CHARLES UNIVERSITY
Second Faculty of Medicine

Summary of the Dissertation

Scapular region topography concerning peripheral nerves and anatomical implication of nerve entrapment

Topografie lopatkové krajiny ve vztahu k periferním nervům a anatomickému podkladu jejich útlaku

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Scapular region topography concerning peripheral nerves and anatomical implication of nerve entrapment

Abstract

The objectives were to identify and detail the suprascapular notch (SSN), a narrow topographical space where the suprascapular nerve (SN) passes through. The goals were to identify the anatomical sites and causes of the suprascapular nerve entrapment (SNE) and to enhance its diagnostic imaging methods and surgical approaches. The morphology of the SSN was observed in 333 unpaired and 180 paired dry scapulae, and classified into five types based on depth versus superior width measurements where the morphometry of each SSN type was analyzed to assess the pattern of SSN stenosis. The topography of the suprascapular canal (SSC) was dissected and observed in 30 cadaveric specimens. The topography of the SSN was dissected and its contents were observed in 159 cadaveric specimens to profile its variations, followed by analyzing the relationships of the SSN surrounding muscles in 115 cadaveric specimens. Systematic and narrative reviews were conducted in order to established the list of SNE anatomical etiologies and their surgical managements. The relevant anatomical terms were discussed through the consensus method of Delphi. Basic imaging modalities (plain film X-rays, 3D-CT reconstructions, MRI and ultrasound) were evaluated for their efficacy in detecting the SSN. The SSC was identified as an osteofibrous canal with a peer-consensus level of 76.4% concerning the new designated term. The SSN has been classified into five types: Type-I (8.3%), Type-II (12.3%), Type-III (51.2%), Type-IV (6.4%), and Type-V (21.8%). The overall incidence of SSN stenosis was 15% and by each SSN type was as follows: Type-I (1.6%), Type-II (2.8%), Type-III (16.3%), Type-IV (1.6%), and Type-V (15.1%). The SN passes under the suprascapular ligament (SSL) in all cases, while the vessels passes above the SSL only in 51%. An internal vessel(s) pass(es) within the SSN in 49% of cases. More than one suprascapular vein was found in 33.3% with a diameter ranging from 0.5 to 5 mm, and more than one suprascapular artery (SA) was found in 3.3% with a diameter ranging from 1 to 5 mm. The subscapularis muscle (SUBM) was covering the anterior surface of the SSN completely in 3.5% and partially in 38.3% of cases. The SN can be compressed dynamically within the SSN by an accompanying pulsating SA, or by SUBM impingement. The SSL was covered by the inserting omohyoid muscle partially in 29.6% of cases. Ultrasound algorithm to detect a suspected SSN stenosis is proposed by measuring the SSN depth and width. Conservative treatment of the SSN does not assure motor recovery with a reported motor impairment in 60% of cases. A surgical ligamentectomy would release the entrapped SN only if it was compressed by the SSL. An osteoplasty is inevitable when the SN is compressed by bone tissue.

Keywords
scapula; spinoglenoid notch; suprascapular artery; suprascapular canal; suprascapular ligament; suprascapular nerve entrapment; suprascapular nerve; suprascapular notch; suprascapular vein.

Topografie lopatkové krajiny ve vztahu k periferním nervům a anatomickému podkladu jejich útlaku

Abstract in Czech

Cílem práce bylo identifikovat a podrobně popsat incisura scapulae (SSN), úzký topografický prostor, jímž prochází neruvs suprascapularis (SN). Zevrubněji šlo o přesné určení anatomických míst a příčin útlaku neruvs suprascapularis (SNE) a o zlepšení diagnostických postupů k jeho odhalení a chirurgických přístupů k jeho operačnímu řešení. Morfologie SSN byla studována na 333 nepárových a 180 párových suchých lopatkách a klasifikována do pěti typů na základě měření hloubky versus horní šířky SSN. Podle toho byla analyzována morfometrie každého typu za účelem posouzení vzoru stenózy SSN. Pomocí klasické anatomické pitvy byla zkoumána topografie canalis suprascapularis (SSC) na 30 kadaverózních vzorcích a topografie SSN na 159 kadaverózních vzorcích, aby se odhalily její možné variace, a poté byly analyzovány vztahy mezi svaly obklopujícími SSN u 115 kadaverózních vzorků. Byly provedeny systematické a narativní přehledy s cílem vytvořit seznam anatomických příčin vzniku SNE a jejich chirurgických řešení. Příslušné anatomické termíny byly prodiskutovány s odborníky pomocí konsensuální metody Delphi. Základní zobrazovací modality (rentgenové snímky, 3D-CT rekonstrukce, MR a ultrazvuk) byly hodnoceny z hlediska jejich účinnosti při hledání a vyšetřování SSN. SSC byl identifikován jako osteofibrózní kanál s konsensuální úrovní 76,4 % ohledně jeho nového názvu. Tvar SSN stenóza byl rozdělen do pěti typů: Typ-I (8,3 %), Typ-II (12,3 %), Typ-III (51,2 %), Typ-IV (6,4 %) a Typ-V (21,8 %). Celkový výskyt SSN byl 15 % a podle typu byl následující: Typ-I (1,6 %), Typ-II (2,8 %), Typ-III (16,3 %), Typ-IV (1,6 %) a Typ-V (15,1 %). SN probíhá ve všech případech pod ligamentum transversum scapulae superius / ligamentum suprascapulare (SSL), zatímco nad SSL procházejí cévy pouze v 51 % případů. Uvnitř SSN se tedy nalézají cévy v 49 % případů. Více než jedna vena suprascapularis byla nalezena v SSN v 33,3 % s průměrem od 0,5 do 5 mm a více než jedna arteria suprascapularis (SA) byla zjištěna u 3,3 % s průměrem od 1 do 5 mm. Musculus subscapularis (SUBM) pokrýval přední plochu SSN zcela ve 3,5 % a částečně v 38,3 % případů. SN může být utlačen dynamicky v rámci SSN doprovodnou tepající SA nebo tlakem blízkého SUBM. SSL bylo částečně zakryto úponem musculus omohyoideus ve 29,6 % případů. Ultrazvukový algoritmus pro odhalení případného zúžení SSN zahrnuje měření hloubky a šířky SSN. Konzervativní léčba SSN nezaručuje motorické zotavení, dle literatury 60 % pacientů trpí výpadky hybnosti. Chirurgická ligamentektomie uvolní utlačený SN pouze v případě, že byl stlačen pomocí SSL. Osteoplastika je nevyhnutelná, je-li SN utlačen kostní tkání.

Klíčová slova

arteria suprascapularis; canalis suprascapularis; incisura scapulae; incisura spinoglenoidalis; ligamentum suprascapulare; nervus suprascapularis; scapula; útlak nervus suprascapularis; vena suprascapularis.

1. Background

The anatomical passage where the suprascapular nerve (SN) courses between the suprascapular notch (SSN) and the spinoglenoid notch (SGN) has been addressed in the literature without an elaborated detail of this topography as a whole (Cummins et al., 2000; Duparc et al., 2010; Tasaki et al., 2015). The described boundaries by the aforementioned authors do not offer a sufficient description of its full morphological topography as well as a solidified description of its contents. Furthermore, no term has been codified in the Terminologia Anatomica (TA) (FIPAT, 2019) as a designated official term for this topographical space.

1.1. The morphology of the suprascapular notch

A concordant morphological classification of the SSN has not been reached in the literature yet. The first traceable study addressing the SSN typing in literature was performed by Hrdlicka (a Czech anthropologist who lived in the United States) in 1942. There are two controversial classification systems describing the SSN on dry bone specimens. One is based on the SSN morphometric measurements (Natsis et al., 2007; Polguj et al., 2011) and the other one is based on subjective observation of the SSN shape (Hrdlicka, 1942; Rengachary et al., 1979a). The morphometric approach is reproducible with less discrepancy than its counter method of visual observation. The morphometric system: Polguj et al. (2011) categorized the SSN into five types:

- Type-I where the depth of the SSN is larger than its superior width.
- Type-II with a SSN of an equal depth to superior width length.
- Type-III SSN with a SSN where its depth is smaller than its superior width.
- Type-IV is a foramen regardless of its parametric measurements.
- Type-V is a discrete appearance of the SSN.

The understanding of the morphological influence of each SSN type on the risk of suprascapular nerve entrapment (SNE) has not been reached prior to this dissertation thesis (Al-Redouan et al., 2021b). Multiple contradictory hypotheses exist but have been neither confirmed nor reached an agreement (Bayramoglu et al., 2003; Urgüden et al., 2004; Polguj et al., 2013; Polguj et al., 2014a; Tubbs et al., 2013).

The literature had addressed the differing gross structural appearance of the SSL (Tubbs et al., 2013; Polguj et al., 2012; Polguj et al., 2014b; Kaledzera et al., 2022; Kumar et al., 2023). Interestingly, the SSN can contain internal ligaments according to several reports in the literature (Avery et al., 2002; Polguj et al., 2013; Gürses et al., 2015; Podgórski et al., 2015; Polguj et al., 2016). A misconception in the literature exists considering the suprascapular ligament (SSL) ossification, it is believed that it is the cause of the SNE without substantial evidence of any mechanism that could affect the passing SN such as evaluating the SSN space (Tubbs et al., 2013; Polguj et al., 2014b; Kaledzera et al., 2022). An ossified SSL leads to a SSN foramen type and is not necessary a pathoanatomical etiology. The literature also reports variations in the contents of the SSN (Ringel et al., 1990; Polguj et al., 2014a; Labetowicz et al., 2017).

1.2. Radiological imaging of the suprascapular notch

The SSN is oriented anatomically in a tilted direction facing antero-medio-inferiorly in regard to the frontal plane. This orientation makes it masked by the base of the coracoid process of the scapula in the frontal as well as the lateral imaging projections. In addition, the clavicle is situated anterior to the SSN. This orientation makes the SSN invisible on plane X-rays. However, 3D-CT reconstructions gives clear boundaries of the SSN resembling what can be seen on dry bones. Even though the SSN is visible on MRI, its borders cannot be captured on MRI sections since they do not align with the standardized MRI sectioning planes (Al-Redouan and Kachlik, 2022b). Ultrasound examination gives the advantage of probe manual rotation to align the beam to transduce through the SSN vicinity (Chan and Pang, 2011; Fernandes et al., 2012; Yamakado, 2015; Laumonerie et al., 2017; Laumonerie et al., 2018; Kamal et al., 2018). The skills of the observer and the variability of the SSN contents adds more challenge to its visualization by ultrasound.

1.3. The current state of approaching suprascapular nerve entrapment

Suprascapular nerve entrapment (SNE) is well understood and documented under pathological conditions such as cyst formation or due to injury such as in rotator cuff tears with focus on the supraspinatus muscle (SUPM) (Zehetgruber et al., 2002; Duparc et al., 2010; Kumar et al., 2014; Labetowicz et al., 2017; Kostretzis, 2017; Katsuura et al., 2019; Leider et al., 2021; Patetta et al., 2021, Cummins et al., 2022; Vij et al., 2022). However, anatomical risk factors leading to SNE in non-pathological situations are not clear in the available literature and rather speculations of encountered variations within the SSN are presented (Al-Redouan et al., 2021b).

The SNE is commonly treated by nerve blocks yielding temporary relief (Chan and Peng, 2011; Leider et al., 2021) or surgically by SSL resection releasing the entrapped SN (Lafosse et al., 2007; Leider et al., 2021). However, a ligamentectomy did not lead to SN pain relief in all the reported cases (Lafosse et al., 2007; Chan and Peng, 2011; Hill et al., 2014; Memon et al., 2018; Cano-Martínez et al., 2021; Nolte et al., 2021; Vaij et al., 2022). The nerve block is commonly performed blindly in the clinical practice (Kamal et al., 2018; Laumonerie et al., 2019b), however, recent studies advise performing such application under visual-aided modalities such as ultrasound or fluoroscope (Schneider-Kolsky et al., 2004; Peng et al., 2010; Laumonerie et al., 2017; Laumonerie et al., 2018; Laumonerie et al., 2019a; Yildizgören, 2020; Prenaud et al., 2021).

2. Objectives

The overall aim was to define the morphological pattern of each site of the suprascapular canal (SSC) that carries a potential risk of anatomical stenosis leading to potential SNE.

The project was intended to be performed at three main levels.

First: at the osteology level to investigate the morphometric variation of the SSN on dry scapulae. The goal was to classify phenotypic appearance and find correlation to clinical implications.

Second: observations at the cadaveric level of the topographical relationship of those varying structures. The goal was to refine the course of the SN and suprascapular vessels' variations, and sites of potential risk of SN compression.

Third: at the diagnostic level by utilizing ultrasound in comparison to MRI. The ultimate aim was to translate the theoretical findings into a potential practical application.

2.1. The hypothesis

Suprascapular notch stenosis is governed by the SSN space capacity to accommodate the cross-sectional diameter of the passing suprascapular nerve and not by the SSN shape. The space capacity of the SSN can be measured by ultrasound imaging and a potential risk of SSN stenosis can be detected in reference to the cross-sectional diameter of the residing SN.

2.2. Outcome benefits

To facilitate an ultrasound diagnostic method in patients suffering from anatomical entrapment syndrome in non-pathological formations, and to provide more clear criteria for the surgical choices performed in orthopedic and neurosurgical units.

3. Material and methodology

3.1. The observed material

Ethical and legal access to all specimens was approved for research and education purposes by the Institutional Review Board (IRB) – The Ethics Committee of the University Hospital Motol and Second Faculty of Medicine, Charles University, Prague, Czech Republic [Reference ID no. EK-353/19].

3.1.1. Osteology specimens

The morphometric variations of the SSN were investigated on 333 unpaired and 180 paired dry scapulae.

3.1.2. Cadaveric specimens

The SSC was dissected and observed in 30 free limbs. The vicinity and contents of the SSN were dissected and observed in 159 SSN cadaveric specimens. In addition, 115 SSN were dissected and observed in cadaveric specimens to study the adjacent muscles' relationship to the SSN boundaries. The cadaveric specimens belonged to denoted cadavers of Central European origin, fixed with the classical formaldehyde method.

3.1.3. Imaging samples

The imaging samples were collected retrospectively from patients' records with a note on the diagnosed disorder, all patients' confidentiality was maintained and kept anonymous. This consisted of 112 plain X-ray images taken in frontal projection and 30 plain X-ray images taken in lateral projection, from 76 adult males and 36 adult females (average ±56 age). Three CTs (adult males who suffered traffic accidents, ages 19, 23, and 47) and twenty bilateral 3D-CT reconstructions (10 females and 10 males, age 19 to 67 (average ±43 age)). The SSC with emphasis on the SSN was investigated in 10 MRI DICOMs (3 females and 7 males, age 23 to 52 (average ±38 age)) in transversal and frontal sections.

The superior of the shoulder region was examined by ultrasound bilaterally in 20 young healthy volunteers (12 females and 8 males; average age ±21), with prior written consent.

