pressure with objective abdominal wall tension recorded by mechanical-pneumatic-electronic sensors.
Methods: In a cross-sectional observational study, thirty-one asymptomatic participants (mean age = 26.77 ± 3.01 years) underwent testing to measure intra-abdominal pressure via anorectal manometry, along with abdominal wall tension measured by sensors attached to a trunk brace (DNS Brace). They were evaluated in five different standing postural-respiratory situations: resting breathing, Valsalva maneuver, Müller's maneuver, instructed breathing, loaded breathing when holding a dumbbell.
Findings: Strong correlations were demonstrated between anorectal manometry and DNS Brace measurements in all scenarios; and DNS Brace values significantly predicted intra-abdominal pressure values for all scenarios: resting breathing ($r = 0.735$, $r^2 = 0.541$, $p < 0.001$), Valsalva maneuver ($r = 0.836$, $r^2 = 0.699$, $p < 0.001$), Müller's maneuver ($r = 0.651$, $r^2 = 0.423$, $p < 0.001$), instructed breathing ($r = 0.708$, $r^2 = 0.501$, $p < 0.001$), and loaded breathing ($r = 0.921$, $r^2 = 0.848$, $p < 0.001$).
Interpretation: Intra-abdominal pressure is strongly correlated with, and predicted by abdominal wall tension monitored above the inguinal ligament and in the area of superior trigonum lumbale. This study demonstrates that intra-abdominal pressure can be evaluated indirectly by monitoring the abdominal wall tension.

1. Introduction

Spinal stability is secured by the bone structures, ligaments, and via coordinated activation between spinal extensors and flexors and all muscles regulating the intra-abdominal pressure (IAP) (Cholewicki and McGill, 1996; Hodges et al., 2005). The diaphragm and pelvic floor form two pistons which push against each other increasing the pressure in the abdominal cavity. Contraction of the abdominal muscles resists lateral movement of the contents within the abdominal cavity (Chaitow et al., 2014; Hodges, 1999). IAP is essentially a hydraulic pressure effective in all directions, stabilizing the torso and reducing axillary compression during activities that increase the demands on spinal stabilization, such as lifting heavy loads (Cobb et al., 2005; Grillner et al., 1978). Hodges et al. has confirmed that an increase in IAP alone without activity of abdominal or back muscles still enhances the stability of the lumbar spine (Hodges et al., 2005).

The amount of IAP can be measured by several different invasive and non-invasive methods. The most accurate is direct laparoscopic measurement using an intra-abdominal catheter (Malbrain et al., 2006). Indirect urethral measurement is considered to be the most frequent and reliable method to monitor IAP; however, this can result in urinary tract infections or urethral injury, therefore, it is not often used in postural function research (Malbrain et al., 2013; Wise et al., 2017).

In rehabilitation medicine, instrumental IAP measurement via rectal

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or gastric probes are mainly used in experimental studies, and are not typically used in routine clinical assessment (Malbrain et al., 2006). Gastric or nasogastric tubes inserted into the stomach provide quite accurate IAP measurements, however, it is quite uncomfortable for patients and an expensive method requiring highly trained personnel (Grillner et al., 1978; Hodges et al., 2005; Wauters et al., 2012). Special catheters or probes inserted into the rectum are used for anorectal measurements. Such pressure sensitive devices convert mechanical signals into electrical signals recorded and displayed on a computer monitor (Pfeifer and Oliveira, 2006). Recently, thin electric probes have become available. Smaller devices lead to fewer artifacts thus offering more exact display and measurement. Small probes are easy to install, temperature resistant, very sensitive to pressure changes and well tolerated by patients, with infrequent side effects (Malbrain et al., 2006; Sugrue et al., 2015). The disadvantage is the high purchase price (Pfeifer and Oliveira, 2006). Such IAP recording has been reported in many studies exploring IAP changes in various postural situations (Kawabata et al., 2010; Sapsford et al., 2013).

IAP measurement has also been combined with simultaneous electromyography or ultrasound assessments of core muscles. However, these methods do not evaluate the global coordination of the trunk muscles but rather local muscle activation. In addition, significant inaccuracies during such recording have been reported (Henry and Westervelt, 2005; Junginger et al., 2010).

In clinical practice, palpation of the abdominal wall tension (AWT), especially in the area above the inguinal ligament and in the upper trigonum lumbale is used to evaluate an individual's ability to regulate their IAP (Kobesova et al., 2020). Available studies suggest that the AWT occurs as a result of increased IAP (Cresswell, 1993; Kumar et al., 2012; Tayebi et al., 2021; van Ramshorst et al., 2011). Different types of sensors have been used to measure the AWT during various postural tasks related to IAP changes (Chen et al., 2015; Malátová et al., 2013, 2008; Novak et al., 2020; van Ramshorst et al., 2011). This study presents simultaneous recording of IAP measured as anorectal pressure and AWT measured via four sensors attached to a trunk brace. In an attempt to further understand the relationship between IAP and outward tension of the abdominal wall, the purpose of this research was to compare anorectal manometry measurements, largely considered the gold standard in ambulatory patients, with abdominal wall outward tension measured by a trunk brace during clinical assessments.

2. Methods

2.1. Participants

Thirty-one asymptomatic volunteers were recruited for the study. Written informed consent was obtained from each participant, and demographic characteristics of the sample including age, weight, height and BMI are shown in Table 1. Exclusion criteria were any symptomatic neurologic, orthopedic, respiratory, internal or musculoskeletal disorder, spine or abdominal surgery, severe trauma during the last year, pregnancy, and history of therapy focusing on IAP training. The study conforms with The Code of Ethics of the World Medical Association and was approved by an Institutional Ethics Committee (Ethics Committee of the University Hospital Motol and 2nd Faculty of Medicine, Charles University in Prague. No.1263.1.15/19; approval date: November 6, 2019). This study adhered to the Helsinki declaration.

Table 1
Participant's anthropometric characteristics. $N = 31$, 15 males, 16 females.

	Age (years)	Height (cm)	Weight (kg)	BMI
Mean	21.3	170.5	63.2	24.1
SD	1.6	6.5	7.9	3
Min	19	160	47	17.3
Max	25	185	80	27.6

2.2. DNS Brace

To monitor AWT, a special new device called DNS Brace was used (Fig. 1 – A,C). The DNS abbreviation is derived from the rehabilitation concept called Dynamic Neuromuscular Stabilization (DNS) (Kobesova et al., 2019, 2016). DNS emphasizes the importance of IAP in spinal stabilization and treatment. The diaphragm, pelvic floor and abdominal wall muscles regulate the IAP (Hodges et al., 2007). IAP increases during postural activity (Hodges and Gandevia, 2000), resulting in a contraction and expansion of the abdominal wall due to muscle activity. Abdominal wall expansion and contraction result in pressure that compresses the DNS Brace sensors. The Brace is an original device produced by Ortotika, FN Motol V Úvalu 84, Praha. Four mechanical-pneumatic-electronic sensors are placed on the inner wall of plastic trunk orthosis. Two ventral sensors are located bilaterally above the groin and two sensors are located on the brace parts adhering to latero-dorsal sections of the abdominal wall (trigonum lumbale superius). Silicon brace sensors contain the inner air-chamber that is deformed by the abdominal wall pressure. The values recorded in kilopascals (kPa) are transferred via Bluetooth, stored and graphically displayed in a smart-phone device. More details about the brace can be found elsewhere (Jacisko et al., 2020). The brace sensors measure the pressure exerted by the abdominal wall in kilopascals (kPa) (Figs. 2. B, 3. B, 4. B) and transfer the data via Bluetooth to a smart-phone or computer so the data can be statistically processed and graphically displayed.

2.3. High resolution anorectal manometry

The intra-abdominal pressure was measured using the ManoScan™ AR HRM system (Given imaging, 15 Hampshire Street, Mansfield, MA 02048 US). It allows for complex assessment of anorectal pressures (Fig. 1 – B,C). The anorectal probe is equipped with 12 channels each measuring 12 circumferentially located spots thus recording pressures from 144 points simultaneously. The diameter of the probe is 10 mm. The pressure values are measured in mmHg (Figs. 2. A, 3. A, 4. A) and transferred at 0.1 s intervals to a computer, where the data can be further processed. The ManoView™ software color-visualizes the measured pressures. Two distal sensors located behind the anal sphincters in the ampulla of rectum monitor the IAP. The remaining 10 probe sensors record the pressures produced by the sphincters. Before starting the measurement, the probe must always be calibrated to 0 atmospheric pressure and a ManoShield rubber protection must be fitted. The probe records pressure in real time.

2.4. Assessments

The assessment of all participants was performed by the same examiners under similar conditions (time of day, assessment room, temperature). All participants were first informed about the procedure in detail. After calibration, the anorectal probe was inserted into the participant's anus in a side lying position. Then, the participant stood up and the correct location of the probe was ensured. By activating the sphincters, it was verified that the 2 distal sensors are located in the rectal ampulla monitoring the IAP but not the activity of the sphincters (McCarthy, 1982; Pfeifer and Oliveira, 2006; Shafik et al., 1997). Then, DNS Brace was fixed to the participant's trunk and the sensors were calibrated to 0 kPa during the tidal exhalation prior to each measurement. The dorsal sensors were adjusted to be placed bilaterally in the superior trigonum lumbale, bellow the floating ribs, and the ventral sensors were placed bilaterally above the groin at the intersection of the mammilar and bispinal connecting line. Then, the participants were instructed to maintain the upright standing position throughout the whole measurement, avoiding increased spinal kyphosis, lordosis or extremity movements. Five postural tests were performed by each subject and evaluated by DNS Brace and Anorectal manometry simultaneously in the same order. The anorectal pressure and AWT values were

Fig. 1. A: DNS Brace, B: Anorectal probe, C: Participant equipped with DNS Brace and anorectal probe during assessment.

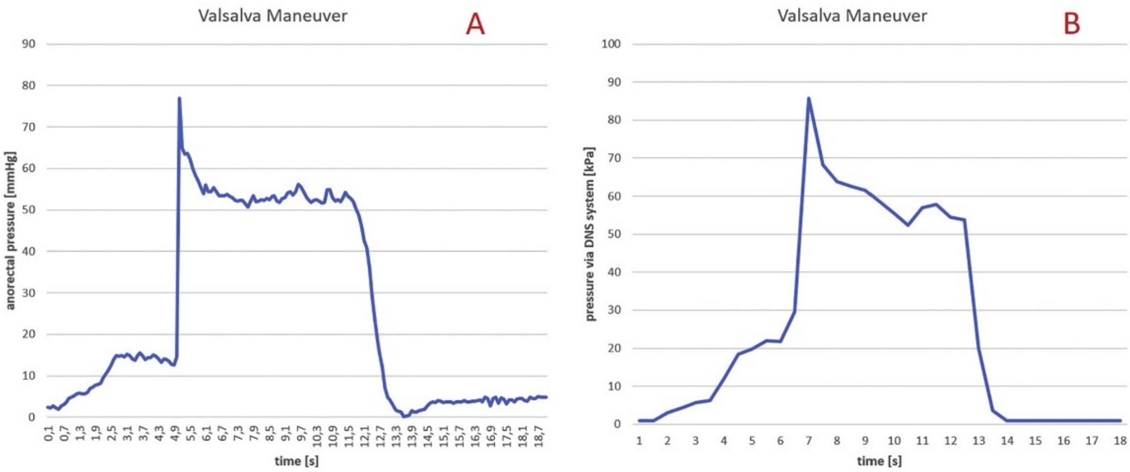

Fig. 2. Example of graphical visualization of the measured pressures (A: anorectal manometry, B: DNS Brace) during Valsalva maneuver scenario. A minor delay in DNS Brace measurement relative to ARM is caused by a minimal delay of AWT relative to IAP and by the fact, that DNS Brace measures AWT in 0.5 s. intervals while ARM measures IAP in 0.1 s intervals. Additionally, brace sensors identify only pressure changes over 1 kPa. These factors may cause negligible inaccuracy. The starting pressure before the maneuver is around 5 mmHg for ARM whereas the DNS system starts from zero and returns to zero after the maneuver. DNS Brace automatically reset to zero starting pressure for user friendly reasons. This has no impact on the results because all indirect measurement techniques are able to monitor the IAP changes rather than estimating the absolute IAP value (Tayebi et al., 2021).

both collected for 10 s during each of the five scenarios, and the average value of each measurement was used for statistical analysis.

The measured scenarios:

1) Resting breathing: The participant was breathing naturally in a standing position.
2) Valsalva maneuver: The participant was forcefully exhaling against closed nostrils and mouth (Talasz et al., 2012, 2011).
3) Müller maneuver: The participant was forcefully inhaling against closed glottis (Mattos Soares et al., 2009).
4) Instructed breathing (The diaphragm test): The participant was expanding the abdominal wall pushing as much as possible against

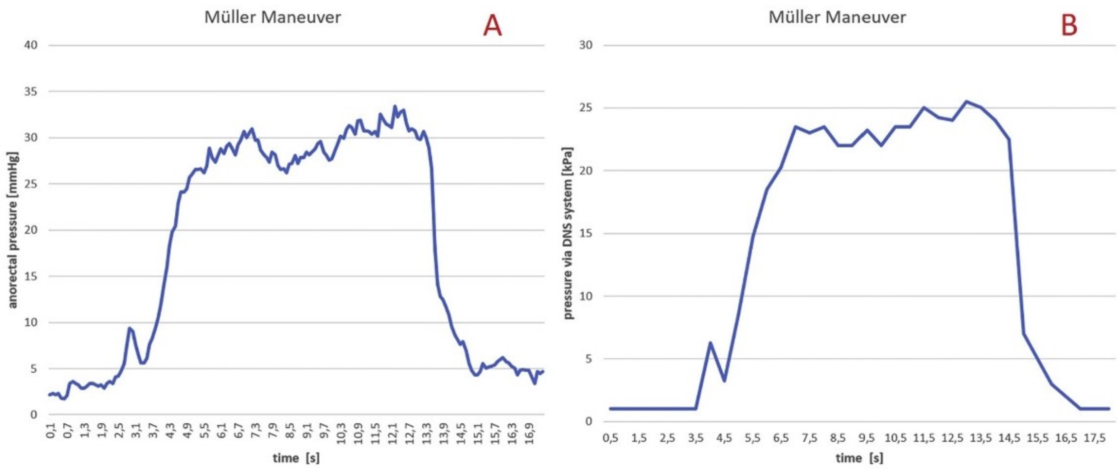

Fig. 3. Example of graphical visualization of the measured pressures (A: anorectal manometry, B: DNS Brace) during Müller maneuver scenario.

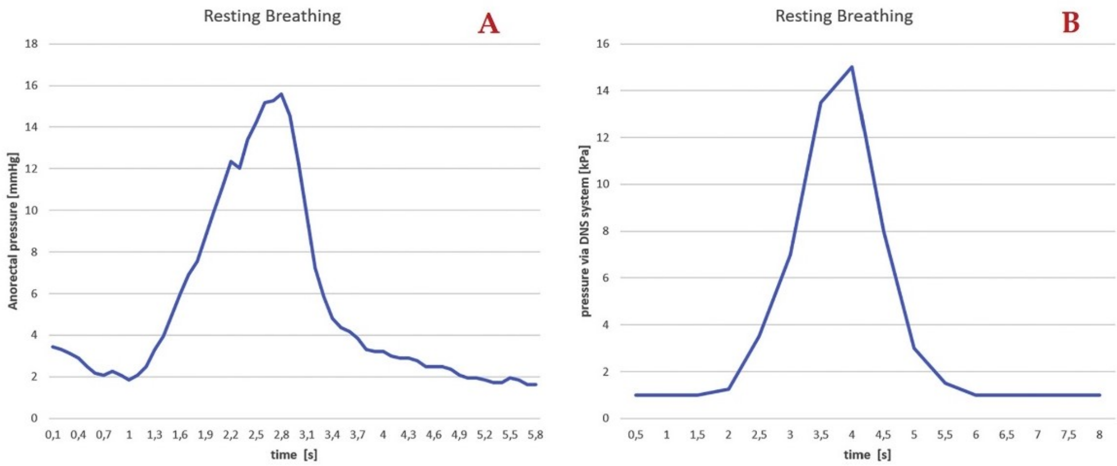

Fig. 4. Example of graphical visualization of the measured pressures (A: anorectal manometry, B: DNS Brace) during resting breathing scenario.

all four sensors both during inhalation and exhalation (Kobesova et al., 2020).

5) Holding a load of 20% of participant's body weight in hands in front of the trunk - loaded breathing (Fig. 1C).

2.5. Statistical analysis

Data analyses were conducted using the Statistical Package for the Social Sciences *v27.0 for Mac (IMBCorp, Armonk, NY)*.. Pearson's correlations and linear regression tests were used to assess the relationship between the 10-s mean anorectal manometry values and DNS Brace values under all five scenarios. Statistical significance was determined a priori at $p < 0.05$, and power analyses revealed in order to achieve a power of 0.80, 29 subjects were needed to identify a large effect size of 0.50 for Pearson's correlations, and 26 subjects were needed to achieve a large effect size of 0.35 for linear regression analyses. The strength of correlations were interpreted as weak (< 0.30), moderate (0.30–0.50), or strong (> 0.50), and the strength of regression predictions were interpreted as weak (< 0.02), moderate (0.15–0.35) or strong (> 0.35) as reported by Cohen, 1988 (Cohen, 1988).

3. Results

Preliminary analyses showed linear relationships, with no outliers as assessed by scatterplots, but not all variables were normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$). Data are mean ± standard deviation unless otherwise stated. Pearson's correlations demonstrated strong statistically significant positive relationships between anorectal manometry pressures and DNS Brace pressures, under all five scenarios: resting breathing: $r(31) = 0.735$, $p < 0.001$; Valsalva maneuver: $r(31) = 0.836$, $p < 0.001$; Müller's maneuver: $r(31) = 0.651$, $p < 0.001$; instructed breathing: $r(31) = 0.708$, $p < 0.001$; and loaded breathing: $r(31) = 0.921$, $p < 0.001$ (Table 2). Simple linear regression models established that anorectal manometry pressure could significantly be predicted from the DNS Brace values under all five scenarios: resting breathing: $F(1, 29) = 34.14$, $p < 0.001$; Valsalva maneuver: $F(1, 29) = 67.42$, $p < 0.001$; Müller's maneuver: $F(1, 29) = 21.29$, $p < 0.001$; instructed breathing: $F(1, 29) = 29.14$, $p < 0.001$; and loaded breathing: $F(1, 29) = 161.2$, $p < 0.001$ (Figs 5 - 9). Table 3 depicts all results from regression analyses.

Table 2
Correlations between Intra-Anal Manometer and DNS Brace Pressures. Values are Mean [Standard Deviation].

Condition	Manometric probe pressure	DNS Brace pressure	Pearson r	Sig
1-Resting Breathing	22.73 [12.38]	20.34 [11.68]	0.735	< 0.001*
2-Valsalva Maneuver	47.20 [27.09]	35.93 [20.19]	0.836	< 0.001*
3-Müller's Maneuver	35.92 [24.96]	20.87 [10.45]	0.651	< 0.001*
4-Instructed Breathing	34.72 [17.45]	26.57 [15.05]	0.708	< 0.001*
5-Loaded Breathing	36.35 [21.46]	30.97 [25.86]	0.921	< 0.001*

Note: DNS = Dynamic neuromuscular stabilization.
* Statistically significant correlation ($P < 0.01$).

4. Discussion

4.1. IAP measurement methods

Currently, various methods to measure the IAP are available. It can be monitored directly via sensors located intraperitoneally or in the inferior caval vein. Intra-vesical, intra-gastric intra-anal or intra-vaginal recording allow to measure the IAP indirectly (Malbrain et al., 2006; Wise et al., 2017). This study utilized intra-anal, i.e. measurement using anorectal manometry, which has been determined the safest and easiest method of assessment (Malbrain et al., 2013, 2006). Other methods posed different challenges, such as intra-vesical catheters may cause urinal infection and urethral trauma, intra-gastric measurement is uncomfortable for participants, and intra-vaginal measurement would exclude male participants. The intra-anal pressure measurement is a reliable way to monitor the IAP, although it does not match with the IAP as accurately as the intra-vesical pressure (Wise et al., 2017). There are only a few inconveniences of intra-anal pressure monitoring such as the presence of residual faeces, incorrect insertion of the probe and participant's embarrassment (Bhatia and Bergman, 1986; Pfeifer and Oliveira, 2006).

In a clinical practice, practitioners often palpate the abdominal wall assuming it to be a non-invasive and indirect way of IAP evaluation. The abdominal wall expands with the IAP increase (van Ramshorst et al., 2011). Palpation can be performed in the area above the inguinal ligament and in the superior lumbar triangle (Kobesova et al., 2020). Poor activation in these specific areas of the abdominal wall are commonly found in individuals with low back pain (LBP) (Frank et al., 2013; Kobesova et al., 2016). The same trunk sections were previously assessed by other researchers when evaluating abdominal wall activity in relation to IAP regulation (Kumar et al., 2012; Malátová et al., 2013; Novak et al., 2020). Therefore, the sensors are placed on the DNS Brace in the parts adhering to the abdominal wall above the inguinal ligaments and in the superior lumbar triangles. Here, only the attachments of the flat abdominal muscles are located and therefore the abdominal wall is easily accessible (Grevious et al., 2006).

Our in vivo correlations between IAP and AWT in asymptomatic individuals are in line with the study by Ramshorst et al. previously performed on corpses. Ramshorst used a special dynamometer to monitor AWT resulting from IAP changes in corpses, in which the IAP was changed artificially by insufflation (van Ramshorst et al., 2011). Ramshorst's study reports that AWT reflects the IAP. The findings from this study demonstrate significant correlations between the natural IAP regulation and AWT in all five measured scenarios with Pearson's coefficient ranging 0.651 to 0.921 which indicates strong correlations, with the ability to predict the IAP from the measured tension values.

4.2. Changes in IAP in response to respiration and postural load

The findings of the current study support prior experiments reported by Davis (Davis, 1959) and Cholewicki (Cholewicki et al., 1999), confirming that IAP increases with progressing demands on postural stability. The IAP increase results in the proportional activation of the abdominal wall which can be objectively monitored by the sensors or subjectively palpated in the area above the inguinal ligament and in the superior lumbar triangle. In other words, these results confirm that subjective palpation of the abdominal wall is an indirect evaluation of IAP.

Breathing has been shown to considerably influence IAP, trunk stability and movement (Bradley and Esformes, 2014). In this study, inhalation during resting breathing caused only slight increases in the

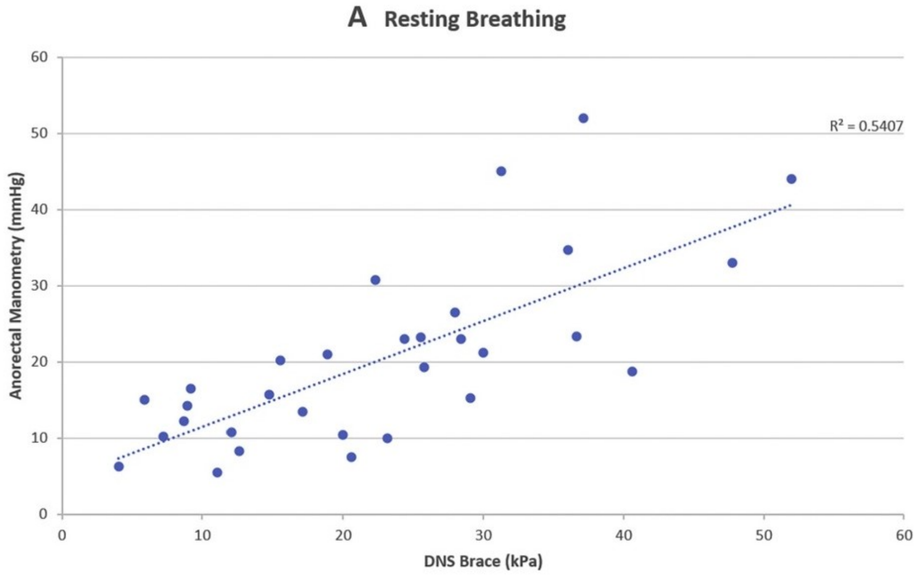

Fig. 5. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during resting breathing.

