Příloha 1

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Supraskapulární neuropatie

Suprascapular neuropathy

Abstrakt
Supraskapulární neuropatie je vzácný úžinový syndrom projevující se bolestí zadní části ramene a slabostí abdukce a zevní rotace paže. Kompletní symptomatika je vyjádřena u postižení kmene nervu v oblasti incisura scapulae či u poúrazových lézí. Izolovaná atrofie musculus infraspinatus s omezením zevní rotace paže vzniká při kompresi distální části nervu paralabrální cystou nebo u chronického přetěžování horní končetiny v abdukci, typicky u vrcholových hráčů volejbalu či tenisu. Zlatým standardem v potvrzení diagnózy je jehlová elektromyografie. V naprosté většině případů dostačuje konzervativní léčba. U 20 % pacientů je indikována operační dekomprese nervu vedoucí u většiny případů k ústupu bolestí a zlepšení svalové síly.

Abstract
Suprascapular neuropathy is a rare compressive neuropathy manifested by dorsal shoulder pain and weakness of shoulder abduction and external rotation. Complete symptoms are expressed in nerve compression under the suprascapular notch or in post-traumatic lesions. Isolated atrophy of the infraspinatus muscle with weakness of external rotation of the shoulder occurs in cases of compression of the distal part of the nerve by a paralabral cyst or in repetitive overhead activities, typically in elite volleyball or tennis players. Needle electromyography remains the gold standard in confirming diagnosis. In the vast majority of cases, conservative treatment is sufficient. In 20% of patients, surgical decompression of the nerve is indicated, leading in most cases to pain relief and improvement in muscle strength.

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Klíčová slova
supraskapulární neuropatie – bolest ramene – ruptura rotátorové manžety – nervus suprascapularis

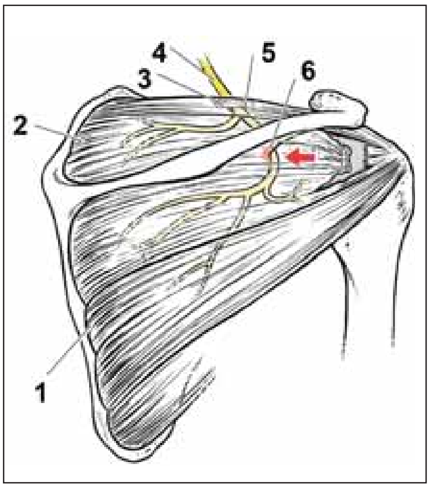
Key words
suprascapular neuropathy – shoulder pain – rotator cuff rupture – suprascapular nerve

Úvod
Supraskapulární neuropatie (SN) je vzácný úžinový syndrom popsaný poprvé Thompsonem a Kopellem roku 1959 [1]. Aiello et al popsali v roce 1982 izolované postižení distální větve n. suprascapularis (NSS) pro m. infraspinatus [2]. Původně se jednalo o diagnózu *per exclusionem*, s rozvojem zobrazovacích a elektrofyziologických technik se tato entita dostává v posledních dvou dekádách do popředí jako jedna z příčin chronických bolestí ramene.

Hluboká dorzální omalgie je velmi častý příznak vznikající z mnoha příčin. Nejčastěji k ní dochází při patologiích ramenního kloubu nebo svalové dysbalanci. Vždy je potřeba vyloučit i radikulopatii C5 a C6, event. i C4. Na diagnózu SN je však potřeba myslet při současné atrofii lopatkových svalů, ke které dochází asi v 80 % případů. SN je zodpovědná až za 4,3 % bolestí ramene [3].

Častou příčinou SN je ruptura rotátorové manžety. Nejčastěji však vzniká trakcí či chronickou mikrotraumatizací při sportech, u nichž dochází k přetěžování končetiny nad úrovní hlavy. Rizikem je rovněž osifikace lig. transversum scapulae či specifické příčiny jako kostní tumor či cysta vzniklá následkem labropatie či poranění kloubního pouzdra. Může být rovněž součástí brachiální neuritidy či vzniknout v rámci zlomeniny lopatky, poranění plexus brachialis či izolovaného penetrujícího poranění [4].

Cílem sdělení je nejen přinést soudobý literární pohled na danou problematiku, ale i zvýšit povědomí o této relativně vzácné pří-



Obr. 1. Anatomie n. suprascapularis a schéma útlaku větve pro m. infraspinatus o hranu spinoglenoidální brázdy po retrakci mm. spinati při ruptuře rotátorové manžety (šipka). Převzato z [9], upraveno.
1 – m. infraspinatus; 2 – m. supraspinatus; 3 – lig. transversum scapulae; 4 – n. suprascapularis; 5 – incisura scapulae; 6 – spinoglenoidální brázda

Fig. 1. Suprascapular nerve anatomy and the scheme of infraspinatus branch compression against the edge of the spinoglenoid notch after retraction of spinati muscles during rotator cuff rupture (arrow). From [9], modified.
1 – infraspinatus muscle; 2 – supraspinatus muscle; 3 – suprascapular ligament; 4 – suprascapular nerve; 5 – suprascapular notch; 6 – spinoglenoid notch

čině chronických bolestí či slabosti ramenního pletence.

Anatomie nervus suprascapularis

Nervus suprascapularis vzniká typicky z kořenů C5–6, v případě prefixovaného typu plexus brachialis dostává vlákna v 18–63 % i z kořene C4 [5]. Kmen nervu odstupuje z truncus superior pažní pleteně a běží podél m. omohyoideus až do incisura scapulae ležící na margo superior lopatky mediálně od baze processus coracoideus, asi 3 cm mediálně od tuberculum supraglenoidale. Incisura je kryta kraniálně lig. transversum scapulae. Nerv běží pod ligamentem, zatímco doprovodná a. suprascapularis běží nad ním. V oblasti incisury vydává nerv obvykle dvě větve pro m. supraspinatus a u téměř 90 % populace i artikulární senzorickou větvičku pro ramenní kloub. Jen asi v 30 % případů inervuje rovněž kůži nad horní polovinou lopatky. Kmen nervu dále běží kaudo-laterálně přes fossa supraspinata, kde vydává asi u tří čtvrtin populace další senzorickou (akromiální) větev pokračující do oblasti úponové šlachy m. infraspinatus. NSS poté probíhá ve spinoglenoidální brázdě pod variantním lig. spinoglenoidale přítomným asi u 60 % populace [6]. Poté obtáčí spina scapulae, dostává se do fossa infraspinata, kterou běží mediálně, a vydává dvě až tři větve pro m. infraspinatus (obr. 1) [7–9].

Musculus supraspinatus je zodpovědný za prvních asi 30° abdukce paže. M. infraspinatus umožňuje přibližně 75 % síly její zevní rotace. Samostatně se uplatňuje při končetině v neutrálním postavení, zatímco druhý, mnohem slabší, zevní rotátor m. teres minor je účinný zejména při končetině v 90° abdukci [10].

Proximální postižení

Nejčastější příčinou útlaku kmene NSS je ruptura rotátorové manžety s retrakcí prasklé úponové šlachy m. supraspinatus, která způsobuje natažení první motorické větve pro m. supraspinatus a komprimuje kmen nervu proti kostní hraně v incisura scapulae [9]. Neuropatie může vznikat u specifických činností při nošení těžkých břemen přes rameno [11] či chronickým přetěžováním končetiny. Raritně může být hodnocena i jako nemoc z povolání [12,13]. Vlastní úžinový syndrom s kompresí kmene NSS v incisura scapulae pod lig. transversum scapulae je méně častý. Příčinou bývají osifikace hypertrofického vazu či opakované pohyby s končetinou v abdukci [9].

Útlak kmene NSS působí dominantně iritace v oblasti senzorické inervace nervu – bolesti vystřelující nad horní částí lopatky do ramene. Dochází k atrofii a oslabení obou mm. spinati s omezením abdukce a zevní rotace ramene [4].

Distální postižení

Izolované postižení terminální větve pro m. infraspinatus v rýze za spina scapulae (spinoglenoid notch) je častější než proximální léze. Dochází k ní opět při ruptuře rotátorové manžety s retrakcí jednoho nebo obou mm. spinati s kompresí nervu o hranu spinoglenoidální brázdy (obr. 1). Nerv může být také utlačen hypertrofickým lig. spinoglenoidale při chronickém přetěžování končetiny v abdukci a vnitřní rotaci [4] či opakovaným útlakem excentricky kontrahovaným m. infraspinatus během specifických pohybů. K útlaku může dojít i paralabrální cystou vzniklou v rámci defektů labrum glenoidale (obr. 1) [14]. V klinickém obraze je vyjádřena izolovaná atrofie m. infraspinatus s omezením zevní rotace paže.

Nález distální SN trakčně-kompresivní etiologie je však tradičně spojován se sporty, u nichž je nadměrně používána horní končetina v abdukci a zevní rotaci. Nejčastěji je popisována u vrcholového volejbalu, méně často u hráčů tenisu, badmintonu či baseballu, u plavců, oštěpařů či vzpěračů [4]. Byla popsána i kazuistika SN vzniklé u atleta provádějícího shyby na hrazdě [15]. Izolovaná atrofie m. infraspinatus s oslabením zevní rotace bez subjektivního sportovního omezení byla nalezena až u 33 % elitních volejbalistů [16]. Bylo prokázáno, že incidence SN je u těchto hráčů spojena s typem podání. Historické vysoké hodnoty byly popisovány v době, kdy se dominantně používala technika plachtícího podání (bez rotace míče). Při něm je míč udeřen velmi ostře palcovou částí ruky. Během úderu je rameno zastaveno okamžitě po kontaktu s míčem. Této rychlé decelerace je dosaženo velmi intenzivní excentrickou kontrakcí m. infraspinatus, která způsobuje kompresi NSS proti spinoglenoidální rýze [14,17]. V posledních dvou dekádách došlo ke změnám v technice tohoto sportu. Jednou z nich byl příklon k rotovanému podání. U něj je míč udeřen rozevřenou dlaní, přičemž končetina po úderu ještě chvíli pokračuje ve směru letu míče. V elitní třídě je plachtící podání vestoje používáno v 1–4 % a použití jeho varianty ve výskoku je udáváno ve 22–47 %. Podání s vrchní rotací v současnosti používá asi polovina žen a 77 % mužů (obr. 2) [18]. Incidence hypotrofie m. infraspinatus tak v současnosti činí 9 % u mužských a 12 % u ženských hráčů elitního volejbalu [17].

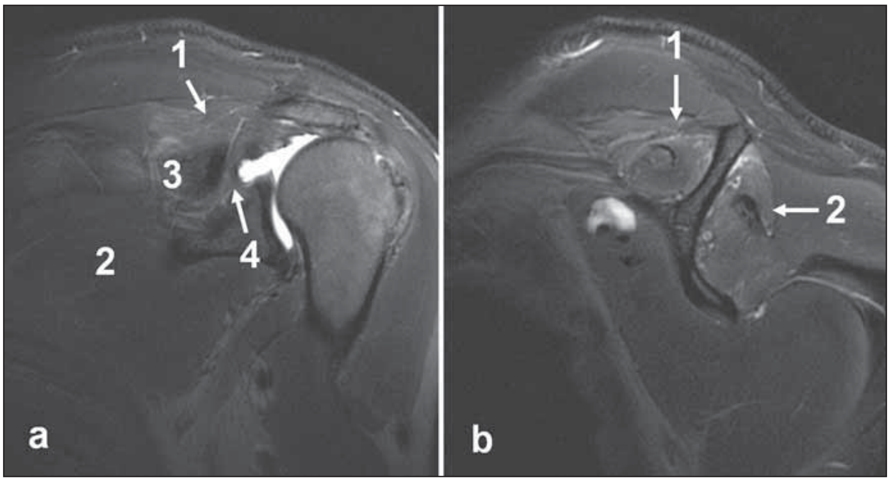
Diagnostika

Kromě anamnestických dat (vrcholoví sportovci – volejbal, tenis apod., pracovníci chronicky přetěžující končetinu v abdukci, nosiči těžkých břemen) je důležité klinické vyšetření. To prokáže případnou atrofii jednoho nebo obou mm. spinati a omezení zevní rotace a eventuálně i iniciální fázi abdukce končetiny. Při podezření na proximální SN je bolest vyvolána či zesílena addukcí extendované končetiny [4]. Klinicky se uplatňuje hodnocení dle Constanta a Murleye (1987). Absolutní skóre 0–100 (norma) je dáno součtem: 1. bolest (0–15); 2. funkce (0–20); 3. bezbolestný rozsah pohybu (0–40) a 4. síla (0–25) [19].

Zásadní roli v diagnostice hraje vyšetření MR. V případě přítomnosti dlouhodobých

Obr. 2. Volejbalové rotované podání. Extrémní zevní rotace ramene při abdukované paži. Převzato z [18].

Fig. 2. Volleyball topspin serve. Extreme external rotation of the shoulder with abducted arm. From [18].



Obr. 3. Rozsáhlá léze rotátorové manžety u 46letého pacienta po úrazu ramene. T2 vážené obrazy. (a) Koronární řez, paralabrální cysta propagující se do fossa supraspinata i do spinoglenoidální brázdy. (b) Sagitální řez, hypersignální nález v obou mm. spinati odpovídající akutním denervačním změnám.

1 – m. supraspinatus; 2 – m. infraspinatus; 3 – spina scapulae; 4 – spinoglenoidální brázda

Fig. 3. Extensive rotator cuff lesion in a 46-year-old male patient after a shoulder injury. T2 weighted images. (a) Coronal cut, paralabral cyst propagating into the supraspinous fossa and spinoglenoid notch. (b) Sagittal cut, hypersignal finding in both spinati muscles corresponding to acute denervation changes.