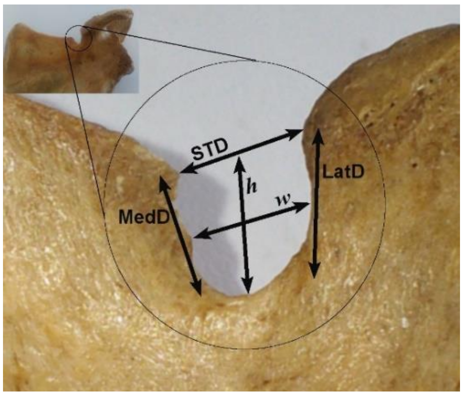
3.2. The experimentation methods and observations

3.2.1. Dry bones morphometric assessment and analysis of the suprascapular notch

The SSN was grouped according to the classification system proposed by Polguj et al., (2011) into their five basic types based on depth versus superior width parameter measurements. Measurements were taken by a *Vernier* caliper (size 150 mm) with an estimated ±0.2 mm range of accuracy.

Five parameters as illustrated in Figure 1 were measured. Statistical analysis was performed to predict the prevalence of each type of the SSN and the incidence of SSN stenosis was indicated by below 3 mm parametric values. The pattern of stenosis of each SSN was described, assessed and accordingly categorized into horizontal versus vertical parametric in value reduction (Al-Redouan et al., 2021b).

Figure 1. The measured parameters of the suprascapular notch borders.



Legend: *h* – height, LatD – lateral distance, MedD – medial distance, STD – superior transverse distance, *W* – width.

*Image source: (*Al-Redouan et al., 2021b*)

3.2.2. Cadaveric dissections and observation of the superior area of the scapular region

The suprascapular canal dissection

The dorsal aspect of the free limbs was prepared first by reflecting the masking large muscles to reveal the underlying layer of interest. The SUPM was released from its origin by scrubbing its fibers from the surface of the supraspinous fossa (SUPF) and was carefully lifted to examine its underlying area which is the spinoglenoid fossa (SGF) including its contents. The length and width of the full SSC were measured in millimeters.

The suprascapular notch dissection

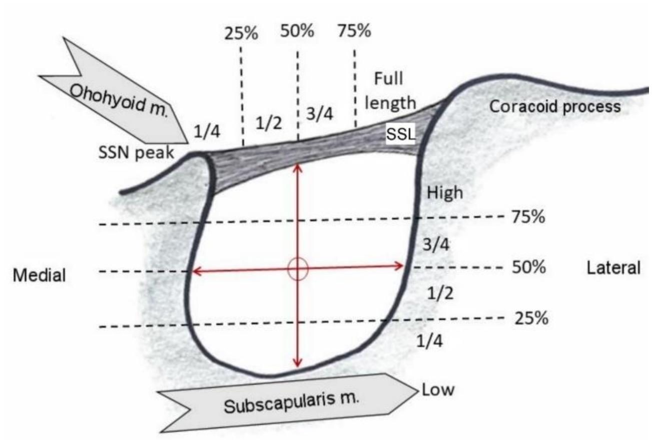
The SSN anterior vicinity was exposed by reflecting the pectoralis major and minor muscles laterally away from their origin sites on the trunk. The sternal end of the clavicle was freed by cutting the sternoclavicular joint capsule and reflected laterally. The contents of the SSN were described with notes on their relationships to how the suprascapular vessels pass in relation to the SN and to the SSL. The SA and SV were quantified and their calibers at the SSN were measured. The SSL morphology was described and its length and width were measured. The omohyoid muscle (OMHM) and subscapularis muscle (SUBM) were specifically focused on since they have been noticed to intervene with the SSN vicinity which was evaluated by intervals of quadrant ratio from zero to full extent (0, 25%, 50%, 75%, and 100%) (Fig. 2).

3.2.3. Imaging evaluation of the suprascapular canal and notch

First, the plain X-rays were screened to evaluate the visibility of the SSN. **Second**, the appearance of the SSN in 3D-CT reconstruction was compared to dry bones scapulae. **Third**, MRI in frontal, sagittal, and transversal planes were examined to navigate throughout the SCC.

Ultrasound imaging was experimented on the volunteers to find the optimum probe angles for localization of the SSN.

Figure 2. Illustration of the parametric intervals of the omohyoid muscle in relation to the extent of its insertion on the suprascapular ligament, and the subscapularis muscle in relation to the anterior vicinity of the suprascapular notch.



Legend: SSL – suprascapular ligament, SSN – suprascapular notch.

The sagittal ultrasound probe approach: The probe was oriented above the SGF utilizing the palpable acromion and spine of the scapula as anatomical landmarks. Then, the probe was adjusted by tilting laterally at approximately 10° degrees until the full length of the SSC extending from the SSN to the SGN was visible.

The posterior above the shoulder ultrasound probe approach: The probe was placed parallel to the spine of the scapula and pushed laterally against the internal angle of the acromioclavicular joint. The probe then was moved in sliding motion in an anterior direction with medial tilt until the SSC was projected in a cross-sectional view. Then, the probe was navigated in sliding and tilting motion towards the SSN until the full length of the SSL came to view. The tilt of the probe at this location was toned to refine a clear cross-sectional visibility of the SN.

The anterior below the clavicle ultrasound probe approach: We designed stepwise maneuvers in lying position to move away the masking structures to projection the transducer to our target of interest, the SSN.

1) Arm abduction in approximately 45° degrees, lifting up both the SUPM and clavicle simultaneously.

2) Arm external rotation with a flexed forearm, lowering the SUBM further away from the SSN anterior vicinity.
3) The probe was placed under the clavicle on the palpable base of the coracoid process of the scapula, which is the lateral border of the SSN.
4) The medial border of the SSN was identified by locating the OMHM which was found and confirmed by neck rotation.

3.2.4. Literature review and analysis

First, a narrative review was conducted to survey the reported SNE to investigate the described etiologies and study the potential anatomical related sites. Relevant articles' abstracts were surveyed of which 71 articles were included and cited in the published work (Al-Redouan et al., 2021a).

Second, a scoping review with meta-analysis was conducted to investigate an encountered variant subclavius posticus muscle (SPM) and its potential involvement in causing SNE. A total of 47 articles revealed a SPM prevalence of 11/2069 (4.9%) (Al-Redouan et al., 2023).

3.2.5. Consensus method of Delphi

There were nine terms (Table 1) concerning the SSC of which five are new terms described and proposed, and four terms that lack unity in terminology usage were revised. The peer consensus method of Delphi was applied in an electronic Google survey form composed of two rounds. First, taxonomy panels and etymology of anatomical terminology were considered in generating the proposed terms. Then 21 expert nominees voted and commented on the proposed terms in the first round of the survey. The nominees then voted on the re-adjusted terms in compliance with their feedback and recommendations. The level of consensus of each term was calculated from the second round based on a scale from 1 to 7 (Al-Redouan and Kachlik, 2022a).

3.3. The experimentation and testing

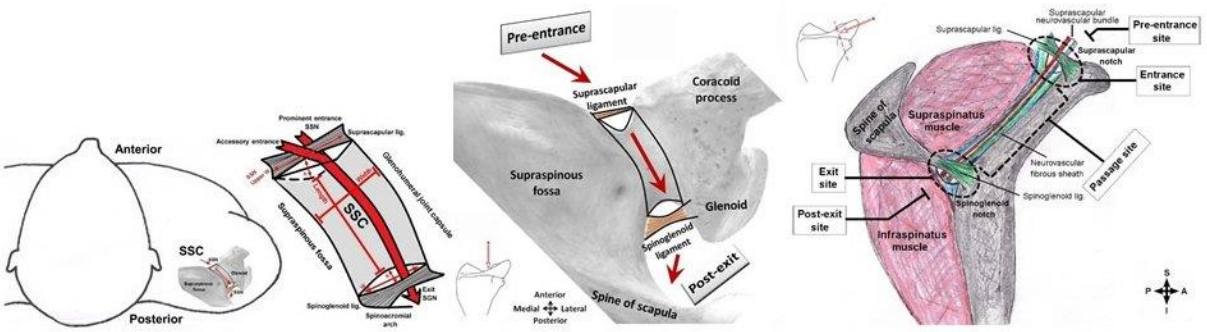
Space capacity of each of the five classified SSN types was investigated by parametric analysis. The SSN parameters running in a vertical plane would lead to vertical oriented SSN stenosis if reached below the critical measurement value of 3 mm, this indicates a SNE caused by the SSL compressing the SN against the inferior bone margin of the SSN. On the other contrary, a decrease in size of horizontally oriented parameters would indicate a SNE caused by the SN compressed between two bony margins (Al-Redouan et al., 2021b).

4. Results

4.1. The suprascapular canal

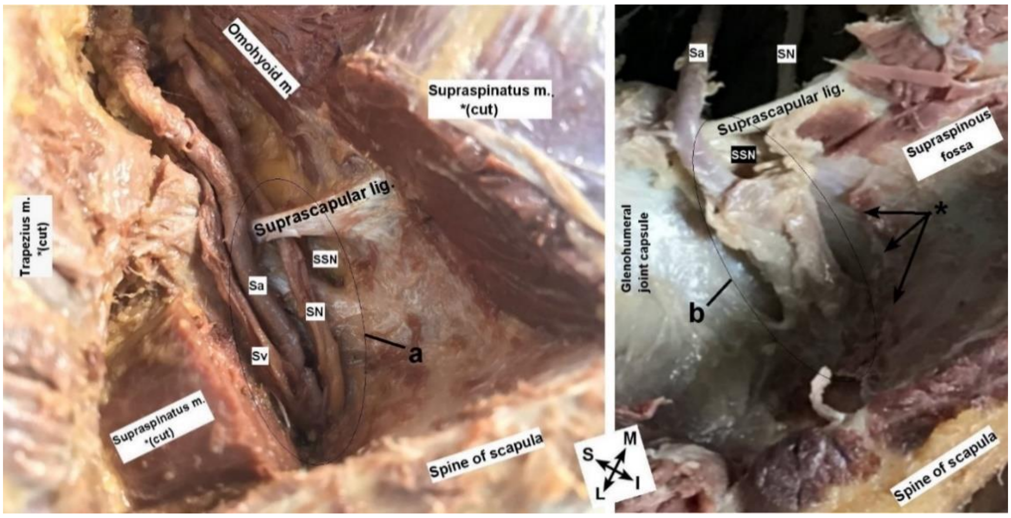
The SSC is defined as a passage (25 mm length x 13 mm width in average) situated in the SGF with an entrance via the SSN and an exit via the SGN (Fig. 3) where the neurovascular bundle containing the SN, SA and SV travels (Fig. 4) (Al-Redouan et al., 2021a).

Figure 3. Schematic presentation of the suprascapular canal illustrating its spatial orientation.



*Modified source: (*Al-Redouan et al., 2021a*).

Figure 4. The suprascapular canal.



Legend: Sa – suprascapular artery, SN – suprascapular nerve, SSN – suprascapular notch, Sv – suprascapular vein, a – spinoglenoid fossa, b – neurovascular bundle, * – lateral margin of the supraspinous fossa.

*Image source: (*Al-Redouan et al., 2021a*).

Structurally, it is an osteo-musculo-fibrous canal which exhibits an osteofibrous morphology at its two openings but a musculofibrous morphology throughout its passage. The roof of the SSC is composed of the SUPM. Medially, it is bordered by the lateral margin of the SUPF, a demarcated line where the origin of the SUPM ends and its muscle belly continues hovering over the SGF. Laterally, it is bordered by the glenohumeral joint capsule (Fig. 4).

4.1.1. The outcome of the relevant proposed terms consensus

The level of consensus of the proposed terms concerning the SSC structures were all above the threshold (57.16%) of acceptable range of agreement (Table 1).

4.2. The suprascapular notch topography and morphology

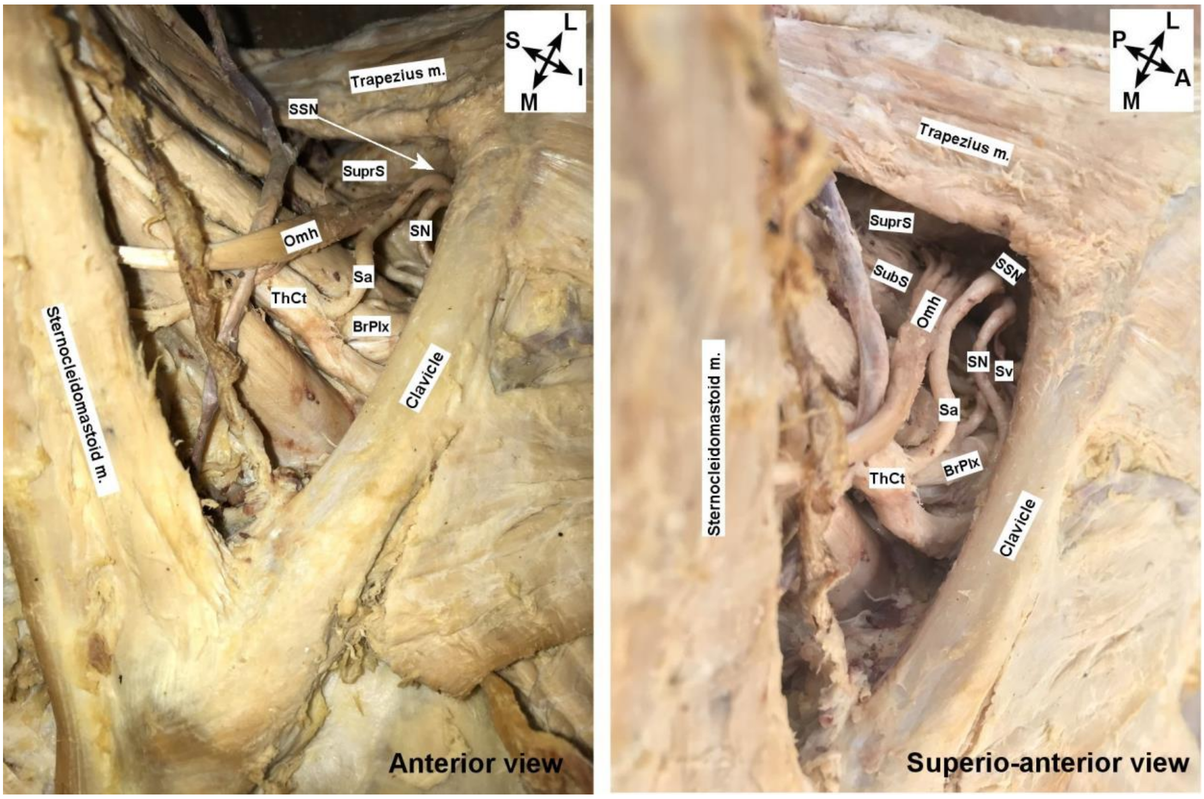
The SSN is impeded deep in the lateral corner of the omoclavicular triangle (Fig. 5). The trapezius muscle forms a roof being in no contact with the superior vicinity of the SSN. The platysma muscle and the underlying superficial layer of the cervical fascia were removed to expose deeper structures. The clavicle masks the SSN anterior visibility.

Table 1. List of the proposed terms with the peer consensus level.