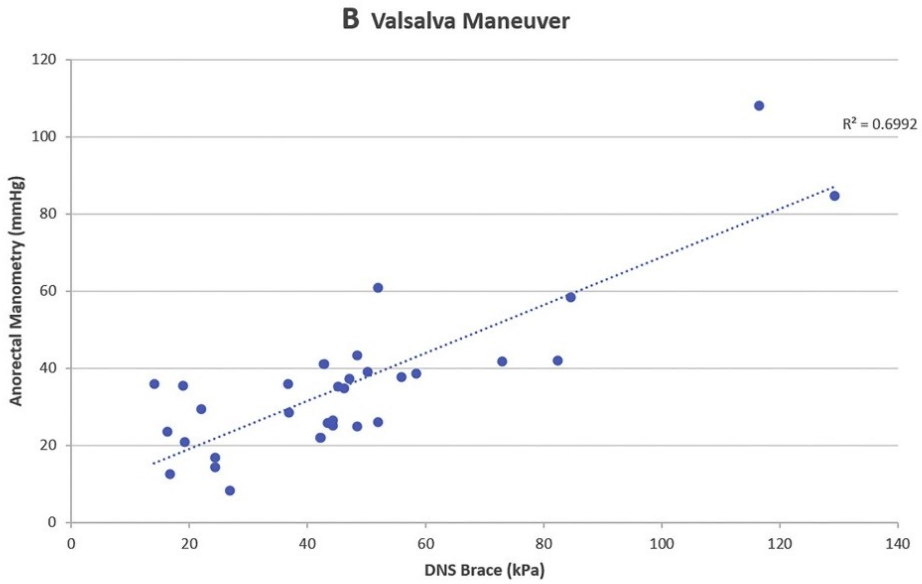

Fig. 6. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during Valsalva maneuver.

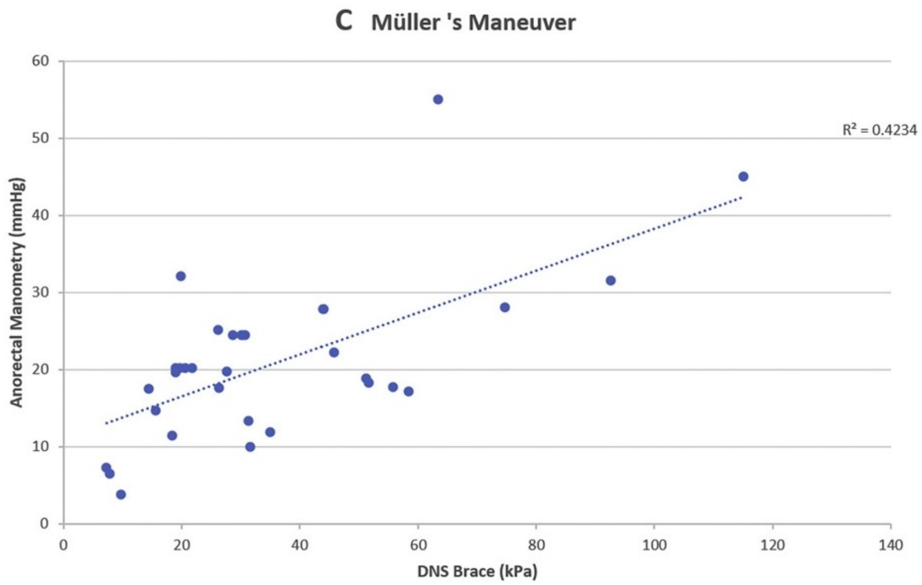

Fig. 7. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during Müller maneuver.

IAP. During exhalation, the AWT and the IAP returned to the basic value. This physiological fluctuation of IAP is normal within the respiratory cycle. Permanent excessive resting IAP would cause organ function failure (Cobb et al., 2005; De Waele et al., 2011; Smit et al., 2016). In this study, the largest increase in the IAP was noted during the Valsalva maneuver. Perhaps this is due to the fact that the muscles of the torso do not have to perform a respiratory function during the Valsalva when the air is not flowing out of the body, the intra-thoracic pressure increases and the cranial displacement of the diaphragm is smaller than with a normal exhalation (Talasz et al., 2012, 2011). During the Müller maneuver, the intra-thoracic pressure is significantly reduced, the diaphragm descends towards the abdominal cavity but no air flows into the lungs (Kushida, 2013). In our study, Pearson's correlation coefficient was the smallest in this scenario (0.651) which was also the most difficult task for the participants to understand and perform. The instructed breathing represents the Diaphragm Test according to DNS concept. The participants voluntarily expand the abdominal wall towards all four sensors, keeping the abdominal cavity pressurized during the entire respiratory cycle (Kobesova et al., 2020). With this scenario, the participant must be able to combine the respiratory and postural functions of the diaphragm, which is a frequent problem in clinical practice (Kawabata et al., 2010; Shirley et al., 2003). It is speculated that

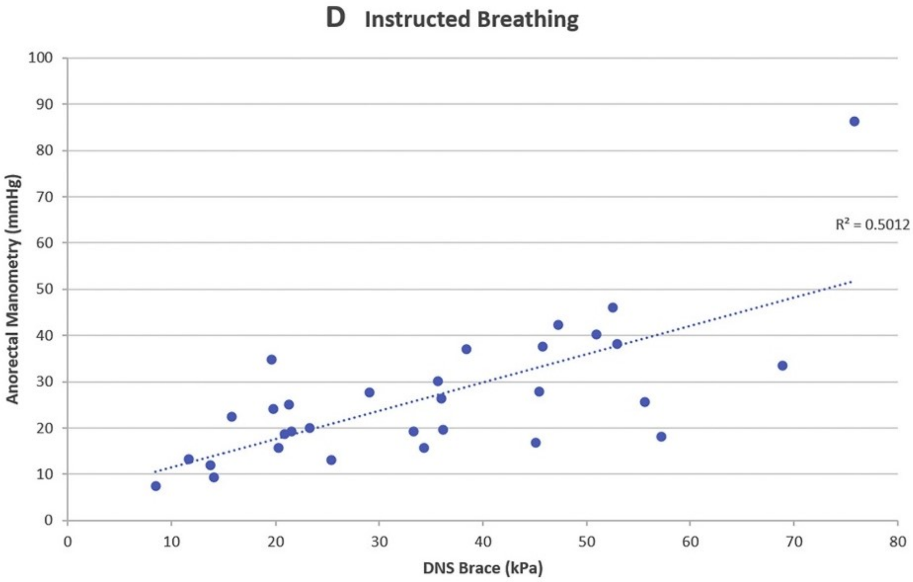

Fig. 8. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during instructed breathing.

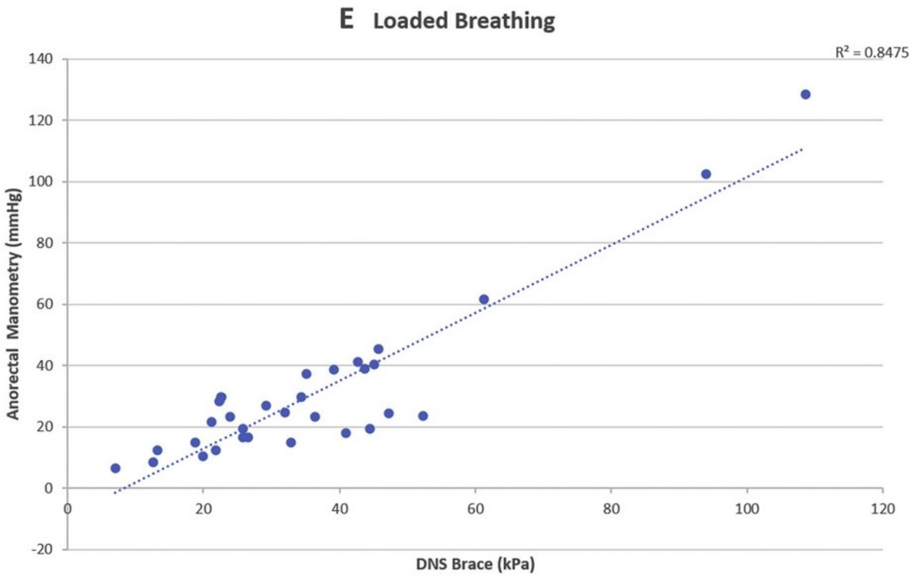

Fig. 9. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during loaded breathing.

individuals unable to do so maybe in a greater risk of developing LBP in the future (Ostwal and Wani, 2014; O'Sullivan and Beales, 2007). During the last scenario, the participants were holding a barbell of a weight corresponding with 20% of body weight. This situation caused less IAP increase than the Valsalva maneuver but more than resting and instructed breathing and Müller maneuver. Other studies also report significant increases in abdominal muscle activity monitored by EMG (Ershad et al., 2009; Mesquita Montes et al., 2017) and in the IAP monitored by anorectal probe (Hodges et al., 2005; Tayashiki et al., 2015) during posturally challenging situations. With normal resting breathing, a decrease in the IAP during exhalation occurs. However, there is only slight pressure fluctuation within the respiratory cycle with postural loading when the IAP must be reflexively maintained on a higher level throughout the whole respiratory cycle. In this test, the correlation between the values obtained from the manometry and from the DNS Brace sensors was the strongest (Pearson $r = 0.921$). When holding a load, the stabilization strategy is purely reflexive, i.e. involuntary, and therefore diagnostically valuable in determining possible risks associated with poor trunk stabilization.

Table 3
Summary of Simple Regression Analyses for Predicting Intra-Anal Manometer Pressure using DNS Brace Pressure ($n = 31$).

Condition	B	SE B	R^2	Adjusted R^2	95% CI	Effect Size (f^2)
1-Resting Breathing	0.78	0.13	0.54	0.53	0.51, 1.05	1.18
2-Valsalva Maneuver	1.12	0.14	0.70	0.69	0.84, 1.40	2.32
3-Müller's Maneuver	1.55	0.34	0.42	0.40	0.87, 2.24	0.73
4-Instructed Breathing	0.82	0.15	0.50	0.48	0.51, 1.13	1.00
5-Loaded Breathing	0.76	0.06	0.85	0.84	0.64, 0.89	5.58

Note: DNS = Dynamic neuromuscular stabilization.
R^2 = R square: proportion of variance explained by model in sample.
Adjusted R^2: proportion of variance explained by model in population.

4.3. Methods to measure abdominal wall tension and abdominal wall activation

The DNS Brace helps to assess both voluntary control and reflex postural activation. It can be used as a feedback tool to train abdominal wall activation and the IAP fluctuations. The DNS Brace can be fixed to the trunk keeping all four sensors in stable contact with the abdominal wall thus allowing evaluation in various body positions. Future studies need to identify the AWT in other postural situations. Other devices like a pressure Biofeedback Unit (Lima et al., 2011) and muscle dynamometry (Malátová et al., 2013), designed to measure or train trunk muscles and lumbopelvic stability may not allow such positional variability. Electromyography (Marshall and Murphy, 2010) or ultrasound (Amerijckx et al., 2020) analyze mainly local activation of the abdominal muscles. The information from the four DNS Brace sensors monitor more global co-activation of all abdominal muscles. Based on the strong correlations identified with the DNS Brace and anorectal manometry it can be concluded that the DNS Brace presents a new simple and non-invasive method to evaluate IAP indirectly. The DNS Brace may prove to be useful in physical rehabilitation medicine and research to monitor AWT in response to postural-respiratory demands, and may help to objectivize therapeutic effects, while also providing biofeedback during self-treatment. In the ideal condition, the DNS system is able to track IAP fluctuations and not measure absolute values of IAP, and therefore would not be suitable for IAP monitoring at intensive care units.

4.4. Study limitations

This study has several limitations. An average value from the four DNS Brace sensors was calculated and used for statistical analysis. Therefore, possible asymmetric tension of the abdominal could not be taken into account. The current version of the DNS Brace is not commercially available, but sensors working on a similar principle called Ohm Track (Novak et al., 2020) can be purchased and used in a similar way. DNS Brace cannot be applied to any participants with very narrow or extremely wide waistlines, therefore a different version of the DNS Brace is needed to increase the variability in testing individuals with different corset circumferences. While BMI seems to have no impact on indirect IAP measurements (Chen et al., 2015), the thickness of the abdominal fat layer may play a role. The relationship between the AWT changes measured by the brace sensors and subcutaneous fat thickness measured by a caliper can be explored in future studies. The research was performed on 31 asymptomatic and rather young individuals. Further studies should investigate larger cohorts of individuals comprised of both asymptomatic and LBP or other musculoskeletal problems.

5. Conclusions

This study established strong correlations between IAP measured as the anorectal pressure through high resolution manometry with AWT measured by the DNS Brace. Such manometry values could be predicted through the measurement of AWT. Strong correlations were identified during various breathing modifications and also during postural stabilization situations when holding a load. It was confirmed that with progressing demands on postural stability, the IAP increases in a direct correlation with proportional tension of the abdominal wall. The AWT was identified by four DNS Brace sensors located above inguinal ligaments and in the upper lumbar triangle bilaterally. For clinical applications, subjective palpation may be an effective indirect evaluation of intra-abdominal pressure.

Credit authorship contribution statement

Jakub Novak: Conceptualization, Project administration, Methodology, Investigation, Data curation, Writing - original draft. **Jakub Jacisko:** Conceptualization, Methodology, Investigation. **Andrew Busch**: Data curation, Software, Writing - review & editing. **Pavel Cerny:** Conceptualization, Interpretation and analysis of data. **Martin Stribrny:** Conceptualization, Methodology, Investigation. **Martina Kovari:** Supervision, Writing - review & editing. **Patricie Podskalska:** Project administration, Data curation. **Pavel Kolar:** Conceptualization. **Alena Kobesova**: Conceptualization, Supervision, Writing - review & editing, Funding acquisition.

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Declarations of Competing Interest

None.

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Příloha 7

EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Wrist and Hand

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This feature is a unique combination of text (voice) and video that more clearly presents and explains procedures in musculoskeletal medicine. These videos will be available on the journal's Website. We hope that this feature will change and enhance the learning experience.

Walter R. Frontera, MD, PhD
Editor-in-Chief

Abstract: In this dynamic protocol, ultrasound evaluation of the wrist and hand is described using various maneuvers for relevant conditions. Scanning videos are coupled with real-time patient examination videos. The authors believe that this practical guide—prepared by the international consensus of several experts—will help musculoskeletal physicians perform a better and uniform/standard examination approach.

Key Words: Finger, Ultrasonography, Tendon, Maneuver, Physical and Rehabilitation Medicine

(*Am J Phys Med Rehabil* 2022;101:e132–e138)

The utility of musculoskeletal ultrasound (US) has already become a routine in the daily clinical practice of physiatrists. As an extension of basic/static scanning, dynamic assessment is a critical advantage of this examination technique. However, protocols for implementing this method in the wrist and hand do not exist in the literature. Like the previous basic scanning protocols in physical and rehabilitation medicine,[1–3] an international group of experts (European Musculoskeletal Ultrasound Study Group in Physical and Rehabilitation Medicine [EURO-MUSCULUS] and Ultrasound Study Group of the International Society of Physical and Rehabilitation Medicine [USPRM]) also prepared this guide for dynamic assessment of wrist and hand disorders.

DORSAL ASPECT OF THE WRIST

Radiocarpal Joint

Technique

The patient should sit face-to-face with the examiner keeping the hand in palm-down position, resting on an examination bed or the patient's ipsilateral knee, while the forearm is pronated and the elbow is semiflexed at approximately 90 degrees. The transducer is placed along the long-axis of the wrist. Bony prominences serve as anatomic landmarks for both orientation and evaluation of the joint stability. The authors also suggest placing a support underneath the patient's wrist or positioning the wrist over the edge of the examination bed/table, that is, to have mild volar flexion.

Clinical Indications

Radiocarpal Joint Effusion

Dynamic scanning allows better visualization of the radiocarpal joint effusion. With the patient's hand in a palm-down position, the wrist joint is slowly bent (dorsal/palmar) while resting on the examination table. This dynamic assessment is commonly performed in the long-axis view, at the level of the lunate bone. During the maneuver, it is possible to observe that the radiocarpal joint recess is stretched with palmar flexion and compressed while the wrist is dorsally flexed (Figs. 1A–C and Video 1, http://links.lww.com/PHM/B597). Of note, mild effusion/synovial hypertrophy can be missed during static scanning of the wrist in neutral position or dorsal flexion. Likewise, differentiating between synovial proliferation and effusion can also be challenging with only static imaging. Furthermore, loose bodies (e.g., cartilage or bony fragments) inside the joint can be better identified during dynamic scanning. As such, using these passive wrist flexion/extension maneuvers will potentially help elucidate the presence of all previously mentioned conditions (Video 2, http://links.lww.com/PHM/B598).

Triangular Fibrocartilage Complex Injuries

For dynamic examination of the triangular fibrocartilage complex, the probe is placed over the extensor carpi ulnaris tendon along its long-axis. The radioulnar deviation allows evaluation of the fibrocartilage disc with its attachment site to the distal radius and of the meniscus homolog (Figs. 1D, E and Video 3,

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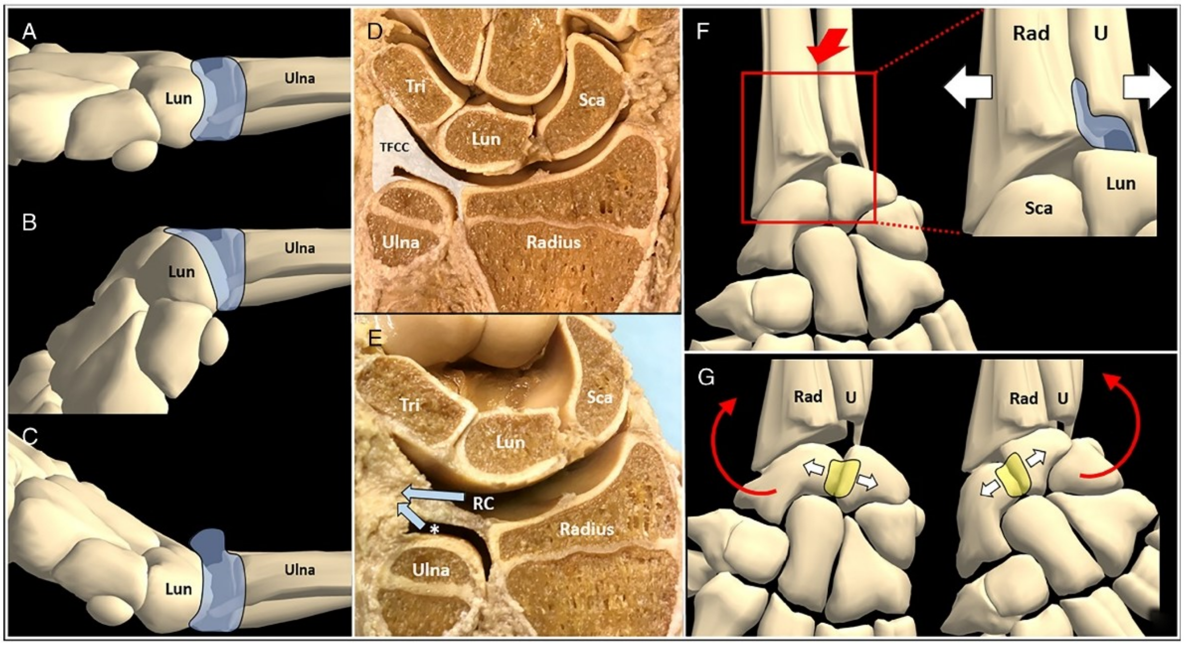

FIGURE 1. Schematic drawings and cadaveric specimens show the dynamic assessment of the radiocarpal synovial cavity (light blue) during flexion/extension of the wrist (A–C), of the triangular fibrocartilage complex located at the level of the ulnocarpal space during radial/ulnar deviation of the wrist (D, E), the distal radioulnar joint (light blue) during the squeeze maneuver (red arrow) of the distal forearm (F), and of the dorsal scapholunate ligament (yellow) during stress movements (red arrows) of the wrist (G). lun, lunate; rad, radius; RC, radiocarpal joint; sca, scaphoid; tri, triquetrum; u, ulna. Blue arrows, flow of the synovial fluid; white arrows, articular diastasis; white asterisk, distal radioulnar joint recess.

http://links.lww.com/PHM/B599). Using ulnar and radial deviations, the stress test can reveal fluid being penetrated within the triangular fibrocartilage complex as an apparent cleft opening toward its inside (indicating a tear; Videos 4 and 5, http://links.lww.com/PHM/B600, http://links.lww.com/PHM/B601). The fluid can also derive from the radiocarpal joint and/or the distal radioulnar joint (Fig. 1E). In some cases, a larger gap can also be observed between the proximal carpal bones and the ulna during radial deviation.[4,5]

Distal Radioulnar Joint Instability

For dynamic assessment, the examiner applies a squeezing force to the interosseous membrane at midforearm level, placing the thumb on the dorsal aspect while the remaining fingers are placed on the volar aspect of the forearm.[6] At the same time, the physician uses his other hand to place the US probe in short-axis view over the distal forearm, visualizing the Lister's tubercle on one side and the apex of the ulnar styloid on the other side of the US screen (Video 6, http://links.lww.com/PHM/B602). When abnormal, the diastasis is associated with the distraction of the previously mentioned bony landmarks (Fig. 1F and Video 7, http://links.lww.com/PHM/B603). The contralateral side can, for sure, be used as the reference.[5] Distal radioulnar joint instability can be congenital (in patients with laxity of the capsuloligamentous structures), or be related to chronic overloads of the wrist, or can be posttraumatic. Particularly, in patients with posttraumatic instability (a high-grade instability), during the dynamic maneuver and the squeezing phase of the technique, the diastasis of bones is associated with a bulging of the dorsal aspect of the synovial membrane—due to dynamic flow of the intra-articular effusion.

Carpal Bones and Ligaments

Technique

The patient sits in front of the examiner with the palm-down, the forearm pronated, and the elbow flexed at approximately 90 degrees. The palmar and dorsal aspects are used to visualize the bony surfaces of the radius, ulna, and carpal bones, and the ligaments that interconnect the above structures. Initially, the transducer is positioned on the Lister's tubercle when scanning from the dorsal aspect and then it is advanced distally toward the fingers. Smooth surfaces of the individual carpal bones can be identified, forming the proximal and distal rows, together with the intrinsic and extrinsic ligaments.

Systematic scanning from the palmar side starts at the distal wrist crease. Moving the transducer distally, the scaphoid tubercle and the pisiform bone can be observed bridging the carpal tunnel. Two important bony landmarks can be observed when advancing the probe further toward the fingers: the trapezium tubercle and the hook of the hamate. Relocating the probe along the fingers, individual metacarpal bones can also be identified.

Ultrasound allows a comprehensive assessment of the extrinsic and intrinsic wrist ligaments as hyperechoic bands connecting the individual bones.[7] It is essential to direct the sound beam as perpendicular as possible to avoid anisotropy artifact that can otherwise be misinterpreted as a pathology (e.g., edema, tear). A ligament tear is suspected if the fibers are discontinuous or the ligament is absent. In addition, corresponding cortical irregularity and/or ligament thinning should also caution the examiner. Herein, dynamic examination will allow for better visualization of the ligament stability (Videos 8 and 9, http://links.lww.com/PHM/B604, http://links.lww.com/PHM/B605).[8] One can either apply stress to the joint to generate tension on the ligaments or directly compress with the probe. Separation of the (torn) ends or penetration of the overlying superficial tissues toward the joint would be the relevant findings for instability and/or rupture. For sure, dynamic testing may also reveal an impingement due to ligament tear/instability.[9]

Clinical Indications

Scapholunate Ligament Dysfunction

The transducer is first placed in the short-axis view over the radiocarpal joint on the distal forearm (dorsal side). While the probe is being moved distally, the two bony structures on the screen will represent scaphoid and lunate. A V-shaped hypoechoic area is apparent between these two bones, while the gap (hypoechoic area) in the scapholunate joint is filled with the dorsal portion of the scapholunate ligament. The ligament can be stressed dynamically by moving the patient's wrist into ulnar deviation and any increase in the width between the two bones can be checked (Fig. 1G) for scapholunate dissociation.[10] Aside from their diastasis, common sonographic findings also include penetration of synovial fluid through a focal gap of the ligament (Video 10, http://links.lww.com/PHM/B606) and abnormal movements of a small bony fragment in case of posttraumatic avulsion. Alternative maneuvers to mechanically stress the ligament—that is, (de)tensioning—would be opening/closing the fist and palmar/dorsal flexions of the wrist.