1 – supraspinatus muscle; 2 – infraspinatus muscle; 3 – scapular spine; 4 – spinoglenoid notch

omalgií (nejen izolované atrofie m. infraspinatus u rizikových skupin) je z diferenciálně-diagnostických důvodů vhodné indikovat zobrazení krční páteře k vyloučení mnohem častější kořenové komprese C5. Při negativním nálezu, resp. primárně při jasném úrazovém mechanizmu (podezření na poranění svalstva či vazů ramenního pletence), je provedeno vyšetření MR ramene. To umožňuje nejen zobrazení atrofie svalů, ale i denervačních signálových změn. V akutním a subakutním stadiu lze prokázat zvýšený signál na T2 vážených řezech (obr. 3) nebo sekvencích STIR (short-tau inversion recovery) jako obraz neurogenního edému, v chronickém stadiu je pak prokazatelná tuková přestavba svalu projevující se zvýšeným signálem na T1 vážených obrazech nebo speciálních sekvencích jako TSE (turbo spin echo) T2 obrazech (obr. 4) [20]. MR navíc může prokázat specifickou příčinu komprese (cysta, tumor) a stav rotátorové manžety s eventuální mediální retrakcí lopatkových svalů [21]. K detekci ruptury rotátorové manžety lze využít i vyšetření UZ [22].

U každého pacienta stěžujícího si na trvalou bolest v zadní části ramene, u kterého je zjistitelná atrofie lopatkových svalů a/nebo známky jejich denervace na MR či při nálezu masivní ruptury rotátorové manžety, by mělo být provedeno elektrofyziologické vyšetření. K verifikaci SN je provedena jehlová EMG prokazující fibrilace či pozitivní ostré vlny a nervové kondukční studie s nálezem snížené amplitudy motorického akčního potenciálu a prodloužené distální motorické latence. Normální hodnota distální motorické latence v m. supraspinatus při stimulaci Erbova bodu je 2,7 ms ± 0,5 a v m. infraspinatus 3,3 ms ± 0,5. Pro diagnózu NS svědčí stranová diference > 0,4 ms [4]. Dle souhrnu literatury byla EMG využita v diagnostice u 94 % pacientů, přičemž 85 % z těchto případů mělo pozitivní nález. Negativní nález však diagnózu SN nevylučuje [3]. Shah et al popsali ve své sérii tři pacienty s negativním elektrofyziologickým vyšetřením, kteří měli ústup bolestí po flouroskopicky navigovaném obstřiku kmene NSS [23]. Autoři tak doporučují provádět takový diagnostický blok ve všech nejasných případech SN [3].

Obr. 4. Těžká tuková přestavba obou mm. spinati u 75leté pacientky s dlouhotrvající lézí rotátorové manžety. Turbo spin echo T2 vážený sagitální obraz.

1 – m. supraspinatus; 2 – m. infraspinatus; 3 – spina scapulae

Fig. 4. Severe fatty changes in both spinati muscles in a 75-year-old female patient with chronic rotator cuff lesion. Turbo spin echo T2 weighted sagittal images.

1 – supraspinatus muscle; 2 – infraspinatus muscle; 3 – scapular spine

Diferenciální diagnostika

Vyjma jednoznačných úrazových lézí (masivní ruptura rotátorové manžety s akutním uskřinutím NSS vlivem retrakce lopatkových svalů, fraktura lopatky či léze plexus brachialis) je pro SN vzniklou v rámci úžinového syndromu či následkem chronického přetěžování typický dlouhý rozvoj příznaků. Z diferenciálně-diagnostického hlediska je tedy nutné odlišit akutně vzniklou „mononeuropatii" NSS v rámci amyotrofické neuralgie brachiálního plexu (neuritis brachialis, Parsonage-Turnerův syndrom) [24]. Etiologie syndromu je nejasná, nejčastěji se hovoří o reakci na prodělanou virovou infekci dýchacích cest či recentní vakcinaci. Kromě idiopatické formy existuje i vzácná varianta hereditární s častými rekurencemi [25] a plexopatie paraneoplastická [26]. Typickým příznakem je náhle vzniklá bolest – nejčastěji omalgie s propagací do paže, nebo bez ní (asi 40 %), cervikalgie s propagací do paže (35 %), méně často bolesti v oblasti lopatky nebo horní části zad propagující se do paže či přední části hrudníku. Dalším příznakem je náhle vzniklá svalová slabost objevující se v 70 % případů asi dva týdny po rozvoji bolestí. V polovině příznaků se objevuje izolovaná paréza svalstva ramenního pletence. I když bývá nejčastěji postižen právě n. suprascapularis, je při detailním klinickém vyšetření obvykle zjistitelná léze i jiných nervů. Kromě mm. spinati jsou tak postiženy i m. serratus anterior, deltoideus, vzácněji i m. biceps či triceps brachii. U dvou třetin pacientů je postižení unilaterální, ve zbylé třetině je pak patrné různě vyjádřené bilaterální postižení. Asi 80 % pacientů udává parestezie či hypestezie, zejména v oblasti deltového svalu a zevní plochy paže. V diagnostice se taktéž uplatňuje vyšetření EMG a nervové kondukční studie provedené 3 týdny po vzniku příznaků prokazující typicky vícečetné nervové postižení. Využít lze i vyšetření MR s podobným obrazem v postižených svalech jako u NSS. Léčba brachiální neuritidy je pouze konzervativní. Prognóza je obecně dobrá, proximální léze se obnoví v 60 % do jednoho roku, celkově lze návrat funkce očekávat u 90 % případů do 3 let [27].

Léčba

V případě SN způsobené rupturou rotátorové manžety či útlakem nervu paralabrální cystou je operační řešení indikováno z hlediska ošetření primární patologie. Prostá punkce cysty může mít sice okamžitý efekt, k recidivě však dochází v 75–100 % případů. U ostatních nálezů je iniciálně vždy indikována konzervativní léčba. K té patří primárně režimová opatření (zabránění vyvolávající příčiny, omezení sportu apod.), dále fyzioterapie a běžná analgetika. Léčebně lze rovněž využít cílenou blokádu nervu pod RTG či UZ kontrolou. Výhodou tohoto postupu je fakt, že i v případě krátkodobého efektu lze tento postup brát jako diagnostické potvrzení místa komprese. Obtíže vymizí během 6–12 měsíců až u 80 % pacientů. Při blokádě anestetikem (s depotním steroidem) nebo pulzní radiofrekvencí je možné použít klasický přístup s lokalizací nervu v incisura scapulae nebo novější proximálnější blok na krku pod m. omohyoideus. Vzhledem k tomu, že NSS senzitivně inervuje asi 75 % ramenního kloubu, lze blokádu provést kromě podezření na diagnózu SN i při chronických bolestivých stavech ramene (adhezivní kapsulitida, syndrom zmrzlého ramene nebo omartróza) [28].

U zbylých případů je u naprosté většiny indikována operační léčba dekompresí NSS protětím lig. transversum scapulae. Distální SN je dominantně řešena artroskopicky v rámci ošetření ramenního kloubu – resekce cysty s případným ošetřením vlastní artropatie [4]. Hlavním efektem uvolnění NS při proximální neuropatii je vymizení bolesti. Zlepšení funkce m. supraspinatus lze očekávat až u 90 % pacientů, naopak ke zlepšení trofiky m. infraspinatus a z toho plynoucí zlepšení zevní rotace paže dochází méně často [29].

Momaya et al publikovali systematický souhrn literatury týkající se léčby SN. Nalezli 276 pacientů s průměrným věkem 41,9 (14–85) let, muži byli postiženi 3× častěji. Většina (59 %) udávala náhlý vznik potíží po chronickém přetěžování končetiny v abdukci při práci či sportu, ve 31 % obtíže vznikly na základě úrazu a v 10 % spontánně (idiopaticky). Nejčastějším symptomem byla hluboká dorzální bolest ramene (98 %) trvající průměrně 19 měsíců před započetím léčby. Téměř 80 % pacientů však mělo i viditelnou atrofii jednoho či obou mm. spinati se zjevným oslabením při fyzikálním vyšetření. Operace umožnila návrat k vrcholovému sportu v 95 % případů (naprostá většina byli volejbalisté, zbytek tvořili plavci, jeden tanečník a oštěpař). Komplikace výkonů byly naprosto raritní (< 1 %). Byla popsána jen povrchová infekce či adhezivní kapsulitida po artroskopické dekompresi distální SN [3].

Největší chirurgickou sérii publikovali Davis et al roku 2019. Popsali výsledky 112 artroskopicky řešených SN během jednoho roku (z celkových 184 operovaných případů). Všichni pacienti podstoupili iniciální konzervativní léčbu nesteroidními antirevmatiky a rehabilitací. U všech byl následně proveden diagnostický blok NSS. Operace byla indikována při pozitivním elektrofyziologickém nálezu a ústupu bolesti po nervové blokádě. Autoři prokázali výrazný ústup bolesti i zlepšení síly postižených mm. spinati po dekompresi nervu [30]. V české literatuře své zkušenosti s operační léčbou 10 pacientů popsali Kanta et al, kteří udávají zlepšení u 90 % případů po dekompresi NSS v oblasti incisura scapulae [31].

Jedinou komparativní studii publikovali Le Hanneur et al, kteří porovnali skupinu 17 operovaných případů a 25 pacientů léčených konzervativně s diagnózou SN. U naprosté většiny jejich pacientů byla zaznamenána denervace v obou mm. spinati, jen u tří pacientů byl postižen pouze m. infraspinatus a pouze v jednom případě bylo zjištěno izolované postižení m. supraspinatus. I když autoři prokázali, že po průměrně 11 měsících nebyl zaznamenán rozdíl v efektu léčby mezi operačně a konzervativně léčenými případy „mononeuropatie" NSS, je nutno dodat, že v 53 % případů byly zjištěny abnormality i jiných nervů pažní pleteně [32]. Lze tak usuzovat, že více než polovina jejich pacientů byla k dekompresi NSS indikována chybně při možné diagnóze amyotrofické neuralgie brachiálního plexu.

Závěr

Na SN je potřeba myslet u každého pacienta s chronickými bolestmi zadní části ramene nebo s progredující slabostí zevní rotace a eventuálně i abdukce paže. Nejčastěji k ní dochází u chronického přetěžování končetiny v abdukci a zevní rotaci (vrcholoví sportovci, specifické profese). Další příčinou bývá přetažení nervu retrahovaným svalem při ruptuře rotátorové manžety. Naopak vlastní úžinový syndrom nervu je vzácnější. U většiny pacientů odezní bolesti či svalová slabost během několika měsíců trvání konzervativní léčby. Asi 20 % pacientů s útlakem nervu je indikováno k operační intervenci, která taktéž vede u většiny k ústupu bolesti a návratu ke sportovní či pracovní činnosti.

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Konflikt zájmů

Autoři deklarují, že v souvislosti s předmětem studie nemají žádný konflikt zájmů.

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Příloha 2

Kaiser R, Waldauf P, Ullas G, **Krajcová A**. *Epidemiology, etiology and types of severe adult brachial plexus injuries requiring surgical repair: systematic review and meta-analysis*. **Neurosurg Rev**. 2020; 43(2):443-452.

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REVIEW

Epidemiology, etiology, and types of severe adult brachial plexus injuries requiring surgical repair: systematic review and meta-analysis

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Abstract
The literature describing epidemiology, etiology, and types of serious brachial plexus injuries (BPIs) is sparse. The aim of this review was to investigate the epidemiological and etiopathogenetical data of serious BPIs undergoing surgical reconstruction. A systematic search was conducted from January 1985 to December 2017. All studies that reported data about prevalence of specific types and causes of BPIs in adults treated surgically were included and cumulatively analyzed. Ten studies including 3032 patients were identified. The pooled prevalence of closed BPIs was 93% (95% CI: 87–97%), lacerations accounted for 3% (95% CI: 1–6%), and gunshot wounds (GSWs) for 3% (95% CI: 0–7%). The prevalence of male patients was 93% (95% CI: 90–96%) and female cases 7% (95% CI: 4–10%). The most common cause of closed BPI was motorcycle accidents with 67% (95% CI: 49–82%) prevalence followed by car crashes with 14% (95% CI: 8–20%). Other causes were rare. Ninety percent (95% CI: 78–98%) of patients suffered from a supraclavicular or combined supra-/infraclavicular trauma, while 10% (95% CI: 2–22%) from isolated infraclavicular injury. The prevalence of complete lesions was 53% (95% CI: 47–58%) followed by upper plexus lesion with 39% (95% CI: 31–48%) and lower plexus injury with 6% (95% CI: 1–12%). This meta-analysis demonstrates that the typical patient suffering from severe BPI is a male after motorcycle accident with closed supraclavicular injury causing complete or slightly less commonly upper plexus palsy. Lacerations and GSWs of brachial plexus are rare.