Term in English	**Term in *Latin***	**Level of consensus %**
Suprascapular canal	*canalis suprascapularis*	76.4%
Spinoglenoid fossa	*fossa spinoglenoidalis*	70.7%
Suprascapular groove	*sulcus suprascapularis*	66.4%
Spinoacromial arch	*arcus spinoacromialis*	75.7%
Base of coracoid process	*basis processus coracoidei*	82.9%
Suprascapular ligament	*ligamentum suprascapulare*	61.4%
Suprascapular foramen	*foramen suprascapulare*	85.7%
Spinoglenoid notch	*incisura spinoglenoidalis*	90.0%
Spinoglenoid ligament	*ligamentum spinoglenoidale*	77.1%

*Modified table, source: (*Al-Redouan and Kachlik, 2022a)*.

Figure 5. Suprascapular notch topography.



Legend: BrPlx – brachial plexus, Omh – omohyoid muscle, Sa – suprascapular artery, SN – suprascapular nerve, SSN – suprascapular notch, SubS – subscapularis muscle, SuprS – supraspinatus muscle, Sv – suprascapular vein, ThCt – thyrocervicak trunk.

*Image source: (*Al-Redouan et al., 2021a*).

4.2.1. Suprascapular notch type classification

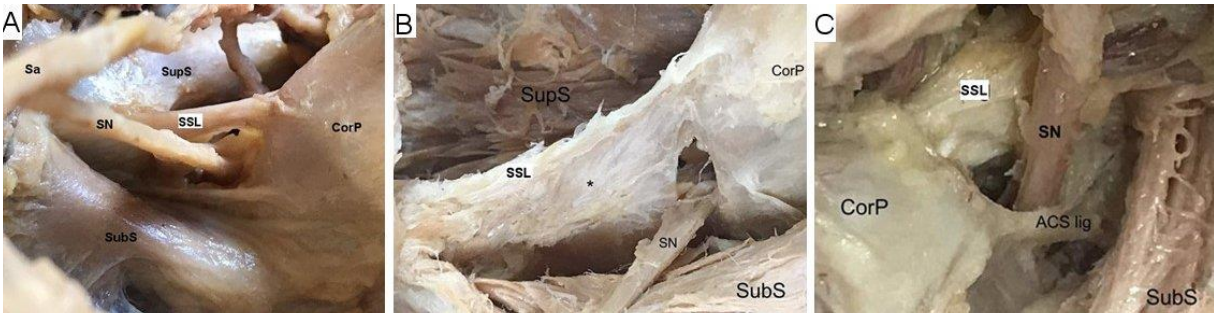
Five types of SSN: Type-I, depth larger than superior width (8.3%); Type-II, depth equal to superior width (12.3%); Type-III, superior width larger than depth (51.2%); Type-IV, foramen (6.4%); and Type-V, discrete (21.8%) out of the 693 observed dry bone scapulae.

4.2.2. Suprascapular notch osteofibrous structure

The SSL varied in shape with an average length of 11.7 mm (3.0 to 27.0 mm) and an average width of 4.6 mm (1 to 13.5 mm). It was found to be thin-rounded in 8 out of 63 (12.7%) specimens, flat in 39 out of 63 (61.9%) specimens, and fanned (narrowing from medial to lateral) in 16 out of 63 (25.4%) specimens (Fig. 6). In addition, an internal ligament named the "anterior coracoscapular ligament" running between the medial and lateral inner margins of the SSN was found in 10 specimens (15.9%) exhibiting a delicate texture with an average length of 11.7 mm (10.0 to 15.0 mm) and a width of 1.0 mm in all cases.

Figure 6. Distinctively observed suprascapular ligament variations.

A) Typical gross appearance. B) Fibrous gross appearance. C) Additional internal variant ligament (anterior coracoscapular ligament).



Legend: ACS lig – anterior coracoscapular ligament, CorP – coracoid process, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein.

4.2.3. Suprascapular notch surrounding muscles

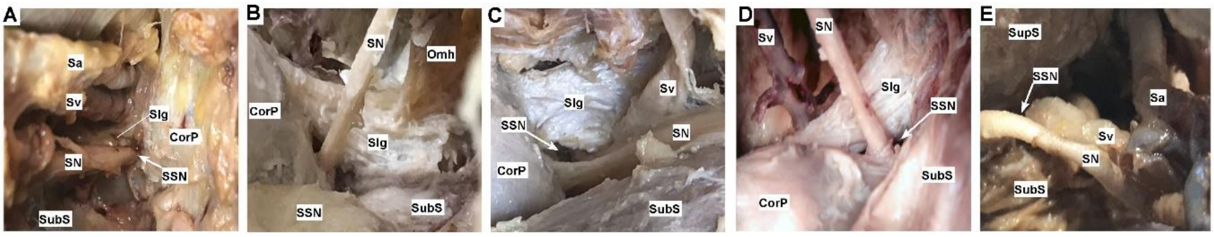
I) Constant muscles not intervening with the SSN space – Supraspinatus muscle.

In all cases, the SUPM was running parallel to the SSL above the SSN.

II) Constant muscles with variable positions that can intervene with the suprascapular notch space – Subscapularis muscle.

The height of the superior margin of the SUBM coursing away from the inferior margin of the SSN exposing the whole visibility of the SSN vicinity in 67 out of the 115 (58.3%) observed specimens (Fig. 7). It was gradually extending upward by approximately 25% of the SSN height in 19 (16.5%), by approximately 50% of the SSN height in 15 (13.0%), and by approximately 75% of the SSN height in 10 (8.7%) specimens, respectively. It was noticed to fully cover the visibility of the SSN anterior vicinity in four out of the 115 (3.5%) specimens (Fig. 7).

Figure 7. The five parametric intervals (none, 1/4th, half, 3/4th, full) of the variable subscapularis muscle superior margin height in relation to the suprascapular notch.

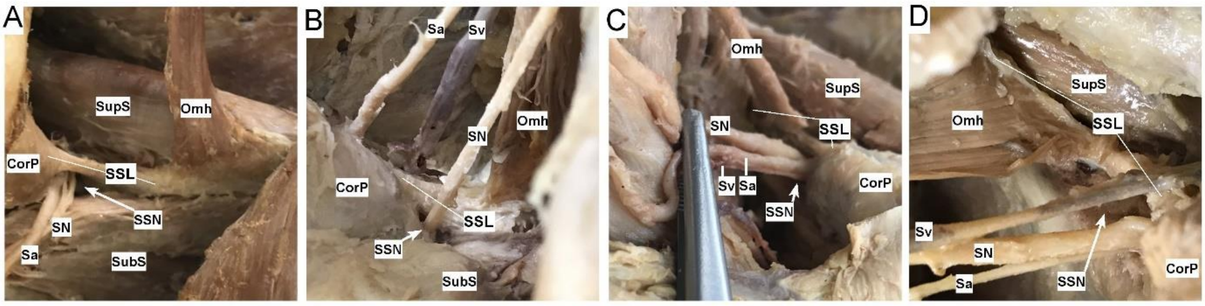


Legend: SSN – suprascapular notch, SSL – suprascapular ligament, SN – suprascapular nerve, Sa – suprascapular artery, Sv – suprascapular vein, SupS – supraspinatus muscle, SubS – subscapularis muscle, CorP – coracoid process.

III) Constant muscles with variable positions that can intervene with the surgical approach – Omohyoid muscle.

Figure 8. The inferior belly of the omohyoid muscle variable insertions in relationship to the suprascapular ligament.

A) No insertion points on the SSL. B) Inserting on 1/4th the length of the SSL. C) Inserting on half the length of the SSL. D) Inserting on 3/4th the length of the SSL.



Legend: CorP – coracoid process, Omh – omohyoid muscle, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein.

The OMHM inserted on the medial border of the SSN without any fibers extending onto the SSL in 80 out of the 115 (69.6%) observed specimens (Fig. 8). However, the OMHM attached onto the SSL in addition to its insertion on the medial peak of the SSN in 34 out of the 115 (29.6%) specimens. The insertion on the SSL was varying in length (Fig. 8). It was found to cover approximately 25% of the SSL margin in 23 (20.0%), approximately 50% of the SSL in eight (7.0%), and approximately 75% of the SSL in three (2.6%) specimens.

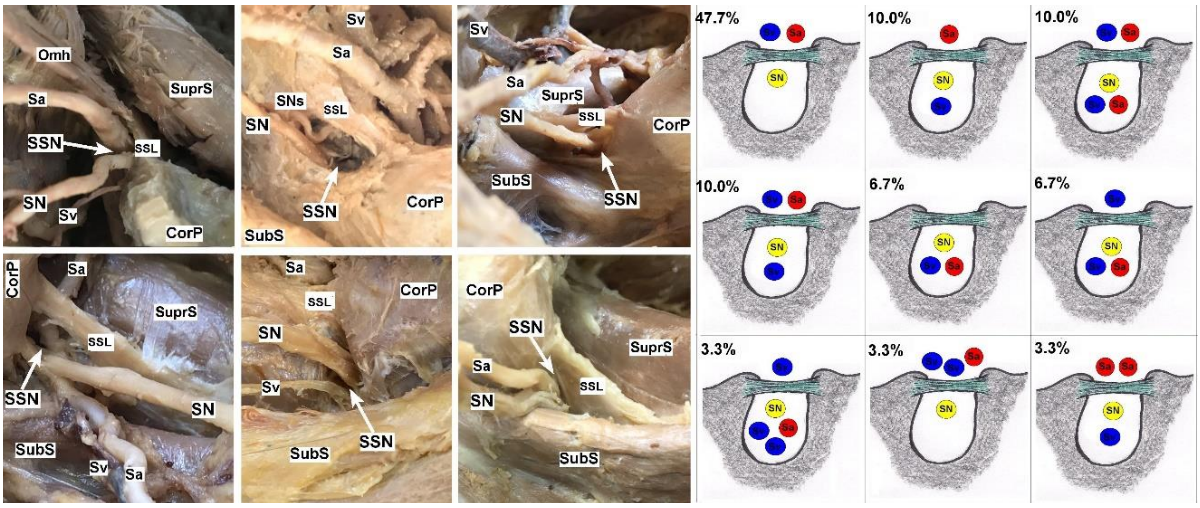
IV) Variable muscles intervening with the suprascapular notch space and surgical approach – Subclavius posticus muscle and Coracoscapularis muscle.

The SPM, with a reported incidence of 4.9% (Al-Redouan et al., 2023), was encountered twice unilaterally on the left side inserting on the full length of the SSL. And a variant "coracoscapularis muscle" was found unilaterally on the left side running parallel to the SSL and sharing the same attachment.

4.2.4. Suprascapular notch content

The SN (2–3 mm in diameter, average ± 2.4 mm) passed through the SSN in all the observed cases. Nine differing patterns of how the SA and SV pass at the SSN were observed (Fig 9) (Al-Redouan et al., 2021a).

Figure 9. Suprascapular notch vessels variations.



Legend: CorP – coracoid process, Omh – omohyoid muscle, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein.

*Image source: (*Al-Redouan et al., 2021a*)

Only in 51.0% a single SA and a single SV passed above the SSL. Suprascapular vessels passed through the SSN underneath the SSL in 49.0% (Fig 9). In addition, a SN accompanied by a single SA and a single SV was found only in 64.4%. More than one artery or vein can exist at the SSN with varying diameters.

4.3. Suprascapular nerve anatomical entrapments

Table 2. Suprascapular notch potential anatomical entrapment etiology by site.

SSN Site	Etiology

Pre-SSN space	• **Retroclavicular suprascapular nerve tension**
	  • Chronic heavy loads (bags' belt)
	  • Shoulder dystonia
	• **Soft tissue impingement**
	  • Tumors (neuroma)
	  • Variant high margin of the subscapularis muscle
	  • Variant subclavius posticus muscle
	• **Scar tissue adhesion**
	  • Fracture of lateral portion of clavicle
	  • Post-inflammatory processes

SSN vicinity	• **Decreased suprascapular notch space capacity**
	  • Suprascapular notch stenosis
	  • Space occupying variant structure(s)
	• **Dynamic compression**
	  • Suprascapular ligament "sling-effect"
	• **Vascular compression**
	  • Abnormal chronic pulsatile pressure

Post-SSN space	• **Fibrous adhesions of the fascia**
	  • Supraspinatus muscular blunt trauma
	• **Suprascapular nerve traction**
	  • Rotator cuff muscles tear
	• **Dynamic compression**
	  • Chronic episodic muscular impingement
	• **Vascular compression**
	  • Tortuous and dilated (varicose) veins

*Table sources (modified): (*Al-Redouan et al., 2021a; Al-Redouan et al., 2023*).

4.3.1. Suprascapular notch stenosis

Suprascapular notch stenosis was detected in 15% of the observed dry bone scapulae (Fig. 10) (Al-Redouan et al., 2021b).

The analysis of the reduced in size parameters revealed three distinctive patterns of SSN stenosis. The statistical analysis illustrated graphically in Figure 11 shows the relative risk of SSN stenosis by type. Type-V SSN had the highest incidence of stenosis. Type-III was the most common type which had an equal incidence in the overall sample (Fig. 11) (Al-Redouan et al., 2021b).

Figure 10. Suprascapular notch stenosis pattern and incidence by type.

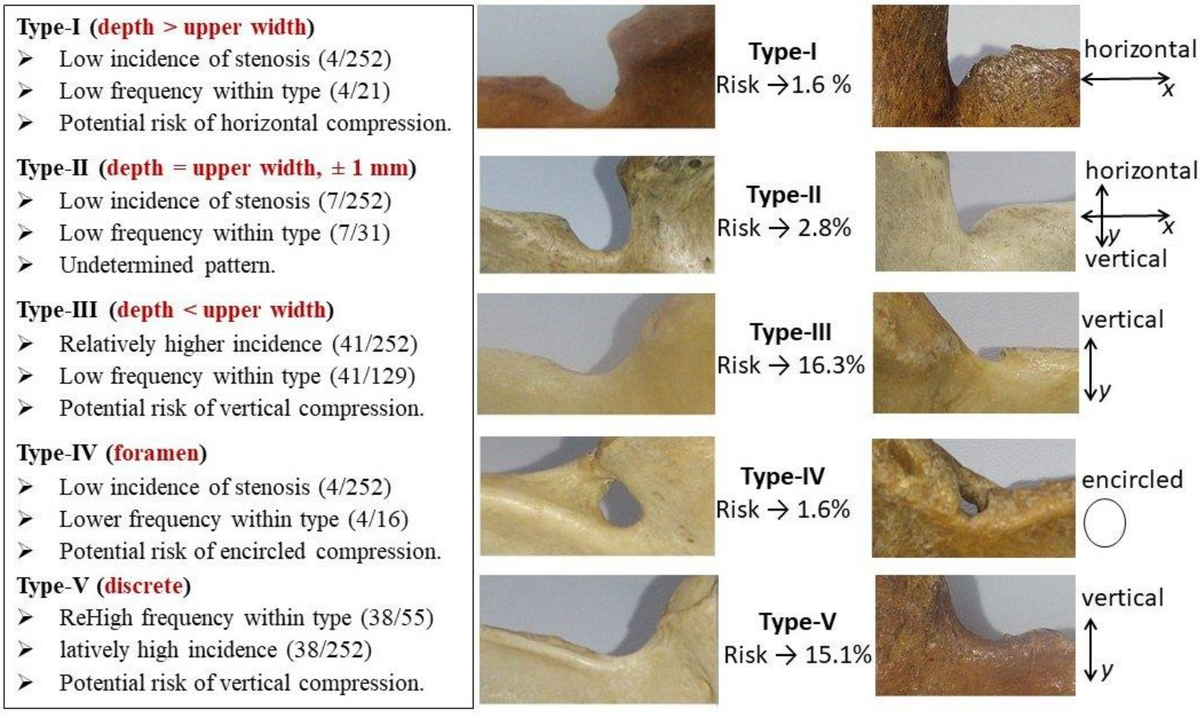


Figure 11. Suprascapular notch stenosis pattern by type.