Scaphoid Fracture

The scaphoid bone should optimally be scanned in short/long-axis while the wrist is positioned in ulnar deviation. The typical finding for fracture is discontinuity of the bony cortex. Indirect signs are radiocarpal hemarthrosis and scapho-trapezium-trapezoid effusion.[11] Needless to say, nearby soft tissues changes, such as callus formation, can easily be detected by US examination.[12] The sonographer can also apply stress tests to check for the (in)stability of the fracture and/or callus. Dynamic maneuvers using passive movements can demonstrate fracture nonunion with apparent motion between the two bone fragments.[13]

Extensor Tendons

Technique

The patient sits in front of the examiner with the palm-down, the forearm pronated, and the elbow flexed at 90 degrees. The probe is placed at the level of the distal radioulnar joint over the Lister's tubercle, which is the bony landmark that separates the second and third compartment. Sliding the probe toward the ulnar/radial side, all six extensor compartments can be systematically evaluated. Dynamic scanning allows evaluation of tendon gliding beneath the extensor retinaculum and within the tendon sheaths (Fig. 2). Active/passive flexion and extension of the fingers will confirm integrity of the normal-appearing hyperechoic tendons from proximal to distal as necessary. Likewise, intersections syndromes—that is, either the first compartment crossing over the second proximally or the third one crossing over the second distally—can also/thoroughly be examined (Video 11, http://links.lww.com/PHM/B607).[14]

Clinical Indications

Extensor Retinaculum Impingement

During the active movement (e.g., flexion/extension of the fingers and radial/ulnar deviation of the wrist; Video 12, http://links.lww.com/PHM/B608), it is possible to identify the location of a mechanical conflict between the extensor tendons and the retinaculum (Fig. 2 and Video 13, http://links.lww.com/PHM/B609). In

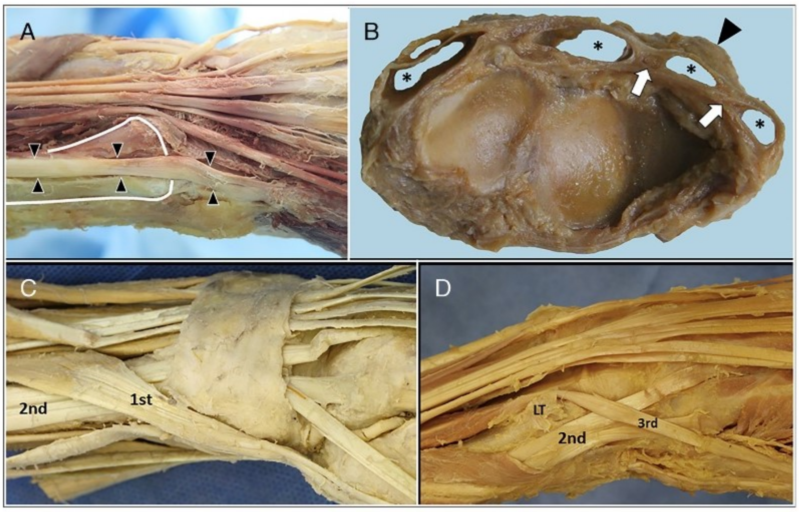

FIGURE 2. Cadaveric specimens show the anatomical location of the extensor carpi ulnaris tendon (black arrowheads) within the bony groove of the ulna (white lines; A), the fibrous sheaths (black asterisks) of the extensor tendons with a dorsal component (black arrowhead) and intercanal septa (white arrows; B) and the sites of proximal (C) and distal (D) intersection syndromes. 1st, first extensor compartment; 2nd, second extensor compartment; 3rd, third extensor compartment. LT, Lister's tubercle.

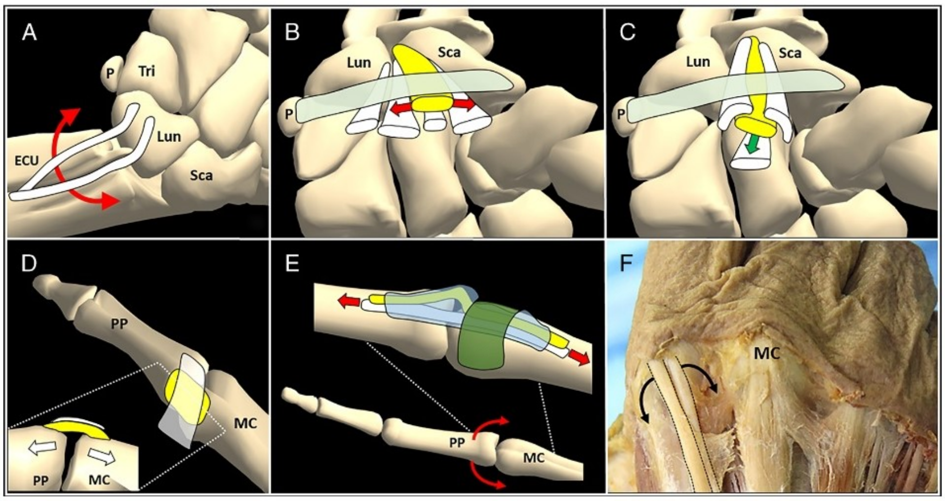

FIGURE 3. Schematic drawings and cadaveric specimens show the dynamic evaluation of the extensor carpi ulnaris tendon during pronation/supination (double red arrow) of the wrist/forearm (A), of the lateral gliding (red arrows) and torsional movements (green arrow) of the median nerve (yellow) within the carpal tunnel among the flexor tendons (white; B, C), of the UCL (yellow) of the thumb—beneath the adductor aponeurosis (white)—during the valgus stress test (D), of the gliding movements (thick red arrows) of flexor digitorum superficialis (yellow) and profundus (white) tendons within the synovial sheath (light blue) and beneath the A1 pulley (green) during flexion/extension (thin red arrows) of the finger (E), and of the extensor tendons (black dotted lines) of the finger while closing the hand into a fist (F). Lun, lunate; MC, metacarpal bone; p, pisiform; PP, proximal phalanx; sca, scaphoid; tri, triquetrum. Black arrows, shifting movements of the extensor tendons; light green, transverse carpal ligament; white arrows, articular diastasis.

some cases, the thickened retinaculum can mimic trigger finger symptoms whereby dynamic US examination would definitely be contributory.[15,16] Similar to other conditions, if a mass or bone fragment is present at this location, dynamic scanning can also explain the exact causal relationship between the pathology and the patient's complaint.

Subluxation of the Extensor Carpi Ulnaris Tendon

During forearm pronation and supination, scanning can be performed in the short-axis view where the tendon is located within its subsheath—separate from the common extensor retinaculum (Fig. 2 and Video 14, http://links.lww.com/PHM/B610). Extensor carpi ulnaris instability can be diagnosed if the tendon is slipping out of the ulnar groove in a volar-ulnar direction during supination and relocating during pronation of the forearm (Fig. 3A and Video 15, http://links.lww.com/PHM/B611). The dislocation can be accompanied by a click sound over the wrist's dorsoulnar aspect.[17] It is noteworthy that increased mobility of the tendon can also be a normal variation, for example, if it resides in a shallow groove.[18]

De Quervain Tenosynovitis

From the basic position over Lister's tubercle, the transducer is shifted radially to depict the first extensor compartment which harbors abductor pollicis longus and extensor pollicis brevis tendons. Sonographic findings of De Quervain tenosynovitis include thickening of the extensor retinaculum and/or tendons and their synovial sheath. Attention should also be paid during the US examination for septa that would cause further compartmentalization and/or extra terminal attachments of the tendons (Video 16, http://links.lww.com/PHM/B612). These conditions might predispose to De Quervain tenosynovitis because of increased friction. Dynamic US examination during thumb extension can reveal snapping phenomena pertaining to an uneven excursion of the extensor pollicis brevis subcompartment[19] or the gliding extensor pollicis brevis over the accessory abductor pollicis longus tendon.[20]

Dorsal Wrist Ganglion

Ganglia are common pathologies at the dorsal wrist where dynamic US evaluation helps determine their origins, for example, joint, nearby tendon sheath. In particular, the articular ganglion shows limited excursion due to its connection with the dorsal joint recess and, in the latter case, the ganglion displays consensual gliding with the extensor tendon.[21] Similarly, as ganglia can expand between the extensor compartments, their relationship can promptly be uncovered to explain the complaint(s) of the patient (e.g., snapping ganglion during ulnar/radial deviation of the wrist).[22] Last, the examiner can also assess the ganglion cyst compressibility before considering an aspiration or planning for the appropriate technique (Video 17, http://links.lww.com/PHM/B613). Needless to say, hypo/anechoic-appearing accessory muscles of the hand should not be misdiagnosed as ganglia and dynamic imaging would again/also be contributory for such a differential diagnosis (Video 18, http://links.lww.com/PHM/B614).

VOLAR ASPECT OF THE WRIST

The patient sits opposite to the examiner with the hand in a palm-up position, resting on an examination bed or a pillow, the forearm supinated, and the elbow semiflexed at 90 degrees. The transducer is placed along the short-axis view on the volar aspect of the wrist to visualize the median and ulnar nerves and the flexor tendons. For sure, the palmar longitudinal window can also be used. During dynamic imaging, active/passive flexion and extension of the fingers is commonly performed whereby flexor tendons' integrity and gliding patterns are examined. In addition, structure/mobility of the median nerve as well as the palmar aponeurosis can also be evaluated.

Clinical Indications

Carpal Tunnel Syndrome

Median nerve mobility is likely to be reduced in patients with carpal tunnel syndrome.[23,24] Dynamic scanning on the short-axis view allows visualization of the mobility of the median nerve while the patient fully flexes the fingers (by slowly making a fist). The grade of its axial mobility at the carpal tunnel can be classified as follows: grade 0 (decreased) refers to minimal movement of the median nerve; grade 1 (slightly decreased) refers to freely moving median nerve in the transverse plane, which does not dive deep toward the flexor tendons; and grade 2 (normal) refers to freely moving median nerve between the flexor tendons (Video 19, http://links.lww.com/PHM/B615 and Figs. 3B, C).[25] Furthermore, dynamic scanning in the transverse plane (during finger flexion/extension) allows differentiation of tendinous structures from synovitis. Importantly, due to anatomical continuity between epimysium and the paraneural sheath, transverse displacement of the median nerve can also be reduced at the midforearm level in carpal tunnel syndrome patients.[26] Likewise, impaired longitudinal excursion of the nerve has also been reported in carpal tunnel syndrome.[27]

Accessory Muscles

Dynamic US examination can reveal accessory muscles that might compress the adjacent nerves (Video 20, http://links.lww.com/PHM/B616).[28] For instance, an anomalous muscle belly of the flexor digitorum superficialis of the index finger can be observed compressing the median nerve during finger flexion and extension.[29] Another common accessory muscle in the wrist and hand area is the abductor digiti minimi, which runs through the Guyon canal—causing ulnar nerve compression. When the patient abducts the little finger, increase in the muscle thickness as well as nerve impingement can be observed.[30] During the dynamic technique, an eventual intrusion of the lumbrical muscles can also be observed within the carpal tunnel (Video 21, http://links.lww.com/PHM/B617).

HAND AND FINGERS

The patient sits face-to-face with the examiner in different positions, depending on the hand/finger aspect studied. On the dorsal side, attachments of the extensor tendons can be visualized. Flexor tendons (Videos 22 and 23, http://links.lww.com/PHM/B618, http://links.lww.com/PHM/B619), annular pulley system, and volar plates can be evaluated on the volar side of the fingers. Each tendon needs to be scanned in short and long-axes—also followed until its insertion. Dynamic maneuvers, for example, passive/active finger flexion and extension, valgus/varus stress tests, and resisted flexion/extension can easily be performed. In certain cases (e.g., finger deformities), the examination inside a water basin can be beneficial to optimize the imaging quality.

Clinical Indications

Midcarpal Instability

Dynamic US evaluation can clarify the painful triquetral catch-up clunk, most commonly present with ulnar deviation. Examination is carried out both during pronation and supination. The patient performs radial and ulnar abduction, while the examiner holds the patient's fingers and follows the screen for clunks produced by translocation of the proximal carpal bones.[31]

Dupuytren Contracture

In some cases, dynamic techniques can help in the differential diagnosis of Dupuytren contracture,[32] including trigger finger, tenosynovitis, ganglion, dermoid cyst, and soft tissue masses.[33] In the early phase of Dupuytren contracture, the tendons are seen to move smoothly below the palmar fibromatosis (Video 24, http://links.lww.com/PHM/B620).[34] In later stages, the adhesion of the nodules to the tendons (due to their mutual cord-like attachments) can be visualized under dynamic imaging.[35]

Gamekeeper's Thumb (Skier's Thumb or Stener Lesion)

Dynamic stress can be applied to evaluate the integrity of the ulnar collateral ligament (UCL) of the metacarpophalangeal (MCP) joint of the thumb.[36] The palm-down position of the hand on the examination table will allow access to the radial aspect of the thumb, which is optimal for UCL imaging. Alternatively, the injured thumb grips a bottle while the examiner's free hand performs a valgus stress test (Video 25, http://links.lww.com/PHM/B621)—checking for an increase in the distance between the proximal phalanx and the first metacarpal bone (Fig. 3D). An intact UCL is best seen longitudinally on the radial side of the first MCP joint. Dynamic maneuver using valgus stress to the MCP joint can be applied to classify the injury into a nondisplaced UCL tear or a Stener lesion (Video 26, http://links.lww.com/PHM/B622). Normally, a limited joint gap opening and tensioning of the UCL are to be observed.[36] If painful, local anesthesia (e.g., vapor coolant spray) can be used during the test. Needless to say, these dynamic tests should be performed gently, that is, avoiding conversion of a nondisplaced injury into a Stener lesion.[37]

Trigger Finger

The patient is seated face-to-face with the examiner, keeping the affected hand in a palm-up position. Enough US gel (alternatively stand-off pad or water filled basin) can allow minimal probe pressure and maintain contact with the finger during dynamic scanning. The transducer is placed along the long-axis of the finger to visualize the flexor tendons as hyperechoic fibrillar bands superficial to the metacarpals/phalanges. Annular pulleys are seen as hypoechoic thickening of (the volar aspect of) the tendon sheath. Thickening and hypervascularization of the A1 pulley (most commonly) are the hallmarks of trigger fingers on sonography.[38] Herewith, dynamic examination during flexion/extension of the finger should be performed to evaluate the gliding of the tendon beneath the pulley system (Fig. 3E, Videos 27 and 28, http://links.lww.com/PHM/B623, http://links.lww.com/PHM/B624). This examination might give a better insight regarding the exact cause/site of triggering (not always at the A1 pulley level).[39,40] Aside from pulley swelling/thickening or effusion inside the synovial sheath, tendon thickening and abnormal tendon motions associated with friction patterns are other typical US findings (Video 29, http://links.lww.com/PHM/B625).[41] In some cases, triggering due to swelling of other pulleys can also be observed during dynamic imaging (Videos 30 and 31, http://links.lww.com/PHM/B626, http://links.lww.com/PHM/B627). Of note, differential diagnosis for trigger finger—for example, fibrous scar due to tendon rupture, tendon sheath tumors, ganglia, and exostoses—can be identified using (dynamic) US as well.[42]

Pulley Rupture

Similar to the trigger finger examination, integrity of the pulley system can be evaluated promptly using US imaging. The annular pulleys are first recognized in their short-axis view (along the long-axis of the fingers) as tiny hypoechoic linear bands overlying the flexor tendons. The pulley system allows stabilization of the flexor tendons on the anterior phalangeal cortex. In cases of ruptures, either the pulley cannot be clearly/directly visualized or the characteristic/indirect finding of flexor tendon dislocation (away from the adjacent cortex) can be observed as "bowstringing." The patient can be asked to perform resisted flexion with his fingertip against the examiner to increase the diagnostic certainty whereby the tendons will normally remain adjacent to the underlying bony surface (Video 32, http://links.lww.com/PHM/B628). While maximal bowstringing over the proximal phalanx indicates an A2 pulley injury (Video 33, http://links.lww.com/PHM/B629), in A4 pulley injuries, the bowstringing is mostly pronounced at the middle phalanx level.[43]

Volar Plate Injuries

Dynamic studies can be used to determine the amount of soft tissue edema and mobility of the volar plate (Video 34, http://links.lww.com/PHM/B630). The unstable volar plate can be visualized during hyperextension—with increased mobility.[44] Dynamic testing should particularly be performed in posttraumatic conditions. The most common pathological US findings are (1) penetration of joint effusion within a focal gap of the volar plate (Video 35, http://links.lww.com/PHM/B631), (2) excessive excursion of the volar plate (chronic instability due to a previous trauma), and (3) aberrant movements of a small (bony) fragment in avulsions of the volar plate attachment on the base of the phalanx. Herewith, in some patients, a posttraumatic exuberant scar of the volar plate can lead to a mechanical conflict of the joint—easily depictable during dynamic imaging.

Proximal Interphalangeal and Distal Interphalangeal Joint Instability

Dynamic imaging under stress (valgus for ulnar and varus for radial ligaments) or with sagittal plane instability induced by hyperextension forces may be useful for assessing interphalangeal joint integrity (Video 36, http://links.lww.com/PHM/B632). Collateral ligament injuries range from sprains and partial-thickness tears with no or minimal loss of articular stability to complete tears with significant joint instability.[45] Sagittal plane instabilities of the proximal interphalangeal and distal interphalangeal joints can be associated with lesions of volar plates, collateral ligaments, or even bone fractures. Accordingly, during the US examination, it should be kept in mind that acute trauma can be associated with collateral ligament sprain, partial tear, or complete disruption. Various levels of valgus/varus instability can be determined using stress under dynamic scanning. Chronic instability of these joints is usually coupled with thickening of the collateral ligaments, fibrosis, formation of enthesophytes, or even avulsion fractures of the collateral ligaments.[46]

Clenched Fist—Human Bite Injury

This injury is frequently associated with complete or partial tears of the extensor tendons. Sonographic characteristics comprise soft tissue hypoechogenicity, consistent with edema and tendon disruption. Dynamic imaging during MCP joint active or passive flexion/extension can be confirmatory in ambiguous cases—showing the extent of the lesion.

Boxer's Knuckle

Dynamic US study in the axial plane, at the level of the distal metacarpal heads, can demonstrate partial/complete instability of the digital extensor tendons during flexion of the extended MCP joint against resistance (Video 37, http://links.lww.com/PHM/B633). The type of tendon instability is related to the seriousness of the sagittal band injury (Fig. 3F). The sagittal bands connect the extensor tendons to the collateral ligaments and the volar plates of the MCP joints. Subluxation may also be congenital (Video 38, http://links.lww.com/PHM/B634) or acquired (Video 39, http://links.lww.com/PHM/B635) because of degenerative/inflammatory changes of the sagittal band.

Insertional Tendinous Ruptures

During active/passive movements, the extensor/flexor tendon integrity can be assessed until its insertion at the base of the distal phalanx (Videos 35 and 40, http://links.lww.com/PHM/B631, http://links.lww.com/PHM/B636). From the dorsal aspect, the extensor tendon tear (Video 41, http://links.lww.com/PHM/B637) or the distal phalanx avulsion fracture (i.e., "Mallet finger") can be clearly exposed.[47] From the volar aspect, a partial or complete tear of the flexor digitorum superficialis/profundus tendon can be easily assessed during the dynamic US (Video 42, http://links.lww.com/PHM/B638). In addition, foreign bodies and their relationship with the tendons can be visualized as well (Video 43, http://links.lww.com/PHM/B639).[48]

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Příloha 8

EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for (Adult) Hip

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This feature is a unique combination of text (voice) and video that more clearly presents and explains procedures in musculoskeletal medicine. These videos will be available on the journal's Website. We hope that this feature will change and enhance the learning experience.

Walter R. Frontera, MD, PhD
Editor-in-Chief

Abstract: In this dynamic scanning protocol, ultrasound assessment of the adult hip is described using different maneuvers for various conditions. Real-time patient examination and ultrasound scanning videos are coupled for convenience as well as for better insight. The text covers the common conditions around the hip where especially dynamic ultrasound scanning provides valuable information in addition to static imaging. The protocol is prepared by an international consensus of several experts in the field of musculoskeletal ultrasound.

Key Words: Ultrasonography, Snapping, Labrum, Piriformis, Acetabulum

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The history of ultrasound (US) assessment of the hip dates back to 1980s—particularly with regard to screening for congenital hip joint dislocation in neonates and infants.[1] Later, coupled with the development of higher-quality US equipment and standard scanning protocols, US assessment has also become commonplace in the evaluation of adult hip disorders.[2,3] As an important part of comprehensive examination, dynamic scanning is crucial in several conditions where static imaging would not fully explain the clinical scenario. To this end, an international group of experts elaborated this scanning protocol for dynamic US examination of the hip.

ANTERIOR AND MEDIAL VIEW

Technique

The examination begins in the neutral position, that is, the patient lying supine on the examination bed with the lower limbs extended. Hip flexion/extension and abduction/adduction can be performed in this position. Notably, flexion can be only "partially" assessed because of the inconvenient/challenging positioning of the probe along the anterior surface of the hip. Having the patient in proximity to the edge of the examination bed, the extension of the hip can be performed to achieve maximal range of motion. The probe is placed anteriorly in the inguinal region to obtain a view of the bony structures (femoral neck and head, acetabular rim) and surrounding soft tissues (eg, labrum, joint capsule, iliofemoral ligament, and iliopsoas muscle), or at the medial aspect of the hip to visualize the hip adductors. Regarding the latter, the initial scanning can start with flexion, abduction, and external rotation of the hip ("frog position")—simulating the FABER (or Patrick) test. Depending on the specific maneuver, the examiner intends to perform, and the probe and patient positioning is changed whenever needed. Given the deep-seated anatomy of the hip joint, low-frequency or curvilinear probes can be used (particularly in obese patients).

Clinical Indications

Joint Effusion

The examiner slowly flexes/extends (or eventually rotates) the hip to reveal an intra-articular effusion in the anterior synovial recess, deep to the iliopsoas muscle (Video 1, http://links.lww.com/PHM/B706; Fig. 1A). In the presence of fluid, hip flexion or rotation is associated with bulging of the iliofemoral ligament-joint capsule complex at the level of the femoral head-neck junction. The echogenicity of the fluid depends on its nature (eg, septic, hemorrhagic, or serous).[4] Furthermore, redistribution/flow of the fluid can help differentiate it from synovial hypertrophy (Video 2, http://links.lww.com/PHM/B707). Eventual communication between the hip joint and the iliopsoas bursa can suggest focal

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EURO-MUSCULUS: European Musculoskeletal Ultrasound Study Group in Physical and Rehabilitation Medicine.

USPRM: Ultrasound Study Group of the International Society of Physical and Rehabilitation Medicine (ISPRM).