Keywords Brachial plexus injury · Brachial plexus palsy · Peripheral nerve · Gunshot wound · Epidemiology

Introduction

Brachial plexus injury (BPI) is a relatively rare trauma; however, it is among the most severe and most mutilating. Thanks to advances in surgical techniques, a successful reconstruction of a large number of cases can be achieved. [23, 39] The most complicated cases, however, remain difficult to treat. [14, 27, 44] It typically affects young men of working age and can have serious socioeconomic impact. [1, 26]

BPIs are generally classified according to the level of injury in relation to the clavicle. Supraclavicular injuries include supraganglionar (root avulsion or intraforaminal rupture) and infraganglionar injury (extraforaminal root rupture below the spinal ganglion or injury of more distal parts of the brachial plexus). Infraclavicular injuries include trauma of the most distal parts of the brachial plexus or individual nerves. They have usually much better prognosis than lesions above the clavicle. [22]

The basic reference when discussing etiopathogenesis of BPI has traditionaly been the Swiss study performed by Narakas who described "the rule of 7 × 70" based on his experience with a series of 1068 patients (however, only 338 operated cases) during 18-year period [30]: (1) more than 70% of the BPIs were caused by road accidents, (2) of which 70% was an accident on a motorcycle or bicycle, (3) 70% of the latter group suffered polytrauma, (4) while 70% of them had supraclavicular lesion, (5) 70% of the patients had at least one root avulsion, (6) 70% of avulsions were in the lower

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plexus (C7-T1), and (7) 70% of patients with avulsion had chronic pain. However, this data is more than 30 years old.

There are only a few studies investigating the epidemiology and pathophysiology of BPIs in current literature. [13, 19, 28] Awareness about the frequency of severe BPI and its relation to the mechanism of injury in the context of multiple trauma appears to be crucial for the early detection of the lesion. Moreover, it is necessary to provide adequate data about the epidemiology and types of lesions when informing patients about the natural course and prognosis of the BPI.

The aim of this systematic review is to provide detailed analysis of epidemiological and etiological data of the current BPIs undergoing surgical reconstruction. A great disparity was observed across studies exploring the prevalence of specific subtypes and causes of BPIs; therefore, this meta-analysis was performed aimed to explore their pooled prevalence.

Methods

Ethical approval

Ethical approval was not required since this meta-analysis utilized published data which were already ethically approved.

Search strategy

This study was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. [29] Electronic databases of PubMed and Scopus were searched from January 1985 (when Narakas's study [30] was published) to December 2017. Instead of using "key words," this study used "title" or "abstract," to enroll more relevant articles. For example, search terms for the database of PubMed was "(((brachial plexus injury[Title/Abstract]) OR brachial plexus palsy[Title/Abstract]) OR brachial plexus lesion[Title/Abstract]) AND (((((surgical treatment[Title/Abstract]) OR reconstruction[Title/Abstract]) OR repair [Title/Abstract]) OR surgery[Title/Abstract]) OR epidemiology[Title/Abstract]) NOT ((((birth[Title/Abstract]) OR obstetric[Title/Abstract]) OR neonatal[Title/Abstract]) OR case report[Title/Abstract])". The reference lists for full articles were also identified in this study.

Eligibility criteria

The inclusion criteria for this meta-analysis were: consecutive case series of adult patients with any type of BPI undergoing surgical repair during a certain period; sample size ≥ 20; provided information at least minimally about one of the following: the proportion of specific types of BPI (closed lesions, lacerations, and gunshot wounds—GSWs), level of closed injuries, clinical extent of the injuries, and causative mechanism of closed BPIs. The exclusion criteria were: full article not written in English and reviews, comments, or case reports. Besides, if repeated data were observed across studies from the same surgical group/department, only the larger study was included.

Data extraction

Two investigators (RK and AK) independently identified the eligibility of articles and extracted data from eligible articles. Any discrepancies between them were resolved by consensus. Data extracted from eligible articles for this study were: first author, year of publication, country, total number of cases, number of male and female patients, mean age, type of BPI-closed lesions, gunshot wounds (GSWs) and other open lesions, level of closed injury (supraclavicular, infraclavicular, and combined), clinical extent of supraclavicular injury (upper, lower, and complete plexus palsy), cause of closed BPI (motorcycle, car or bicycle/pedestrian accidents, falls, and others).

Statistical analysis

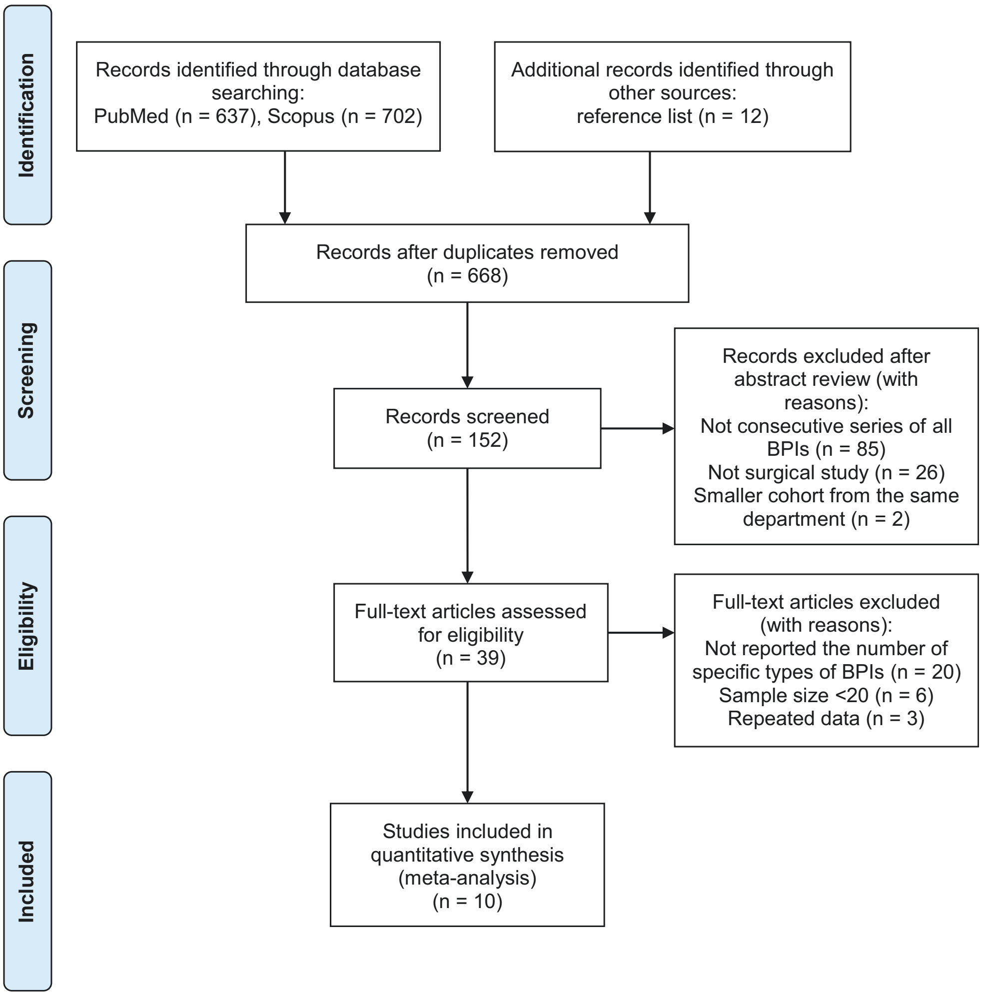
A random-effects meta-analysis was performed to summarize the proportions and the 95% confidence intervals (CI) using Metaprop [31] command in the Stata 15.1 (StataCorp LLC Texas, USA). The inter-study heterogeneity was assessed using the I^2 statistic, which quantifies the percentage of variation across studies due to heterogeneity rather than to chance. $I^2 \geq 25$, ≥ 50, and $\geq 75\%$ indicate low, moderate, and high heterogeneity, respectively. [16] The pooled prevalence of male and female gender and type of BPI among all operated patients, level of closed BPI, type of supraclavicular BPI, and cause of closed BPI was assessed. Publication bias was evaluated using the Egger's linear test and a funnel plot for asymmetry was presented. The significance level was set at $p < 0.05$.

Results

Search results

A total of 1351 articles were yielded by the search strategy of this study. After removing duplicates, 668 articles were screened for eligibility. After abstracts screening, 39 full articles were shortlisted for eligibility. Among the 39 articles, 20 were excluded for not reporting anything from the following information: types of operated BPIs, level of closed injuries, and clinical extent of supraclavicular injuries or cause of closed BPIs. Six were excluded for having a sample size of less than 20, and 3 were excluded for repeated data. Finally, 10 eligible articles were included in this meta-analysis (Fig. 1).

Fig. 1 Study selection flowchart



Study characteristics

Table 1 shows the characteristics of eligible studies. Ten studies totalling 3032 patients were identified.

Subgroup analyses

Pooled prevalence of male and female involvement, specific types of BPIs, and causes are summarized in Table 2. The most common type was closed traction injury with pooled prevalence 93% (95% CI: 87–97%, Fig. 2). Open lesions including lacerations, sharp, and iatrogenic injuries with 3% (95% CI: 1–6%, Fig. 3) prevalence and GSWs with 3% (95% CI: 0–7%, Fig. 4) prevalence were rare. Seven studies (1555 patients) provided information about number of men and women involved. The pooled prevalence of male patients was 93% (95% CI: 90–96%) and female cases 7% (95% CI: 4–10%). The combined male/female ratio is 13.3:1 (95% CI: 9:1; 24:1).

From eight studies (1886 patients), it can be inferred that the most common cause of closed BPI was motorcycle accidents with 67% (95% CI: 49–82%) pooled prevalence. This was followed by car crashes with 14% (95% CI: 8–20%) and "other" mechanisms (occupational or sport injuries, snowmobile accidents etc.) with 10% (95% CI: 3–20%) prevalence. Bicycle or pedestrian accident accounted for 3% (95% CI: 1–8%) and falls for 0% (95% CI: 0–2%) prevalence. Eight studies (1898 patients) provided information about the level of closed injury. Ninety percent (95% CI: 78–98%) of patients suffered from supraclavicular or combined supra-/infraclavicular trauma, while 10% (95% CI: 2–22%) from isolated infraclavicular injury. Six studies showed data about the level of supraclavicular injury. The most common type was complete lesion with 53% (95% CI: 47–58%) pooled prevalence followed by upper plexus lesion (C5–6 ± 7) with 39% (95% CI: 31–48%) and lower plexus injury (C8-T1 ± C7) with 6% (95% CI: 1–12%).

Publication bias was not observed in this meta-analysis, with P value for the Egger's linear test being 0.158–0.928. Consistent with the results of Egger's linear test, the funnel plots were symmetrical.

The heterogeneity was high within most subgroups. However, the heterogeneity was moderate when estimating the pooled prevalence of complete palsies among closed lesions ($I^2 = 52.65\%$, $P = .06$).

Table 1 Characteristics of eligible studies

Study (year of publication)	Country	No of patients	M:F ratio	Mean age	GSWs [a]	Lacerations [a]	Closed lesions [a]	Supra [b]	Upper [c]	Lower [c]	Complete [c]	Infra [b]	Motorcycle [b]	Car [b]	Bicycle/ pedestrian [b]	Fall [b]	Others [b]
Narakas (1985) [31]	Switzerland	338 (1068) *	–	–	1.5% (5)	1.2% (4)	97.3% (329)	–	–	–	–	–	–	–	–	–	–
Songcharoen (1995) [40]	Thailand	520	14.3:1	23	2.7% (14)	1.7% (9)	95.6% (497)	–	–	–	–	–	81.9% (426)	9% (47)	0%	0%	4.7% (24)
Terzis et al. (1999) [44]	USA	204	7.5:1	25.9	9.8% (20)	0%	90.2% (184)	76.6% (141)	–	–	–	23.4% (43)	35.8% (73)	22.5% (46)	4.9% (10)	0%	27% (55)
Kim et al. (2003) [22]	USA	698 (1019) *	–	34 for all	16.9% (118)	10.2% (71)	72.9% (509)	71.9% (366)	35% (128)	8% (29)	57% (209)	28.1% (143)	–	–	–	–	–
Ahmed-Labib et al. (2007) [1]	Canada	31	4.2:1	32.7	0%	9.7% (I) (3)	90.3% (28)	60.7% (17)	29.5% (5)	17.6% (3)	52.9% (9)	39.3% (11)	12.9% (4)	29% (9)	6.4% (2)	12.9% (4)	29.1% (9)
Lanaras et al. (2008) [28]	Germany	42	7.4:1	33	0%	4.8% (2.4% I) (2)	95.2% (40)	88% (35)	21.6% (8)	18.9% (7)	59.5% (20)	12% (5)	78.6% (33)	7.1% (3)	2.4% (1)	2.4% (1)	7.1% (2)
Jain et al. (2012) [14]	India	304	42.4:1	24	0%	0.7% (2)	99.3% (302)	99% (301)	50% (149)	0.3% (1)	49.7% (151)	1% (1)	85.2% (259)	6.9% (21)	2.3% (7)	0.7% (2)	4.9% (13)
Kaiser et al. (2012) [21]	Czech Republic	441	–	–	0.2% (1)	6.4% (1.1% I) (28)	93.4% (412)	91.6% (404)	–	–	–	1.8% (8)	46.7% (206)	17% (75)	10.2% (45)	0%	19.6% (86)
Faglioni et al. (2013) [10]	Brazil	406	17.5:1	28.4	4.1% (17)	2.1% (9)	93.8% (380)	92.8% (353)	51% (180)	2.9% (10)	46.1% (163)	7.2% (27)	84.6% (343)	3.8% (15)	3.2% (13)	2.2% (9)	0%
de Moares et al. (2015) [7]	Brazil	48	47:1	30.6	4.2% (2)	6.4% (3)	89.6% (43)	100% (43)	31.9% (15)	4.3% (2)	63.8% (26)	0%	60.4% (29)	20.8% (10)	2% (1)	0%	6.2% (3)