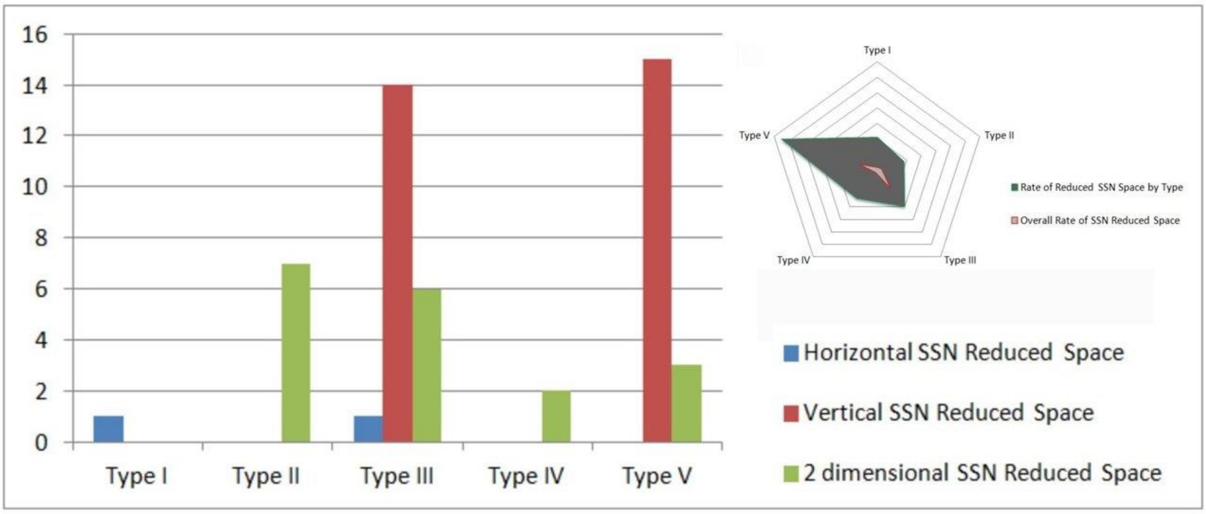
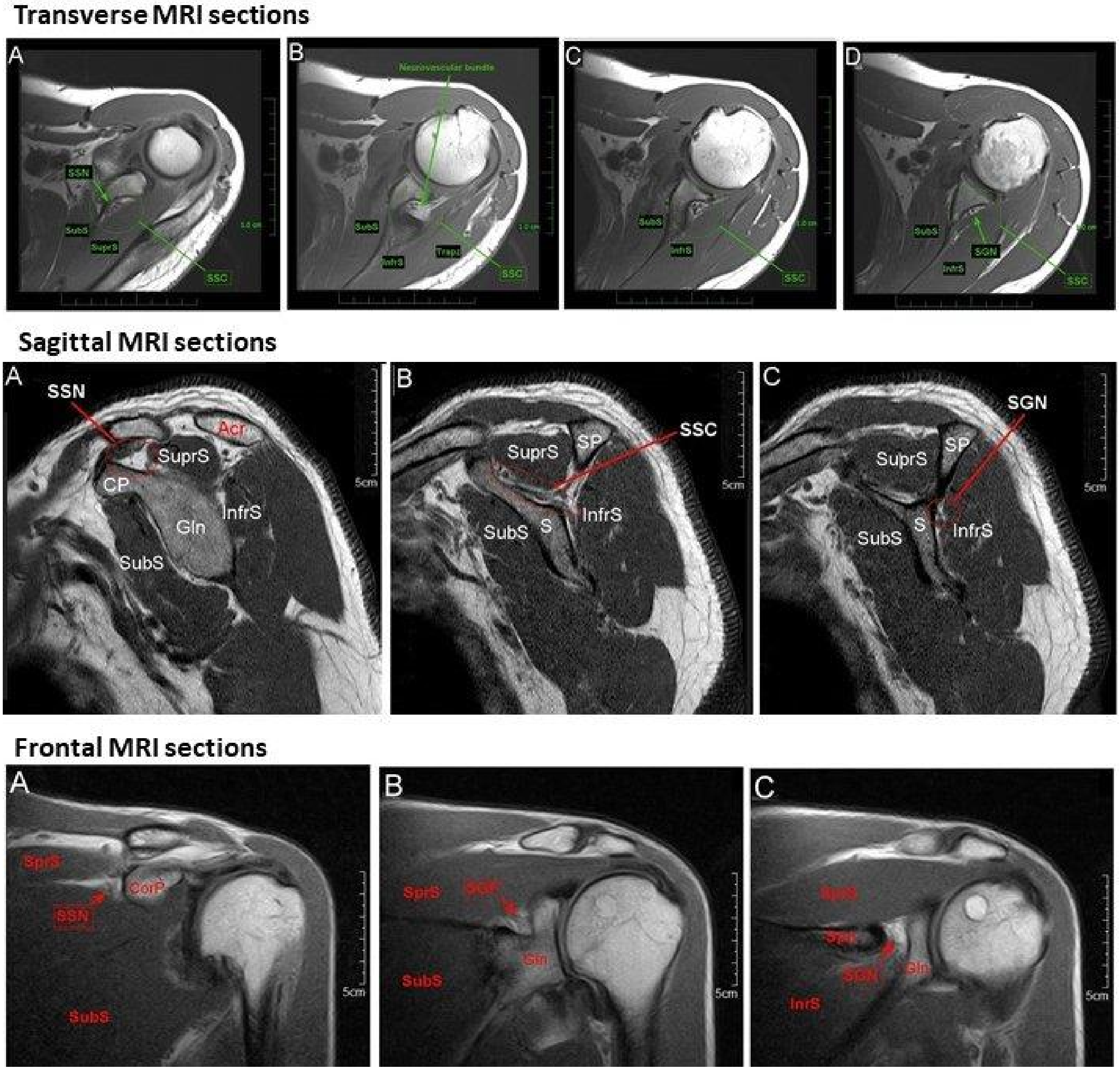


*Image source: (*Al-Redouan et al., 2021b*).

4.4. Suprascapular canal and suprascapular notch imaging

4.4.1. Suprascapular canal MRI anatomy

Figure 12. T1-weighted magnetic resonance image (MRI) sections of a left shoulder navigating through the suprascapular canal.

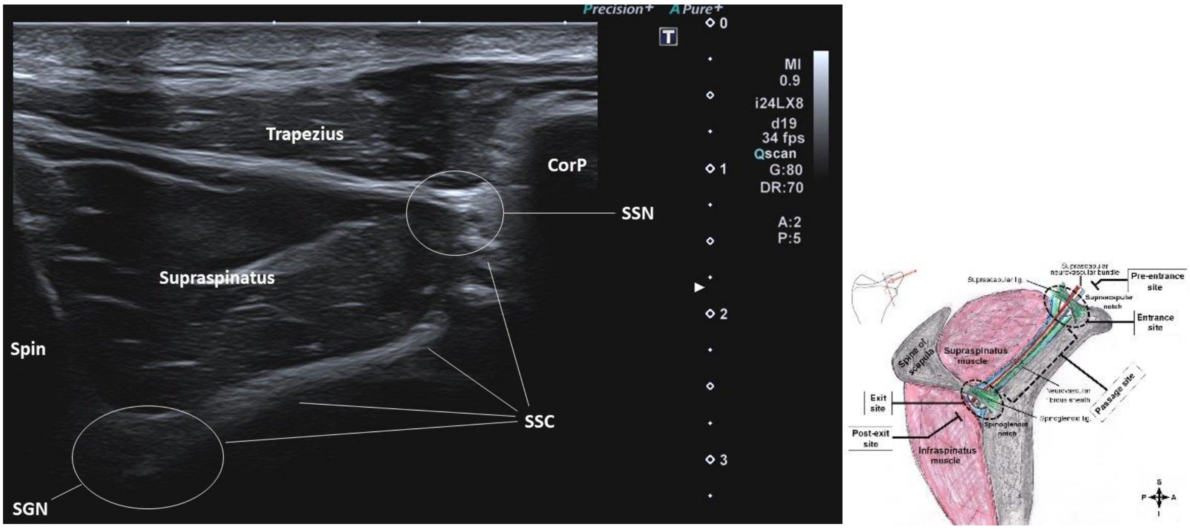


Legend: Gl – glenoid, Gln – glenoid, InfrS – infraspinatus muscle, SGF – spinoglenoid fossa, SGN – spinoglenoid notch, Snv – suprascapular neurovascular bundle, spin – spine of scapula, SSC – suprascapular canal, SSN – suprascapular notch, SubS – subscapularis muscle, SuprS – supraspinatus muscle, Trapz – trapezius muscle.

4.4.2. Suprascapular canal ultrasound anatomy

The full length of the SSC was captured by placing the ultrasound probe above the shoulder at the site of the SGF in a diagonal orientation with a medial tilt (Fig. 13).

Figure 13. Diagonal sonographic section of a left shoulder through the suprascapular canal.

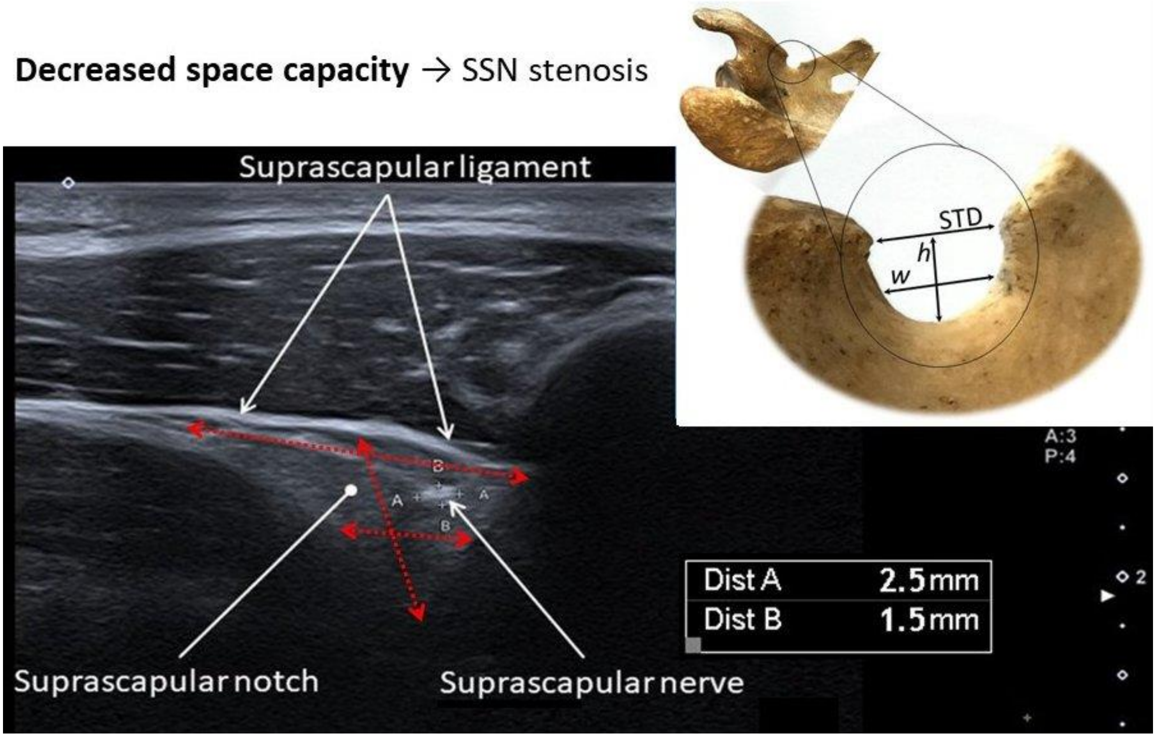


Legend: CorP – coracoid process, SGN – spinoglenoid notch, SSC – suprascapular canal, SSN – suprascapular notch.

4.4.3. Suprascapular notch stenosis ultrasound diagnostic algorithm

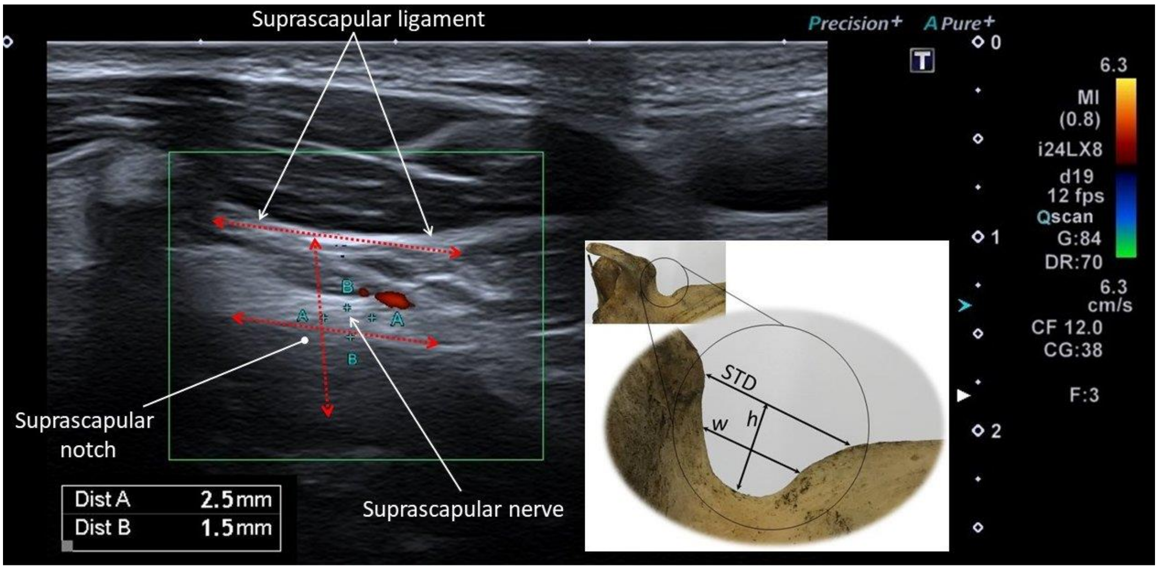
A suspected SSN stenosis can be assessed by measuring the space determining parameters on an ultrasound examination using the posterior (Fig. 14) and anterior (Fig. 15) ultrasound views. A SSN height or widths below 3 mm are considered critical values indicating a SSN anatomical stenosis (Fig. 14,15). Specifically, the anterior view approach can detect dynamic SNE by the SUBM as its superior margin can be observed while in motion by internal and external rotation of the flexed arm.