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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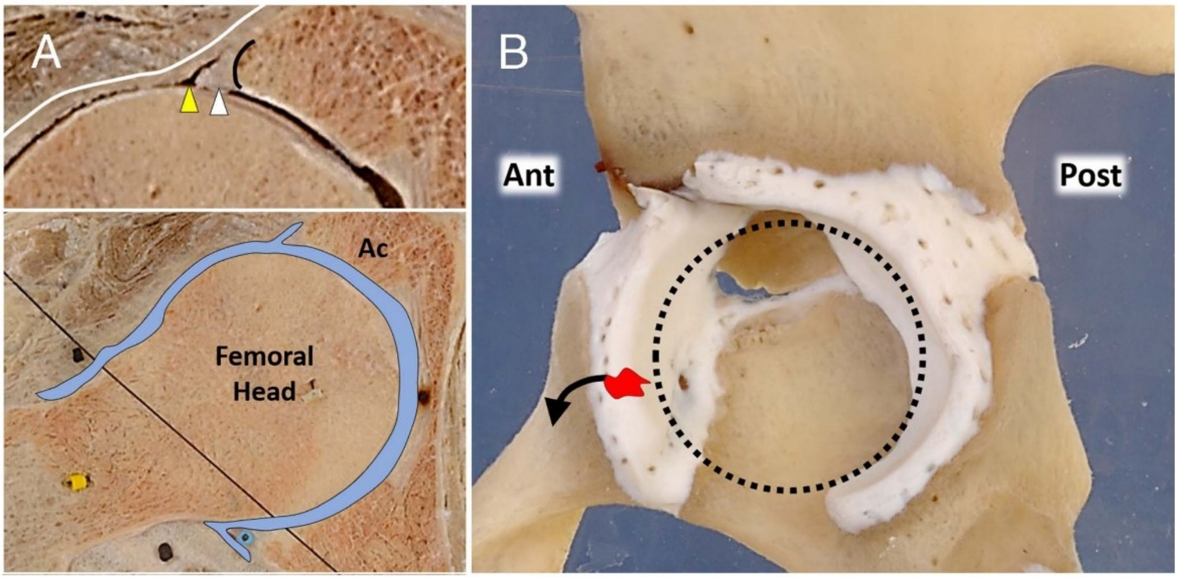

FIGURE 1. Dynamic assessment of the hip joint allows real-time visualization of the motions of the intra-articular effusion (blue) within the anterior capsular recess (white line) observing "how" the synovial fluid interacts with the surrounding anatomical structures—the labrum (white arrowhead), the paralabral recess (yellow arrowhead), and the chondrolabral junction (black line, A). Of note, in pathological conditions, active movements of the femoral head (black dotted line) can increase the intracapsular pressure "pushing" the articular effusion (black arrow) through a focal defect (red spot) of the hip labrum (B). Ac, acetabulum; Ant, anterior; Post, posterior.

capsular gaps, either congenital or degenerative in patients with hip osteoarthritis. Herein, it is important to maintain the same (symmetric) hip rotation/position when comparing the right-left sides for femoral neck-joint capsule distance, to interpret fluid presence in mild cases (≥7–9 mm).[5]

Labral Injury

To elucidate acetabular labrum tear, the bony acetabulum, anterosuperior portion of the acetabular labrum, and the femoral head and neck are first imaged in its long axis (Fig. 1B). The examiner then performs hip flexion and internal/external rotation to stress the labrum and to assess its morphological integrity (Video 3, http://links.lww.com/PHM/B708). Abnormal motion of the anterior labrum during the dynamic assessment can be associated with the avulsion of the base of the fibrocartilage (Video 4, http://links.lww.com/PHM/B709). In addition, the examiner may apply manual long-axis traction of the hip to elicit potential gapping of the labral tear.[6] Notably, the hypoechoic cleft extending through the labrum can also result from the presence of sublabral recess, a normal anatomical variant.[7,8] An advantage of the dynamic assessment over the static one is the possibility to see the "flow" of the synovial fluid (as a "natural contrast agent") within a focal gap of the fibrocartilage, hence better visualizing the injury. Occasionally, small gas microbubbles (physiologically dissolved in the synovial fluid) can be seen moving during the dynamic maneuver. A paralabral cyst, if present, can also be assessed dynamically for its (non)compressibility and mobility (Video 5, http://links.lww.com/PHM/B710).

Femoroacetabular Impingement

Different types of femoroacetabular impingement can be confirmed by the evidence of abnormal mechanical contact/motion between the acetabular/labral side and the femoral head/neck during real-time imaging (with hip flexion and internal rotation; Video 6, http://links.lww.com/PHM/B711, Video 7, http://links.lww.com/PHM/B712, Video 8, http://links.lww.com/PHM/B713).[9,10] To assess femoral head instability, the hip joint is stressed using the "apprehension position." To achieve stress on the anterior structures, the patient holds the contralateral knee to maintain the contralateral hip flexion in the supine position. Meanwhile, the ipsilateral hip is being extended, the knee is flexed, and the shin hangs over the bed. The probe is positioned in the long axis along the acetabulum-femoral head and neck junction. The examiner then applies hip external/internal rotation to evaluate anterior translation of the femoral head (Video 9, http://links.lww.com/PHM/B714).[11]

Intra-Articular Loose Bodies

Mobile/suspected loose bodies within the anterior capsule-synovial recess of the hip joint can be observed during dynamic examination. In this way, differential diagnosis for a loose body versus hypertrophic synovium can also be possible. While the former can show "random" movements within the anterior capsular recess, the latter usually presents with an anchor pedicle attached to the capsule-synovial wall of the hip joint with limited ("floating") movements. Likewise, dynamic maneuvers can be used for the differential diagnosis of intra-articular calcific loose body versus dystrophic calcification of the hip labrum. Indeed, the latter is "attached" to the anterior acetabulum with no movements within the joint capsule. Notably, loose bodies, torn labrum, osteochondral fractures, and hip joint effusion can also be possible causes of "intra-articular snapping hip."[12,13]

Anterior Snapping Hip Syndrome

Ultrasound imaging allows for static/dynamic imaging of the periarticular tendons/muscles. For sure, dynamic examination better serves to uncover any mechanical conflict under real-time imaging—also interacting with the patient and simulating/eliciting the daily life symptoms. When there is a perceptible or audible click during the hip motion, the condition is commonly called "snapping hip" (alternatively "coxa saltans"). Notably, pain might also accompany the scenario, and it would be paramount to unmask the exact cause.

Iliopsoas muscle–preinsertional segment is one of the common causes of snapping hip syndrome. A specific maneuver by moving the leg from extension, adduction, and internal rotation to the "frog position" and back to the neutral position can be performed while the transducer is held in an oblique transverse plane over the femoral head (Video 10, http://links.lww.com/PHM/B715).[14] In healthy individuals, the tendon moves laterally and anteriorly when the maneuver is performed and returns back when the leg is straightened in the initial position.[15] In patients with snapping hip syndrome, dynamic examination can detect the abnormal motion of the iliopsoas tendon during the "snapping" sensation (Video 11, http://links.lww.com/PHM/B716). Of note, it is sometimes challenging to detect the rapid rotatory or lateral-medial movement of the tendon.

The tendon-muscle rotation is a commonly accepted mechanism despite variations among patients.[16] This theory assumes the transitional wedging of the medial fibers of the iliacus muscle between the superior pubic ramus and the psoas major tendon in the frog position. During movement to the neutral (extended) position, the iliacus muscle's medial fibers move laterally, while the psoas muscle rolls dorsally.[15] (Nother theory assumes the role of iliopsoas muscle/tendon snapping over the iliopectineal eminence.)[17] Less common causes such as tendon bifurcation (with heads flipping over each other) or mass lesions (eg, paralabral cyst, iliopsoas bursitis) would be other imaging findings as well.[18–20]

Other Mechanical Muscle/Tendon Problems

Iliopsoas muscle–insertional segment can also be examined using the FABER maneuver.[21] The transducer is initially placed over the femoral head in the anterior longitudinal view and then moved slightly oblique, after the iliopsoas tendon crossing the hip joint and distally inserting on the lesser trochanter.[21] Herein, if the patient performs resisted adduction, partial/complete tear of the muscular belly, tendon, and the myotendinous junction, or even avulsion of the lesser trochanter can be examined. In clinical practice, these could be useful during preoperative planning or for posttenotomy evaluation.[21]

The FABER positioning also allows for dynamic visualization of the contact between the tendon and the acetabular cup in diagnosing iliopsoas impingement syndrome after total hip arthroplasty.[22] In symptomatic patients, the iliopsoas tendon was reported to be displaced anteriorly and medially by the acetabular component.[23] Friction between the tendon and the acetabular cup (a piece of cement) or the cup fixation screws could be verified using dynamic examination, observing abnormal motion of the swollen and hypodense muscle/tendon.[24]

Rectus femoris muscle can be scanned to visualize its direct head as the transducer is placed at the level of the anterior inferior iliac spine.[14] Moving the transducer laterally and inferiorly (while the sound beam is being directed perpendicular to the lateral acetabular cortex to eliminate anisotropy), the indirect head can be visualized.[25] Possible pathologies such as bursitis, tendon tears, or tendinosis (including those with calcium deposits leading to snapping) can be examined with dynamic techniques.[26,27] For instance, extension and external rotation of the hip joint can be used to provoke the snapping phenomenon in such patients.

As a side note, the term "subspine impingement" refers to the mechanical conflict between the femoral neck against the bony protuberance at the anteroinferior iliac spine, which is commonly curved toward the femoral neck.[28,29] The impingement at this site can also develop because of avulsion fracture of the anteroinferior iliac spine or calcific tendinitis of the proximal insertion of the rectus femoris tendon. Likewise, these conditions can also be examined as described previously.

Adductor muscles/tendons can be imaged for substance tears or avulsion injuries, while the examiner applies resistance against active hip adduction again in the "frog position" (Video 12, http://links.lww.com/PHM/B717, Video 13, http://links.lww.com/PHM/B718, Video 14, http://links.lww.com/PHM/B719; Fig. 2A).[30]

Symphysis Pubis Diastasis/Instability

Measurement of the interpubic gap is commonly the criterion standard to assess postpartum diastasis. The diagnosis is supported if the distance between the narrowest level between upper branches of the pubic bones is more than 10 mm (Fig. 2B).[31] To scan the symphysis dynamically, pelvic compression and distraction can be performed while the probe is held in the transverse plane over the pubic bones. During this maneuver, the examiner (or an assistant) places hands on the anterior and medial aspects of the patient's right and left anterior superior iliac spine while applying a gentle posterior force (Video 15, http://links.lww.com/PHM/B720). Of note, a postpartum diastasis recti abdominis can be assessed with US—first at a resting state and in a sit-up position. The increased interrectus distance can usually be seen at the umbilicus level.[32]

LATERAL VIEW

Technique

Dynamic examination of the lateral hip is performed in the lateral decubitus position. The transducer is held in the transverse view over the greater trochanter.[33] The examiner or the patient moves the adducted hip from extension to flexion and back to the initial position to detect abnormal motion (Video 16, http://links.lww.com/PHM/B721). The "bicycle test" can be used by asking the patient to simulate the pedaling motion with the affected lower limb. For sure, the patient may be asked to reproduce his/her symptoms in any position possible. In some cases, the patient needs to stand and bear weight on the affected limb while performing the provoking movement. For imaging the tensor fascia lata's proximal attachment, the examiner can ask the patient to actively abduct the hip—with or without resistance—to visualize the motion abnormalities reproducing the pain at the iliac crest.

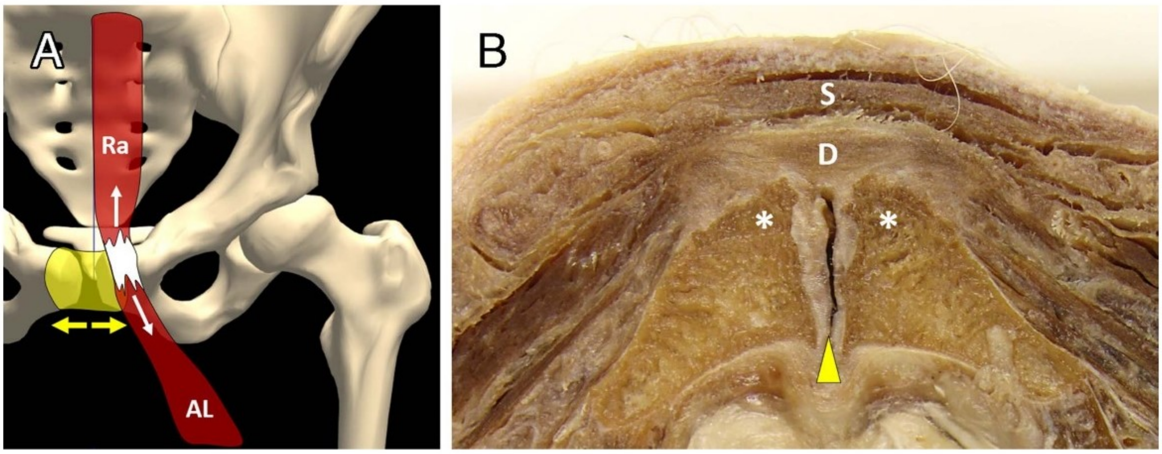

FIGURE 2. Dynamic assessment can be performed in adduction against resistance—to put in tension (white arrows), the common aponeurosis (white) linking the tendons of AL and Ra muscle (A). In addition, an eventual diastasis (yellow arrows) of the pubic symphysis (yellow) can be evaluated during the dynamic technique (A). Of note, anatomically, the pubic symphysis (yellow arrowhead), at the level of pubic tubercles (white asterisks), presents a thick wad of aponeurotic tissue—the pubic plate (B). In the S layer, the superficial fibers of the AL and the external oblique (of the opposite side) interact with each other; instead, in the D layer, the anterior capsule merges with the Ra, the inguinal ligament, the deep fibers of AL, and the anterior fibers of adductor brevis (B). AL, adductor longus; D, deep; Ra, rectus abdominis; S, superficial.

Clinical Indications

Lateral Snapping Hip Syndrome

Dynamic examination can visualize the movement of the posterior border of the iliotibial band or the anterior portion of the gluteus maximus muscle across the greater trochanter (Figs. 3A–C, 4A–C).[14] This subluxation of the affected structures accompanied by snapping is sometimes called external (or "lateral") snapping hip. Furthermore, the examiner can visualize possible thickening or hypoechoic changes of the iliotibial band and the underlying thickened trochanteric bursa or calcifications of the soft tissues (Video 17, http://links.lww.com/PHM/B722, Video 18, http://links.lww.com/PHM/B723).[34]

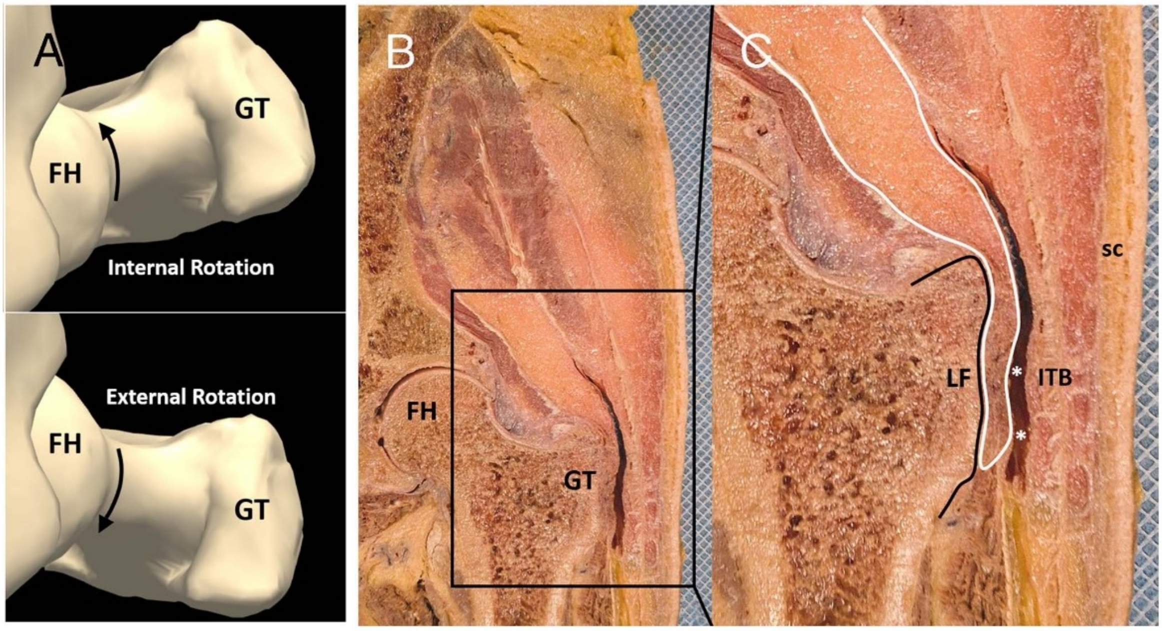

FIGURE 3. Internal/external rotation (black arrows) of the hip joint (A) allows real-time visualization of the dynamic interactions between the GT and the surrounding soft tissues (B). Of note, cadaveric specimen clearly shows the anatomical interface between the gluteus medius tendon (white line) and the ITB where a large synovial bursa (white asterisks) is located (C). GT, greater trochanter; FH, femoral head; ITB, iliotibial band; LF, lateral facet; sc, subcutaneous tissue.

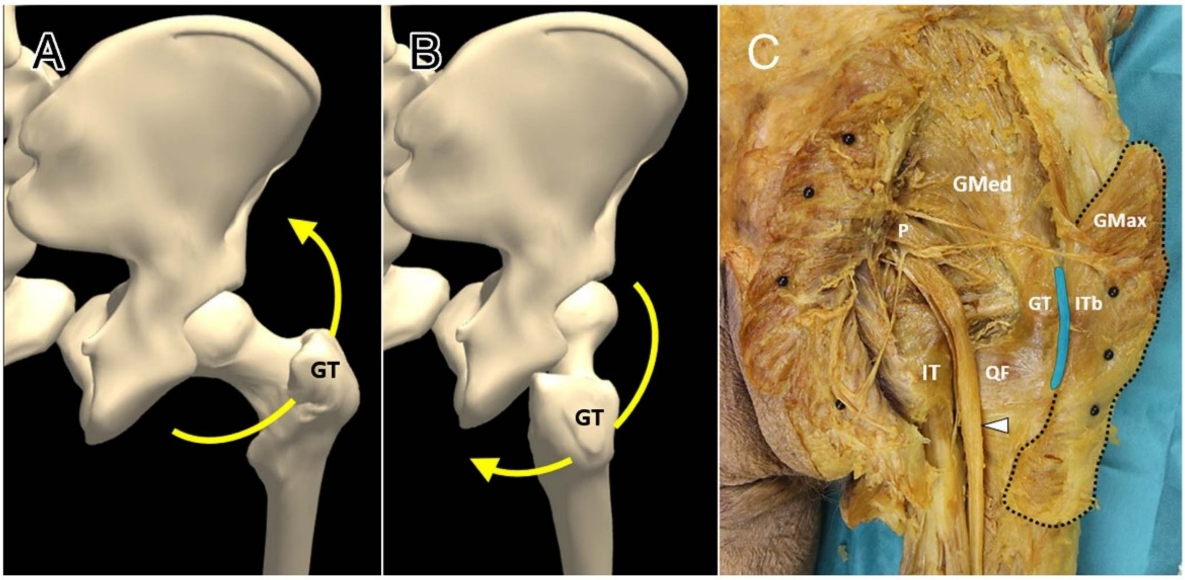

FIGURE 4. Dynamic assessment of the lateral hip can be performed—during active or passive movements (yellow arrows; A, B)—to directly observe an eventual impingement of the gluteus maximus-iliotibial band complex (black dotted line) over the GT (C). Of note, not only the muscle-tendon structures but also the trochanteric synovial bursa (blue) should be considered among the potential pain generators. GMax, gluteus maximus; GMed, gluteus medius; GT, greater trochanter; IT, ischial tuberosity; ITb, iliotibial band; P, piriformis; QF, quadratus femoris; white arrowhead, sciatic nerve.

(Tensor) Fascia Lata Problems

Dynamic examination can be performed to detect partial/complete tears of the muscular belly/tendon, myotendinous junction, or proximal avulsion over the iliac crest.[35] Of note, gluteus maximus insertion to the fascial layers can be assessed during external/internal rotation of the hip. In cases of injury, the fascial detachment can be better defined dynamically (Video 19, http://links.lww.com/PHM/B724).

POSTERIOR VIEW

Technique

The patient is lying in prone position on the examination table with the gluteal region exposed. The knee is flexed to 90 degrees and held by the examiner, allowing passive internal and external rotation to perform a dynamic examination.

Piriformis muscle can be imaged by placing the probe in transverse plane over the sacrum toward the site being examined. The probe is then moved caudally to visualize the bony landmarks—sacroiliac joint and posterior superior iliac spine. Moving the probe caudally to the sacroiliac joint, the piriformis muscle can be visualized. To align the transducer with the long axis of the muscle, the lateral part of the transducer is placed more caudally (in the direction of the greater trochanter) in relation to the medial part of the transducer. As for dynamic examination, passive hip rotation can be performed to precisely evaluate the piriformis movement compared with more static gluteus maximus muscle.

Obturator internus muscle is assessed while the probe is moved caudally and medially from the "piriformis view" until the rounded structure of the ischium is seen. With passive hip rotation, the obturator internus muscle can be visualized and dynamically examined as it courses around the ischium. To align the probe with the long axis of the muscle's medial part, the probe is moved slightly caudally.

Quadratus femoris muscle can be assessed after moving the probe from the "obturator internus view" caudally and laterally, holding the probe in a transverse plane and looking for two bony landmarks—lateral aspect of the ischial tuberosity and the intertrochanteric ridge of the femur. The quadratus femoris muscle runs in between these two bony structures. Dynamic evaluation of the ischiofemoral impingement is performed via rotating the hip externally (Figs. 5A–C).

Hamstring muscles can be evaluated by initially detecting the ischial tuberosity as the bony landmark. The examination begins with an axial view at the level of the ischial tuberosity. Turning the probe 90 degrees, the hamstrings are also evaluated in their long axis. In obese or muscular patients where US identification might be difficult, the examination starts at the proximal midthigh. At this site, the helpful landmark would be the "Mercedes Benz sign" between the long head of the biceps femoris, semitendinosus, and adductor magnus muscles.[36] For dynamic examination (during hip flexion), the patient needs to be positioned sideways at the edge of the examination bed. Alternatively, the patient can be examined standing on the contralateral lower limb. The patient is asked to reproduce his/her symptoms by performing (alternatively resisted) hip flexion or forward flexion at the lumbar level.

Clinical Indications

Piriformis Syndrome

Piriformis muscle/tendon integrity can be evaluated statically and dynamically (Video 20, http://links.lww.com/PHM/B725).[37] The latter is similar to the Freiberg test, which assesses

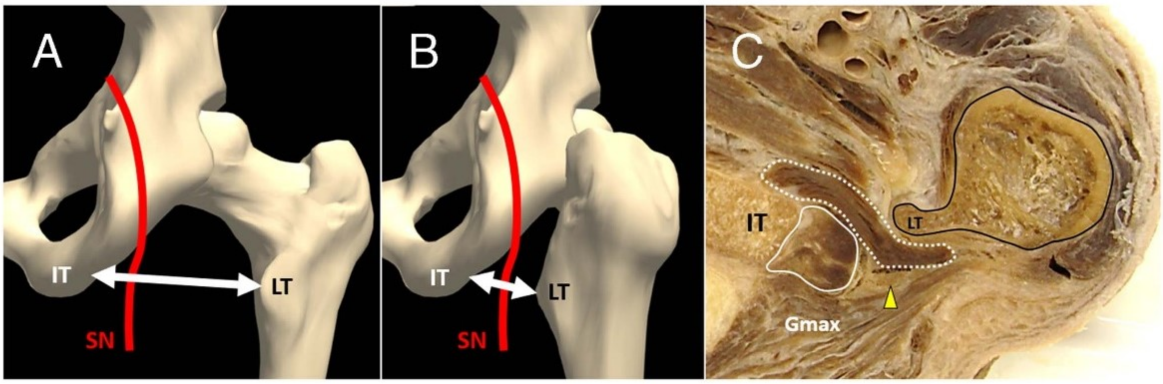

FIGURE 5. Internal (A) and external (B) rotation of the hip joint can be performed to dynamically assess the anatomical space (double white arrow) between the IT and the LT; within which, sciatic nerve and quadratus femoris muscle are located. Cadaveric image clearly shows how the quadratus femoris muscle (white dotted line) slips in between the hamstrings tendon (white line) and the LT of the femur (black line) in close proximity to the sciatic nerve (yellow arrowhead, B). GMax, gluteus maximus; IT, ischial tuberosity; LT, lesser trochanter; SN, sciatic nerve.

compression of the sciatic nerve caused by the piriformis muscle. Ultrasound examination to evaluate nerve compression by the piriformis muscle, the sciatic nerve snapping (Video 21, http://links.lww.com/PHM/B726), or the presence of anatomic variants such as double-headed piriformis that can cause sciatic nerve compression can easily be performed in subjects with normal body weight; however, it would be difficult in obese patients.[37,38] Significant increase in muscle thickness (compared with the asymptomatic side) measured by US has been reported.[39] Todorov and Batalov[40] also reported nonsmooth movements (catching and jumping) of the deep portion of the piriformis muscle over the iliac bone in piriformis syndrome. Notably, an anechoic fat pad overlying the piriformis tendon insertion should not be misinterpreted as fluid collection.[41] When there is a doubt regarding the previously mentioned hypoechoic/anechoic area, dynamic scanning aids to elucidate if there is any fluid being redistributed during hip rotation.