*Number of patients operated for BPI from the whole case series in brackets

[a] % (number of cases) from all cases

[b] From all closed lesions

[c] From all supraclavicular injuries

I iatrogenic injuries, *Supra* all supraclavicular and combined supra-/infraclavicular lesions, *Infra* all isolated infraclavicular lesions, *Upper*, *Lower*, and *Complete* brachial plexus palsy

Table 2 Pooled prevalence of male and female involvement, specific types of BPIs and their causes

		Number of studies	Pooled prevalence (95% CI), %	*P* value of Egger's test	*P* value for heterogeneity	I^2, %
Gender	Males	7	93 (90–96)	0.327	< 0.001	79.27
	Females	7	7 (4–10)	0.327	< 0.001	79.27
Type of BPI	GSWs	10	3 (0–7)	0.394	< 0.001	96.21
	Lacerations	10	3 (1–6)	0.666	< 0.001	91.92
	Closed lesions	10	93 (87–97)	0.453	< 0.001	96.68
Level of closed BPI	Supraclavicular injury	8	90 (78–98)	0.928	< 0.001	97.65
	Infraclavicular injury	8	10 (2–22)	0.342	< 0.001	97.65
Type of supraclavicular BPI	Upper plexus palsy	6	39 (31–48)	0.244	< 0.001	84.57
	Lower plexus palsy	6	6 (1–12)	0.556	< 0.001	89.64
	Complete palsy	6	53 (47–58)	0.928	0.06	52.65
Cause of closed BPI	Motorcycle accident	8	67 (49–82)	0.43	< 0.001	98.17
	Car accident	8	14 (8–20)	0.315	< 0.001	92.38
	Bicycle/pedestrian acc.	8	3 (1–8)	0.95	< 0.001	92.69
	Fall	8	0 (0–2)	0.158	< 0.001	80.64
	Other	8	10 (3–20)	0.569	< 0.001	97.22

Discussion

This meta-analysis included 10 eligible articles conducted in 8 countries with a total of 3032 participants. To the best of our knowledge, this is the first systematic review and meta-analysis to estimate the epidemiological and etiological factors and specific types of operated BPIs.

Although some of the analyzed studies [7, 13] and a series of motorcycle-related BPIs from UK [33] showed very high male predominance (33–47: 1), the pooled male and female prevalence was 93% (95% CI: 90–96%) and 7% (95% CI: 4–10%), respectively. The male/female ratio is therefore 13.3:1 (95% CI: 9:1; 24:1). The mean age varied between 23 and 34 years. However, we were unable to

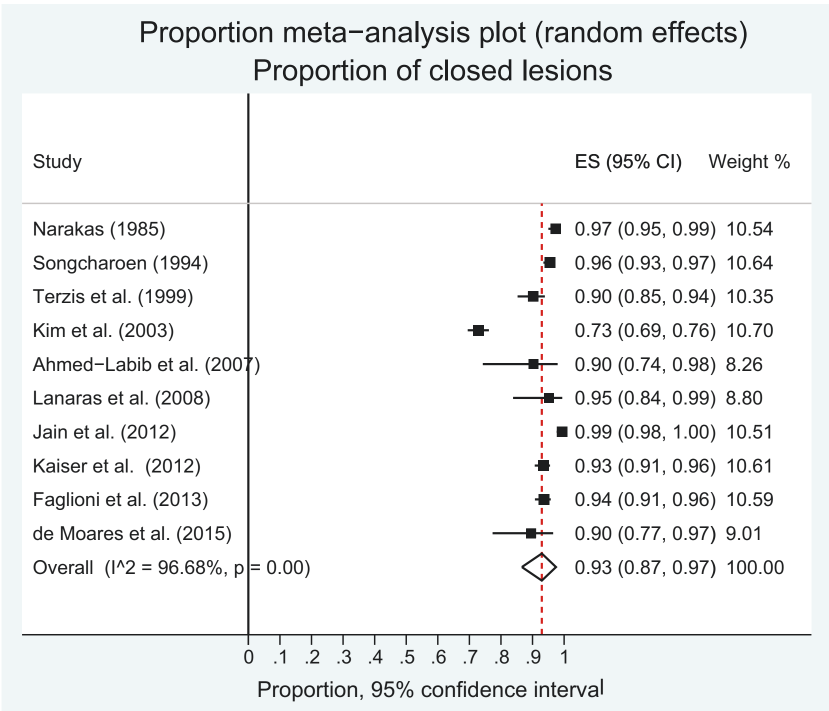


Fig. 2 Forest plot showing prevalence of closed BPIs (n = 2724). For all figures, horizontal lines denote 95% CIs; solid squares represent the point estimate of each study and the diamond represents the pooled estimate of the intervention effect. The size of the solid squares is proportional to the weight of the study

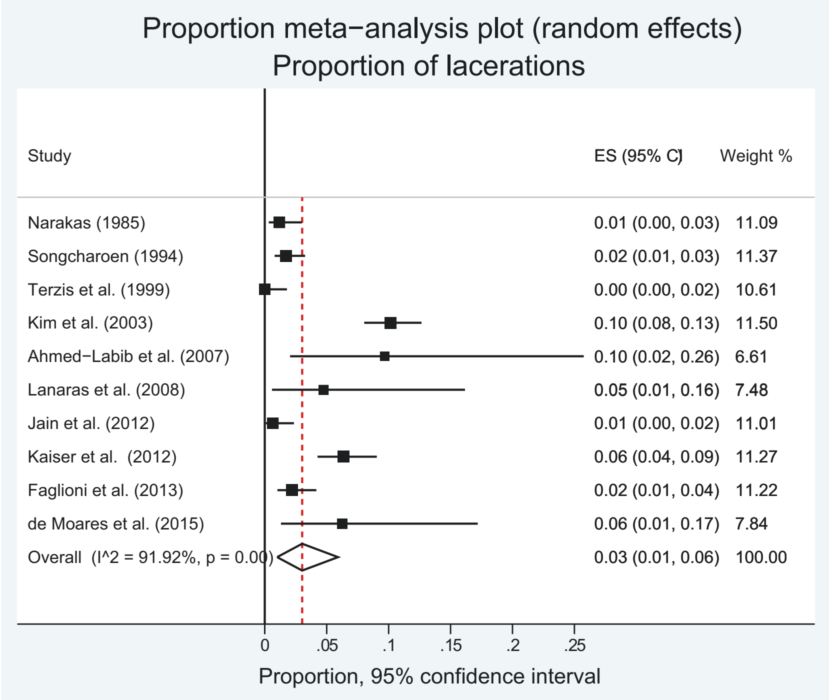


Fig. 3 Forest plot showing prevalence of open lesions including lacerations, sharp, and iatrogenic injuries ($n = 131$)

calculate the pooled mean age due to missing values of standard deviation in all studies.

Closed injuries

Etiology of BPI has changed historically from the initial dominance of open war injuries to the present majority of closed lesions caused by traction mechanism. [21] The reported prevalence of closed BPIs ranged from 72.9% [23] to 99.3% [13] among eligible studies, and the pooled prevalence is 93% (95% CI: 87–97%).

The mechanism of closed BPI may be traction, compression, or a combination of both. The typical traction BPI is caused by high-energy trauma during traffic accidents. These

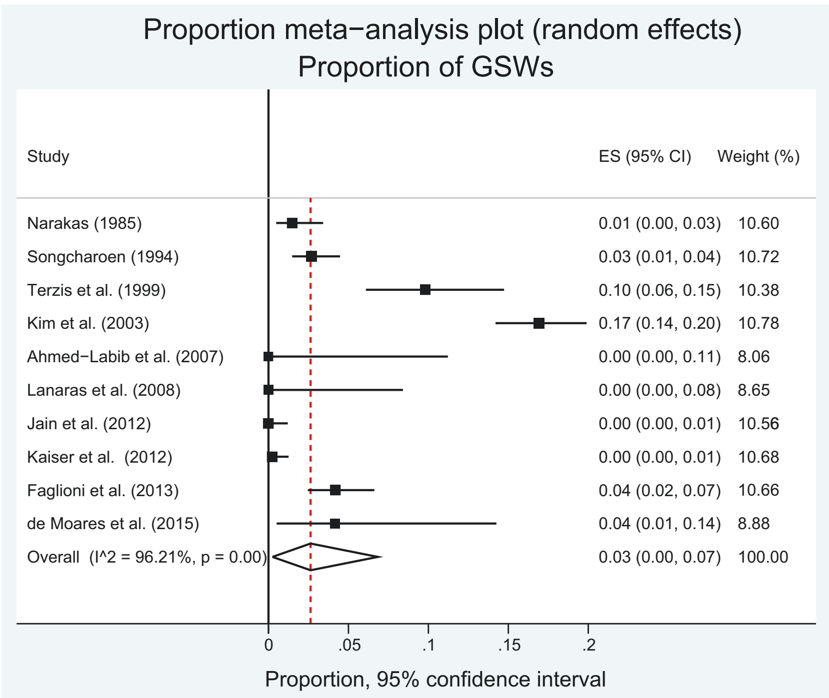


Fig. 4 Forest plot showing prevalence of GSWs ($n = 177$)

also occur less frequently by falls during winter sports (skiing, snowboarding) or from a snowmobile. In these accidents, the head and neck are strongly pulled away from the ipsilateral arm. Supraclavicular upper BPI usually dominates when the limb is along the chest and the force acts from above. In these cases, the first rib transmits forces directly to the upper parts of the plexus. If the arm is forcibly pulled into the abduction and extension, the elements of the lower plexus may be affected too. Complete lesions arise either by severe forces or by a combination of several different forces during the fall. [28] The infraclavicular portion of brachial plexus is susceptible to stretch lesions when skeletal injuries occur in the area. These lesions typically occur when a 90° abducted arm is extended behind the frontal plane of the body or in falls with hyperabducted and internally rotated arm. In these cases, usually posterior cord or axillary nerve are damaged. [6]

The upper roots are protected against avulsion by dural sleeves and fibrous connections between epineurium and intervertebral foramina. They have much greater tendency to rupture. Preganglionar lesion of upper roots may be caused either by rupture or avulsion of C5–6 (C7) roots, while the lower plexus injury almost always by avulsion of the roots C8-T1. [15] Ventral roots are shorter than the dorsal ones which make them more susceptible to rupture. [42] Similarly, motor roots have fewer fila radicularia and are thinner than their sensation counterparts; therefore, they rupture more easily. [40]

Epidemiology

Midha stated that the estimated incidence of closed BPIs in the US is 0.64–3.9/100,000/year. Their prevalence in multitrauma patients is 1.2%. It is assumed that the BPIs are about 9 times rarer than spinal cord injury and about 60 times rarer than brain injury. [28] The incidence of all types of BPIs in the UK (including minor injuries with spontaneous recovery) is 0.58, [11] in Japan 0.17 to 0.22, [21] in Switzerland 0.3 to 0.75, [30] in the Czech Republic and Slovakia combined 0.2 [19] and conversely in Brazil 1.75 cases/100,000/year. [10]

BPI occurs in 4.2 [28] to 5% [1] cases of multitrauma after motorcycle accidents, in 3–4.8% after falling while skiing or snowboarding, respectively, [1, 28] and in 3% after fall from snowmobile. [41] BPIs account for 6–11% of all operated lesions of peripheral nerves. [9, 37] They are present in 0.6–0.7% of the patients with spinal cord injury and these combined lesions that are typically caused by motorcycle accidents (over 70%). [2] On the other hand, 12.2% of patients with BPI have any type of spinal cord lesion (0.8% complete spinal cord injury and 1.6% Brown-Séquard syndrome). [32]

Midha published, so far, the largest epidemiological study including 54 cases of BPI out of 4538 multitrauma patients (1.2%). BPI was associated with unconsciousness in 72% (19% in coma), cervical spine fractures in 13%, fractures of the clavicle, humerus or scapula in 20%, and multiple rib fractures in 41%. [28] The most common associated injury in the surgical series was fracture of the upper limb (55%) followed by spinal injury in 43%. Almost one third of cases involved at least one of the following: parenchymal organ injuries, fractures of the lower limbs, or coma. Approximately 25% of the patients involved at least one of the following: scapular fractures, severe head trauma, and rib or clavicle fractures. However, it has been stated that patients with BPI do not present any "typical accompanying injuries," whose presence would be directly pointed to the possibility of neural structure injuries. Lower and complete lesions are more often associated with severe polytrauma. [20]

Etiology

The dominant cause of closed BPIs was motorcycle accidents with 67% (95% CI: 49–82%) pooled prevalence. The mean speed of the motorcycle at the time of the accident was 88 km/h (40–193) in the US study, [43] while only 47 km/h (10–120) in the Indian series. [13] Jain et al. found that the dominant limb is affected more often in motorcycle accidents, irrespective of the side of the traffic. [13]

Prevalence of car accidents was 14% (95% CI: 8–20%) and "other" mechanisms (occupational or sport injuries, snowmobile accidents, fall of an object onto the shoulder or injury caused by water shot from a fire hose etc.) was 10% (95% CI: 3–20%). Bicycle or pedestrian accidents and falls were rare causes. None of the studies provided data about the specific causative mechanisms of supra- and infraclavicular closed lesions.