Figure 14. Ultrasound algorithm in detecting suprascapular notch stenosis (right shoulder, posterior transducer approach).



Legend: h – height, STD – superior transverse distance, w – width.

Figure 15. Ultrasound algorithm in detecting suprascapular notch stenosis (right shoulder, frontal transducer approach).



Legend: h – height, STD – superior transverse distance, w – width.

5. Discussion

5.1. The suprascapular canal defined as a topographical site

5.1.1. The newly identified and proposed terms

The “suprascapular canal” as a term is not listed in TA (FIPAT, 1998; 2019). The overall level of consensus of the nine terms was high (Table 2). Even though the consensus level of the “suprascapular ligament” was above the threshold (57.16%), it was relatively lower than in the other terms (61.43%) (Al-Redouan and Kachlik, 2022a). Some anatomists still prefer the old codified in TA term, the “superior scapular transverse ligament”.

5.2. Suprascapular notch variation

5.2.1. Suprascapular notch classification systems

Our morphometric classification system is in concordance with the proposed classification system by Polguj et al. (2011) as well as with all the authors using this morphometric system (Natsis et al., 2007; Iqbal et al., 2011; Kumar et al., 2014; Jezierski et al., 2017) with varying reported prevalence. The discussion and debate of classifying the SSN shape is persisting throughout the literature. We had demonstrated that a morphometric based classification of the SSN type has its application, in which we had driven the morphometric risk pattern of SSN stenosis (Fig. 10, 11) (Al-Redouan et al., 2021b).

5.2.2. Suprascapular notch content

The SSL was found to vary morphologically (Fig. 6) as addressed in the literature (Polguj et al., 2012). The prevalence of the variant anterior coracoscapular ligament 15.9% (ten out of 63 SSNs). It was presented to occur in 18.8% to 60.0% (Polguj et al., 2016). The reported 41% bilateral and 60% unilateral occurrence by Avery et al. (2002) seemed to be very high in comparison to our report. Piyawinijwong and Tantipoon (2012) reported 6% bilateral and 22% unilateral occurrence, which is relatively in agreement to our report.

It is widely believed that the SA and SV pass above the SSL (Lambert, 2016; Ward, 2016), and it is taught in the anatomical curricula as a reliable fact. However, the SA was found running within the SSN underneath the SSL in 26.7%, while the SV passed underneath the SSL in 50.0% out of the 159 observed SSN specimens (Fig. 9) (Al-Redouan et al., 2021a). Polguj et al. (2015) reported a SV running under the SSL in 61.3% and the SA in 9.4%, while both vessels coursed under the SSL in 12.3% out of a sample of 106 SSN cadaveric specimens. According to their study, only 17% exhibited the well-known classical description of the SA and SV passing above the SSL (Polguj et al., 2015). It is also widely believed that there is only one SA and one SV (Lambert, 2016), and additional number is perceived as a rare variant (Ward, 2016). Meanwhile, only in 47.7% out of our 159 observed SSN specimens exhibited a single SA accompanied by a single SV. A duplicated SV was found in 30.0%, while a tripled SV in 3.3% of cases. However, the SA was less likely to be duplicated and was found only in 3.3% of cases (Fig. 9) (Al-Redouan et al., 2021a).

The insertion of the OMHM on both the medial peak of the SSN and the SSL is a well-established fact (Lambert, 2016) with some documented variation (Ward, 2016). In our study, we illustrated that the OMHM can be inserting only on the medial peak of the SSN and that was found in 69.6% out of the 115 observed specimens. Only in 29.6%, the SSL was involved as an insertion site for the OMHM (Fig. 8). On the contrary, Bayramoglu et al. (2003) and Bhat et al. (2018) reported an isolated insertion of the OMHM on the SSL without the involvement of the medial peak of the SSN. We had encountered two variant muscles involving the margins of the SSN. The anterior coracoscapular muscle has never been reported before. The SPM was reported inserting on the SSL with a prevalence of 11.8% (Rabi et al., 2008; Cogar et al., 2015; Moyano et al., 2018; Ulusoy et al., 2018; Buitrago et al., 2021). The superior margin of the SUBM can run more cranially covering the anterior surface of the SSN (Fig. 7). The inferior margin of the SUPM runs parallel to the SSL forming a secondary opening into the SSC through which the SA and/or SV pass in 93.3% of the observed 159 SSN cases in varying combinations (Al-Redouan et al., 2021a). This opening can be regarded as a fibromuscular foramen (Al-Redouan et al., 2021a). Iatrogenic lesion to the OMHM is a risk factor that can lead to omohyoid muscle syndrome causing swallowing and phonation disturbance (Ong et al., 2021).

5.3. Suprascapular nerve entrapment at the suprascapular notch

5.3.1. Mechanism of suprascapular nerve entrapment at the suprascapular notch

The SN can be subjected to anatomical compression (Rengachary et al., 1979a; Avery et al., 2002; Zehetgruber et al., 2002; Duparc et al., 2010; Moen et al., 2012; Kostretzis et al., 2017; Al-Redouan et al., 2021a; Al-Redouan et al., 2021b) or dynamic impingement and stress (Rengachary et al., 1979b; Zehetgruber et al., 2002; Tasaki et al., 2015; Al-Redouan et al., 2021a). The SSN stenosis (below a critical point of 3 mm) can occur with an incidence of 15% (Al-Redouan et al., 2021b) due to ossification of the SSN margins. This form of stenosis can take three distinctive patterns. A horizontal pattern where the SN is compressed between two bone margins, and a vertical pattern where the SN is compressed by the SSL against the inferior bony margin of the SSN, or a mixed pattern of compression between bones and the SSL (Fig. 11). On the contrary to the popular believe, an ossified SSL (Mohd, 2006; Tubbs et al., 2013; Polguj et al., 2014b; Lambert, 2016; Ward, 2016) does not necessary cause SNE if it does not affect the internal space capacity of the SSN vicinity. This was evidenced in our study where only 1.6% of the suprascapular foramina where stenosed (Al-Redouan et al., 2021b). Another mechanism that could lead to SSN stenosis is a space occupying structure (Al-Redouan et al., 2021a) saucy as the variant anterior coracoscapular ligament (Fig. 6C). The SN can be entrapped dynamically during shoulder movements. A common predisposing risk factor (12−33%) is sports with strenuous overhead arm motions such as volleyball, swimming, and basketball (Ravindran, 2003; Moen et al., 2012; Shi et al., 2012; Memon et al., 2019). A repetitive arm abduction movement can rub the SN against the SSL, a phenomenon referred to as the "sling effect" (Rengachary et al., 1979b; Zehetgruber et al., 2002; Tasaki et al., 2015). Further, a SN traction can occur in such strenuous movement or in cases such as shoulder dystonia where the SN is subjected to stretching tension (Parvizi and Kim, 2010; Mandal et al., 2019). Furthermore, the superior margin of the SUBM (Fig. 7) can impinge on the SN if it runs covering the anterior surface of the SSN (Tasaki et al., 2015; Katsuura et al., 2019). Nevertheless, vascular compression could be considered as a dynamic form of compression. An abnormal chronic pulsatile pressure against the SN can press and occlude the SN vasa nervorum leading to microembolic damage (Ringel et al., 1990; Czihal et al., 2015).

5.3.2. Imaging detection of the suprascapular nerve entrapment at the suprascapular notch

MRI (Fig. 12) is useful to search for soft tissue pathologies (Katsuura et al., 2019; Rubin, 2020) within the SSC intervals (Al-Redouan et al., 2021a). A distention along the course of the SSC can be an indicator of a mass formation (Katsuura et al., 2019; Rubin, 2020). A narrowing along the course of the SSC can indicate a surrounding tissue impingement.

Ultrasound is an instant and non-invasive low-cost method for fast screening of the SSC surrounding soft tissue (Fig. 13). It is an excellent tool for fellow-ups screening (Kim et al., 2009; Leider et al., 2021). The SSN stenosis can be assessed in two views, posterior (Fig. 14) and anterior views (Fig. 15). A decrease in the superior and/or middle width of the SSN indicates a horizontally oriented stenosis compressing the SN between the bony margins of the SSN, while a decrease in the depth of the SSN indicates a vertically oriented stenosis compressing the SSN against the SSL (Al-Redouan et al., 2021b). Nevertheless, classifying the SSN type is essential in this method where Type-IV SSN is a foramen bordered fully by bone tissues (Fig. 10). A discrete type of the SSN (Type-V) indicates a higher risk of developing a SNE over time by dynamic mechanism of SN compression due to the "sling-effect" against the SSL (Al-Redouan et al., 2021b).

5.3.3. Surgical treatment of the suprascapular nerve entrapment at the suprascapular notch

The SN anesthetic block brings a quick short-term pain relief (Chan and Peng, 2011; Fernandes et al., 2012) with reported 85.3% efficacy in acute SN pain management (Chan and Peng, 2011). Pain recurrence is common and requires a frequent SN block application (Chan and Peng, 2011). The pulsed radiofrequency showed more efficacy with longer-term sustainability and requires less therapeutic sessions (Chan and Peng, 2011; Chang et al., 2015; Vij et al., 2022). However, this method had showed more aggressive types of post-procedure complications with recurrent higher intensity pain (Chang et al., 2015; Vij et al., 2022). Neuromodulation by neurostimulation is used in treatment of chronic SN pain (Taskaynatan et al., 2012; Ilfeld et al., 2019; Leider et al., 2021). The pain usually subsides within 1–14 days after the procedure (Ilfeld et al., 2019). Another recently introduced method in treating SN neuropathy is SN cryoneurolysis (Gabriel et al., 2019; Leider et al., 2021). These methods are enhanced when performed under imaging modality-guidance (Laumonerie et al., 2017; Laumonerie et al., 2018; Ilfeld et al., 2019; Laumonerie et al., 2019a; Laumonerie et al., 2019b; Leider et al., 2021). The anatomical access to the SN in these aforementioned procedures includes posterior and anterior approaches (Chan and Peng, 2011; Leider et al., 2021). The posterior approach leads through the SUPF either by utilizing the spine of the scapula as the guided landmark under imaging guidance (Yildizgören et al., 2020; Leider et al., 2021) or blindly (Laumonerie et al., 2019b). The anterior approach comprises the supraclavicular approach, the subomohyoid approach, and the retroclavicular approach (Chan and Peng, 2011; Kamal et al., 2018).

Surgical treatment is indicated when detecting a reversible pathoanatomical SNE (Strauss et al., 2020; Al-Redouan et al., 2021a; Al-Redouan et al., 2021b; Leider et al., 2021; Al-Redouan et al., 2023).

Two main imaging-guided surgical procedures: (1) aspiration and (2) arthroscopic decompression. Percutaneous aspiration is an effective procedure in draining cysts (Chiou et al., 1999). However, ganglionic cysts tend to be recurrent in majority of the cases (Phillips et al., 2018). On the other hand, arthroscopic decompression procedures showed better long-term resolution (Lafosse et al., 2007; Chan and Peng, 2011; Leider et al., 2021).

Two surgical approaches are performed in open surgical SNE decompression (Leider et al., 2021). The posterior surgical approach is through the SUPF by splitting the trapezius muscle and the SUPM which gives access to the SSL for its decompression by ligamentectomy (Lafosse et al., 2007; Leider et al., 2021). The anterior surgical approach is through the omoclavicular triangle (Shupeck and Onofrio, 1990; Tender et al., 2006; Elzinga et al., 2016; Leider et al., 2021; Maurya et al., 2021), which gives access to the SN as it emerges from the brachial plexus prior to the SSN (Leider et al., 2021; Al-Redouan et al., 2023).

The arthroscopic approach utilizes multiple portals (Leider et al., 2021).

In this thesis we have illustrated the inevitability of osteoplasty when the SN is compressed by bone margins and would not be released by a SSL resection (Al-Redouan et al., 2021b). Agrawal (2009) had illustrated an arthroscopic resection of a SSN composed of a foramen type where they resected the superior bony margin of the SSN. We also suggest assessing the OMHM and assessing its insertion after SSL radical resection. In addition, the SUBM can cause dynamic compression which may require an additional surgical intervention.

6. Conclusion

The SSC was identified and studied through cadaveric dissections and imaging methods observation with emphasis on the SSN. The shortage in the relevant terminology and nomenclature was absolved by applying the consensus method of Delphi. The new and revised terms were then proposed for incorporation into the anatomical and clinical practice. The SSN morphology was observed in detail. The SSN types were classified through dry bones observation and measurements analysis. The morphological pattern of the SSN stenosis was established and the risk of stenosis by type was achieved. The etiologies and mechanisms of the SNE were sorted and categorized by anatomical sites in relation to the SSN topography. The SSN topography and contents were studied and detailed with elaboration on its clinical significance in the diagnostics and surgical applications. The MRI and ultrasound of the SSC with emphasis on the SSN was evaluated in regard to their efficiency to expose the anatomical boundaries of the topographical spaces. Ultrasound protocol of the SSN was introduced showing an optimal up-to-date state of anatomical visualization. We proposed an ultrasound procedure with potentials to detect a suspected SSN stenosis. The current SNE conservative and surgical treatment methods were discussed through literature survey and correlated to our collective findings. The SSN should be examined by its morphological type and the underlying anatomical cause of compression should be relieved surgically. SSN stenosis is a critical diagnostic measure. Pain management in SNE will not maintain full motor recovery. Enriched knowledge of the SSN morphological variation would enhance the surgical approaches and the procedure planning.

7. Summary of dissertation findings

7.1. Suprascapular notch morphology

The suprascapular notch (SSN) was classified into five SSN types based on its morphometric measurements (Fig. 10): Type-I (depth larger than superior width), Type-II (depth equal to superior width), Type-III (superior width larger than depth), Type-IV (foramen), Type-V (discrete).

The suprascapular ligament (SSL) is composed of dense collagen fibers with an admixture of elastic fibers, and can be ossified partially or completely. It appears thin-rounded, or fanned from medial to lateral. An internal variant ligament can occur splitting the SSN into internal compartments. The SSN can be covered by a delicate fibrous membrane pierced by the SN.

The suprascapular nerve (SN) runs within the SSN while the suprascapular artery (SA) and the suprascapular vein (SV) course either externally outside the SSN above the SSL or internally inside the SSN below the SSL in different nine combinations (Fig. 9): (1) single external SA and SV, (2) single external SA and single internal SV, (3) duplicated SA and SV – one external SA and SV with one internal SA and SV, (4) duplicated SV – single external SA and SV with one internal SV, (5) single internal SA and SV, (6) duplicated SV – single internal SA and SV with one external SV, (7) tripled SV – single internal SA and two SV with one external SV, (8) duplicated SV – single external SA and two SV, and (9) duplicated SA – two external SA with single internal SV.