Obturator internus can also/similarly be evaluated for muscle tears, tendon pathologies, and bursitis using dynamic examination.[42]

Ischiofemoral Impingement Syndrome

As the place between ischial tuberosity and the intertrochanteric ridge is being reduced, quadratus femoris muscle becomes squeezed and displaced upwards ("eruption sign"; Video 22, http://links.lww.com/PHM/B727). The sciatic nerve can also be seen displaced during dynamic examination.[43]

Snapping Buttock—Coxa Saltans

There are reported cases of coxa saltans after proximal hamstring injuries. For instance, partial avulsion of the proximal hamstrings might cause snapping because of medial or lateral dislocation of the conjoint tendon over the ischial tuberosity (Video 23, http://links.lww.com/PHM/B728). Notably, the dislocated tendon can also displace the sciatic nerve.[44–46]

Apophyseal Injuries

The apophyseal region of the ischial tuberosity is the weakest part of the bone-tendon-muscle unit of the hamstrings in young athletes. Injuries might cause avulsion of the bony fragment. Ultrasound examination can depict the avulsed fragment and retracted tendon. It can also dynamically assess stability of the fragment during isometric contraction of the hamstrings. The probe is placed in the long axis of the hamstrings over the ischial tuberosity and the apophysis. Dislocation of the apophysis and the ischial tuberosity can be compared with the other (healthy) side.[47,48]

Proximal Hamstring Tears

The myotendinous junction is the weakest part of the hamstrings in young athletes. Ultrasound examination should be performed no earlier than 48 hrs after the injury to increase sensitivity. Ultrasound findings of the tear are alterations of the muscle structure and/or hypo/anechoic hematoma. Complete tear with muscle retraction can be confirmed with dynamic examination under isometric contraction (flexion of the knee against resistance).[47] Opening the gap within the injured tendon/muscle fibers can be observed. Noteworthy is also "sonopalpation" to locate the site of maximal tenderness. Dynamic evaluation can also be used to evaluate the "stability" of the scar after injury (eg, to plan for return to play).

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Příloha 9

Mnemonics and Metaphorical Videos for Teaching/Learning Musculoskeletal Sonoanatomy

Jakub Jačisko, MD, Kamal Mezian, MD, PhD, Orhan Güvener, MD, Vincenzo Ricci, MD, Alena Kobesová, MD, PhD, and Levent Özçakar, MD

This feature is a unique combination of text (voice) and video that more clearly presents and explains procedures in musculoskeletal medicine. These videos will be available on the journal's Website. We hope that this feature will change and enhance the learning experience.

Walter R. Frontera, MD, PhD
Editor-in-Chief

Abstract: Musculoskeletal ultrasonography, despite various advantages, is a user-dependent modality. There are several approaches to facilitate the learning process of novice sonographers, for example, on-site courses, textbooks, and online lectures. However, the need for specific (sono)anatomy knowledge can be an obstacle, particularly in the beginning. With the aim of helping novice sonographers understand and retain topographic (sono)anatomy, we have prepared this article that follows a modern approach to teaching known as "entertainment education." It consists of images, schematic drawings, and multimedia videos that provide a simple, visual explanation accompanied by auditory content.

Key Words: Ultrasonography, Musculoskeletal, Education, Funny, Multimedia

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Because of its numerous advantages and various applications in musculoskeletal (MSK) medicine, ultrasonography (US) has become a routine examination tool in the clinical practice of physical and rehabilitation medicine specialists.[1] On the other hand, because of its user dependency, MSK US remains a complex discipline that requires knowledge of (sono)anatomy, appropriate/lengthy training, experience, and interpretation capabilities. To cover these needs as well as to shorten the learning curve, several resources (books, courses, etc.) also including new technologies, for example, artificial intelligence, applications, (online) courses, or standardized protocols, are yet available.[2–7]

Among several classical/modern teaching methods,[8] the use of mnemonic aids has been shown to improve information retention and better understanding.[9–11] In addition, it has been confirmed that pictures and characteristic sounds are associated with significantly better recall than verbal labels alone.[12] Herein, an essential approach in modern pedagogy is "entertainment education," which can be defined as the intentional placement of educational messages within an entertaining content.[13,14] Likewise, we have tried to incorporate all the previously mentioned techniques in this comprehensive, expert-, and consensus-based set of images, schematic drawings, and multimedia videos. Our primary/eventual aim was to facilitate the learning in MSK US.

In this sense, we have gathered (as many as possible) the characteristic appearances in daily MSK US images. Using metaphoric nomenclature and the pertinent/typical sounds, several normal structures ($N = 26$) are being illustrated. We believe that the used names/signs will help the novice sonographers easily imagine/recall the relevant standard scans. While the text exemplifies only 5 of the 26 structures, to avoid repetition, the rest is given in the video gallery. Of note, the second article of this series will comprise US of different MSK pathologies.

HONEYCOMB (Video 1, http://links.lww.com/PHM/B749)

Peripheral nerves contain many nerve fibers grouped into fascicular bundles. Transverse scan of a nerve shows several hypoechoic "bubbles"—representing these nerve fascicles—inside the hyperechoic epineurium. This highly organized structure looks like a delicious honeycomb where nerve fascicles represent the tunnels for the bees. Its recognition might prompt the distinction from a tendon which is fibrillar instead.

FEATHER (Video 2, http://links.lww.com/PHM/B750)

Muscle fascicles run parallel to the length of the muscle (fusiform muscles) or attach at an angle to the aponeurosis (pennate muscles). Longitudinal scan of a bipennate muscle shows its hyperechoic fibroadipose component branching within the hypoechoic muscular tissue. This pattern is very similar to the esthetic structure of a feather with its central beam and multiple peripheral ramifications. Its recognition might facilitate accurate measurements of the muscle architecture.

STARRY SKY (Video 3, http://links.lww.com/PHM/B751)

The internal structure of a muscle consists of hypoechoic fascicles and hyperechoic perimysium. Transverse scan of muscles shows the physiological alternation of these two compartments. While the former corresponds to the dark sky, the latter forms the stars. Accordingly, the relaxing starry sky is commonly used to recognize a transverse scan of a muscle tissue wherever present/needed. Its recognition might prompt the differential diagnosis of normal versus pathological muscle.

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SPAGHETTI (Video 4, http://links.lww.com/PHM/B752)

Tendons are highly organized structures made of overlapping collagen fascicles and septa planes. Longitudinal scan of a tendon shows the (physiological) fibrillar pattern, that is, regularly aligned multiple hyperechoic lines. Multiple collagen fibers arranged parallel to each other look like a bunch of spaghetti—savory with the right sauce. Its recognition might facilitate the distinction from other tubular structures. In addition, because of fibrous or fibrocartilaginous tissue, their attachment sites (entheses) can also appear in the shape of free spaghetti ends giving anisotropy.

MICKEY MOUSE (Video 5, http://links.lww.com/PHM/B753)

Neurovascular structures run together. Transverse scan of a vascular bundle shows three anechoic "bubbles"—similar to the sympathetic face and ears of Mickey Mouse. Of note, gentle compression can be performed with the probe to collapse the "venous ears" and distinguish the artery (A). Another simple way would be to use the Doppler for visualizing different (steady *vs.* pulsatile) vascular flow patterns. The recognition of Mickey mouse might avoid possible injury during neuromusculoskeletal interventions.

BIRD BEAK (Video 6, http://links.lww.com/PHM/B754)

The supraspinatus tendon passes under the acromioclavicular joint and attaches to the greater tuberosity of the humerus. With the shoulder in neutral position, longitudinal scan of the supraspinatus tendon looks like the bird beak whereby the acromion also corresponds to its head. The strong beak avoids the (pathological) cranial subluxation of the humeral head toward the acromion. Its recognition might indicate the presence of a normal tendon (supraspinatus critical zone).

TIRE (Video 7, http://links.lww.com/PHM/B755)

The modified crass position is a maneuver used to better view the superior/posterior parts of the supraspinatus tendon (Fig. 1). The patient is asked to place the volar surface of the hand on the ipsilateral hip, and the anterior transverse scan shows the intact rotator cuff as a tire. When "inflated" (i.e., intact covering the humeral head), it absorbs the shocks and avoids subluxation. Its examination is paramount for describing the width and thickness of a possible rotator cuff tear.

HAMBURGER (Video 8, http://links.lww.com/PHM/B756)

At the elbow, the median nerve passes between the pronator teres and the brachialis muscle. When the probe is placed in a transverse-oblique plane, the median nerve appears like an essential ingredient (cucumber) of a hamburger. Another cucumber represents the brachial vessels. The 'cheese' resembles the intermuscular fascia. Recognition of the hamburger might be contributory when targeting spastic muscles with botulinum toxin injections.

MOON OVER A HOUSE (Video 9, http://links.lww.com/PHM/B757)

The interosseous transverse septum between the bones of the forearm divides the muscles into superficial and deep layers. Flexor digitorum superficialis, pronator teres, palmaris longus, flexor carpi radialis, and flexor carpi ulnaris (the most medial one) form the superficial layer. During transverse sonotracking of the forearm, the ulna typically acquires a quadrangular shape resembling a house. At the same level, the flexor carpi ulnaris muscle resides superficially—like a moon illuminating it. Again, its recognition might be contributory during specific muscle targeting.

FULL MOON (Video 10, http://links.lww.com/PHM/B758)

The flexor pollicis longus tendon passes between the superficial and deep layers of the flexor pollicis brevis muscle. Transverse oblique scan on the volar aspect of the thenar eminence shows a hyperechoic round structure, that is, the flexor pollicis longus tendon. Among the surrounding hypoechoic muscles, it looks like the terrifying "full moon." Its recognition—especially via testing anisotropy—might be noteworthy to assess the tendon morphology and vascularity.

PYRAMID (Video 11, http://links.lww.com/PHM/B759)

The greater trochanter is an important landmark when evaluating the lateral hip. Transverse scan shows the triangular

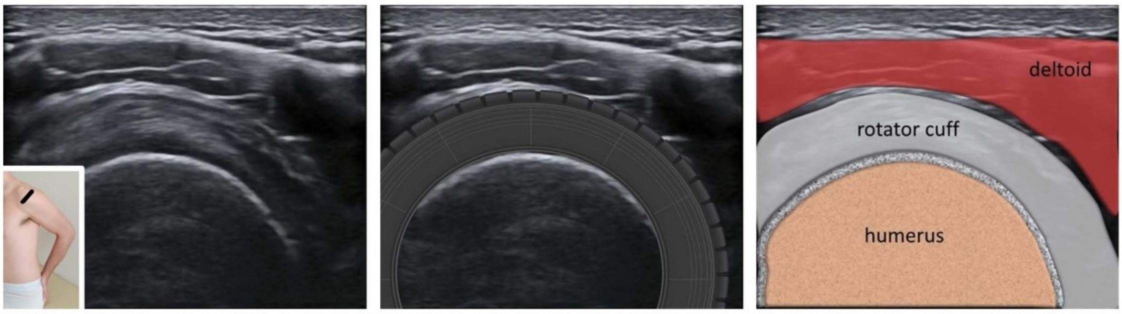

FIGURE 1. Shoulder rotator cuff. Normal, ridiculoUS, and schematic (from left to right) images show the shoulder rotator cuff in its shorts axis. Its ring shape resembles a tire surrounding a wheel's rim.

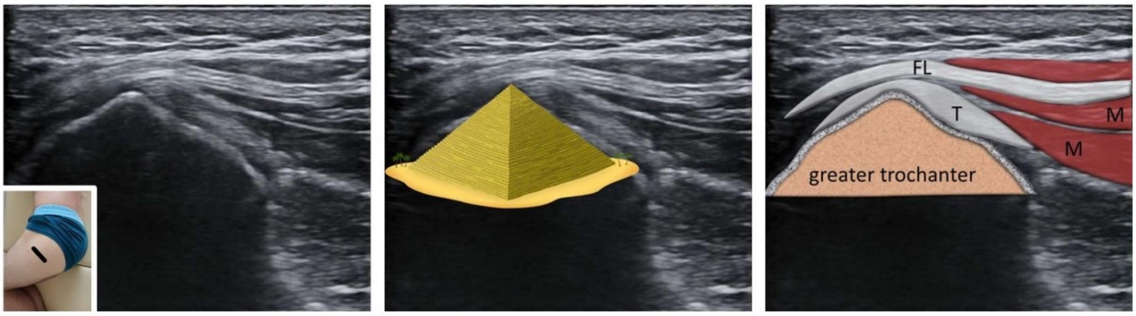

FIGURE 2. The greater trochanter. Normal, ridiculoUS, and schematic (from left to right) images show the greater trochanter's bony surface in the lateral short-axis view of the thigh. Its triangular shape converging to a single step at the top resembles an ancient Egyptian pyramid. FL, fascia lata; M, muscle; T, rotator cuff of the hip.

hyperechoic shape of the greater trochanter—similar to the ancient Egyptian pyramid (Fig. 2). Its recognition might guide while navigating for its different facets as well as for ensuring the transition from the femoral shaft (rather round in shape) to the trochanter (triangular).

WINDMILL (Video 12, http://links.lww.com/PHM/B760)

Transverse scan of the dorsal thigh at the proximal third shows the "famous" windmill formed by the conjoined tendon of semitendinosus-biceps femoris, sciatic nerve, and the adductor magnus muscle (Fig. 3). Similar to the windmill blades (metaphorically), these anatomical structures are pivotal to guaranteeing the "energy" for lower limb movements. Practically, their recognition might help physicians better locate the sciatic nerve and avoid an otherwise detrimental injury. This appearance had also been mentioned in the literature as the Mercedes-Benz sign, but in the near/green future, we hope/believe that the windmills will rather "overwhelm."

RAILWAY (Video 13, http://links.lww.com/PHM/B761)

The biceps femoris is a long muscle—also named as the lateral hamstring muscle in the posterior thigh. As the name suggests, it has two different heads, one of which extends deeply. Transverse scan of the posterior thigh (distally) shows the short head of the biceps femoris muscle appearing like a hopeful railway in between the long head of the biceps femoris and vastus lateralis muscles. Its recognition might facilitate guided electromyography or interventions.

CHERRY ON THE CAKE (Video 14, http://links.lww.com/PHM/B762)

Semimembranosus and semitendinosus are the medial hamstring muscles in the posterior thigh. Transverse scan (distal third) shows the semitendinosus tendon progressively shifting over the semimembranosus muscle—like the attractive cherry on the cake. Again, recognizing these structures is helpful for better/local orientation.

SUNGLASSES (Video 15, http://links.lww.com/PHM/B763)

The gastrocnemius is the most superficial calf muscle with two (medial and lateral) heads separated from the femur. Transverse scan of the proximal calf shows these two heads like a pair of fashionable sunglasses. Their recognition would be important for several diagnostic/interventional procedures (e.g., tennis leg, spasticity).

SEAL WITH A BALL (Video 16, http://links.lww.com/PHM/B764)

Tibialis posterior is a deep muscle covered by flexor hallucis longus and flexor digitorum longus muscles located on the posteromedial side of the leg. Transverse scan shows

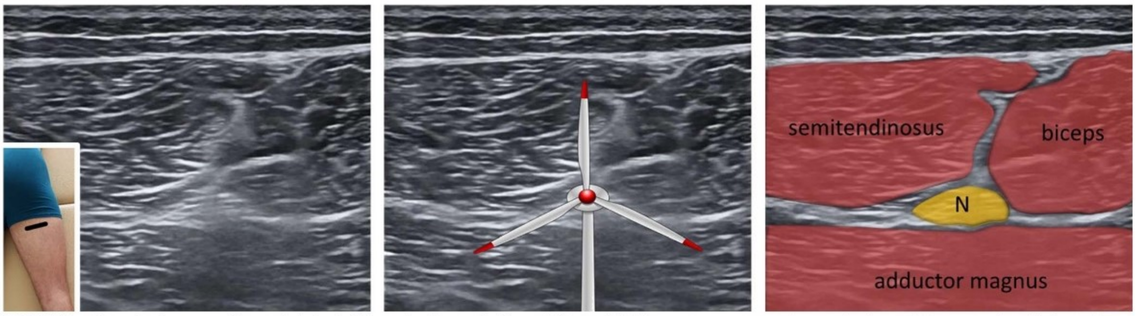

FIGURE 3. The sciatic nerve. Normal, ridiculoUS, and schematic (from left to right) images represent short-axis view of the posterior thigh at the proximal third. The biceps femoris and semitendinosus muscles (all together with their conjoined tendon) form a superficial layer, while the adductor magnus is situated deeply. The connective tissues appear like a windmill with the sciatic nerve in the middle. N, sciatic nerve.

FIGURE 4. The calcaneofibular ligament. Normal, ridiculoUS, and schematic (from left to right) images show the lateral ankle scan along the calcaneofibular ligament with the overlying fibular tendons. The hammock, representing the calcaneofibular ligament, relates to an indirect dynamic test commonly used to assess ligamentous injuries. CFL, calcaneofibular ligament; FB, fibularis brevis; FL, fibularis longus.

the tibialis posterior muscle, posterior tibial artery, and the tibial nerve, which altogether picture the sweet seal with a ball. Identifying these structures is important in daily practice to target the right muscle and avoid the nerve/artery during botulinum toxin injections.

HAMMOCK (Video 17, http://links.lww.com/PHM/B765)

The calcaneofibular ligament is one of the three parts of the ankle lateral ligament complex (Fig. 4). It extends from the lateral malleolus to the tubercle on the lateral aspect of the calcaneus. Longitudinal (oblique) scan can be performed to visualize the calcaneofibular ligament—appearing like a comfortable hammock on which the fibularis brevis and longus tendons swing. In case the ligament cannot be easily imaged, the outward movement of the tendons from the joint (during active ankle dorsiflexion) would indirectly confirm the presence of an intact ligament.

PAC-MAN (Video 18, http://links.lww.com/PHM/B766)

Plantar intrinsic muscles of the foot are adjacent to the tendons of the extrinsic muscles of the foot. Transverse scan of the plantar surface shows the hungry Pac-Man and the nearby flexor digitorum longus and flexor hallucis longus tendons. When tracking the two previously mentioned tendons proximally, their crossover—known as the knot of Henry—can easily be visualized. Henry's knot identification can be important during the examination of plantar intersection syndrome.

TRAFFIC LIGHTS (Video 19, http://links.lww.com/PHM/B767)

After the cervical nerve roots exit the neural foramina, they course between the scalene muscles. Transverse scan of the lateral neck (from proximal to distal) shows the C5, C6, and C7 nerve roots position between the anterior and middle scalene muscles—reminiscent of the classical traffic lights. Their recognition would indisputably be crucial during a broad range of neck interventions.

GRAPES (Video 20, http://links.lww.com/PHM/B768)

In the suprascapular region, the cervical roots form the trunks, which then divide into upper and lower divisions. Transverse scan of the lateral neck shows the brachial plexus coursing between the anterior and middle scalene muscles. Recognition of this juicy bunch of grapes is the mainstay of several neck procedures from different perspectives.

SAW TEETH (Video 21, http://links.lww.com/PHM/B769)

Facet joints are angled approximately 45 degrees at the upper cervical level, and they are more vertical in the lower

FIGURE 5. The lumbar vertebra and erector spinae muscle. On transverse scan of the lumbar spine, the shape of the vertebral bony surface resembles a bat, while the muscles appear like a butterfly. ES, erector spinae; F, facet joint; TP, transverse process.

cervical region. Posterior parasagittal scan of the cervical vertebrae shows the regularly aligned facet joints that appear like the dangerous saw teeth. Their recognition aids for better targeting the joints or the neighboring anatomical structures (e.g., medial branches).

TRIDENT (Video 22, http://links.lww.com/PHM/B770)

Longitudinal paramedian scan of the lumbar spine shows the three transverse processes giving sharp shadowings. Recognizing this frightening trident can ensure the interventional physician that the imaging pertains to a far lateral view—for a potential use during lumbar root targeting.

CAMEL HUMPS AND HORSE HEADS (Videos 23 and 24, http://links.lww.com/PHM/B771, http://links.lww.com/PHM/B772)

The typical lumbar vertebra consists of a body, arch (two laminae and two pedicles), and two transverse and one spinous processes. Longitudinal paramedian scans of the lumbar spine show the facet joints and the laminae that look like camel humps and horse heads, respectively. Both structures are targeted during pertinent interventions.

BAT AND BUTTERFLY (Video 25, http://links.lww.com/PHM/B773)

Transverse scan of the lumbar vertebra shows the deep bony lining and the erector spinae muscles, which respectively look like a bat and a butterfly (Fig. 5). Bony structures serve as important landmarks during pertinent interventions. Imaging the erector spinae can also be important during exercise therapy when using "sono-feedback."

FROG EYES (Video 26, http://links.lww.com/PHM/B774)

Sacrum (formed by the fusion of sacral vertebrae) is the continuation of the vertebral canal. The 5th sacral laminae do not fuse, resulting in a bony defect, that is, the sacral hiatus. Lateral walls of the sacral hiatus are formed by the tubercles of the inferior articular processes of the 5th sacral vertebrae (sacral cornua). Transverse scan shows the sacral cornua, which appear as the overwhelming frog eyes. Recognizing the hyperechoic band between the eyes (i.e., the sacrococcygeal ligament) would be important while planning for US-guided procedures in this region.

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Příloha 10

Mnemonics and Metaphorical Videos for Detecting/Diagnosing Musculoskeletal Sonopathologies

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This feature is a unique combination of text (voice) and video that more clearly presents and explains procedures in musculoskeletal medicine. These videos will be available on the journal's Website. We hope that this feature will change and enhance the learning experience.

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Editor-in-Chief

Abstract: Musculoskeletal ultrasound identifies a broad range of pathologies. Typical sonographic images of certain pathological/abnormal conditions can be rendered and "highlighted" for the daily practice/language of musculoskeletal sonographers. The following text and accompanying figures/videos represent a collection of findings pertaining to commonplace pathological conditions. This article is the second part of a series—after the characteristic/metaphoric descriptions of normal musculoskeletal structures.

Key Words: Ultrasonography, Muscle, Nerve, Funny, Multimedia

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Musculoskeletal ultrasound (US) identifies a broad range of pathologies, that is, traumatic, inflammatory, and neoplastic. Similar to other imaging modalities, for example, x-ray, computed tomography, and magnetic resonance imaging; typical sonographic images of certain pathological/abnormal conditions can be rendered and "highlighted" for the daily practice/language of musculoskeletal sonographers. Of note, metaphoric "signs" promote learning and retention of the characteristic appearances (via the limbic system, affecting memory consolidation and retrieval) and allow the examiners to easily recall the specific condition.[1,2] In this regard, the following text and accompanying figures/videos represent a collection of findings pertaining to commonplace pathological conditions. This article is the second part of a series—after the characteristic/metaphoric descriptions of normal musculoskeletal structures.[3]

CROCODILE MOUTH

Most of the supraspinatus tendon tears ensue in the distal insertion (critical) zone. Whereas short-axis view ("tire appearance") is quite demonstrative for a detailed description of the rupture,[3] long-axis view of the tendon distal to the acromion would also be guiding in the initial step. In other words, the convex "bird's beak"[3] might no more be present or, even worse, be replaced by an irregular and "scary" *crocodile mouth* (Fig. 1).[4]

FLAT TIRE

Supraspinatus tendon tears often appear as anechoic or hypoechoic on US. During short-axis imaging, a healthy tendon is convex (looking like a "tire")[3] and cannot be compressed under sono-palpation. In case of a full-thickness tear, the appearance will turn into a *flat tire* whereby deltoid muscle and the subdeltoid bursa would be filling the space.[5] Needless to say, if the image of a flat tire is not straightforward, compression with the probe would be noteworthy to make it apparent (Video 1, http://links.lww.com/PHM/B859).