Types of lesions

We performed the calculation of the combined prevalence of all supraclavicular BPIs because we were unable to extract exact information about the frequency of supra- and infraganglionar injuries from most studies. Moreover, combined supra- and infraclavicular injuries were analyzed together with isolated supraclavicular injuries due to their similar pathophysiology and prognosis. The frequency of these lesions in closed BPIs requiring surgery ranged between 60.7% [1] and 100%. [7] However, their pooled prevalence was 90% (95% CI: 78–98%) compared to the 10% (95% CI: 2–22%) prevalence of isolated infraclavicular lesions. This is in concordance with the results of the recent Bertelli et al. study about 565 surgically treated brachial plexus stretch palsies. [4] Although Narakas [30] found 70% prevalence of these lesions in all his 1068 patients (including cases not undergoing surgery), the higher value in this meta-analysis of surgical cases may be partially explained by higher tendency of infraclavicular BPIs to spontaneous recovery. Midha found that surgical revision was required in 52% of supraclavicular and in only 17% of infraclavicular lesions in large study of multitrauma patients. [28] Although the upper plexus syndrome predominated in the traffic accidents victims (73.9%) [19] and in a series of 13 operated rugby players with closed supraclavicular BPI (61%), [3] the pooled prevalence of upper plexus lesion was 39% (95% CI: 31–48%). Supraclavicular lesion was most commonly associated with complete brachial plexus palsy with prevalence 53% (95% CI: 47–58%) while lower plexus injury with 6% (95% CI: 1–12%) prevalence was rare. It was found, however, that lower plexus palsy is relatively more frequent in car accidents (9%) and complete BPIs are not present in injured pedestrians. [28] Data regarding the extent of the infraclavicular BPIs was missing in most of the studies.

The study about BPIs after traffic accidents showed that 71.8% of patients had at least one avulsion. A total of 26.1% of the patients had avulsion of all roots or avulsion of the lower roots, while 45.7% of the patients had avulsion only in the upper region. [19] The data showed similarity to the results of the Narakas study, [30] the only major difference was the reversed frequency of upper and lower avulsions. The authors hypothetized that this fact could be explained by differences in traffic conditions and mechanisms of injury in the last 20 years and in the period before 30–40 years.

It was found that all the passengers wearing seatbelts during a car crash suffered from upper BPI on the side where the seatbelt crossed the shoulder. In contrast, 86% patients with complete palsy did not wear a seatbelt. Safety belt probably acts as a tight barrier which compresses the supraclavicular region. Subsequent traction resulting in sharp depression of the shoulder and ventro-cranial relative movement of the head and neck leads to rupture or avulsion of the upper roots. In cases without the use of belts, more severe BPI is caused probably by summation of more different forces. [17]

Lacerations

Open BPIs including cut or stab wounds, lacerations, and iatrogenically caused trauma are uncommon. The pooled prevalence is 3% (95% CI: 1–6%) of all cases undergoing surgical repair. They typically affect the infraclavicular region and are often accompanied by simultaneous fracture of the humerus or injuries of large vessels. [23, 43] Iatrogenic trauma can be caused during axillary plexus block, resection of the tumors in the neck, or in the supraclavicular region or in the operations on large vessels. [23]

Severe lacerations of brachial plexus are extremely rare. Injuries caused by metal objects, fan or engine blades [24], and animal bites [10, 24] have been published. Rarely, BPIs may be caused by a chainsaw. Although Kim et al. described chainsaw injury as a cause of some plexus lacerations, they did not specify neither the number of such cases nor the injured level (supra- or infraclavicular). [24] Chainsaw kickback is the reactive force which can occur when the tip of the guide bar comes into contact with a relatively massive or immovable object with the chain under power. The chain may jam hard into the wood and hurl the bar upwards towards the operator. These injuries occur most typically in upper (36%) and lower limbs (43%) and head (9%). Neck is affected less frequently, but such cases have usually severe prognosis or end fatally due to common vascular or airways injuries. [5] Only two cases of non-fatal neck injury with isolated supraclavicular BPI have been published to date. [8, 18]

Gunshot injuries

Gunshot BPIs are rare and usually very severe. The extent of the lesion is caused by the self-destructive behavior of projectile itself and cavitation, which depends both on the size, shape, design, and speed of the projectile. High velocity projectile injury is typical for war surgery. It has a worse prognosis than injuries caused by civilian weapons due to larger, often devastating injuries of soft and bone tissues as well as significant contamination of the wound. Bone fragments in these cases may act as secondary projectiles increasing extent of the lesion. [12]

The prevalence of GSWs in civilian reports is 3% (95% CI: 0–7%). The highest proportion of GSWs was found in two US studies—9.8% (20/204 patients) [43] and 19.9% (118/698 patients with BPI). [23] The injuries were caused by handguns, rifles, or shotguns and most of the wounds were from bullets, but a few were due to shell fragments. [25] On comparison, the case series from Canada, [1] India [13], and Germany [27] did not include any patient suffering from GSW.

There are only two war studies studying the evaluation of BPIs caused by GSWs from the Iraq-Iran war (20 cases) [34] and from the Yugoslav war (54 cases) [35] that have been published. Secer et al. described the largest series of 256 patients with 288 BPIs caused by GSWs operated during 41-year period (1966–2007) in Turkey. The mean age was 22 years. [38] GSWs typically affect the infraclavicular elements of brachial plexus (90–92%), while supraclavicular BPIs are much less common (8–10%). [34, 38] Due to similar mechanism of injury, it is necessary to mention the two cases of BPI described in the 112 survivors of the Beirut bomb attack (prevalence 1.8%). [36]

Limitations

There are some limitations to this study. First, this meta-analysis included 10 eligible articles with none of them providing detailed decriptions of age (standard deviation). Most of the articles also did not show the proportion of supra- and infraganglionar injuries, extent of the lesion in lacerations, GSWs and closed infraclavicular injuries and specific causes of closed supra- and infraclavicular lesions. Second, the heterogeneity was high within most subgroups. Third, the studies provided information only about operated patients but not about serious BPIs which were not indicated for surgery due to late presentation or severity of the injury.

Despite the preceding limitations, this study has several strengths. First, to the best of our knowledge, this is the first meta-analysis estimating the pooled prevalence of epidemiological and etiopathogenetical factors of the current BPIs undergoing surgical treatment. Second, no risk of publication bias identified in this meta-analysis significantly adds confidence when interpreting the results of this study.

Conclusion

BPI most commonly affects males in their third or fourth decade of life. Closed BPI is typically caused by motorcycle accident. Most of them are supraclavicular and causing complete and slightly rarely upper plexus palsy. Lacerations and GSWs are rare.

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Compliance with ethical standards

Ethical approval Not needed. Ethical approval was not required since this meta-analysis utilized published data which were already ethically approved (see Methods section).

Informed consent Not needed (review article).

Conflict of interest The authors declare that they have no conflict of interest.

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Příloha 3

Kaiser R, **Krajcová A**, Makel M, Ullas G, Němcová V**.** *Anatomical aspects of the selective infraspinatus muscle neurotization by spinal accessory nerve*.

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ARTICLE

Anatomical aspects of the selective infraspinatus muscle neurotization by spinal accessory nerve

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ABSTRACT
The suprascapular nerve (SSN) is commonly reconstructed by spinal accessory nerve (SAN) transfer. However, reinnervation of its branch to the infraspinatus muscle (IB-SSN) is poor. Reconstruction of the SSN in cases of scapular fractures is frequently neglected in clinical practice. The morphological study was performed on 25 adult human cadavers. The course and the length of SSN of minimal diameter of 2 mm within the trapezius muscle, the length of the distal stump of IB-SSN to its branching point and the length of the SSN available for reconstructive procedure were measured. The feasibility study of the SAN - IB-SSN neurotization performed by using a bony canal under the spine of scapula was performed. The mean distance of the SAN from the spine was 8.5 cm (±0.88) at the point where it perforates the trapezius muscle and 4.49 cm (±0.72) at the most distal part of the nerve. The mean length of the intramuscular portion of the nerve was 14.74 cm (±1.99). It ran under a mean latero-medial angle of 15.54° (±2.51). The mean distance between the medial end of the scapular spine and the SAN was 2.44 cm (± 0.64). The mean length of the IB-SSN was 3.6 cm (± 0.67). The mean length of the SAN stump which was mobilized from its original course and transferred to the infraspinous fossa to reach distal stump of the IB-SSN was 8.09 cm (±1.6). Direct SAN to IB-SSN transfer is anatomically feasible in the adult population.

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Suprascapular nerve; spinal accessory nerve; nerve transfer; brachial plexus injury; scapular fracture

Introduction

Lesions of the suprascapular nerve (SSN) are a typical finding in brachial plexus injury. In adults, restoration of glenohumeral stability, abduction and external rotation of the shoulder is the first priority for treatment of such injuries. Lesion of the SSN is usually reconstructed by spinal accessory nerve (SAN) neurotization *via* an anterior approach; however, a dorsal approach to reconstruction may potentially lead to a better outcome, potentially due to a shorter reinnervation distance [1]. Even though the success rate of restoration of shoulder abduction after this neural transfer is high, functional external rotation is achieved in less than half [2].

SSN injury is present in up to one third of scapular fractures [3]. Fractures of the scapular body or spinoglenoid notch are typically associated with injury of the infraspinatus branch of the SSN (IB-SSN). The loss of shoulder external rotation caused by infraspinatus muscle palsy is a severely debilitating consequence of these injuries [4].

Although direct neurotization of IB-SSN has been described in obstetric brachial plexus palsy [5], anatomical feasibility in the adult population has never been investigated. To our knowledge, reconstruction of SSN injury after scapular fracture has not been published before. Even though anatomical studies on SAN innervation of the sternocleidomastoid and trapezius muscle in the neck have been widely reported [6], detailed morphology of the distal part of the nerve (its course within the trapezius muscle) is not as well described.

The aim of the study is to describe the anatomy of the thoracic portion of the SAN and determine the feasibility of the dorsal SAN to IB-SSN nerve transfer in the adult population.

Basic anatomy

Spinal accessory nerve anatomy

SAN is a motor nerve, supplying the sternocleidomastoid and the trapezius muscles. After exiting the skull it descends medial to the styloid process and stylohyoid and digastric muscles. It then passes into (70–80%) or under (20–30%) the sternocleidomastoid and exits the posterior border at a point 7–9 cm above the clavicle. It crosses the posterior triangle of the neck in an inferolateral direction, superficial to the levator scapulae. It then pierces the trapezius muscle, most commonly on at a point 2–4 cm above the clavicle [7]. After providing the perforating branches to the upper trapezius muscle, it runs distally from the point lying on the line between C7 and acromion as the isolated main trunk [8]. Although at least one communicating branch between the SAN and the roots of the cervical plexus can be found in each cadaver dissection [9,10], motor input from the cervical plexus to the trapezius muscle is seen in only one third of cases [9].

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Suprascapular nerve anatomy

SSN arises from the upper trunk of the brachial plexus which is formed by the union of the ventral rami of the C5 and C6 and rarely from C4 root. The nerve passes across the posterior triangle of the neck parallel to the inferior belly of the omohyoid muscle and deep to the trapezius muscle. It then runs along the superior border of the scapula, passes through the suprascapular notch inferior to the superior transverse scapular ligament and enters the supraspinous fossa. It then passes beneath the supraspinatus, relatively fixed on the floor of the supraspinatus fossa, and curves around the lateral border of the spine of the scapula through the spinoglenoid notch to the infraspinous fossa. In 84%, there were no more than two motor branches to the supraspinatus muscle and in 48% the infraspinatus muscle had three or four motor branches of the same size [11]. The mean diameter of the suprascapular nerve at the suprascapular notch is 2.48 ± 0.6 mm [12].

Material and methods

This study was performed on 25 human cadavers prepared for anatomical dissection courses (4% phenolic acid and 0.5% formaldehyde). The bodies were donated with the agreement of usage for teaching and research purposes. Only specimens without signs of previous surgery or any other severe abnormality in the regions of interest were used. For standardization, all of the dissections were performed on the left side.

Spinal accessory nerve course and length

After transection of the skin and removal of the subcutaneous fat, the trapezius muscle was dissected, cut vertically paravertebrally, detached from the scapular spine and rotated cranio-lateraly. The entire course of the SAN was dissected from its entry into the trapezius muscle from the posterior triangle of the neck to the terminal branches. The position of the nerve was marked at two locations (Figure 1(A)):

Point A (upper red pushpin): on the line between the vertebra prominens (C7, upper green pushpin) and the acromion;

Point B (lower red pushpin): at the point of the most distal branch of the SAN measuring 2 mm in diameter. This diameter was set as the minimal usable size of the SAN for reconstruction because the diameter of the entire SSN is approximately 2.5 mm [12].

Then, the muscle was lifted up and another set of red pushpins was inserted from its outer surface to the same position as the inner ones, which were then removed. The muscle was rotated back to its original position (Figure 1(B)). The length of the intramuscular portion of the SAN (SAN length) was measured between points A and B.

To calculate the course of the SAN, the distance of the nerve from the midline was measured at two positions:

Distance 1: between point A (upper red pushpin) and C7 vertebra (upper green pushpin);

Distance 2: on a horizontal line between point B (lower red pushpin) and the corresponding spinous process marked by lower green pushpin.

The course of the nerve at angle β was defined in relation to the vertical line crossing the upper position of the nerve (point A). The angle was calculated according to formula $\beta = \arcsin(b/c)$. Line b was calculated as the difference between both distances and line c was the length of the nerve. The line c and resultant angle β are approximate because the course of the nerve is not linear (Figure 2).