The supraspinatus muscle (SUPM) runs parallel to the SSL forming an opening above the SSN where SA and SV can pass through in some cases. The subscapularis muscle (SUBM) superior margin runs below the SSN, or covers its anterior surface partially or completely. The omohyoid muscle (OMHM) inserts on the medial peak of the SSN and its insertion can extend onto the SSL partially or completely. The subclavius posticus muscle (SPM) is a rare variant and can insert onto the SSL. Another rare small thin muscle can occur internally within the SSN.

7.2. Suprascapular nerve anatomical entrapment etiologies

Two pathoanatomical mechanisms contribute to suprascapular nerve entrapment (SNE) syndromes: (1) SSN stenosis due to reduced internal space of the SSN boundaries or due to a space occupying structure; and (2) SN dynamic compression by any adjacent structure with an inherent strenuous mobility. The SNE can occur at three anatomical localizations in relation to the SSN topography by differing etiologies (Fig. 3). At the SSN pre-entrance space by: (1) retroclavicular SN tension due to chronic heavy loads (bags' belt) or shoulder dystonia; (2) soft tissue impingement due to tumors (neuroma), ganglion cyst, a variant muscle (SPM) or a varying muscle size (hypertrophic superior margin of the SUBM); (3) scar tissue adhesions due to adjacent bone fracture or post-inflammatory processes in SUPM and fascia tears. Within the SSN by: (1) a decreased SSN space capacity due to SSN stenosis or a space occupying variant structure (internal ligament or vessel); (2) dynamic compression by the SSL (the "sling-effect") or by a vessel causing an abnormal chronic pulsatile pressure. At the post-SSN space by: (1) fibrous adhesions of the fascia due to SUPM trauma; (2) SN traction in rotator cuff tears and sports injuries; and (3) dynamic compression due to chronic episodic muscular impingement or vascular compression due to tortuous and dilated (varicose) veins.

7.3. Suprascapular notch stenosis detection

SSN stenosis progresses in three morphological patterns (Fig. 10): (1) vertical SSN stenosis compressing the SN by the SSL against the underlying SSN structures; (2) horizontal SSN stenosis compressing the SN between the medial and lateral bone margins; and (3) mixed form of SSN stenosis where the SSL and bone margins are both involved.

SSN Type-V and Type-III are at higher risk of SSN stenosis. Ultrasound assessment of the SSN by measuring its depth, superior width, and middle width is proposed as a SSN stenosis diagnostic algorithm (Fig. 14,15). Three imaging modalities: (1) 3D-CT reconstruction for visualizing the SSN type; (2) MRI for soft tissue evaluation; and (3) ultrasound for SSN morphology and topography screening.

We provide three sonographical views: (1) superior-sagittal approach projecting an oblique longitudinal view of the SSC (Fig. 13); (2) posterior-frontal view projecting the SSN space from its posterior surface (Fig. 14); and (3) anterior-frontal view projecting the SSN space from its anterior surface (Fig. 15).

7.4. Suprascapular nerve surgical release

A ligamentectomy would release an entrapped SN compressed by the SSL, osteoplasty is inevitable when the SN is compressed by bone tissues. Conservative treatment will manage to relieve the manifested pain but would fail to recover the motor function of the SUPM and infraspinatus muscle (INFM), if the compressed SN is not anatomically released. Ultrasound and fluoroscopy are excellent image-guidance modalities for the SN access in anesthesiology as well as arthroscopic procedures.

The SN block is approached by: (1) the posterior approach through the SUPF; or (2) the anterior approach including supraclavicular, subomohyoid, and retroclavicular approaches.

Two surgical approaches are performed in open surgical decompression: (1) the posterior surgical approach through the supraspinous fossa (SUPF) to access the SSL; or (2) the anterior surgical approach through the omoclavicular triangle to access the SN at its emerging site from the brachial plexus.

The arthroscopic surgical approaches utilize multiple portals: (1) the posterior portal placed under the base of the acromion for initial inspection; (2) the lateral subacromial portal is then placed for visualization and guidance through the structures; (3) the anterolateral portal is placed to perform a bursectomy and navigate to the base of the coracoid process; (4) the Neviaser portal (a superior medial portal inserted underneath the acromioclavicular joint) is placed to bluntly dissect and transect the compressing structures; and (5) the SN portal is placed to verify the mobility of the released SN.

8. Summary of dissertation findings in Czech

8.1. Morfologie incisura scapulae

Incisura scapulae (SSN) byla na základě morfometrických měření klasifikována do pěti typů (Obr. 10): Typ-I (výška větší než horní šířka), Typ-II (výška rovna horní šířce), Typ-III (horní šířka větší než výška), Typ-IV (otvor), Typ-V (drobná).

Ligamentum transversum scapulae superius / ligamentum suprascapulare (SSL) je složeno z hustých kolagenních vláken s příměsí elastických vláken a může být částečně nebo úplně osifikováno. Tvarově je mediolaterálně slabě zaoblené nebo vějířovité. Rovněž může být přítomen přídatný nekonstantní vaz, rozdělující SSN na menší vnitřní oddíly. SSN může být pokryta jemnou vláknitou blánou, jíž proráží nervus suprascapularis (SN).

SN běží skrz SSN, zatímco arteria suprascapularis (SA) a vena suprascapularis (SV) probíhají buď mimo SSN nad SSL nebo uvnitř SSN pod SSL, a to v devíti různých kombinacích (Obr. 9): (1) jedna SA a SV vně, (2) jedna SA vně a jedna SV uvnitř, (3) dvojitá SA a SV – jedna SA a SV vně s jednou SA a SV uvnitř, (4) dvojitá SV – jedna SA a SV vně s jednou SV uvnitř, (5) jedna SA a SV uvnitř, (6) dvojitá SV – jedna SA a SV uvnitř s jednou SV vně, (7) trojitá SV – jedna SA a dvě SV uvnitř a jedna SV vně, (8) dvojitá SV – jedna SA a dvě SV vně (9) dvojitá SA – dvě SA vně a jedna SV uvnitř.

Musculus supraspinatus (SUPM) běží souběžně s SSL a tvoří otvor nad SSN, kudy v některých případech mohou procházet SA a SV. Horní okraj musculus subscapularis (SUBM) probíhá pod SSN a částečně nebo úplně pokrývá jeho povrch. Musculus omohyoideus (OMHM) se upíná na mediální vrchol okraje SSN a jeho úpon může částečně nebo úplně zasahovat až na SSL. Musculus subclavius posticus (SPM) je vzácný variabilní sval a může se upínat na SSL. Další vzácný malý úzký sval se může vyskytovat uvnitř samotné SSN.

8.2. Příčiny anatomického útlaku nervus suprascapularis

K syndromu útlaku nervus suprascapularis (SNE) přispívají dva strukturální mechanizmy: (1) zúžení (stenóza) SSN v důsledku zmenšeného vnitřního prostoru SSN nebo v důsledku struktury zabírající část tohoto prostoru; a (2) dynamický útlak SN jakoukoli přilehlou strukturou s vlastní obtížnou pohyblivostí. SNE se může vyskytovat ve třech anatomických umístěních ve vztahu k topografii SSN a různým příčinám jejího vzniku (Obr. 3). V předvstupním prostoru SSN: (1) retroklavikulární napětí SN v důsledku chronické těžké zátěže (popruhy batohu) nebo dystonie ramen; (2) útlak (impingement) měkkých tkání v důsledku nádoru (neurom), gangliové cysty, variabilního svalu (SPM) nebo proměnlivé velikosti svalu (hypertrofický horní okraj SUBM); (3) srůsty (adheze) jizevnaté tkáně v důsledku zlomeniny sousední kosti nebo pozánětlivých dějů v SUPM a trhlinách jeho fascie. V rámci SSN: (1) snížená prostorová kapacita SSN v důsledku zúžení SSN nebo nekonstantní struktury zabírající část prostoru (vnitřní vaz nebo céva); (2) dynamický útlak pomocí SSL („smyčkový účinek") nebo cévou způsobující abnormální chronický tlak svým tepen. V prostoru po výstupu z SSN: (1) vazivové srůsty fascie v důsledku poškození SUPM; (2) přetažení SN u natržení rotátorové manžety a sportovních zranění; a (3) dynamický útlak v důsledku chronického epizodického svalového útlaku (impingementu) nebo cévní útlak v důsledku klikatých a rozšířených (varikózních) žil.

8.3. Odhalení zúžené incisura scpaulae

Zúžení (stenóza) SSN se vyskytuje ve třech morfologických vzorech (Obr. 10): (1) svislé zúžení SSN utlačující SN pomocí SSL proti základním strukturám SSN; (2) vodorovné zúžení SSN utlačující SN mezi mediálním a laterálním okrajem kosti; a (3) smíšená forma zúžení SSN, v níž jsou zahrnuty okraje kosti i SSL.

SSN typu V a typu III jsou vystaveny vyššímu riziku zúžení SSN. Ultrazvukové hodnocení SSN měřením její hloubky, horní šířky a střední šířky je navrženo jako diagnostický algoritmus pro odhalení zúžení SSN (Obr. 14,15). Tři způsoby zobrazení zahrnují: (1) 3D-CT rekonstrukce pro stanovení typu SSN; (2) MR pro hodnocení měkkých tkání; a (3) ultrazvuk pro hodnocení morfologie a topografie SSN.

Lze využít tři ultrazvukové přístupy: (1) přístup shora a sagitálně poskytující šikmý podélný pohled na SSC (Obr. 13); (2) zadní a frontální přístup poskytující pohled na prostor SSN z jeho zadní strany (Obr. 14); a (3) přední a frontální přístup poskytující pohled na prostor SSN z jeho přední strany (Obr. 15).

8.4. Chirurgické uvolnění nervus suprascapularis

Přetětí SSL (ligamentektomie) uvolní uvězněný SN utlačený vazem, zatímco osteoplastika je nevyhnutelná, je-li SN utlačen kostními tkáněmi. Konzervativní léčba dokáže zmírnit bolestivé projevy, ale nepodaří se obnovit motorickou funkci SUPM a musculus infraspinatus, pokud není utlačený SN anatomicky uvolněn. Ultrazvuk a skiaskopie jsou vynikajícími zobrazovacími metodami pro přístup k SN v anesteziologii i při artroskopických výkonech.

K blokádě SN se přistupuje: (1) zadním přístupem skrz fossa supraspinata (SUPF); nebo (2) přední přístupem včetně supraklavikulárního, subomohyoidního a retroklavikulárního přístupu.

K otevřené chirurgické dekompresi lze využít dva chirurgické přístupy: (1) zadní chirurgický přístup skrz SUPF pro přístup k SSL; nebo (2) přední chirurgický přístup skrz trigonum omoclaviculare k SN v místě jeho odstupu z plexus brachialis.

Artroskopické přístupy využívají více portů: (1) zadní port umístěný pod základnou nadpažku (basis acromii) pro počáteční kontrolu; (2) laterální subakromiální port je určen pro ozřejmění a navádění skrz další struktury; (3) anterolaterální port slouží k provedení burzektomie a navádění k základně zobákovitého výběžku lopatky (basis processus coracoidei scapulae); (4) Neviaserův port (horní mediální port vložený pod articulatio acromioclavicularis) je určen k tupé preparaci a přetětí utlačujících struktur; a (5) port SN je umístěn pro ověření pohyblivosti uvolněného SN.

9. References

1. Agrawal V. Arthroscopic decompression of a bony suprascapular foramen. Arthroscopy. 2009;25(3):325-328. doi:10.1016/j.arthro.2008.06.014.
2. Al-Redouan A, Benes M, Abbaspour E, Kunc V, Kachlik D. Prevalence and anatomy of the anomalous subclavius posticus muscle and its clinical implications with emphasis in neurogenic thoracic outlet syndrome: Scoping review and meta-analysis. Ann Anat. 2023;247:152046. doi: 10.1016/j.aanat.2023.152046.
3. Al-Redouan A, Holding K, Kachlik D. "Suprascapular canal": Anatomical and topographical description and its clinical implication in entrapment syndrome. Ann Anat. 2021a;233:151593. doi: 10.1016/j.aanat.2020.151593.
4. Al-Redouan A, Hudak R, Nanka O, Kachlik D. The morphological stenosis pattern of the suprascapular notch is revealed yielding higher incidence in the discrete type and elucidating the inevitability of osteoplasty in horizontally oriented stenosis. Knee Surg Sports Traumatol Arthrosc. 2021b;29(7):2272-2280. doi: 10.1007/s00167-020-06168-1.
5. Al-Redouan A, Kachlik D. Scapula revisited: new features identified and denoted by terms using consensus method of Delphi and taxonomy panel to be implemented in radiologic and surgical practice. J Shoulder Elbow Surg. 2022a;31(2):e68-e81. doi: 10.1016/j.jse.2021.07.020.
6. Al-Redouan A, Kachlik D. Suprascapular notch cross-sectional area on MRI is not highly accurate in the diagnosis of suprascapular nerve entrapment – counter point of view. Korean J Anesthesiol. 2022b;75(6):536-538. doi: 10.4097/kja.22413.
7. Avery BW, Pilon FM, Barclay JK. Anterior coracoscapular ligament and suprascapular nerve entrapment. Clin Anat. 2002;15(6):383-386. doi: 10.1002/ca.10058.
8. Bayramoğlu A, Demiryürek D, Tüccar E, Erbil M, Aldur MM, Tetik O, Doral MN. Variations in anatomy at the suprascapular notch possibly causing

suprascapular nerve entrapment: an anatomical study. Knee Surg Sports Traumatol Arthrosc. 2003;11(6):393-398. doi: 10.1007/s00167-003-0378-3.

9. Bhat N, Pandey AK, Divya C, Kotian SR, Kalthur SG. Omohyoid muscle: an anatomical study. JKIMSU. 2018;7:21-26.
10. Buitrago QER, Quintero PID, Ballesteros ALE. Morphological evaluation of the subclavian muscle in a sample of autopsy material. Clinical Inferences. Int J Morphol. 2021;39:1559-1563.
11. Cano-Martínez JA, Nicolás-Serrano G, Villodres Corpás J, Bento-Gerard J. Arthroscopic release of proximal supra-scapular nerve entrapment: Medium-term results. Liberación artroscópica del atrapamiento proximal del nervio supraescapular: resultados a medio plazo. Rev Esp Cir Ortop Traumatol (Engl Ed). 2021;65(2):91-98. doi: 10.1016/j.recot.2020.10.001.
12. Chan CW, Peng PW. Suprascapular nerve block: a narrative review. Reg Anesth Pain Med. 2011;36(4):358-373. doi: 10.1097/AAP.0b013e3182204ec0.
13. Chiou HJ, Chou YH, Wu JJ, Hsu CC, Tiu CM, Chang CY, Yu C. Alternative and effective treatment of shoulder ganglion cyst: ultrasonographically guided aspiration. J Ultrasound Med. 1999;18(8):531-535. doi: 10.7863/jum.1999.18.8.531.
14. Cogar AC, Johnsen PH, Potter HG, Wolfe SW. Subclavius posticus: an anomalous muscle in association with suprascapular nerve compression in an athlete. Hand (N Y). 2015;10(1):76-79. doi: 10.1007/s11552-014-9652-8.
15. Cummins CA, Messer TM, Nuber GW. Suprascapular nerve entrapment. J Bone Joint Surg Am. 2000;82(3):415-424. doi: 10.2106/00004623-200003000-00013.
16. Czihal M, Banafsche R, Hoffmann U, Koeppel T. Vascular compression syndromes. Vasa. 2015;44(6):419-434. doi: 10.1024/0301-1526/a000465.
17. Duparc F, Coquerel D, Ozeel J, Noyon M, Gerometta A, Michot C. Anatomical basis of the suprascapular nerve entrapment, and clinical relevance

of the supraspinatus fascia. Surg Radiol Anat. 2010;32(3):277-284. doi: 10.1007/s00276-010-0631-7.