BRIDGE

Soft tissue calcifications can be caused by a broad range of pathologies, that is, tendinopathy, myositis ossificans, rheumatic conditions, and malignancy.[6] Notably, whereas dense (hard) and large calcific deposits produce a typical posterior acoustic shadowing,[6,7] less dense (soft) or small calcifications may not always be accompanied by shadowing. Likewise, the phase of calcification may also impact whether the lesion will produce this artifact.[6] Although calcifications vary in density, location, size, and shape, the sonographic appearance of superficial ones can resemble a "single-cistern" *bridge* (Fig. 2) and the river represents the acoustic shadowing artifact.

HALO/EYE OF THE TIGER

Synovial (parietal and visceral) sheaths are structures that facilitate the sliding of tendons.[8] In the presence of inflammation within tendon sheaths (long head of the biceps tendon, wrist extensor tendons etc.), the fluid appears as a dark *halo* on US examination. Of note, because the synovial sheath can sometimes be associated with the joint space (e.g., shoulder), it is necessary to differentiate primary tendon problems from other articular pathologies. Furthermore, as comparison is an important advantage (as well as a prerequisite) of US examination, bilateral halos may be reminiscent of *tiger eyes* (Fig. 3) (Video 2, http://links.lww.com/PHM/B860).

SNOWSTORM

In gout(y arthritis), the main sonographic findings suggestive for monosodium urate crystal deposition are tophi,

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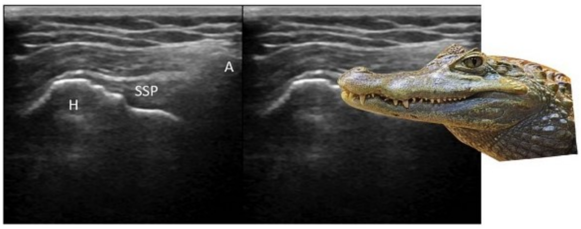

FIGURE 1. Crocodile mouth. Long-axis view of the distal insertion of the supraspinatus tendon (SSP). H indicates humerus; A, acromion.

the double contour sign, and the *snowstorm*. The characteristic image of the latter consists of multiple hyperechoic spots floating within the synovial fluid and surrounded by the synovium (Fig. 4). These microtophi correspond to aggregates of monosodium urate monohydrate crystals. Concerning the *snowstorm* appearance, the sensitivity and specificity in detecting monosodium urate deposition have been reported as 30.3% and 90.9%, respectively.[9]

BOTTLE NECK

When a peripheral nerve becomes entrapped, the deformation results in pressure gradients, which redistributes the tissue to areas of lower pressure. In addition, compression inhibits normal intraneuronal axoplasmic transport and various substances; for example, transmitter substance vesicles and cytoskeletal elements accumulate.[10] Eventually, mechanical/ischemic factors can cause nerve swelling usually just proximal to the entrapment site. In certain cases (e.g., after carpal tunnel surgery), nerve edema can also be present distal to the entrapment site and appear as an hourglass.[11] In daily clinical practice, peripheral nerves are usually/easily tracked in short axis, and if an abnormality (e.g., increased nerve caliper or hypoechogenicity) is detected, the probe is rotated 90 degrees and the typical appearance of *bottle neck* can be observed in the long-axis view. Needless to say, the neck represents the point of nerve compression (Fig. 5).

COMET TAIL

In the universe, a family of asteroids is usually identified for their brilliant tails. Likewise, in the musculoskeletal system, metallic foreign objects (screw, implant, etc.) give this reverberation artifact (long hyperechoic bands) owing to their feature of randomly reflecting the US beams. In daily clinical practice, it is also not uncommon to detect certain (otherwise unknown) foreign objects after recognizing these *comet tails* (Fig. 6) (Video 3, http://links.lww.com/PHM/B861).

RAT TAIL, TARGET, AND BAG OF WORMS

High-resolution US is considered as the mainstay for detecting/diagnosing peripheral nerve sheath tumors. The most prevalent types of solitary (benign) tumors in adults are schwannoma and neurofibroma. The former is derived from neoplastic schwann cells and the latter originates from schwann cells as well as from other tissues of the nerve sheath. Although the definitive diagnosis is histopathological, both display some characteristic findings on US examination. For instance, a round shape strongly suggests a schwannoma, a fusiform shape is relatively typical for a neurofibroma, and an oval shape is common for both. In contrast to neurofibromas, schwannomas appear in an eccentric position with regard to the peripheral nerve trunk.[12] Accordingly, the characteristic *rat tail* (a thin hyperechoic line entering and exiting the nerve) appearance (Fig. 7) is present in approximately half of the schwannoma patients.[13] Another US feature—which is more common in neurofibromas—is the *target* sign.[14] It is characterized by a hyperechoic fibrous center with a hypoechoic periphery (Fig. 8) that contains predominantly myxomatous material.[15] A subtype of neurofibromas that frequently develops in individuals with neurofibromatosis type 1 is plexiform neurofibroma. In contrast to localized neurofibromas that arise from a single peripheral nerve, plexiform neurofibromas originate from multiple nerves and involve perineural components as well as other soft tissue components. As such, a bulging mass that comprises tortuous bundles of enlarged, disorganized nerves and connective tissues appears as *bag of worms* on macroscopic inspection and US alike.[16] The US appearance is that of multiple hypoechoic nodules, poor margins,

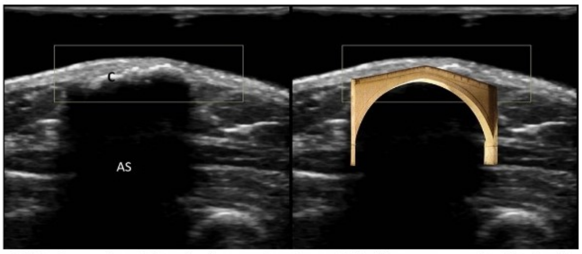

FIGURE 2. Bridge. Calcific deposition (C) in hypodermis in the long-axis view. AS indicates acoustic shadowing artifact.

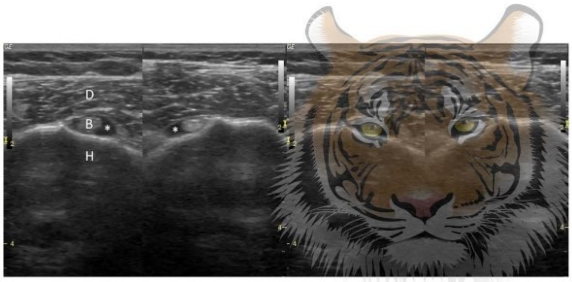

FIGURE 3. Tiger eyes. Bilateral effusion (*) around the long head of biceps brachii tendon (B) in short-axis views. D indicates deltoid muscle; H, humerus.

and several feeding vessels within hyperechoic connective tissue (Fig. 9). Notably, these tumors are at significant risk for eventual malignant transformation.

BLACK HOLE

Sono-tracking of a skeletal muscle in short-axis view can show sudden disappearance of the normal "starry sky" appearance (alternation of hypoechoic fascicles and hyperechoic perimysium)—being replaced by a large black hole. Similar to the absence of light in *black holes* of the universe, no acoustic interfaces can be identified inside an acute/subacute muscle injury due to hemorrhage instead of connective tissue and muscle fibers. Under prompt sono-palpation, compressibility/displacement of the black hole can confirm the lesion as well as the possibility of aspiration[5] (Video 4, http://links.lww.com/PHM/B862).

MISTY MUSCLE

Sono-tracking of a denervated skeletal muscle in short-axis view can clearly show fibroadipose involution. In other words, unlike the "starry sky," a coarse pattern with low visibility of the hypoechoic background (muscle fibers) and increased hyperechoic connective tissues (perimysium) can be observed, that is, a *misty muscle* (Fig. 10). Of note, the blurred muscle tissue would also reduce the sonographic visibility of deeper anatomical layers—owing to the presence of excessive/pathological acoustic interfaces that attenuate the ultrasonic beam.

CLOUDS

Myositis ossificans is a rare complication that mostly occurs after traumatic large muscle injury. US can significantly be contributory in the early diagnosis, even at stages when radiographs are negative.[17] Multiple/irregular hypoechoic and hyperechoic layers accompanied by posterior acoustic shadowing (as discussed above) is the main scenario mimicking *clouds* or cloudy weather[18] (Video 5, http://links.lww.com/PHM/B863).

PISTOL GRIP DEFORMITY

Femoroacetabular impingement syndrome is a clinical entity that refers to the disrupted relationship between the two bones due to morphological abnormalities from either side. The two basic types (i.e., cam and pincer) can be evaluated by x-ray, magnetic resonance imaging, and computed tomography,[19] but US examination might be of additional values if performed dynamically.[20] During long-axis imaging for a cam lesion, the shape of the proximal femur resembles a *pistol grip* (Video 6, http://links.lww.com/PHM/B864).

BOOMERANG AND SPEECH BUBBLE

The bursa between semimembranosus and medial head of the gastrocnemius tendons is the place of origin for popliteal/

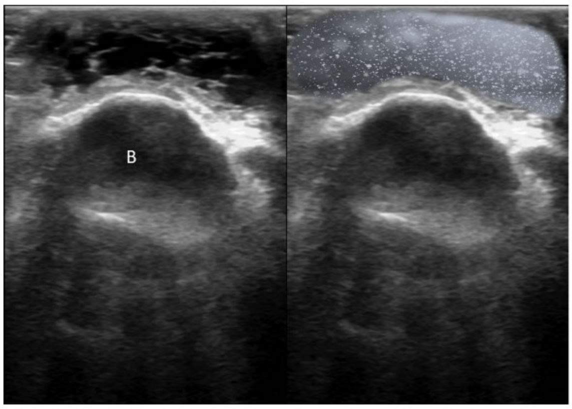

FIGURE 4. Snowstorm. Short-axis view of the olecranon bursa. B indicates bone.

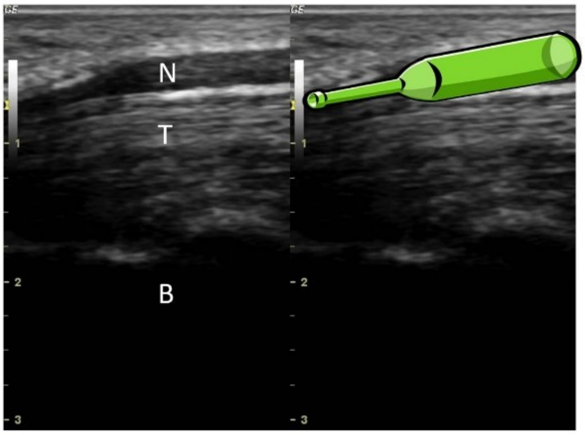

FIGURE 5. Bottle neck. Long-axis view of the median nerve (N) and flexor tendons (T). B indicates carpal bone.

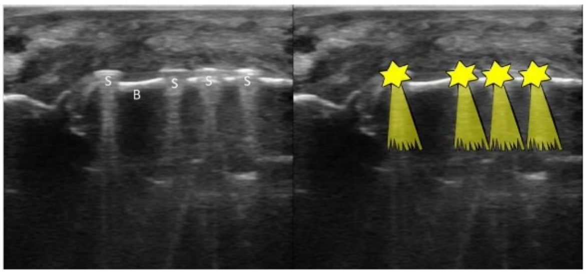

FIGURE 6. Comet tail. Short-axis imaging of the distal forearm in a patient operated for radius fracture. S indicates screw; B, bone.

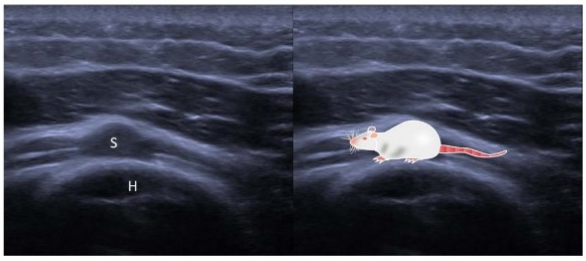

FIGURE 7. Rat tail. Radial nerve schwannoma (S) in long-axis view. H indicates humerus.

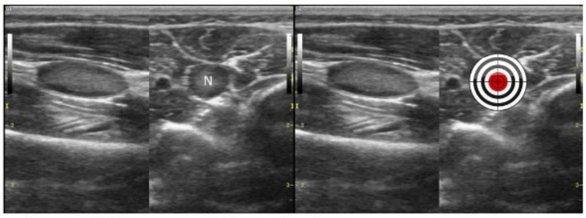

FIGURE 8. Target. Median nerve neurofibroma (N) in long- and short-axis views.

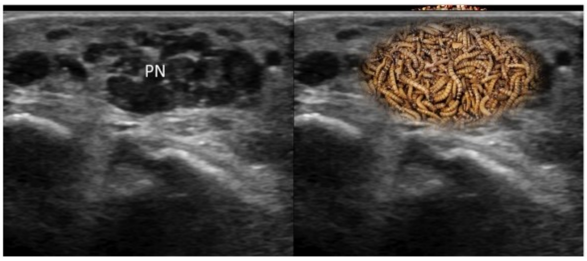

FIGURE 9. Bag of worms. Plexiform neurofibroma (PN) originating from superficial/subcutaneous nerve(s).

Baker's cyst. While its normal or mildly swollen shape resembles a *boomerang*, the appearance looks more like a *speech bubble* in case of further fluid collection (Fig. 11). The latter ensues mainly because of the dilatation of the superficial arm of the bursa. Of note, although the accumulation often contains homogeneous/anechoic fluid, different sonographic findings—ranging from fibrous septa to hypertrophic/floating synovial villi floating inside the cavity—might not be uncommon. Accordingly,

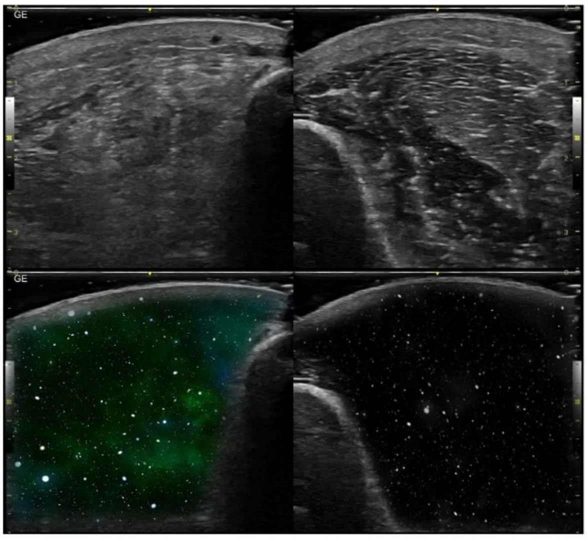

FIGURE 10. Misty (left) *vs.* starry (right) sky. Short-axis view shows fibrofatty involution due to chronic denervation of tibialis anterior muscle.

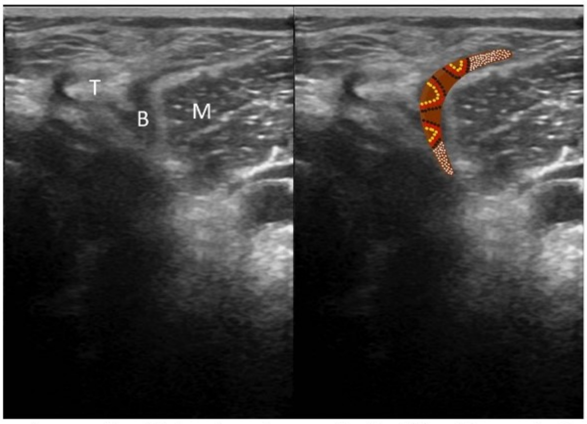

FIGURE 11. Boomerang. Short-axis imaging over the distal semimembranosus tendon (T) and the proximal gastrocnemius muscle (M). B indicates Baker's cyst.

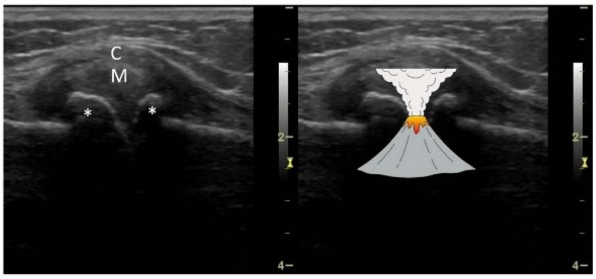

FIGURE 12. Volcano (eruption). Long-axis view shows the meniscal (M) and capsular (C) bulging. *Femoral and tibial osteophytes.

in addition to the shape of a Baker's cyst, the appearance of its content would also be important before an onward intervention (Video 7, http://links.lww.com/PHM/B865).

VOLCANO (ERUPTION)

In several joints of the musculoskeletal system, the presence of an intra-articular triangular fibrocartilage can be related to a peculiar pathological finding that looks like a *volcano (eruption)*. For instance, longitudinal scan over the acromioclavicular joint or the medial aspect of the knee joint shows—in some patients—the bulging of the aforementioned intra-articular fibrocartilage also bulging the overlying capsular tissue. In this sense, the joint line can be considered as the mouth of the volcano and the ejected/extruded meniscocapsular tissue as the boiling magma. Needless to say, clear recognition of these pathologies might easily navigate the clinician for prompt interventional planning to "cool down" the natural phenomenon (Figs. 12 and 13) (Video 8, http://links.lww.com/PHM/B866).

SHARK HEAD AND LIPS

Tennis leg refers to strain lesions of the myotendinous junction of the medial head of the gastrocnemius muscle. Intramuscular tear, deteriorated pennation pattern, fluid in the fascial planes, and hematoma can be visualized under US examination.[5,21] Especially, the presence of fluid between the medial head of the gastrocnemius and soleus muscles/aponeuroses might appear as a *shark head* with open mouth during long-axis view. On the other hand, in short-axis imaging, the same vista

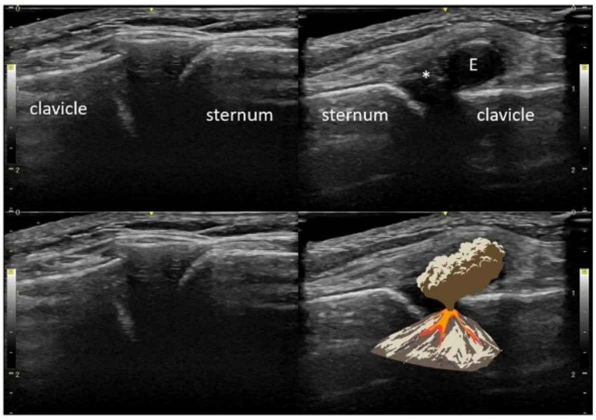

FIGURE 13. Volcano (eruption). Long-axis view over the sternoclavicular joint shows normal and extruded (E) sides. *Fibrocartilage.

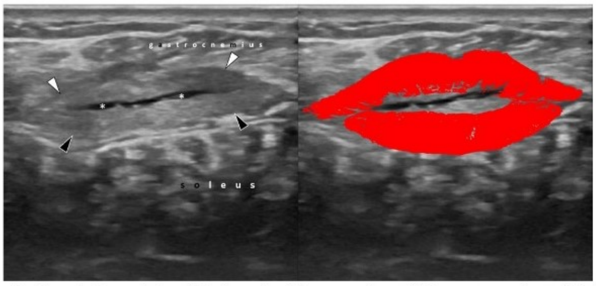

FIGURE 14. Lips. Tennis leg in short-axis view. * Organizing (black and white arrowheads) hematoma (asterisks). The annotations for the videos have been embedded for the reader's convenience.

might sometimes look like *lips* (Fig. 14) (Video 9, http://links.lww.com/PHM/B867).

ATOMIC MUSHROOM

In patients with clinical suspicion of Morton's neuroma, (short-axis view) dynamic assessment can be performed over the metatarsal heads using the Mulder maneuver. A hypoechoic mass protruding outward or a typical artifact when it is located inward can be quite pathognomonic.[5] The outward "jumping" neuroma can appear as the activation of an atomic bomb, that is, exploding and generating an *atomic mushroom* (Video 10, http://links.lww.com/PHM/B868).

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Příloha 11

EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Knee

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This feature is a unique combination of text (voice) and video that more clearly presents and explains procedures in musculoskeletal medicine. These videos will be available on the journal's Website. We hope that this feature will change and enhance the learning experience.

Walter R. Frontera, MD, PhD
Editor-in-Chief

Abstract: In this dynamic scanning protocol, ultrasound examination of the knee is described using various maneuvers to assess different conditions. Real-time patient examination and scanning videos are used for better simulation of the daily clinical practice. The protocol is prepared by several/international experts in the field of musculoskeletal ultrasound and within the umbrella of European Musculoskeletal Ultrasound Study Group in Physical and Rehabilitation Medicine/Ultrasound Study Group of the International Society of Physical and Rehabilitation Medicine.

Key Words: Ultrasonography, Knee, Examination, Maneuver, Physiatry

(*Am J Phys Med Rehabil* 2023;102:e67–e72)

Ultrasound (US) examination of the knee has already become routine in the daily clinical practice of physiatrists. Although dynamic evaluation is an absolute/added value in knee examination, a comprehensive approach for knee pathologies does not exist in the literature. Accordingly, as the extension of basic scanning,[1] an international group of experts elaborated this scanning protocol for dynamic US examination of the knee.

ANTERIOR VIEW

Relevant anatomic structures in the suprapatellar and infrapatellar regions that are amenable to dynamic US examination are the quadriceps tendon, suprapatellar synovial recess, suprapatellar fat pad, prefemoral fat, distal femoral metaphysis, the trochlea, patellar tendon, Hoffa's fat pad, peripatellar bursae, and the anterior cruciate ligament.

Technique

Scanning starts in the neutral position, that is, the patient lying supine on the examination bed with the knee in mild flexion (20–30 degrees)—possibly supported with a pillow under the popliteal fossa. Different angles of knee flexion/extension and patient positioning can easily be performed during the examination. The probe is placed anteriorly in the suprapatellar, juxtapatellar, and infrapatellar regions to assess several bony structures and surrounding soft tissues (e.g., tendons, recesses, entheses). As elsewhere, short- and long-axis imaging is done while bony prominences serve as anatomical landmarks for prompt orientation.

Clinical Indications

Suprapatellar Extensor Pathologies

While sitting on the examination bed and the ankle/foot hanging outside, long-axis imaging over the quadriceps tendon can be performed during active/passive knee movements. Contraction of the quadriceps muscle and gliding of its tendon can be evaluated for different injuries. For instance, a tear in the quadriceps tendon might become (more) evident with passive stretching or isometric contraction, that is, "opening the gap" (Videos 1, 2, and 3, http://links.lww.com/PHM/B907, http://links.lww.com/PHM/B908, and http://links.lww.com/PHM/B909). Moreover, this maneuver can be useful also to evaluate an eventual bony avulsion of the superior pole of the patella (stable or unstable).

Impingement and Intraarticular Loose Body

After evaluating the femoral trochlea and the overlying cartilage in maximum flexion, a mechanical conflict that blocks/impedes the knee extension (i.e., bony spur, hypertrophic synovium, loose body) can be observed during active/passive movements. In case of a loose body (e.g., cartilage/bone fragment or calcium deposit), especially the suprapatellar recess needs to be thoroughly scanned for other "floating objects."[2]

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EURO-MUSCULUS: European Musculoskeletal Ultrasound Study Group in Physical and Rehabilitation Medicine.