Spinal accessory to infraspinatus branch of suprascapular nerve transfer technique

The deltoid and upper part of the infraspinatus muscle were detached from the lower margin of the scapular spine and from the floor of the infraspinous fossa as in the standard Judet approach [13] for the treatment of scapular body fractures. IB-SSN was dissected at the spinoglenoid notch, transected and followed distally into its branching. The length of the distal stump of the IB-SSN to its branching was measured.

After performing SAN and IB-SSN measurements, the trapezius muscle was attached back to the spine using pins. Its fascia was cut horizontally medially from the scapular spine. Then, SAN was dissected between the muscle fibres (Figure 3) and the distance between SAN and medial end of the scapular spine was measured. The SAN was followed by blunt dissection as far caudally as

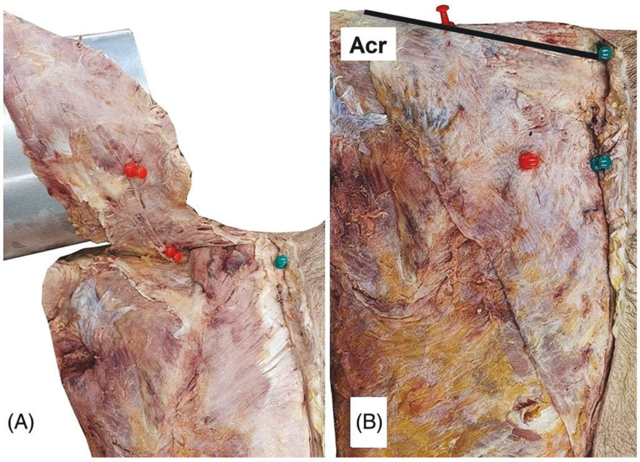

Figure 1. The technique of morphological mapping of the SAN. (A) Trapezius muscle was detached from the spinous processes and the scapular spine and rotated cranio-laterally. The SAN was dissected from its entry into the trapezius muscle to the terminal branches. It was then marked by upper red pushpin on the line between the vertebra prominens (C7, upper green pushpin) and the acromion (Acr), and by lower red pushpin at the point of the most distal branch of the SAN measuring 2 mm in diameter. (B) Trapezius muscle rotated back to its original position after the insertion of another set of red pushpins from its outer surface to the points corresponding to the location of the inner pushpins. The lower green pushpin was put in the horizontally corresponding thoracic spinous process.

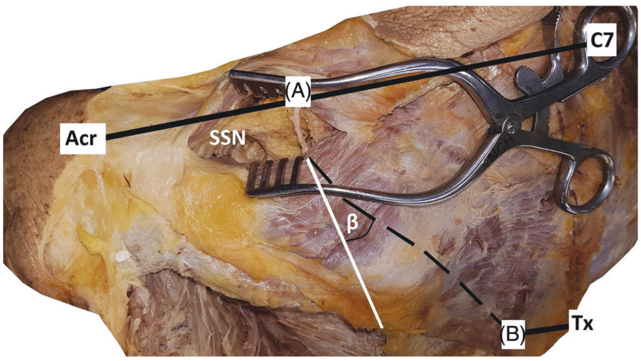

Figure 2. The position of (A) the entry point of the SAN into the trapezius muscle on the line between acromion (Acr) and C7 spinous process and (B) the most caudal part of the nerve with minimal 2 mm of diameter. Distance 1 measured between the points A and C7, Distance 2 between B and corresponding thoracic vertebral spinous process (Tx). Dashed line – presumed course of the nerve within the trapezius muscle. White line – vertical line from the point A. β – angle between vertical line and the SAN.

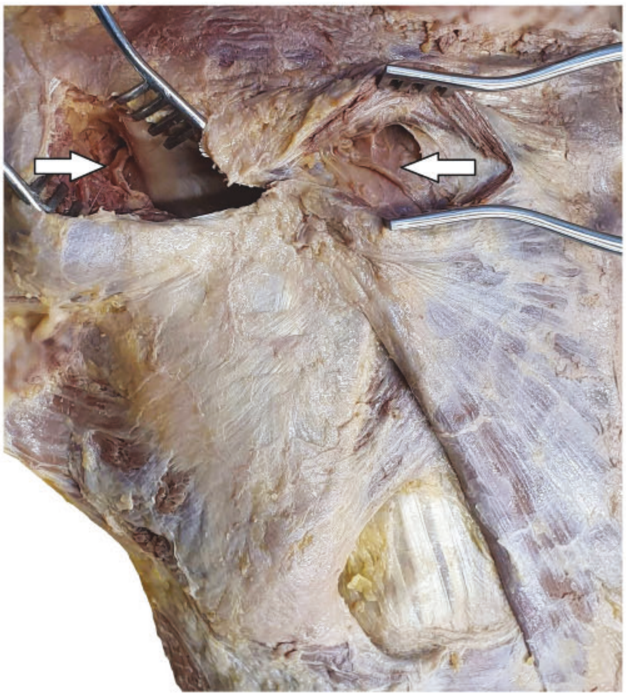

Figure 3. Anatomical situation after separation of the infraspinatus muscle from the spine of scapula and floor of the infraspinous fossa and dissection of the SAN between the muscle fibres of the trapezius muscle. Left arrow – IB-SSN, right arrow – SAN.

possible, where it was cut. The end of the nerve was shortened at a point with a minimum diameter of 2 mm. The SAN stump was then mobilized cranially to the upper portion of the trapezius muscle.

Then, the muscle fibres of the supraspinatus muscle were detached from the medial half of the cranial margin of the scapular spine. The central weakened area (Figure 4(A)) was simply perforated by sharp scissors and the hole of 10 mm in diameter was created. The length of the mobilized stump of the SAN was measured from the cranial-most point to which the nerve was mobilized at the cranial portion of the trapezius muscle and it was then transferred under the spine of the scapula through the prepared canal into the infraspinous fossa (Figures 4(B) and 5).

Results

The measurements are summarized in Table 1. The mean distance of the SAN from the spine on the acromion-C7 line was 8.5 cm (± 0.88) (Distance 1) and 4.49 cm (± 0.72) at the most distal part of the nerve with minimal diameter of 2 mm (Distance 2). The mean length of the intramuscular portion of the nerve (SAN length) was 14.74 cm (± 1.99) and it run under the mean angle of $\beta = 15.54^{\circ}$ (± 2.51).

The mean distance between the SAN and the medial end of the scapular spine was 2.44 cm (± 0.64). The mean length of the distal stump of IB-SSN to its branching was 3.6 cm (± 0.67).

The nerve transfer appeared anatomically feasible in all cases. The mean length of the SAN stump of minimal diameter of 2 mm, which was mobilized from its original course and transferred to the infraspinous fossa *via* the prepared bony canal to reach distal stump of the IB-SSN, was 8.09 cm (± 1.6).

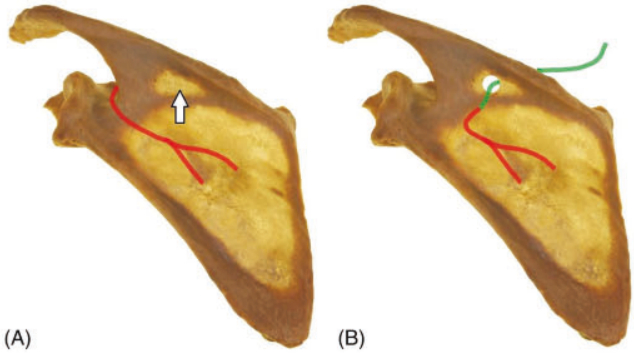

Figure 4. Transilluminated scapula, postero-inferior view [23]. A. SSN (red) passes through the spinoglenoid notch, arrow – central weakened area. B. Schematic drawing of the SAN (green) to SSN (red) transfer. SAN running through the bony canal in the weakened area under the spine of the scapula.

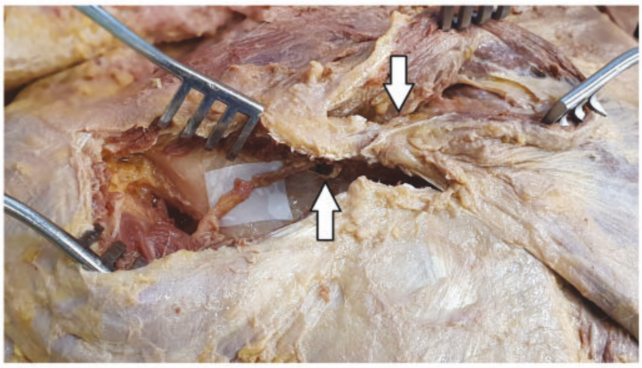

Figure 5. Direct SAN to IB-SSN transfer. Left arrow – SAN transferred through the bony canal performed in the central weakened area of the scapular spine, right arrow – proximal part of the SAN.

Discussion

SSN is one of the most commonly affected nerves in upper or complete brachial plexus injury. It innervates the supraspinatus muscle, which initiates shoulder abduction; and infraspinatus muscle, which acts as the main external rotator of the glenohumeral joint. It is also an important stabilizing muscle [7]. The SSN is usually reconstructed by SAN transfer through the same access as would be done for an anterior approach to the brachial plexus. The SAN is dissected through a supraclavicular incision, it is then divided retroclavicularly, and is directly transferred to the SSN [14].

The trapezius muscle originates from the skull and the spinous processes of all thoracic vertebrae and inserts primarily along the spine of the scapula. It is separated into three functional components. The superior portion elevates the scapula and rotates the lateral angle upwardly, the middle portion adducts and retracts, and the inferior portion depresses the scapula and rotates the inferior angle medially. Typical presentation of trapezius palsy includes the symptoms of stiffness, pain, and weakness of the shoulder girdle, especially with overhead activity and upon prolonged exertion. Consistently, patients are limited in all overhead activities. Functional impairment does not occur if the upper part of the trapezius is preserved [15]. The lower portion of the muscle is used in various reconstructive procedures as a 'vertical trapezius musculocutaneous flap' without obvious adverse neurological effect [16]. In order to shorten the reinnervation distance, some authors began to investigate the performance of SSN transfer *via*

Table 1. Morphological analysis of intramuscular portion of spinal accessory nerve (SAN) and intraspinous branch of suprascapular nerve (IB-SSN).

Cadaver	Distance 1 (cm)	Distance 2 (cm)	SAN length (cm)	β (degrees)	Distance SAN – scapular spine (cm)	Length of SAN for reconstruction (cm)	Length of IB-SSN (cm)
1	9.4	4.2	17.2	17.32	2.8	10.7	3.8
2	8.2	5.0	13.1	14.00	1.8	6.6	2.9
3	6.8	3.3	13.4	14.97	2.6	6.4	2.6
4	9.4	4.7	18.0	14.96	2.3	11.1	2.6
5	9.3	3.9	15.8	19.58	3.4	9.8	4.2
6	7.8	4.1	13.4	15.82	2.4	7.1	3.4
7	8.5	3.8	16.0	16.83	2.6	7.4	4.0
8	9.1	5.7	17.4	11.20	1.4	9.0	4.6
9	10.1	4.2	17.2	19.65	3.8	11.8	4.5
10	7.4	4.3	12.7	13.99	2.1	7.1	3.2
11	6.9	3.4	12.0	16.71	2.7	6.8	2.8
12	8.8	5.1	15.8	13.42	2.3	8.4	3.4
13	9.5	5.1	16.7	15.10	2.3	10.5	4.8
14	9.2	2.8	16.4	22.36	4.1	9.6	3.5
15	8.1	5.2	12.1	13.73	2.0	7.1	3.1
16	7.5	5.1	11.4	12.06	1.9	6.9	3.7
17	7.9	4.3	12.4	16.63	2.8	6.8	3.4
18	7.4	4.4	12.4	13.86	2.1	6.7	3.5
19	9.0	4.9	16.2	14.50	2.4	7.5	4.9
20	9.2	5.6	15.9	12.97	1.7	8.1	3.2
21	8.8	5.2	14.9	13.84	1.6	7.8	3.2
22	8.4	4.1	14.0	17.60	3.0	6.7	3.9
23	7.9	4.3	13.1	15.87	2.2	6.9	4.1
24	9.2	5.1	16.0	14.68	2.4	8.3	2.8
25	8.8	4.4	15.2	16.81	2.7	7.3	4.1

Distance 1 – distance of the SAN (point A) from the spine measured on the acromion-C7 line; Distance 2 – distance of the most distal part of the SAN with minimal diameter of 2 mm (point B) from the spine; SAN length – length of the intramuscular portion of the nerve between points A and B; β – angle between the vertical line crossing point A and the SAN; Distance SAN – scapular spine – distance between the SAN and the medial end of the scapular spine; Length of SAN for reconstruction – the length of the donor stump available by blunt dissection and mobilized into the infraspinous fossa for reconstruction of IB-SSN; Length of IB-SSN – length of the available distal stump of the IB-SSN to its branching which can be mobilized for the suture with SAN.

a posterior approach, which allows neurotization closer to the target muscles. Although functional recovery of shoulder abduction after SAN to SSN transfer is high (>70%) [17], both anterior and posterior techniques are associated with poor reinnervation of the infraspinatus muscle (40 – 55% of the cases) [1,2,14]. Infraspinatus muscle produces 75% of the glenohumeral external rotation torque and is the most effective in the first 90° of shoulder elevation [18]. Restored abduction without adequate external rotation of the arm limits the function of the extremity. It is arguably more important than other shoulder motions, as it allows the patient to position the forearm and hand in front of the body for function [4].