18. Elzinga KE, Curran MWT, Morhart MJ, Chan KM, Olson JL. Open Anterior Release of the Superior Transverse Scapular Ligament for Decompression of the Suprascapular Nerve During Brachial Plexus Surgery. J Hand Surg Am. 2016;41(7):e211-e215. doi: 10.1016/j.jhsa.2016.03.005
19. Federative International Program for Anatomical Terminologies Terminologia Anatomica. 2nd ed. 2019. https://FIPAT.library.dal.ca/TA2, Date accessed: August 15, 2022.
20. Fernandes MR, Barbosa MA, Sousa AL, Ramos GC. Suprascapular nerve block: important procedure in clinical practice. Rev Bras Anestesiol. 2012;62(1):96-104. doi: 10.1016/S0034-7094(12)70108-3.
21. Gabriel RA, Ilfeld BM. Peripheral nerve blocks for postoperative analgesia: From traditional unencapsulated local anesthetic to liposomes, cryoneurolysis and peripheral nerve stimulation. Best Pract Res Clin Anaesthesiol. 2019;33(3):293-302. doi: 10.1016/j.bpa.2019.06.002
22. Gürses İA, Gayretli Ö, Coşkun O, Kale A, Öztürk A. Anatomical relations between anterior coracoscapular ligament and suprascapular neurovascular structures and a proposal for classification. Acta Orthop Traumatol Turc. 2015;49(4):433-437. doi: 10.3944/AOTT.2015.14.0333.
23. Hill LJ, Jelsing EJ, Terry MJ, Strommen JA. Evaluation, treatment, and outcomes of suprascapular neuropathy: a 5-year review. PM R. 2014;6(9):774-780. doi: 10.1016/j.pmrj.2014.02.003.
24. Hrdlicka A. The scapula: visual observations. Am. J. Phys. Antropol. 1942;29:73-94
25. Ilfeld BM, Finneran JJ 4th, Gabriel RA, Said ET, Nguyen PL, Abramson WB, Khatibi B, Sztain JF, Swisher MW, Jaeger P, Covey DC, Meunier MJ, Hentzen ER, Robertson CM. Ultrasound-guided percutaneous peripheral nerve stimulation: neuromodulation of the suprascapular nerve and brachial plexus

for postoperative analgesia following ambulatory rotator cuff repair. A proof-of-concept study. Reg Anesth Pain Med. 2019;44(3):310-318. doi: 10.1136/rapm-2018-100121

26. Iqbal K, Iqbal R. Classification of suprascapular notch according to anatomical measurements in human scapulae. J Coll Physicians Surg Pak. 2011;21(3):169-170.

27. Jezierski H, Podgórski M, Stefańczyk L, Kachlik D, Polguj M. The Influence of Suprascapular Notch Shape on the Visualization of Structures in the Suprascapular Notch Region: Studies Based on a New Four-Stage Ultrasonographic Protocol. Biomed Res Int. 2017;2017:5323628. doi: 10.1155/2017/5323628.

28. Kaledzera T, Matundu B, Adefolaju GA, Manda J, Mwakikunga A. Morphometric study of the suprascapular notch and scapular dimensions in adult Malawian cadavers and implications of completely ossified superior transverse scapular ligament. Pan Afr Med J. 2022;41:324. doi: 10.11604/pamj.2022.41.324.33205.

29. Kamal K, Dahiya N, Singh R, Saini S, Taxak S, Kapoor S. Comparative study of anatomical landmark-guided versus ultrasound-guided suprascapular nerve block in chronic shoulder pain. Saudi J Anaesth. 2018;12(1):22-27. doi: 10.4103/sja.SJA_123_17.

30. Katsuura Y, Hill AJ 4th, Colón LF, Dorizas JA. MRI diagnosis of suprascapular neuropathy using spinoglenoid notch distension. Radiol Med. 2019;124(7):643-652. doi: 10.1007/s11547-019-01005-z.

31. Kim SH, Kim SJ, Sung CH, Koh YG, Kim YC, Park YS. Arthroscopic suprascapular nerve decompression at the suprascapular notch. Knee Surg Sports Traumatol Arthrosc. 2009;17(12):1504-1507. doi: 10.1007/s00167-009-0858-1.

32. Kostretzis L, Theodoroudis I, Boutsiadis A, Papadakis N, Papadopoulos P. Suprascapular Nerve Pathology: A Review of the Literature. Open Orthop J. 2017;11:140-153. doi: 10.2174/1874325001711010140.
33. Kumar A. Sharma A. Singh P. Anatomical study of the suprascapular notch: quantitative analysis and clinical considerations for suprascapular nerve entrapment. Singapore Med J. 2014; 55(1):41-44. doi: 10.11622/smedj.2014009.
34. Kumar R, Ansari MA, Borthakur D, Nomani K, Gupta S, Singh S. Ossification of Superior Transverse Scapular Ligament - Incidence, Embryology and Association with Suprascapular Neuropathy. Clin Ter. 2023a;174(2):185-188. doi: 10.7417/CT.2023.2517.
35. Łabętowicz P, Synder M, Wojciechowski M, Orczyk K, Jezierski H, Topol M, Polguj M. Protective and Predisposing Morphological Factors in Suprascapular Nerve Entrapment Syndrome: A Fundamental Review Based on Recent Observations. Biomed Res Int. 2017;2017:4659761. doi:10.1155/2017/4659761.
36. Lafosse L, Tomasi A, Corbett S, Baier G, Willems K, Gobezie R. Arthroscopic release of suprascapular nerve entrapment at the suprascapular notch: technique and preliminary results. Arthroscopy. 2007;23(1):34-42. doi:10.1016/j.arthro.2006.10.003.
37. Lambert S.M. Shoulder girdle and arm. in: Standring S. Gray's anatomy: the anatomical basis of clinical practice. Churchill Livingstone/Elsevier, New York. 2016; pp. 801-810.
38. Laumonerie P, Blasco L, Tibbo ME, Panagiotis K, Fernandes O, Lauwers F, Bonnevialle N, Mansat P, Ohl X. Ultrasound-Guided Versus Landmark-Based Approach to the Distal Suprascapular Nerve Block: A Comparative Cadaveric Study. Arthroscopy. 2019b;35(8):2274-2281. doi:10.1016/j.arthro.2019.02.050.

39. Laumonerie P, Blasco L, Tibbo ME, Renard Y, Kerezoudis P, Chaynes P, Bonnevialle N, Mansat P. Distal suprascapular nerve block-do it yourself: cadaveric feasibility study. J Shoulder Elbow Surg. 2019c;28(7):1291-1297. doi:10.1016/j.jse.2018.11.073.
40. Laumonerie P, Ferré F, Cances J, Tibbo ME, Roumiguié M, Mansat P, Minville V. Ultrasound-guided proximal suprascapular nerve block: A cadaveric study. Clin Anat. 2018;31(6):824-829. doi:10.1002/ca.23199.
41. Laumonerie P, LapÈgue F, Chantalat E, Sans N, Mansat P, Faruch M. Description and ultrasound targeting of the origin of the suprascapular nerve. Clin Anat. 2017;30(6):747-752. doi:10.1002/ca.22936.
42. Leider JD, Derise OC, Bourdreaux KA, Dierks GJ, Lee C, Varrassi G, Sherman WF, Kaye AD. Treatment of suprascapular nerve entrapment syndrome. Orthop Rev (Pavia). 2021;13(2):25554
43. Mandal A, Papanna MC, Bryant R. Isolated suprascapular nerve palsy following childbirth: A case study and literature review. Shoulder Elbow. 2019;11(2):113-115. doi:10.1177/1758573218781510.
44. Maurya S, Renganathan G, R V, Bharti R. Outcomes of Shoulder Functions in Spinal Accessory to Suprascapular Nerve Transfer in Brachial Plexus Injury: A Comparison between Anterior and Posterior Approach. Indian J Plast Surg. 2021;54(2):152-156. doi:10.1055/s-0041-1731255.
45. Memon AB, Dymm B, Ahmad BK, Sripathi N, Schultz L, Chandok A. Suprascapular neuropathy: A review of 87 cases. Muscle Nerve. 2019;60(3):250-253. doi:10.1002/mus.26630.
46. Memon M, Kay J, Ginsberg L, Simunovic N, Bak K, Lapner P, Ayeni OR. Arthroscopic management of suprascapular neuropathy of the shoulder improves pain and functional outcomes with minimal complication rates. Knee Surg Sports Traumatol Arthrosc. 2018;26(1):240-266. doi:10.1007/s00167-017-4694-4.

47.Moen TC, Babatunde OM, Hsu SH, Ahmad CS, Levine WN. Suprascapular neuropathy: what does the literature show?. J Shoulder Elbow Surg. 2012;21(6):835-846. doi:10.1016/j.jse.2011.11.033.
48.Mohd AK. Complete ossification of the superior transverse scapular ligament in an Indian male adult. Int J Morphol. 2006;24:195–196. doi:10.4067/S0717-95022006000300013.
49.Moyano PJ, Capurro M, Apa SN, Albanese EF. Subclavius posticus muscle with anomalous posterior insertion: case report. Int J Morphol. 2018;36:22-25.
50.Natsis K, Totlis T, Tsikaras P, Appell HJ, Skandalakis P, Koebke J. Proposal for classification of the suprascapular notch: a study on 423 dried scapulas. Clin Anat. 2007;20(2):135-139. doi: 10.1002/ca.20318.
51.Nolte PC, Woolson TE, Elrick BP, Tross AK, Horan MP, Godin JA, Millett PJ. Clinical outcomes of arthroscopic suprascapular nerve decompression for suprascapular neuropathy. Arthroscopy. 2021;37(2):499-507. doi: 10.1016/j.arthro.2020.10.020.
52.Ong JZ, Tham AC, Tan JL. A Systematic Review of the Omohyoid Muscle Syndrome (OMS): Clinical Presentation, Diagnosis, and Treatment Options. Ann Otol Rhinol Laryngol. 2021;130(10):1181-1189. doi:10.1177/0003489421995037.
53.Parvizi J, Kim GK. Brachial Plexus Injury. In: Parvizi, J., Kim, G.K. (Eds.), High Yield Orthopaedics. Saunders, Philadelphia. 2010; pp. 68-69.
54.Patetta MJ, Naami E, Sullivan BM, Gonzalez MH. Nerve Compression Syndromes of the Shoulder. J Hand Surg Am. 2021;46(4):320-326. doi: 10.1016/j.jhsa.2020.09.022.
55.Peng PW, Wiley MJ, Liang J, Bellingham GA. Ultrasound-guided suprascapular nerve block: a correlation with fluoroscopic and cadaveric findings. Can J Anaesth. 2010;57(2):143–148. doi:10.1007/s12630-009-9234-3.

56. Phillips CJ, Field AC, Field LD. Transcapsular Decompression of Shoulder Ganglion Cysts. Arthrosc Tech. 2018;7(12):e1263-e1267. doi:10.1016/j.eats.2018.08.011.
57. Piyawinijwong S, Tantipoon P. The anterior coracoscapular ligament in Thais: possible etiological factor of suprascapular nerve entrapment. Siriraj Medical Journal. 2012;64:S12–S14.
58. Podgórski M, Topol M, Sibiński M, Domżalski M, Grzelak P, Polguj M. What is the function of the anterior coracoscapular ligament? - a morphological study on the newest potential risk factor for suprascapular nerve entrapment. Ann Anat. 2015;201:38-42. doi:10.1016/j.aanat.2015.06.005.
59. Polguj M, Jędrzejewski K, Majos A, Topol M. Coexistence of the suprascapular notch and the suprascapular foramen--a rare anatomical variation and a new hypothesis on its formation based on anatomical and radiological studies. Anat Sci Int. 2013a;88(3):156-162. doi:10.1007/s12565-012-0165-7.
60. Polguj M, Jędrzejewski K, Majos A, Topol M. Variations in bifid superior transverse scapular ligament as a possible factor of suprascapular entrapment: an anatomical study. Int Orthop. 2012;36(10):2095-2100. doi:10.1007/s00264-012-1618-2.
61. Polguj M, Jędrzejewski K, Podgórski M, Topol M. Morphometric study of the suprascapular notch: proposal of classification. Surg Radiol Anat. 2011;33(9):781-787. doi:10.1007/s00276-011-0821-y.
62. Polguj M, Jędrzejewski K, Topol M. Variable morphology of the anterior coracoscapular ligament - a proposal of classification. Ann Anat. 2013;195(1):77-81. doi:10.1016/j.aanat.2012.06.003.
63. Polguj M, Rożniecki J, Sibiński M, Grzegorzewski A, Majos A, Topol M. The variable morphology of suprascapular nerve and vessels at suprascapular notch: a proposal for classification and its potential clinical implications. Knee

Surg Sports Traumatol Arthrosc. 2015;23(5):1542-1548. doi:10.1007/s00167-014-2937-1.