USPRM: Ultrasound Study Group of the International Society of Physical and Rehabilitation Medicine (ISPRM).

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Effusion/Synovitis/Fat Edema

Similar to other joint examinations, the presence of intraarticular fluid is usually the initial parameter to be assessed in the knee. Herein, as the knee joint is quite superficial, caution as to not apply unnecessary compression with the probe is paramount. Likewise, it is also important to recall which position of the joint facilitates fluid accumulation in which compartment. While flexion will separate the layers of the suprapatellar recess that will lodge the fluid, extension will commonly push it toward the lateral recesses.[1,3,4]

The normal synovium is thin and hardly detected upon US imaging. Herewith, synovitis is seen as irregularly thickened, hypoechoic, nondisplaceable, and poorly compressible tissue in a great spectrum of inflammatory conditions. As such, in addition to joint movements, probe or manual compressions (to aid accumulation) would also be contributory.

Peripatellar fat pads are intracapsular extrasynovial adipose cushions that accommodate the changing shape.[5] Dynamic scanning with joint/probe movements also allows for better visualization by mobilizing the fluid/edema content (Videos 4 and 5, http://links.lww.com/PHM/B910 and http://links.lww.com/PHM/B911). Moreover, dynamic scanning can also be used to visualize a snapping or an abnormal displacement of the fat pads of the knee.[6]

Anterior Cruciate Ligament

Having oblique trajectory and deeper location, the ligament is considered to be a challenging structure for US imaging.[7–10] In practice, it can be evaluated statically and dynamically, that is, during anterior drawer test[11] (Fig. 1). The distal stump can be observed freely mobile (Video 6, http://links.lww.com/PHM/B912) during the (increased) anterior translation of the tibia.[12]

Patellar Tendinopathy (Jumper's Knee)

Commonly due to overuse activities, for example, running and jumping, chronic microtrauma to the tendon is the main underlying mechanism.[13] Although static US scanning provides high-resolution/quality images, the sensitivity/specificity of the examination can notably be furthered with dynamic assessment (Fig. 2). Addition of sono-palpation or stretching would be of great help for better localization of the (minor) lesion or understanding the real-life complaint of the subject (Video 7, http://links.lww.com/PHM/B913). Moreover, this maneuver can also be useful to evaluate an eventual bony avulsion of the inferior pole of the patella (stable or unstable).

FIGURE 1. Long-axis imaging of (A) healthy (arrowheads) and (B) ruptured (?) anterior cruciate ligaments.

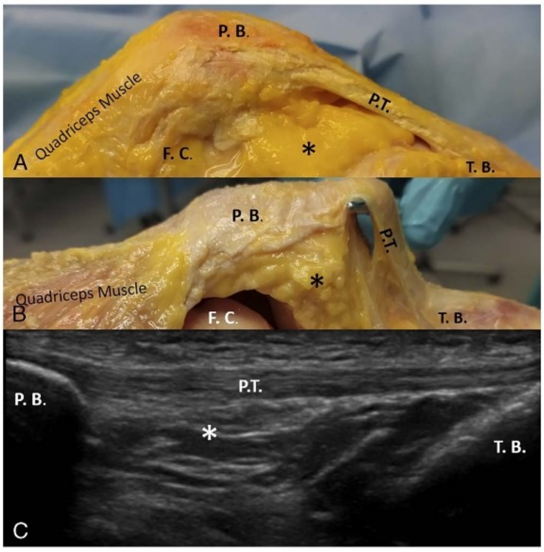

FIGURE 2. (A, B) Cadaveric dissection and long-axis imaging (C) shows the patellar tendon and Hoffa fat pad. P indicates patella; FC, femoral condyle; T, tibia; *, Hoffa fat pad.

Hoffitis

The Hoffa's fat pad is interposed between the trochlear articular surface and the superior tibia posteriorly and patellar ligament anteriorly[5] (Fig. 2). Sustained friction and repetitive microtrauma can lead to the clinical manifestation whereby pain is commonly exacerbated by hyperextension.[14] Likewise, dynamic US examination during knee extension can reveal the fat pad edema and/or impingement.[15] In addition, the origin of certain cystic lesions within the fat pad (i.e., intraarticular) can be confirmed—possibly related to the anterior cruciate ligament—with mobilization of the ligament.

Osgood-Schlatter and Sinding-Larsen-Johansson Syndromes

These two syndromes represent traction enthesopathy on either side of the patellar tendon attachments.[16] Reactive secondary heterotopic bone formation, resulting in a visible and palpable lump on the enthesis, is the main clinical finding. Thickening of the patellar tendon with low-reflective changes and associated intratendinous calcifications can be seen during US examination where dynamic imaging can also reveal stiffness and reduction of movement in the tendon. Findings pertaining to cartilage swelling/fragmentation and bursitis (Videos 8 and 9, http://links.lww.com/PHM/B914 and http://links.lww.com/PHM/B915) can accompany the scenario as well.[17,18]

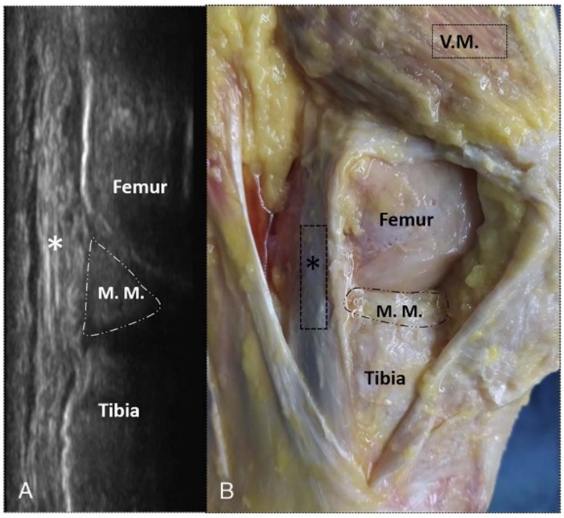

FIGURE 3. (A) Long-axis imaging and (B) cadaveric dissection shows the anatomical location of medial collateral ligament (*) and medial meniscus (MM). VM indicates vastus medialis muscle.

Bursitis

Several peripatellar bursae can be involved either secondary to concomitant knee joint disorders or as the primary pathology, for example, Housemaid's knee. The underlying cause is commonly overuse and the typical finding is fluid accumulation.[18] Therefore, the aforementioned technical tips for joint fluid and synovitis would also be valid for the examination/diagnosis of bursitis.

MEDIAL VIEW

The medial aspect of the knee joint is examined with the leg externally rotated. Relevant anatomic structures in this area that are amenable to US examination are the medial collateral ligament, medial femorotibial joint space, medial meniscus, and the pes anserinus complex.

Technique

Dynamic US imaging with valgus stress can improve the assessment for integrity of the above-quoted anatomical structures. For this purpose, the patient is asked to lean on the same side, with slight knee flexion. After coronal images are obtained at rest, either a small stiff pillow is placed under the lateral aspect of the knee or external manipulation is applied to produce valgus stress. Widening of the medial joint space can increase the overall visibility of structures whereby flexion/extension might better show reciprocal relations between femur, menisci, ligaments and tibia.

Clinical Indications

Medial Collateral Ligament Injury

Commonly in different sports players, overuse injuries of the medial collateral ligament can ensue and cause joint instability.[19] Involvement of the meniscofemoral ligament is more frequent and dynamic examination under valgus stress would be noteworthy, especially for partial-thickness tears. Further detailed examination of this area can be done as described previously, also/especially the histological junction between the medial meniscus and the meniscofemoral or meniscotibial ligament after trauma.[20] While a reproducible anechoic gap is the hallmark for tears, attachment site calcifications might also develop (i.e., Pellegrini-Stieda syndrome) and hamper the movement during valgus stress.

Similar to other sites, bursitis between the superficial and deep fibers of the meniscotibial ligament (Video 10, http://links.lww.com/PHM/B916) can be observed (i.e., bursitis of Voshell).[21,22] Assessing the real-time interactions between fluid and fibrous components (Video 11, http://links.lww.com/PHM/B917) can be contributory to better ascertain the diagnosis and treatment.[23]

Medial Meniscopathy

The medial meniscus can be visualized in coronal and coronal oblique views by placing the probe perpendicular to its (superficially located) base (Fig. 3). Again, widening the medial joint space by valgus stress increases the visibility for better evaluating its stability. Moreover, extrusion—defined as the extension of meniscus beyond the medial edge of the tibiofemoral joint[24]—can even be examined/measured in lying and standing positions. Previous studies have demonstrated that extrusion increases with weight-bearing in both healthy and arthritic knees.[25–28] By adding maneuvers (e.g., flexion/extension, valgus/varus stress), dynamic US assessment can further help to better evaluate mobility of the medial meniscus to highlight microinstability or macroinstability and/or extrusion. In extreme conditions (e.g., snapping, locking), understanding the exact mechanism would, for sure, guide the management as well (Videos 12, 13, and 14, http://links.lww.com/PHM/B918, http://links.lww.com/PHM/B919, and http://links.lww.com/PHM/B920). In some patients, during the dynamic maneuver, a subluxation or luxation of the medial meniscus can be visualized slipping under the superficial fibers of the medial collateral ligament.[29] Another interesting "indirect" sonographic sign of medial meniscus instability is the dynamic bulging of superior/inferior para-meniscal recesses during the dynamic assessment. Indeed, articular effusion flows inside the aforementioned recesses during the valgus stress in patients with instability of the medial compartment of the knee.[29]

Pes Anserine Pathologies

The pes anserine complex is composed by the intermingling tendons of the sartorius, gracilis, and semitendinosus muscles. It inserts into the anteromedial aspect of the tibial metaphysis,

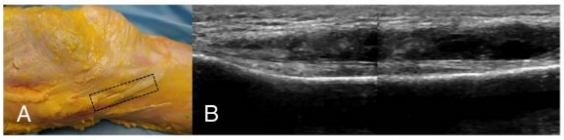

FIGURE 4. (A) Cadaveric dissection shows the anatomical location of pes anserine tendons. (B) Long-axis imaging shows the pes anserine complex (tendons and bursa) in a scenario of bursitis.

5–6 cm below the joint line[19] (Fig. 4). Although difficult, individual tendons can be distinguished with their shapes/locations and flexion/extension movements.

Snapping pes anserine tendons are the main cause of extra-articular knee snapping.[30] During dynamic assessment with repetitive flexion/extension of the knee, snapping of the pes anserine tendons can be visible (as well as audible).[31] The examiner must take care to keep the transducer anchored on the anatomical structures in question while performing relevant/dynamic maneuvers.

Tendinitis/bursitis of the pes anserine region or ganglion cysts can be observed in various patients, for example, rheumatoid arthritis and diabetes mellitus.[32] Like elsewhere, while sono-palpation can help to localize/differentiate the exact cause, passive/active movements might help to confirm structural lesions.

Medial Retinaculum or Patello-Femoral Ligament Problems

Dynamic US scanning from the medial patellar window can improve the assessment of medial ligamentous complex integrity. As the patient lies supine, the examiner can mobilize the patella in the lateral direction. This way, complete/partial avulsion of these structures from the patella, for example, torn edges or gap filled with fat, might become more evident.[33,34]

LATERAL VIEW

Technique

The lateral aspect of the knee joint is best examined by asking the patient to rotate the leg internally. From anterior to posterior, the structures to be evaluated are the distal aspect of the iliotibial band, the external femorotibial joint space with the lateral meniscus, the lateral collateral ligament, the popliteus tendon, and the distal biceps femoris tendon. Imaging the peroneal nerve is also commonplace in daily practice. The patient is asked to lean on the contralateral side of the examined knee, maintained in slight flexion. Then, a small stiff pillow is placed under the medial aspect of the knee to produce varus stress with the weight of the leg. For sure, varus stress can also be produced with manual compressions, and extra active/passive movements can help to better visualize the different anatomical structures simulating daily life.

Clinical Indications

Iliotibial Band Syndrome (Runner's Knee)

Iliotibial band (friction) syndrome is an overuse disorder of the lateral knee. It is commonly reported in athletes, such as runners and cyclists, and refers to local pain related to physical activity.[35] The friction against the lateral condyle is more apparent at 30 degrees flexion of the knee. As such, dynamic US examination can uncover the precise mechanical conflict during joint movements—especially when combined with sono-palpation and the clinical findings. Of note, the presence of a bursa in between can also be observed during mobilization of the joint/probe (Videos 15 and 16, http://links.lww.com/PHM/B921 and http://links.lww.com/PHM/B922).

Lateral Collateral Ligament Injury

This ligament is the primary stabilizer with regard to varus instability of the knee.[36] Similar to the medial side, long-axis imaging with varus stress can easily be applied. Considering the difficulty of (otherwise static) imaging for this ligament, especially in partial tears, such a maneuver might significantly facilitate the imaging of an anechoic gap between the fibers of the ligament or between the ligament and its insertions. Again, insertional lesions can be accompanied by bony avulsions and overt lesions might cause joint instability whereby both scenarios can be explored under US (Videos 17, 18, and 19, http://links.lww.com/PHM/B923, http://links.lww.com/PHM/B924, and http://links.lww.com/PHM/B925).

Lateral Meniscopathy

Peripheral (vascular) zone problems of the meniscus (e.g., radial tear, instability) can dynamically be tested. The painful catch-up clunk, most commonly present with active flexion/extension knee movements, can indicate translocation of the lateral meniscus or associated meniscal cyst.[37]

Lateral Retinaculum or Patello-Femoral Ligament Problems

Similar to the medial complex, the examiner can mobilize the patella toward the opposite direction, trying to cause patellar dislocation. Likewise, the probe can also be used to apply mechanical stress while the integrity of the lateral complex can be assessed.[38,39] For sure, the physician is free to test extra maneuvers in light of the clinical/physical examination findings.

Snapping Biceps or Popliteus Tendons

During flexion/extension of the knee joint and depending on the probe localization, snapping biceps femoris or popliteus tendons can be visualized over the fibular head or along the popliteal groove, respectively.[40–43] Needless to say, in case of snapping, relevant structures can also display findings of overuse, for example, edema, partial tear and swollen bursa (Video 20, http://links.lww.com/PHM/B926).

Peroneal Neuropathy/Entrapment

Whereas static imaging can show several forms/reasons of peroneal nerve entrapment around the fibula, dynamic examination might provide additional information using sono-Tinel and knee movements (Video 21, http://links.lww.com/PHM/B927), especially in the presence of nerve dislocation (because of space-occupying lesions, fractures, osteophytes, and fibular deformities.[44]

POSTERIOR VIEW

The posterior aspect of the knee joint is examined by asking the patient to settle in prone position. The structures to be evaluated are semimembranosus-gastrocnemius bursa, popliteal neurovascular structures, and the posterior cruciate ligament. Active flexion/extension movements can help to better visualize the different anatomical structures. Moreover, the examiner can study the stability of these structures with the help of counter-resistance (maneuvers).

Baker (Popliteal) Cyst

While evaluating the popliteal fossa, it is important to examine the semimembranosus-gastrocnemius bursa from which Baker cysts originate. They generally communicate with the joint space through a thin neck and a valvular opening, which allows flow during knee flexion but (because of the tension between the aforementioned muscles) not during extension.[45] Accordingly, dynamic US assessment may help to visualize this "fluid behavior," as well as its content. In addition, in case of ruptured cysts, fluid may be seen tracking inferiorly in the calf (gastrocnemius-soleus complex), possibly causing a painful scenario also known as pseudothrombophlebitis (Video 22, http://links.lww.com/PHM/B928).

Popliteal Artery Entrapment Syndrome

This clinical condition refers to compression of the popliteal artery secondary to its relationship with abnormal proximal insertion of the medial gastrocnemius or popliteus muscles. It is a rare condition, with higher prevalence in young healthy males, whereby the symptomatology consists of vascular insufficiency in the absence of any atherosclerotic disease. Initially, it can be asymptomatic but later on might cause calf claudication and loss of arterial pulses during ankle motions.[46] Dynamic US and Doppler scanning might really be contributory if performed during ankle plantar/dorsiflexion.

Intraarticular Effusion

Similar to the anterior side, especially a massive amount of joint effusion can be assessed from the posterior side as well. As the patient is lying prone, active flexion with counter-resistance may mobilize the fluid and make it (more) apparent. Like elsewhere, the examiner should be cautious while using the probe, because excessive compression might be misleading but—on the other hand—also necessary to evaluate its nature.[3]

Impingement and Intraarticular Loose Body

Various types of intraarticular lesions may produce a mass effect with subsequent impingement of neighboring anatomic structures in the posterior knee. The spectrum might comprise osteochondral body, ganglion cyst,[47,48] localized nodular synovitis,[49] lipoma,[50] exostosis,[51] and rheumatoid nodule.[52] Dynamic US is well suited for analyzing the behavior of a mass while the patient is asked to reproduce the snaps and/or other knee movements.

Posterior Cruciate Ligament

Similar to the anterior cruciate ligament, it can be evaluated statically and dynamically. Its thickening greater than 1 cm or hypoechogenicity might indicate injury, whereas focal disruptions or diffuse thickening might rather be suggestive of a tear.[7,9,53–55] During active movements together with the use of counter-resistance or posterior drawer test, the examiner can better evaluate the integrity (Video 23, http://links.lww.com/PHM/B929).

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THE SIGNIFICANCE OF INTRA-ABDOMINAL PRESSURE ON POSTURAL STABILIZATION: A LOW BACK PAIN CASE REPORT

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ABSTRACT

Intra-abdominal pressure is a hydraulic pressure within the abdominal cavity. Previous studies confirmed its direct association with both spinal stability and spinal unloading. The literature review part of the paper summarizes intra-abdominal pressure physiology and pathophysiology and explains the underlying mechanisms of intra-abdominal pressure regulation and its effects on the human body, especially spinal stability. Current methods of invasive and non-invasive intra-abdominal pressure measurement are described in detail. Second part of a paper presents a case report of a competitive athlete suffering from low back pain. The functional assessment and treatment focused on quality of patient's trunk stabilization. Training following principles of Dynamic Neuromuscular Stabilization resulted in better ability to activate abdominal wall muscles which is a critical mechanism of intra-abdominal pressure regulation and in this case caused significant low back pain reduction. The effect of the therapy was evaluated by DNS Brace which measures activity of the abdominal wall, thus intra-abdominal pressure indirectly, along with clinical Dynamic Neuromuscular Stabilization assessment tests.

Keywords: Intra-abdominal pressure, diaphragm, abdominal wall, spinal stability, objectification of postural stabilization

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INTRODUCTION

Stabilization of the lumbar spine - physiology

Postural stabilization is necessary for human body movement (1). External forces affect the human body during each movement. The body responds with the formation of internal forces mainly by muscular activity. This is so-called postural activity (2). The abdominal cavity is the space limited by the diaphragm superiorly and the musculo-aponeurotic perineum inferiorly, the lumbar spine posteriorly and the walls of the abdominal cavity anterolaterally (3). Postural activity is represented by strengthening/stabilizing function of these muscles and its ability to create intra-abdominal pressure IAP (4). It is all under the control of the central nervous system (CNS). The consequences of the pathological action of internal forces are often underestimated and the measurement options are still limited. The evaluation of IAP may be useful in a variety of clinical outcomes (5).

The postural role of IAP has been subject to research for almost 100 years. Dating back to 1923, Keith et al. suggested that IAP may affect spinal loading (6). In 1942 Bradford a Spurling published a study stating that spinal erectors put a 680 kg load on the spine during movement (7). In 1957 Bartelink experimented with a stress tests on intervertebral discs reporting structural damage occurring at the level of 136 kg load (8). In 1959

Davis reported IAP increase during load lifting (9). Without any compensatory unloading mechanism, the spine and especially the intervertebral discs would easily be damaged with every strenuous movement. Ground-breaking studies conducted by Hodges and colleagues have confirmed that IAP alone without any trunk muscle activity increases the stability of the lumbar spine, protects the spine from excessive loading, reduces axillary compression, and transfers the load to a larger area (4,10). For the stability in the lumbar spine is necessary proper coactivation between previously mentioned muscles that regulate IAP such as the diaphragm, pelvic floor muscles, abdominal muscles and spine extensors (4,11). It is important to mention that the diaphragm not only provides respiration and sphincter function but also a postural function (12,13). Electromyography (EMG) has shown that diaphragmatic contraction is modulated by postural and ventilation requirements (12). If the diaphragm contracts physiologically, the central tendon of the diaphragm drops inferiorly, creating a pressure gradient that drives air into the lungs and with the help of pelvic floor and abdominal wall activity increases the pressure in the abdominal cavity (14,15).

Activation of the trunk muscles keeps all segments of the spine in a biomechanically neutral position during movement (8). The pelvis and lumbar spine are reflexively stabilized before limb movements (12,16). Even if IAP is an important phenomenon in rehabilitation and is often studied, its specific function and role remains unclear (17,18). An obstacle in the studying IAP is the measurement complexity in experimental conditions especially in vivo. Many authors have already described the positive effect of IAP on spinal stability and spinal unloading but its importance still needs to be objectively studied (18).

Although several studies (4,11,19,20) have shown a connection between the increased IAP and spinal stability, it is not entirely clear whether this mechanical support for the spine is due to the increased IAP or the abdominal muscle activity itself which contributes to IAP (4). According to Mokhtarzadeh et al., the relative role of the IAP in spine mechanics has remained controversial and IAP alone without current muscle co-activation is not sufficient (15). On the other hand, Hodges et al. showed in their study that the stiffness of the lumbar spine during various functional movements is increased when IAP is elevated even without simultaneous muscle contraction (3). They suggest that IAP may be a beneficial tool for the CNS to increase spinal stability in all directions (4). Similarly, Stokes et al. reported that elevated IAP increased lumbar spine stability regardless of the primary muscle involved (18). Among others, Hodges et al. also described the fact that crura of diaphragm, by its contraction, causes direct traction of the lumbar spine in the area of their attachment and it promotes the effect of IAP (4). McGill et al. created a theory that elevated IAP increases lumbar spine stability by limiting intervertebral rotation and translation (16). According to these authors, the IAP helps to maintain the correct position of the moving parts of the spine by minimizing, or even completely eliminating, very small movements of shear forces in the area of the facet joints. This hypothesis could be a possible reason why patients, who are forced to move even with severe lumbar spine pain, hold their breath (21).

The lumbar spine complex is adapted to carry an external load. Stress is transmitted to the solid bodies of the vertebrae and relatively elastic disks. Excessive mechanical loading leads to damage to the intervertebral discs (22). Arshad et al. showed in a biomechanical model that IAP significantly reduced the compressive forces on the spine and at the same time reduced the need for muscle force involvement (23). According to some authors, higher IAP values lead to spinal relief, but maximum challenging activation such as the Valsalva maneuver have got the opposite effect due to the hight levels of muscle coactivation (24). However, Stokes et al. argue that the extension effect of IAP is greater than the flexion moment created by the abdominal wall muscles. In a biomechanical model of the spine, they have shown that IAP has the effect of relieving the spine in all directions of movement (18).

Other authors suggest that IAP creates a force caudally against the pelvic floor and cranially against the diaphragm, thus creating an extension moment of the spinal (4). Although IAP alone does not produce spine extension, it is associated with an antagonistic co-activation of flexors and extensors that increases the stability and strength of the spine (4). In addition, according to Daggfeldt et al., this mechanism could help reduce lumbar spine overloading indirectly by creating an extension moment thus reducing the need for spinal extensors activation (25). This thought is also supported by Cholewicki et al. that IAP is active in movements that require trunk strength for extension such as lifting objects or jumping can increase the stability of the spine without simultaneous co-activation of the spinal erectors (20). In order to achieve the greatest possible spinal protection, the cross-section of the lumbar part of the trunk must be as large as possible. The diaphragm and the pelvic floor must work exactly opposite each other (25). According to some authors, it is also important that IAP maintains the hoop-like shape of the muscles around the abdominal cavity, thus preventing their shortening and collapse towards the abdominal cavity which could impair their ability to contract (21).