In addition to brachial plexus injury, SSN involvement is also typical of scapular fractures. They account for 3–5% of injuries of the shoulder girdle. As a rule they are sustained as the result of marked force applied in the course of high-velocity trauma. Fractures of the scapular body or glenoid neck account for the majority of all scapular fractures [19]. SSN palsy is present in 2.4% – 32% of these injuries [3], especially in fractures of the surgical neck. Due to the course of the SSN through the spinoglenoid notch, typically the IB-SSN is injured. Fractures of the scapular body or surgical neck are often unstable and require open reduction and internal fixation *via* a Judet posterior approach [13].

The idea of direct IB-SSN neurotization in selected brachial plexus injury cases has been proposed by some authors. Sommarhem *et al.* analyzed eight patients with brachial plexus birth injuries who underwent neurotization of IB-SSN by SAN. At the one-year follow-up, the mean improvement in active external rotation was 47° (20° to 85°) regarding adduction and 49° (5° to 85°) regarding abduction [5]. Tavares *et al.* performed IB-SSN neurotization by the radial nervés branch for the medial head of the triceps muscle. They stated that, although anatomically feasible, this transfer results in poor clinical outcomes [20]. Unfortunately, the management of IB-SSN palsy associated with scapular fractures is often neglected in clinical practice [21]. In the acute stage, it is often difficult to distinguish between nerve palsy that is due to the original injury and those that occur as a complication of surgery. The preoperative examination can be limited by pain due to scapular fracture and concomitant injuries [21]. However, every nerve palsy persisting more than three months after the trauma without signs of reinnervation on electromyography study deserves surgical revision. Generally, lesions in continuity with positive neurograms are managed by simple external neurolysis. Neuromas with negative neurogram or lacerated nerves with preserved proximal and distal stumps can be reconstructed by using nerve grafts. Very proximal lesions or complex injuries with inaccessible proximal stumps are good candidates for nerve transfer. In cases of very complicated scapular fractures with persistent IB-SSN palsy, it can be extremely risky to dissect the whole nerve within scar tissue. Furthermore, nerve reconstruction in the area of the spinoglenoid notch can be surgically challenging [22]. Therefore, SAN to IB-SNN transfer might be useful in these cases.

Although Sommarhem's study lacks detailed anatomical descriptions, the clinical photos show that the transfer was performed over the scapular spine [5]. We believe that the SAN running between the bone and skin can suffer from chronic pressure injury. Therefore, we evaluated the anatomical possibility of transfer of the SAN through the central weakened area of the scapular spine [23]. This technique carries no significant risk of SAN traction during the scapular movements, because the upper part of the scapula including scapular spine is not very mobile during the normal range of glenohumeral motion. Normal scapular movements during humeral elevation are upward rotation followed by posterior tilt and external rotation of the inferior part up to 24 degrees [24].

The advantage of this transfer is that the SAN is transected within the lower portion of the trapezius muscle, leading to denervation of the lower muscle fibres only. Therefore the main trapezius muscle function can be preserved by maintaining innervation of the superior muscle fibres between the occipital skull and lateral third of the clavicle and acromion. Bae *et al.* analyzed the location of the perforating branch pattern of the accessory nerve in the descending part of the trapezius muscle and thereby described the most efficient botulinum toxin injection site. The mean distance of the SAN from the spine measured on the line between C7 spinous process and acromion was 7.98 cm (± 1.17) [8]. This is similar to our result (8.5 cm ± 0.88). The mean distance of the SAN from the medial end of the scapular spine was approximately 2.5 cm. Knowing this fact can help in preoperative planning of the site of the SAN dissection. After identifying the nerve trunk, the dissection follows its oblique course at a mean angle of 15 degrees. The cadaver dissection of the nerve from a small incision was possible over a relatively long distance and we believe this should be similar in an operative setting. There were large variations in the length of the SAN stump available for reconstruction (6.4 – 11.8 cm), which can be explained by different sizes of the cadavers. However, we believe such diversity corresponds to clinical practice. The basis of the successful nerve reconstruction is the suture of the nerve stumps without tension even during excessive movements of the extremity. Due to morphological variations in body types, we did not aim to define a 'minimal' length of SAN for reconstruction. Although we have found that the anastomosis was possible in the cadavers even with short SAN stumps (approx. 6.5 cm), we recommend dissecting as long a donor nerve stump as possible and eventually shortening it according to the individual anatomical situation as in some of our cases. The main finding of our study, therefore, is that SAN – IB-SSN transfer was possible in all cases.

The direct dorsal SAN to IB-SSN transfer can be used especially in patients with scapular fracture suffering from palsy of the external rotation of the shoulder. It can also be useful for augmenting the results of spontaneous recovery or nerve grafting procedures in children with obstetric brachial plexus palsy [25]. It may also be of use in adult brachial plexus injuries, for example when SSN was reconstructed using the phrenic nerve [26] without adequate reinnervation of the infraspinatus muscle. As with any technique, its efficacy in restoring external rotation, will also partly depend on the stability of the glenohumeral joint. If this joint is unstable, the neurotization will provide limited effect as the joint itself is unable to make the movement.

Limitations

This is an anatomical feasibility study without proof of its success in clinical practice. We did not perform axonal counts at the level of transection due to both stumps being of a similar size. Given the fact that reinnervation of the supraspinatus muscle after classical SAN to SSN neurotization is high, it can be assumed that direct SAN to IB-SSN reconstruction will lead to similar results with restoration of infraspinatus muscle function. This hypothesis needs to be demonstrated by clinical study. Although the line c and resultant angle β are approximate due to non-linear course of the SAN, we believe this small measurement error is not of a major clinical importance.

Conclusion

The spinal accessory nerve enters the trapezius muscle on average 8.5 cm laterally from the spine, runs in an oblique course at a mean angle of 15 degrees latero-medially and divides into small terminal branches 4.5 cm laterally from the spine. Its mean length is almost 15 cm. It can be easily dissected approximately 2.5 cm medially from the medial end of the scapular spine and used for neurotization of the infraspinatus branch of suprascapular nerve *via* a prepared bony canal under the spine of the scapula. This procedure might find its place mainly in cases of infraspinatus palsy associated with scapular fractures and in some cases of brachial plexus palsy.

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Disclosure statement

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Příloha 4

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Anatomical feasibility study of the infraspinatus muscle neurotization by lower subscapular nerve

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ABSTRACT

Objectives: To investigate the anatomical feasibility of the infraspinatus branch of the suprascapular nerve (IB-SSN) reconstruction by lower subscapular nerve (LSN) transfer.

Methods: The morphological study was performed on 18 adult human cadavers. The length of the distal stump of the IB-SSN, the length of the LSN available for reconstruction and diameter of both stumps were measured. The feasibility study of the LSN to IB-SSN transfer was performed.

Results: The mean length of the IB-SSN to the end of its first branch was 40.9 mm (±4.6). Its mean diameter was 2.3 mm (±0.3). The mean length of the LSN stump, which was mobilized from its original course and transferred to reach the distal stump of the IB-SSN was 66.5 mm (±11.8). Its mean diameter was 2.1 mm (±0.3). The mean ratio between LSN and IB-SSN diameters was 0.9 (±0.1). The nerve transfer was feasible in 17 out of 18 cases (94.4%).

Conclusion: This study demonstrates that direct LSN to IB-SSN transfer is anatomically feasible in most cases in the adult population. It may be used in cases of complex scapular fractures resulting in severe suprascapular nerve injury.

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Introduction

The suprascapular nerve (SSN) innervates the spinati muscles. The supraspinatus muscle initiates shoulder abduction and the infraspinatus muscle acts as the main external rotator of the glenohumeral joint, but it is also an important stabilizing muscle [1]. A traumatic lesion of the SSN is most commonly found in brachial plexus injuries [2]. In these cases, it is usually reconstructed using the spinal accessory nerve. Although the success rate of restoration of shoulder abduction after this transfer is high, the external rotation function is achieved in less than half of cases [3].

The loss of shoulder external rotation caused by infraspinatus muscle palsy is also seen in up to one-third of scapular fractures [4]. Isolated lesion of the infraspinatus branch of the SSN (IB-SSN) occurs in fractures of the scapular body or spinoglenoid notch. Direct suture or reconstruction by nerve grafts may be impossible in complex scapular fractures. Due to its anatomical proximity, we hypothesise that the lower subscapular nerve (LSN) may be used as a donor nerve for the IB-SSN neurotization. LSN is also almost exclusively a motor nerve, making it an ideal donor for nerve reconstruction. Furthermore, the trunks of the SSN and LSN are of similar diameter [5,6].

The aim of the study is to describe the anatomy of the IB-SSN and LSN dissected from the posterior approach and determine the feasibility of the dorsal LSN to IB-SSN nerve transfer in the adult population.

Basic anatomy

Suprascapular nerve anatomy

SSN arises from the upper trunk of the brachial plexus, which is formed by the union of the ventral rami of the C5 and C6 and rarely from the C4 root [7]. It runs along the superior border of the scapula, passes through the suprascapular notch inferior to the superior transverse scapular ligament and enters the supraspinous fossa. It then passes beneath the supraspinatus muscle, and curves around the lateral border of the spine of the scapula through the spinoglenoid notch to the infraspinous fossa (Figure 1) [8]. The mean diameter of the suprascapular nerve at the suprascapular notch is 2.48 ± 0.6 mm [6].

Lower subscapular nerve anatomy

LSN originates in 79% from the posterior cord of the brachial plexus and in 21% directly from the proximal segment of the axillary nerve [9]. It is formed not only by fascicles arising from C5 and C6 but also from C7

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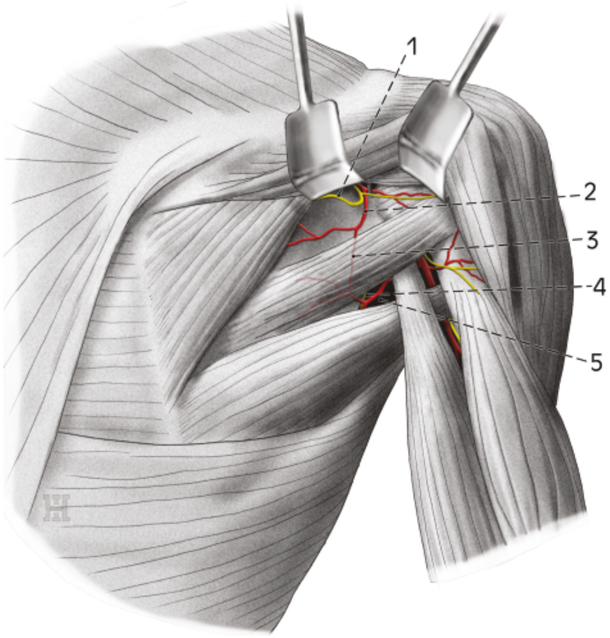

Figure 1. Schematic of the nerves and arteries anatomy in the dorsal scapular region on the right side. (1) the infraspinatus branch of the suprascapular nerve (IB-SSN), (2) Suprascapular artery, (3) Circumflex scapular artery, (4) Lower subscapular nerve (LSN), (5) Triangular space.

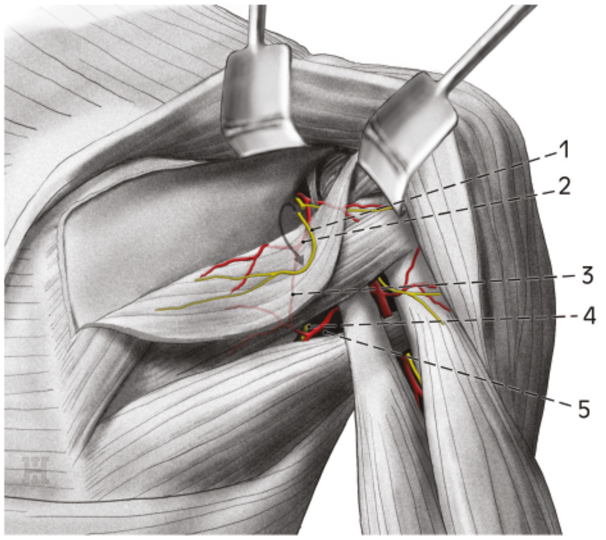

Figure 2. View after detachment of the infraspinatus muscle from the scapular spine and floor of the infraspinous fossa on the right side and its rotation caudo-laterally. The IB-SSN transected in the spinoglenoid notch and then rotated caudally under the infraspinatus muscle (arrow). Legend – see Fig. 1.

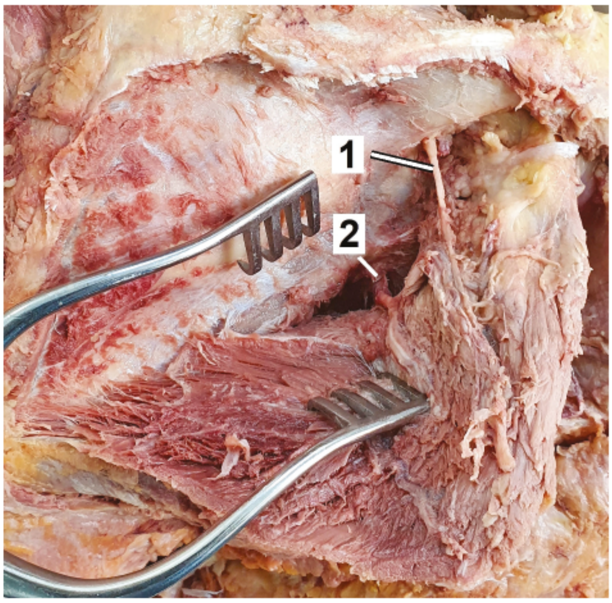

Figure 3. Infraspinatus muscle detached from the scapular spine and floor of the infraspinous fossa on the right side, and rotated caudo-laterally. The IB-SSN was dissected from the spinoglenoid notch to its branching. (1) IB-SSN, (2) circumflex scapular artery.