Impairment of the trunk stabilization

Low back pain (LBP) is one of the most common reasons for seeing a health care provider (26). This is also often the cause of inability to work, as it mainly affects individuals of working age (26,27). Deficits in the lumbar spine stabilization are mostly of muscular or neural origin so the right chosen physical therapy and motor control training that would induce proper co-activation between muscles is recommended (28–30).

Poor postural muscle coordination and deficiency in its stabilizing function is considered to be an important etiological factor in spinal disorders associated with back pain such as deformed spondyloarthritis, intervertebral disc protrusion or spondylolisthesis (19,28,31). The results of studies confirm that abnormalities in motor control may be not only the cause of LBP but also its consequence (32,33). The dependence between the disorder of postural control and the delay in the reaction time of the trunk muscles is a prerequisite for the development of pathology in the lumbar spine. This disorder can be a significant risk factor for lumbar spine injuries (34).

Based on the research results stated above, in clinical practice it appears to be important to evaluate the quality of postural stabilization, to measure IAP and to objectivize individual's ability to regulate the IAP in response to postural load. However, the methods of objective postural trunk assessment and especially of IAP evaluation in relation to postural stabilization are still not unequivocally defined and routinely used. This paper further summarizes currently available methods to evaluate the IAP within clinical assessment.

IAP evaluation

If IAP corresponds with postural stability (4,19,35), we can evaluate postural stability by assessing the IAP. There are various methods of

IAP evaluation with its pros and cons. IAP measurement can be divided into direct and indirect methods. Invasive measurement of the IAP can be done using the caval catheter or transperitoneal measurement during laparoscopic operation. Indirect measurement of IAP can be done using gastric/anorectal/vesical or vaginal probe. The common disadvantage of such IAP evaluation methods is that it is invasive and uncomfortable for the subject. On the other hand, it is the most accurate way of assessing the IAP (37,38).

A. Transperitoneal measurement

This method of direct IAP evaluation is the most accurate (36). In clinical applications it is used for peritoneal dialysis or continuous paracentesis. In the research field it is considered the gold standard for comparison with other invasive methods in case of evaluating IAP. However, it is not used in the rehabilitation and musculoskeletal research and practice because of its invasiveness (37,38).

B. Intracaval measurement

Another example of direct IAP measuring is intracaval measurement. The catheter is inserted via femoral vein to inferior vena cava. The position of the catheter is monitored by ultrasound or x-ray. This procedure is time consuming but allows continuous and accurate results. Disadvantage of this method is possibility of circulatory system infection, bleeding or thrombosis (39).

C. Intravesical measurement

Intravesical measurement is the most common and the most reliable indirect method of monitoring intra-abdominal hypertension (39). This method is recognized as the gold standard for monitoring intra-abdominal compartment syndrome. It may be advantageous way of IAP monitoring in patients having an intravesical catheter because of urinary drainage (39). This method is based on the fact that the urinary bladder can transduce IAP. The measuring itself is done in laying supine position (38).

D. Intravaginal measurement

In this method the pressure sensor is situated in the vagina. Advantage of this method is that wireless sensors can be used, so the IAP can be evaluated during everyday activities (40,41). Disadvantage is that it can only be used in women.

E. Intrarectal measurement

Another method is performed via the rectum. Advantage of this method is that the patient can move and do some physical activities, while the IAP is measured (42). According to Dolan et al., 20% of women refuse to undergo this examination because of fear and they prefer intravaginal measuring (43). Contraindications for examination are bleeding from lower gastrointestinal tract or diarrhea (38).

F. Intragastric measurement

The last option of indirect IAP measuring is a naso/orogastric or gastrostomy probe. Gastric measurement is not used in daily praxis because the patients report it as very uncomfortable. Moreover, it is more expensive compared to intravesical measurement. The other disadvantage of gastric measurement is that the IAP can be influenced by stomach contractions, which occur every 90 minutes lasting about 2 minutes (44). Advantage of this approach is that the IAP can be recorded continuously and can be measured during natural movements such as walking or running (45).

In conclusion, because of its invasiveness these methods are used more for evaluating IAP hypertension, compartment syndrome and for research, then in clinical care.

Trunk muscle activity evaluation

A. Electromyography (EMG)

A standard testing method for muscle activation is EMG. It can be assessed either by non-invasive surface EMG or invasive needle EMG.

Disadvantage to both is that they evaluate more local muscle changes versus coordination of all trunk muscles. Surface EMG cannot be used to assess deep spinal stabilizing muscles. EMG is used more in research than in clinical care (46).

B. Ultrasonography (US) evaluation

Trunk muscle activation can be assessed by real time US to measure the thickness of abdominal or spinal muscles. This method is non-invasive and quite inexpensive, but its reliability is dependent on the experience of the examiner. Compared to EMG, US evaluation can be utilized to assess the deep muscles (47). Similarly to EMG ultrasound provides information about local muscle contraction rather than global muscle coordination.

C. Dynamometry

Dynamometry represents another method to evaluate trunk muscle activation. This non-invasive method measures external forces produced by abdominal wall expansion. Malatova et al. described a tool which consists of four sensors attached to the human body (48). Similar method was introduced by van Ramshorst et al. who correlated IAP with abdominal wall tension. Ramshorst et al. used a special dynamometer to monitor abdominal wall tension resulting from IAP changes in corpses, in which the IAP was changed artificially by insufflation. This study reports that abdominal wall tension reflects the IAP (49).

D. Pressure biofeedback unit

Another possibility of evaluating trunk muscle activation is pressure biofeedback unit. It is basically a tool made from three air chambers and pressure sensors that is placed under the patient. Disadvantage of this method is that activation of the trunk muscles can be evaluated only in certain positions such as lying down. This method of assessment is not useful in dynamic evaluation in difficult postural positions (50).

E. OhmTrak sensor

A non-invasive measurement of the force production of the abdominal wall are sensors inserted in belt such as Ohmbelt device with the OhmTrak sensor (Ohm Belt, Nilus Medical LLC, 2019 © OHMBELT, Redwood City, CA, USA). It is a core activation and breathing tracker. A research version of the device was designed by the manufacturer for the trial purposes, which differs from the commercial version operating with one sensor. The research version utilizes two sensors recording data simultaneously with a software app to display and record both sensor force data. It consists of two capacitive force sensors of 15 mm diameter, 0.35 mm thickness, full scale range 0.45 kg, minimal detectable force 0.9 g, attached to the abdominal wall by adjustable straps. The force sensor which faces the subject's skin, is pressed against the abdominal wall by an adjustable strap. Abdominal wall expansion and retraction is recorded by the sensor as a force. The sensors register the force exerted by the abdominal wall during respiration and various postural tasks. The research version of Ohmbelt allows to monitor simultaneously the instantaneous muscle force at two different trunk locations. Both the amount of the force and its dynamics over time can be analyzed. The sensors are also equipped with accelerometers to capture any kyphotic trunk synkinesis, i.e. substitutive trunk movement replacing abdominal muscle activation. A built-in tensometric transducer converts the force to the digital signal that is transmitted wirelessly via Bluetooth to the computer where the software graphically displays the results. The program records any time sequences with the numerical values being automatically exported into Microsoft Excel. Immediate data analysis, graphical imaging and data saving is available (51).

F. Dynamic Neuromuscular Stabilization (DNS) Brace

DNS Brace device (Produced by Ortotika, FN Motol V Úvalu 84, Praha) is a trunk orthosis equipped with four sensors working on a mechanical-pneumatic-electronic principle. The brace can be fixed firmly to the trunk while not preventing the expansion of soft tissues.

Four mechanical-pneumatic-electronic sensors are placed on the inner wall of plastic trunk orthosis. Two ventral sensors are located bilaterally above the groin and two sensors are located on the brace parts adhering to latero-dorsal sections of the abdominal wall specifically the trigonum lumbale superius. The sensors consist of an air chamber, which detects changes in hydraulic pressure when the sensor is deformed. This chamber is connected by a capillary silicone tube to a digital pressure sensor. As the abdominal wall expands, the IAP increases, which is monitored through the pressure sensor and the pressure value is transmitted via a tube to the digital sensor. The brace sensors measure the pressure exerted by the abdominal wall in kilopascals (kPa) and transfer the data via Bluetooth to a smart-phone or computer so the data can be statistically processed and graphically displayed (52).

G. Clinical tests

The most common and used approach for trunk muscle activation assessment is subjective evaluation using clinical tests (53). Clinicians use their fingers to palpate the quality and symmetry of abdominal wall during client's activation. Further description of clinical tests can be found elsewhere (52,54,55).

Suggestions for clinical practice

80% of western population will experience a LBP at some time during their lives (56). To treat LBP properly and to achieve long lasting results it is necessary to measure trunk stabilization objectively. Evidence based data will help to set up optimal treatment plan, to review the therapy results, to evaluate self-treatment effect and to compare various methods of treatment. Monitoring and training postural stabilization also plays an important role in athletic population to treat and prevent repetitive strain back pain and to promote sports performance (57–59). Since human posture is dynamic, we need a tool to measure IAP and trunk muscle stabilization function in various postural situations. We need to combine clinical assessment with objective measurement. One way to do it, is to use core activation trackers such as Ohmbelt, DNS Brace and alike during dynamic clinical testing. Sensors attached to trunk can inform us objectively about trunk stabilization function and IAP regulation since the IAP correlates with the abdominal wall tension monitored by the sensors (60,61). Body position has significant effects on abdominal wall tension thus also IAP (62). Bellow we present a short case study of a patient with LBP demonstrating how a core tracker device specifically the DNS Brace can be used in an athlete to evaluate and train postural stabilization.

CASE REPORT

An 18-year-old male, competitive canoeist, training 5 times a week 4 hours a day (2 hours rowing, 2 hours gym work) presented with acute low back pain, radiating in L5 nerve root projection to his left leg and thumb. He reported 5/10 intensity of pain on visual analogue scale (VAS). During the preparation for a championship canoeing event, the patient could no longer straighten up after training. Magnetic resonance imaging (MRI) revealed narrowing of the spinal canal at the level of a broadly mediodorsally arched disc L4/5 (3 mm), small dorsal osteophytes L4-S1 and hypertrophic intervertebral joints L4-S1 bilaterally due to spondylarthrosis.

Clinical examination consisted of three tests according to DNS examination protocol, i.e. resting breathing, loaded breathing and the diaphragm test (52,54). All three tests showed that the patient was not able to sufficiently activate the dorsolateral parts of the abdominal wall, lacked lateral expansion of the lower part of the thorax, there was cranial migration of the ribs and the thoracic spine became kyphotic during DNS testing. At the same time, there was excessive activity of the upper part of the rectus abdominis muscle, cranial migration of the umbilicus, concavities of the abdominal wall above the inguinal canal and there was shoulder protraction. Clinically, these are the signs of compromised core stabilization and poor IAP regulation (54,63–65). When analyzing the patient's sport training stereotypes, the same abnormal patterns as in DNS testing were identified including insufficient uprighting of the lumbar and thoracic spine, lack of rotation at the thoracic spine, protraction of the head and shoulders along with de-centration of the shoulder blades. Such signs of suboptimal postural stabilization were present also in sitting positions which is a basic position for canoeing. For objective assessment DNS Brace measurement were performed to analyze abdominal wall activity during resting breathing, diaphragm testing and loaded breathing (51,52)(see Fig. 1,2, and 3 and Table 1).

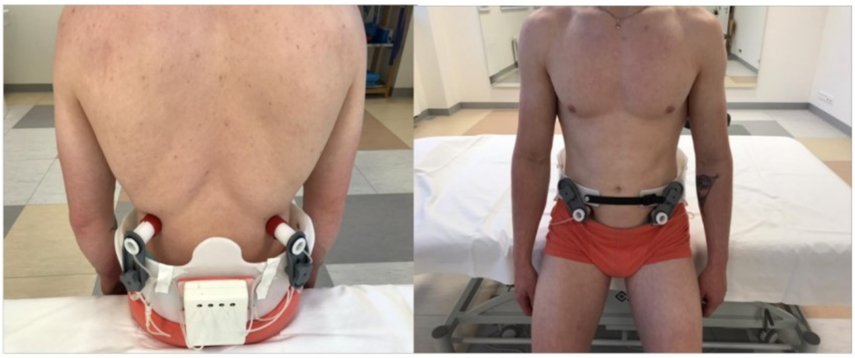
The patient underwent 12 individual therapies provided by an experienced physiotherapist. During each 60 minutes physiotherapy session soft tissue and mobilization techniques were first applied to treat trigger points and joint blockages in thoracic and lumbopelvic area. Following this, the main part of the therapy focused on trunk stabilization training utilizing DNS principles (63–65). Another goal was to train isolated movement in the hip and shoulder joints while maintaining optimal core stabilization and correct sitting position. During the first few physiotherapy sessions mostly static DNS developmental positions were trained (63–65). Later the training focused on dynamic variants of the DNS development exercises. At the end of the 3 months rehabilitation period load was added to the exercises. The patient was advised to perform DNS self-treatment daily and to integrate principles of DNS to sport training.

The clinical assessment after the therapy revealed improvement**.** In all three tests, resting breathing, loaded breathing and the diaphragm test, patient's lower chest aperture expanded proportionally in all directions during inhalation, the intercostal spaces expanded appropriately and the patient was able to keep the spine upright during the entire tests. Balanced activation of all portions of the abdominal wall was observed and the ability to keep the chest in a neutral position was established. In the sitting position typical for canoeing, there was a noticeable adjustment in trunk stabilization, straightening of the thoracic and lumbar spine as well as proportional activation of all sections of the abdominal wall. Stability of the trunk allowed for improved optimal functional stereotypes of the upper limbs. At the end of the 3 months therapeutic intervention, the patient reported a VAS score of 1/10.

DNS Brace measurements

To monitor abdominal wall tension, a DNS Brace (52) was utilized. This was chosen specifically over other approaches because it allows non-invasive assessment with simultaneous recording from four sensors. It is safe, easy and fast method providing the most comprehensive information about the abdominal wall activity.

Figure 1 Initial position of the patient with DNS Brace before measurement



The following measured scenarios were taken with the patient sitting (Figure 1):

1) Resting breathing: The participant was breathing naturally
2) Loaded breathing: The participant held a load of 20 % of his body weight in hands in front of the trunk
3) Diaphragm test: The participant was expanding the abdominal wall pushing as much as possible against all four sensors attached to DNS Brace (two sensors located above inguinal ligament, two sensors in upper lumbar triangle bilaterally) both during inhalation and exhalation (54)

Fig 2-4 and Table 1 depict abdominal wall activity measured before and after the therapy. An improvement was identified in all three DNS Brace tests after the 3 months treatment period.

Figure 2 Resting breathing - comparison of DNS brace values before and after intervention

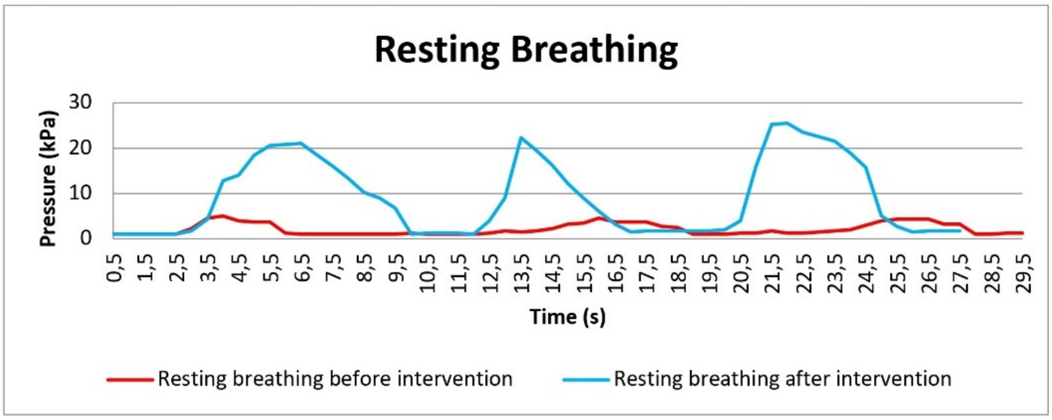


Figure 3 Loaded breathing - comparison of DNS brace values before and after intervention

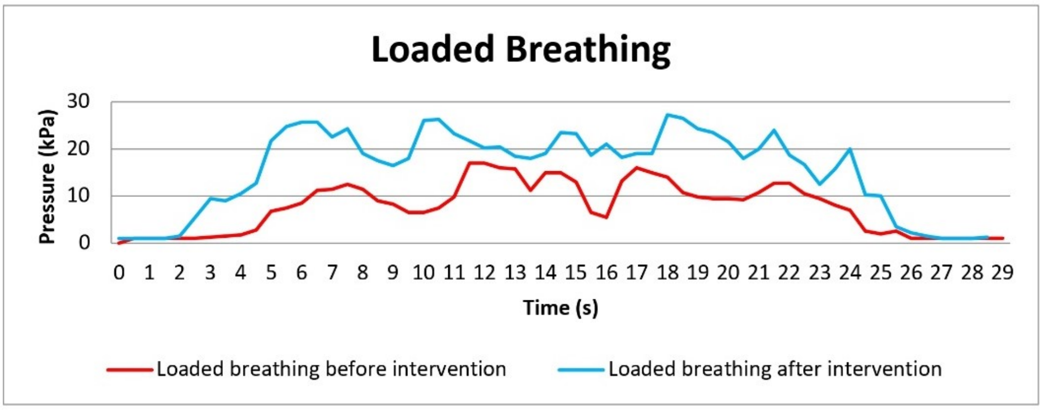


Figure 4 Diaphragm test - comparison of DNS brace values before and after intervention

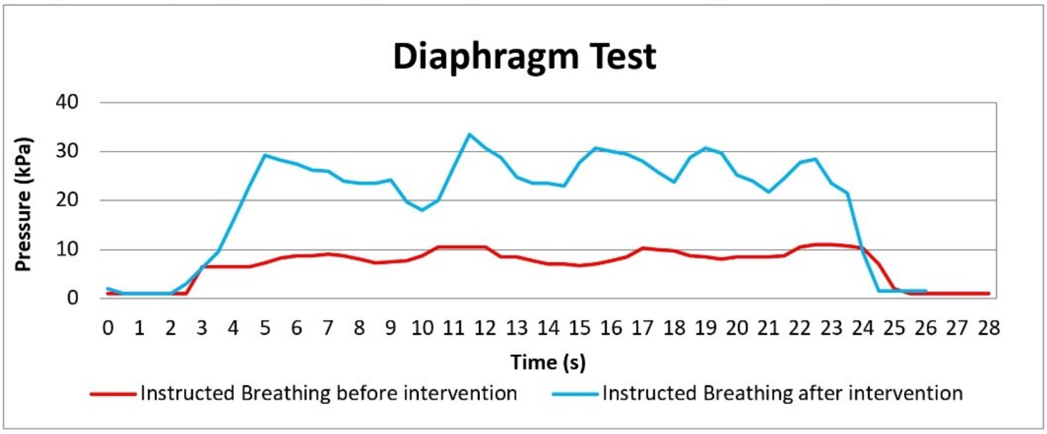


Table 1 DNS assessment protocol and DNS Brace measurement results

SCENARIO	RESTING BREATHING		LOADED BREATHING		DIAPHRAGM TEST	
	DNS assessment protocol (16 points max)	DNS Brace Average value (kPa)	DNS assessment protocol (28 points max)	DNS Brace Average value (kPa)	DNS assessment protocol (28 points max)	DNS Brace Average value (kPa)
Before intervention	6	2,28	13	11,06	11	8,13
After intervention	14	10,09	24	21,02	24	26,42
Difference	+57,2%	+ 79,1%	+45,8%	+ 47,4%	54,2%	+ 69,23%

Note: Clinical assessment performed according to DNS Assessment protocol (54): Breathing stereotype: 16 points = optimal stereotype; Loaded breathing and Diaphragm test: 28 points = optimal stereotype. The smaller the number the worse the stereotype (54).

DNS Brace: the values are given as the average of all 4 sensors

DISCUSSION

After the 3 months therapeutic intervention focusing on trunk stabilization training the patient became almost painless and was able to return to full training regime and competition. The critical part of rehabilitation was integration of proper postural stabilization in sports training to prevent repetitive overstrain of the musculoskeletal system. The positive effect of DNS training on the reduction of pain and the enhancement of sport performance has been previously demonstrated by Davidek et al (66). Six weeks DNS training resulted in significant increase of paddling force measured at kayak ergometer and in reduced pain when moving the arms above the head which is an important aspect in paddling (66). DNS exercises targeting trunk stabilization and segmental movement in the mid-thoracic spine also proved to be effective in the population of competitive cross-country skiers by decreasing back pain and improving sensory perception in thoracic region (67). The positive effect of DNS stabilization strategies on race walker performances has been proven by Panse et al (68). Jebavy et al. report that stabilization-oriented exercises prevent injury and overloading in elite futsal players (69). Jebavy (69) used the same DNS tests for deep stabilization system assessment, however, they evaluated the stabilization function only subjectively on a five-point scale using modified DNS examination protocols (54) without any additional objective measurement. Our case report combined clinical DNS assessments with objective measurements of abdominal wall tension using a DNS Brace.

The main goal of the canoeist's DNS treatment and training was to straighten the lumbar spine, practice segmental rotation in the thoracic spine segments and stabilize the pelvis when moving the upper limbs. Such movements form the basic paddling stereotypes. Similar strategy previously proved to be effective in training of other contralateral sport locomotion stereotypes such as flat water kayaking (66), cross country skiing (67) or futsal. (69) At the end of the therapy the patient was able to practice DNS positions with good quality as defined by DNS assessment protocols (54) as well as in the gym and on the rowing machine. Both clinical and DNS Brace measurements before therapy illustrate almost no expansion of the abdominal wall during resting inhalation. The red curve in the Figure 2 shows only a minimal increase in IAP during inspiration relative to resting expiration baseline. This is related to clinical observation that the patient elevated his chest during inspiration, i.e. used accessory respiratory muscles especially sternocleidomastoid and scalenes to assist in the rib cage elevation, instead of primary inspiratory muscles such as the diaphragm and external intercostal muscles. The post-treatment blue curve depicts much larger inspiratory wave which reflected in clinical assessment as abdominal wall expansion. At the end of quiet exhalation, the curve returns to the baseline, which we consider to be normal since at the end of quiet expiration the IAP value should be minimal (70). Based on DNS Brace and clinical assessment, it can be concluded that after the therapy, the respiratory function of the diaphragm and trunk muscle coordination were optimized.

The aim of the second measurement (Figure 3) was to verify how the patient reflexively reacts to holding a load and whether he uses IAP to stabilize the core during the postural challenging situation. Comparing to the red curve before the therapy, the blue post-treatment curve reflects more intensive activation of the abdominal wall both during inhalation and exhalation indicating higher IAP and better stabilization throughout the movement and more appropriate dual respiratory and postural function of the diaphragm. IAP increase during weight holding (31,35,61) is a critical mechanism of spinal stabilization and protection from injury and should be noted both clinically and by objective measurements.

The third test is called the diaphragm test (Figure 4). It serves to evaluate a patient's voluntary ability to engage the abdominal muscles with proper coactivation of the diaphragm and pelvic floor (54). During clinical assessment the individual is instructed to inhale and push actively against clinician's fingers palpating the latero-dorsal sections of the abdominal wall. With the DNS Brace he activates the abdominal wall against all four sensors placed in the upper lumbar triangle and above the inguinal ligament bilaterally. Prior to therapy, the patient could exert only very little force indicating an incorrect respiratory-stabilization pattern. After the DNS training period a similar increase in abdominal wall activation is observed as in the previous scenario of loaded breathing.

CONCLUSION

This paper summarizes available methods of intra-abdominal pressure assessment and indirect measurements of trunk stabilization. The competitive canoeist case report demonstrates positive results of postural DNS training confirmed by clinical testing, objective DNS Brace measurements and subjective pain perception reported in VAS. This case report methodology may serve as a pilot study for future larger randomized blinded studies where the complete DNS examination protocol (54) could possibly be used to analyze postural stabilization in full detail.

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Declaration of interest

The authors declare that they have no conflict of interest

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