(40% of nerve fibers) [10]. It innervates the lower part of the subscapularis and teres major muscle (Figure 1). The mean length of the teres major branch is 6 cm (3.3–8.9) and its mean diameter is 1.9 mm (1.1–3.1) [9].

Material and methods

The study was performed on 18 human cadavers prepared for anatomical dissection courses (4% phenolic acid and 0.5% formaldehyde). The bodies were donated with the agreement for usage in teaching and research purposes. Only specimens without signs of previous surgery or any other severe abnormality in the regions of interest were used. Due to standardization, all the dissections were performed on the right side.

Dissection of the infraspinatus muscle branch of suprascapular nerve

After transection of the skin and removal of the subcutaneous fat, the infraspinatus muscle was dissected, cut along the inferior border of the scapular spine and from the medial edge of the scapula. It was then detached from the floor of the infraspinous fossa and rotated caudo-laterally as in the standard Judet approach [11] for the treatment of scapular body fractures. The entire course of the IB-SSN was dissected from the spinoglenoid notch to the terminal branches (Figures 2, 3). It was then cut as proximally in the spinoglenoid notch as possible and mobilized from the muscle. Then, the circumflex scapular artery was found within the infraspinatus muscle and followed by blunt dissection caudo-laterally outside the scapular body. The length of the distal stump of the IB-SSN was measured to the end of the first branch and it was then rotated inferiorly into the triangular space along the circumflex scapular artery. The infraspinatus muscle was then rotated back to its original position.

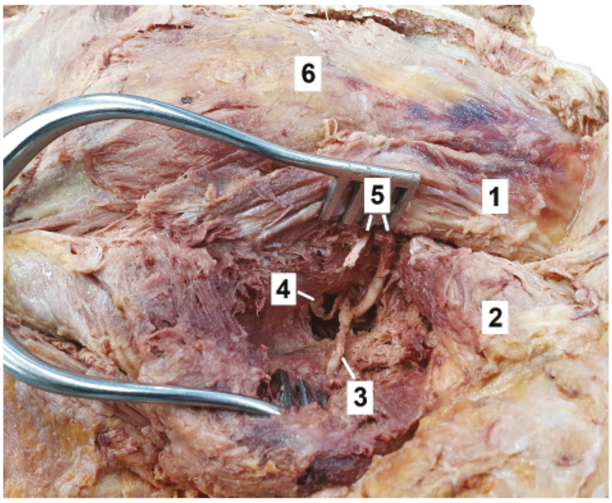

Figure 4. Dissection of the triangular space on the right side between (1) teres minor cranially, (2) long head of the triceps laterally and (3) teres major muscle caudally. Arrow (3) – LSN entering the teres major, (4) branch of the LSN for the subscapularis muscle, (5) left arrow – distal stump of the IB-SSN after its rotation under the infraspinatus muscle, right arrow – circumflex scapular artery, (6) infraspinatus muscle.

Lower subscapular to infraspinatus branch of suprascapular nerve transfer technique

The triangular space [12] was bluntly dissected between teres minor cranially, teres major caudally and long head of the triceps muscle laterally. After spreading the muscles and identification of the circumflex scapular artery, the LSN was found running slightly medially to the vessel and entering the teres major muscle (Figure 4) where it was cut. It was then dissected proximally as far as possible and its length was measured to the point of arising a branch for the subscapularis muscle. Diameters of both distal stump of the IB-SSN and proximal stump of the LSN were measured by microcaliper. They were then brought together to demonstrate the possibility of performing their end-to-end suture without tension (Figures 5, 6).

Results

The measurements are summarized in Table 1.

The mean length of the distal stump of the IB-SSN to the end of its first muscle branch was 40.9 mm (±4.6). Its mean diameter was 2.3 mm (±0.3). In two cases (No. 5 and 14), two branches were found instead of one IB-SSN trunk at the level of the spinoglenoid notch. Therefore, the IB-SSN diameter was calculated as a sum of diameters of both branches in these cases.

The mean length of the terminal branch of the LSN, which was mobilized from its original course and rotated cranially to reach the distal stump of the IB-SSN was 66.5 mm (±11.8). Its mean diameter was 2.1 mm (±0.3).

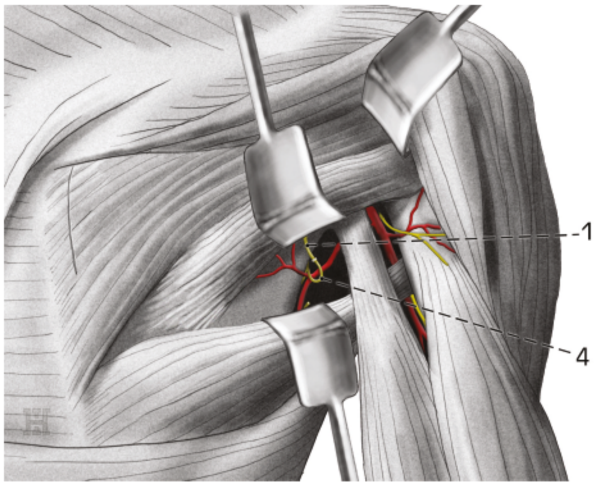

Figure 5. Suture of the distal stump of the IB-SSN after its rotation to the triangular space with the proximal stump of the LSN (after its transection before its entering the teres major muscle). Legend – see Fig. 1.

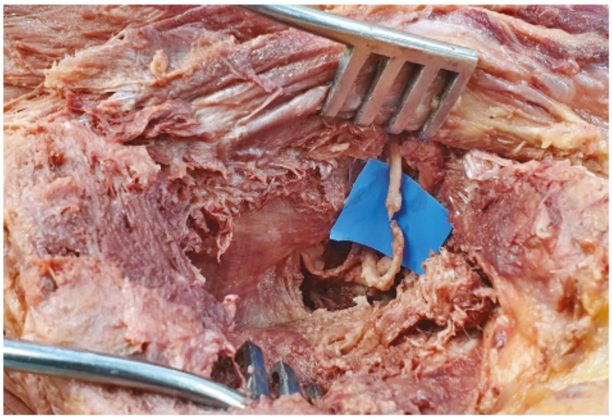

Figure 6. Anatomical situation after transection of the LSN (caudally) before its suture with the distal stump of the IB-SSN (cranially).

The mean ratio between LSN and IB-SSN diameters was 0.9 (±0.1). The nerve transfer was anatomically feasible in 17 out of 18 cases (94.4%). In case 12 (the length of the SSN stump 28 mm and LSN stump 35 mm), the gap between the stumps after their rotation was 6 mm. Therefore, a direct end-to-end connection without tension was not possible.

Discussion

Infraspinatus muscle produces 75% of the glenohumeral external rotation torque and is the most effective in the first 90° of shoulder elevation [13]. Loss of external rotation of the arm severely limits the function of the limb [14]. The SSN injured as a part of the brachial plexus injury is usually reconstructed by SAN transfer. Although the functional recovery of the supraspinatus muscle after this transfer is high, the

Table 1. Morphological analysis of the terminal branch of the lower subscapular branch (LSN) and the infraspinatus branch of the suprascapular nerve (IB-SSN). Values are in mm. Diameter of IB-SSN in case 5 and 14 is calculated as a sum of the diameters of two main branches.

Cadaver	Diameter of IB-SSN	Diameter of LSN	LSN:IB-SSN diameter ratio	Length of IB-SSN	Length of LSN
1	2.8	2.3	0.82	48	85
2	2.5	2.2	0.88	42	76
3	2.6	2.2	0.85	42	71
4	2.4	2.0	0.83	37	69
5	2.7	2.2	0.82	39	68
6	2.7	2.6	0.96	41	67
7	1.9	1.5	0.79	49	75
8	2.2	1.9	0.86	43	71
9	2.4	2.5	1.04	38	78
10	2.6	2.4	0.92	39	47
11	2.3	2.0	0.87	41	69
12	1.7	1.8	1.05	28	35
13	1.8	2.1	1.2	41	73
14	2.6	2.3	0.88	46	67
15	2.1	1.8	0.86	40	57
16	2.0	1.9	0.95	38	54
17	2.4	2.1	0.88	41	68
18	2.6	2.2	0.85	44	67

recovery of the infraspinatus muscle is achieved in only 40–55% of the cases [3,15,16].

In addition to brachial plexus injury, loss of external rotation due to the injury of SSN may be found in 2.4%–32% of scapular fractures, especially those involving the surgical neck [4,17,18]. Fractures of the scapular body or surgical neck are often unstable and require open reduction and internal fixation [19]. It is often difficult to distinguish between nerve palsy that is due to the original injury or as a complication of surgery. The preoperative examination can be limited by pain due to scapular fracture and concomitant injuries [17]. In cases of very complicated scapular fractures with persistent IB-SSN palsy, it can be surgically challenging to dissect the whole nerve from the infraspinous to the supraspinous fossa through the spinoglenoid notch [20]. Moreover, laceration or traction injuries would have to be reconstructed by using a nerve graft. Neurotization (nerve transfer) has generally produced high rates of success in other nerves reconstructions, which is comparable [21] or even better comparing to nerve grafting [22]. From these reasons, nerve transfer seems to be an ideal option for IB-SSN reconstruction.

Complex scapular fractures are operated via the Judet posterior approach in which the skin incision is made along the scapular spine and curved caudally along the medial edge of the scapular body. Then, the infraspinatus muscle is detached from the floor of the infraspinous fossa [11,23]. Therefore, we used the same approach in our study. The circumflex scapular artery, a branch of the subscapular artery, is the only structure (with accompanying veins) passing through the triangular space [12]. It then runs on the ventral surface of the infraspinatus muscle. After the mobilization of the IB-SSN, this vessel can be therefore used as a guiding structure for dissecting the 'tunnel' from the infraspinous fossa into the triangular space [12] (formed by teres minor and major muscles and long head of the triceps). For approaching this space, it is recommended to cut the skin between the teres muscles. Therefore, we propose to make a U-shaped skin incision for LSN – IB-SSN nerve transfer (Figure 7). In revision cases after previous orthopaedic procedure for scapular fracture performed via the Judet approach, the incision should follow the primary cut and then be prolonged caudo-laterally parallel to the scapular spine.

Figure 7. Proposed skin incision for the LSN to IB-SSN transfer. Green – Judet approach for the dissection of the IB-SSN, red – variable prolongation for the dissection of the LSN.

Only two studies reported the clinical results of direct IB-SSN neurotization. Sommarhem et al. reported good results with SAN – IB-SSN transfer used in brachial plexus birth injuries [24]. On contrary, IB-SSN neurotization by the radial nerve branch for the medial head of the triceps muscle resulted in poor clinical outcomes [25]. Unfortunately, the management of IB-SSN palsy associated with scapular fractures is neglected in clinical practice [17].

LSN seems to be an ideal donor nerve for neurotization, because the larger pectoralis and latissimus dorsi muscles would compensate for the loss of internal rotation typically provided by the subscapularis and teres major muscles [26]. However, if the entire nerve was used for neurotization, the subscapularis muscle would be still partially innervated by upper subscapular nerve [27]. Samardzic et al. found in their clinical series that sectioning of the LSN does not alter shoulder and arm movement significantly [28]. Moreover, Tubbs et al. showed that the teres major branch can be used as a donor for neurotization of musculocutaneous or axillary nerve without disconnecting the branch to the subscapularis muscle. They found that the mean length of the terminal branch of the LSN was 6 cm (3.3–8.9) [5]. These data are similar to our results (mean length 6.64 cm). We found that the nerve transfer was feasible in more than 94% of the cases without denervation of the subscapularis muscle. In one case (No 12), however, both nerve stumps were so short that direct end-to-end suture would not be possible without using a nerve graft.

The teres major muscle, innervated by the LSN, is an internal rotator of the shoulder, while the infraspinatus muscle innervated by the IB-SSN rotates the shoulder externally. Although post-operative rehabilitation would be easier when donor and recipient nerves had a synergistic action, several neurotization techniques with antagonistic nerves have been described with good results [29]. The mean diameter of the LSN stumps found in our study is similar to the previously published results [9]. We proved that the mean diameters of both nerve stumps are very similar (LSN to IB-SSN ratio 90%). This fact contributes to the expected good applicability of this technique, especially in patients with scapular fracture suffering from palsy of the external rotation of the shoulder. However, the efficacy of the proposed technique can only be confirmed with a clinical study. Since the LSN originates from the C5 – C7 roots, this technique would not be feasible in most adult patients with an upper or complete brachial plexus injuries. Its use can only be considered in very selected casesfor example, a very distal suprascapular nerve rupture.

Limitations

This study is limited to an anatomical feasibility of surgical technique. Furthermore, we did not assess the axonal counts at the level of transection; however, due to the diameters of both stumps being similar, the axonal counts should be comparable. The classical SAN to SSN neurotization provides high levels of reinnervation; therefore, it follows that LSN to IB-SSN reconstruction should allow comparable results in restoring infraspinatus muscle function. The dissections were performed on specimens with the intact anatomical fields. However, the anatomy of both nerves may be disrupted after the trauma leading to a scapular fracture. Therefore, this study does need substantiation with a clinical study.

Conclusion

Direct lower subscapular to infraspinatus branch of the suprascapular nerve transfer is anatomically feasible in most of the cases. This technique may find its place in cases of serious suprascapular nerve injury caused by complex scapular fractures.

Disclosure statement

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