64. Polguj M, Sibiński M, Grzegorzewski A, Grzelak P, Stefańczyk L, Topol M. Suprascapular Notch asymmetry: a study on 311 patients. Biomed Res Int. 2014a;2014:196896. doi:10.1155/2014/196896.
65. Polguj M, Sibiński M, Grzegorzewski A, Waszczykowski M, Majos A, Topol M. Morphological and radiological study of ossified superior transverse scapular ligament as potential risk factor of suprascapular nerve entrapment. Biomed Res Int. 2014b;2014:613601. doi:10.1155/2014/613601.
66. Polguj M, Synder M, Borowski A, Wojciechowski M, Wysiadecki G, Topol M. Anterior Coracoscapular Ligament as a Factor Predisposing to or Protective for Suprascapular Neuropathy. Biomed Res Int. 2016;2016:4134280. doi:10.1155/2016/4134280.
67. Prenaud C, Loubeyre J, Soubeyrand M. Decompression of the suprascapular nerve at the suprascapular notch under combined arthroscopic and ultrasound guidance. Sci Rep. 2021;11(1):18906. doi: 10.1038/s41598-021-98463-1.
68. Rabi S, Madhavi C. Case reports with special reference to the innervation, development and clinical significance of the subclavius posticus and the termination of the facial vein in South Indian cadavers. Eur J Anat. 2008;12:133-136.
69. Ravindran M. Two cases of suprascapular neuropathy in a family. Br J Sports Med. 2003;37(6):539-541. doi:10.1136/bjsm.37.6.539.
70. Rengachary SS, Burr D, Lucas S, Hassanein KM, Mohn MP, Matzke H. Suprascapular entrapment neuropathy: a clinical, anatomical, and comparative study. Part 2: anatomical study. Neurosurgery. 1979a;5(4):447-451. doi:10.1227/00006123-197910000-00007.
71. Rengachary SS, Neff JP, Singer PA, Brackett CE. Suprascapular entrapment neuropathy: a clinical, anatomical, and comparative study. Part 1: clinical

study. Neurosurgery. 1979b;5(4):441-446. doi:10.1227/00006123-197910000-00006.
72. Ringel SP, Treihaft M, Carry M, Fisher R, Jacobs P. Suprascapular neuropathy in pitchers. Am J Sports Med. 1990;18(1):80-86. doi:10.1177/036354659001800113.
73. Rubin DA. Nerve and Muscle Abnormalities. Magn Reson Imaging Clin N Am. 2020;28(2):285-300. doi:10.1016/j.mric.2019.12.010.
74. Schneider-Kolsky ME, Pike J, Connell DA. CT-guided suprascapular nerve blocks: a pilot study. Skeletal Radiol. 2004;33(5):277-282. doi:10.1007/s00256-003-0733-y.
75. Shi LL, Freehill MT, Yannopoulos P, Warner JJ. Suprascapular nerve: is it important in cuff pathology?. Adv Orthop. 2012;2012:516985. doi:10.1155/2012/516985.
76. Shupeck M, Onofrio BM. An anterior approach for decompression of the suprascapular nerve. J Neurosurg. 1990;73(1):53-56. doi:10.3171/jns.1990.73.1.0053.
77. Strauss EJ, Kingery MT, Klein D, Manjunath AK. The Evaluation and Management of Suprascapular Neuropathy. J Am Acad Orthop Surg. 2020;28(15):617-627. doi:10.5435/JAAOS-D-19-00526.
78. Tasaki A, Nimura A, Mochizuki T, Yamaguchi K, Kato R, Sugaya H, Akita K. Anatomic observation of the running space of the suprascapular nerve at the suprascapular notch in the same direction as the nerve. Knee Surg Sports Traumatol Arthrosc. 2015;23(9):2667-2673. doi:10.1007/s00167-014-3129-8.
79. Taskaynatan MA, Ozgul A, Aydemir K, Koroglu OO, Tan AK. Accuracy of ultrasound-guided suprascapular nerve block measured with neurostimulation. Rheumatol Int. 2012;32(7):2125-2128. doi:10.1007/s00296-011-1948-1.
80. Tender GC, Kline DG. Anterior Supraclavicular Approach to the Brachial Plexus. Oper Neurosurg. 2006;58(4):360-365. doi:10.1227/01.NEU.0000209027.52848.A3.

81. Tubbs RS, Nechtman C, D'Antoni AV, Shoja MM, Mortazavi MM, Loukas M, Rozzelle CJ, Spinner RJ. Ossification of the suprascapular ligament: A risk factor for suprascapular nerve compression?. Int J Shoulder Surg. 2013;7(1):19-22. doi:10.4103/0973-6042.109882.
82. Ulusoy OL, Alis D, Oz A, Barlas SB, Sokmen BK, Sever S, Mutlu A, Colakoglu B. The prevalence and characteristics of the subclavius posticus muscle in the adult population on MRI. Surg Radiol Anat. 2018;40(10):1141-1145. doi:10.1007/s00276-018-2065-6.
83. Urgüden M, Ozdemir H, Dönmez B, Bilbaşar H, Oğuz N. Is there any effect of suprascapular notch type in iatrogenic suprascapular nerve lesions? An anatomical study. Knee Surg Sports Traumatol Arthrosc. 2004;12(3):241-245. doi:10.1007/s00167-003-0442-z.
84. Vij N, Fabian I, Hansen C, Kasabali AJ, Urits I, Viswanath O. Outcomes after minimally invasive and surgical management of suprascapular nerve entrapment: A systematic review. Orthop Rev (Pavia). 2022;14(3):37157. doi: 10.52965/001c.37157.
85. Ward PJ. Scapula. in: Tubbs SR, Shoja MM, Loukas M. Bergman's comprehensive encyclopedia of human anatomic variation. Wiley-Blackwell, Hoboken, NJ. 2016; pp. 40-50.
86. Yamakado K. Quantification of the learning curve for arthroscopic suprascapular nerve decompression: an evaluation of 300 cases. Arthroscopy. 2015;31(2):191-196. doi:10.1016/j.arthro.2014.08.029.
87. Yildizgören MT. Ultrasonographic Diagnosis and Treatment of Suprascapular Neuropathy Secondary to Ganglion Cyst. J Med Ultrasound. 2020;29(3):221-222. doi:10.4103/JMU.JMU_63_20.
88. Zehetgruber H, Noske H, Lang T, Wurnig C. Suprascapular nerve entrapment. A meta-analysis. Int Orthop. 2002;26(6):339-343. doi:10.1007/s00264-002-0392-y.

10. Publications *in extenso*

1. **Al-Redouan, Azzat**; Benes, Michal; Abbaspour, Ehsan; Kunc, Vojtech; Kachlik, David. **Prevalence and anatomy of the anomalous subclavius posticus muscle and its clinical implications with emphasis in neurogenic thoracic outlet syndrome: Scoping review and meta-analysis.** Annals of Anatomy. 2023; 247:152046. ISSN 0940-9602. DOI: 10.1016/j.aanat.2023.152046. IF 2.2/2022 (Q2)
2. **Al-Redouan, Azzat**; Holding, Keiv; Kachlik, David. **"Suprascapular canal": Anatomical and topographical description and its clinical implication in entrapment syndrome.** Annals of Anatomy. 2021; 233:151593. ISSN 0940-9602. DOI: 10.1016/j.aanat.2020.151593. IF 2.26/2022 (Q2).
3. **Al-Redouan, Azzat**; Hudak, Radovan; Nanka, Ondrej; Kachlik, David. **The morphological stenosis pattern of the suprascapular notch is revealed yielding higher incidence in the discrete type and elucidating the inevitability of osteoplasty in horizontally oriented stenosis.** Knee Surgery, Sports Traumatology, Arthroscopy. 2021;29(7):2272-2280. ISSN 0942-2056. DOI:10.1007/s00167-020-06168-1. IF 3.8/2022 (Q1).
4. **Al-Redouan, Azzat**; Kachlik, David. **Scapula revisited: new features identified and denoted by terms using consensus method of Delphi and taxonomy panel to be implemented in radiological and surgical practice.** Journal of Shoulder and Elbow Surgery. 2022; 31(2):e68-e81. ISSN: 1058-2746. DOI: 10.1016/j.jse.2021.07.020. IF 3.0/2022 (Q2)
5. **Al-Redouan, Azzat**; Salavova, Sarka; Cvrček, Jan; Velemínská, Jana; Velemínský, Petr; Kachlik, David. **Osseous suprascapular canal: rare variant that would hinder suprascapular nerve block and posterior surgical approach.** Surgical and Radiological Anatomy. 2022; 44(12), 1507–1511. ISSN: 1279-8517. DOI: 10.1007/s00276-022-03045-z. IF 1.4/2022 (Q3)

LETTERS TO EDITORS

1. **Al-Redouan, Azzat**; Kachlik, David. **Suprascapular notch cross-sectional area by MRI do not yield accuracy in the diagnosis of suprascapular nerve entrapment - counter point of view.** Korean Journal of Anesthesiology. 2022; 75(6):536-538. ISSN:2005-7563. DOI: 10.4097/kja.22413. IF 2.9/2022 (Q2)
2. **Al-Redouan, Azzat**; Kachlik, David. Letter to the Editor: **Commentary to "Morphometry and Contents of the Suprascapular Notch with Potential Clinical Implications: A Cadaveric Study".** Journal of Brachial Plexus and Peripheral Nerve Injury. 2022; 17(01): e10-e11. ISSN: 1749-7221. DOI: 10.1055/s-0042-1747960.
3. **Al-Redouan, Azzat**; Kachlik, David. **In regard to "Unusual case of absence of suprascapular notch and foramen".** European Journal of Anatomy. 2021; 25(2):253-254. ISSN: 2340-311X.
4. **Al-Redouan, Azzat**; Kachlik, David. Letter to the Editor: **Commentary to "Anatomical Variations of the Suprascapular Notch and its Importance in Suprascapular Entrapment Neuropathy".** MAEDICA – a Journal of Clinical Medicine. 2021; 16(2):332-333. ISSN: 1841-9038. DOI: 10.26574/maedica.2021.16.2.332.
5. **Al-Redouan, Azzat**; Kachlik, David. Letter to the Editor: **Regarding "An Unusual Bilateral Duplication of the Suprascapular Vein and Its Relation to the Superior Transverse Scapular Ligament Revealed by Anatomage Table".** Acta Medica Academica. 2020; 49(3):297-298. ISSN: 1840-2879. DOI: 10.5644/ama2006-124.320.

11. Conference abstracts *in extenso*

INDEXED CONFERENCE ABSTRACTS

1. **Al-Redouan, Azzat**; Hudak, Radovan; Kachlik; David. **Morphological stenosis pattern of suprascapular notch in human concerning suprascapular nerve anatomical entrapment**. In: Proceedings of the 19th Congress of the International Federation of Anatomists (IFAA); 2019 Aug 9-11. London, UK. Journal of Anatomy. 2020, 236(1):295-296. ISSN: 0021-8782. DOI: 10.13140/RG.2.2.19149.79844. IF 2.638/2018 (Q1)

CONFERENCE PRESENTATIONS – Oral

1. **Al-Redouan, Azzat**; Theodorakioglou, Aimilia; Shailesh, Deeksha; Sadat, Mehdi S.; Raposo da Fonte, Pilar D.; Glazer, Omer; Hofmann, Ida; Kriskova, Petra; Kachlik, David. **Ultrasound Protocol to Visualize the Suprascapular Notch Anatomy: A Diagnostic Algorithm in Detecting Suprascapular Notch Stenosis**. the 20th Congress of the International Federation of Anatomists; Sep 8/2024. IFAA 2024 Gwangju, South Korea.
2. **Al-Redouan, Azzat**; Theodorakioglou, Aimilia; Shailesh, Deeksha; Sadat, Mehdi S.; Raposo da Fonte, Pilar D.; Glazer, Omer; Kriskova, Petra; Kachlik, David. **Suprascapular notch cross-sectional area on MRI is not highly accurate in the diagnosis of suprascapular nerve entrapment in comparison to sonography**. The 15th International Symposium Clinical and Applied Anatomy; Jun 30/2024. ISCAA 2024 Swansea wales.
3. **Al-Redouan, Azzat**; Sadat, Mehdi S.; Theodorakioglou, Aimilia; Shailesh, Deeksha; Hofmann, Ida; Kachlik, David. **Enhancing ultrasound visibility of the suprascapular notch as a diagnostic algorithm for suprascapular notch stenosis.** The 14th International Symposium Clinical and Applied Anatomy; Sep 14/2023. ISCA 2023 Prague, Czech Republic.
4. **Al-Redouan, Azzat**; Kachlik, David. **The potentials of using the consensus method of Delphi in absolving discrepancy in anatomical classifications and terminology.** The 54th International Congress of the

Czech Anatomical Society; Sep 9/2023. Morphology 2023 Martin, Slovakia.

5. **Al-Redouan, Azzat**; Sadat, Mehdi S.; Theodorakioglou, Aimilia; Benes, Michal; Holding, Keiv; Zhauyrova, Madina; Nesterenko, Polina; Kunc, Vojtech; Salavova, Sarka; Hudak, Radovan; Nanka, Ondrej; Kachlik, David. **Comprehensive view of the suprascapular notch topographical variation as it applies into its suprascapular notch stenosis and surgical feasibility in suprascapular nerve entrapment.** The 13th International Symposium Clinical and Applied Anatomy; Sep 16/2022**.** ISCAA 2022 Vilamoura- Algarve, Portugal.
6. **Al-Redouan, Azzat**; Kachlik, David. **Scapula: new anatomical terminology to be implemented in radiological and surgical practice.** The 53rd International Congress of the Czech Anatomical Society; Sep 11/2022. Morphology 2022. Hradec Kralove, Czech Republic.
7. **Al-Redouan, Azzat**; Holding, Keiv; Kachlik, David. **Suprascapular canal": Anatomical and topographical description and its clinical implication in entrapment syndrome.** The 52nd International Congress of the Czech Anatomical Society; Sep 10/2021**.** Morphology 2021 Prague, Czech Republic.
8. **Al-Redouan, Azzat**; Holding, Keiv; Kachlik, David. **"Suprascapular canal": Anatomical and topographical description and its clinical implication in entrapment syndrome.** The Second Faculty/Motol Scientific Conference; Oct 2/2020. 2020 Prague, Czech Republic.

CONFERENCE PRESENTATIONS – Posters

1. **Al-Redouan, Azzat**; D'Souza, Ayrton; Kachlik, David. **Scapula revisited: new features identified and denoted by terms using consensus method of delphi to be implemented in radiological and surgical practice.** The

Second Faculty/Motol Scientific Conference; Nov 2/2023. 2023 Prague, Czech Republic.

2. **Al-Redouan, Azzat**; Sadat, Mehdi S.; Benes, Michal; Theodorakioglou, Aimilia; Kunc, Vojtech; Kachlik, David. **Suprascapular notch muscular variations intervening with arthroscopic feasibility in suprascapular nerve decompression.** The Second Faculty/Motol Scientific Conference; Nov 2/2023. 2023 Prague, Czech Republic.
3. **Al-Redouan, Azzat**; Bash, Shayan; Benes, Michal; Abbaspour, Ehsan; Kunc, Vojtech; Kachlik, David. **Prevalence and anatomy of the variant subclavius posticus muscle and its clinical implications.** The Second Faculty/Motol Scientific Conference; Nov 2/2023. 2023 Prague, Czech Republic.
4. **Al-Redouan, Azzat**; Raposo da Fonte, Pilar Dominguez; Kachlik, David. **Suprascapular notch cross-sectional area on mri is not highly accurate in the diagnosis of suprascapular nerve entrapment.** The Second Faculty/Motol Scientific Conference; Nov 2/2023. 2023 Prague, Czech Republic.
5. **Al-Redouan, Azzat**; Theodorakioglou, Aimilia; Olson, Carl V.L.; Sadat, Mehdi; Hudak, Radovan; Abbaspour, Ehsan; Salavova, Sarka; Whitley, Adam; Kachlik, David. **A call to unify a morphometric practical approach to the suprascapular notch shape classitfication as base for detecting suprascapular notch stenosis.** The Second Faculty/Motol Scientific Conference; Nov 2/2023. 2023 Prague, Czech Republic.
6. **Al-Redouan, Azzat**; Shailesh, Deeksha; Sadat, Mehdi; Theodorakioglou, Aimilia; Hofmann, Ida; Raposo da Fonte, Pilar Dominguez; Kachlik, David. **Enhancing ultrasound visibility of the suprascapular notch as a diagnostic algorithm for suprascapular notch stenosis.** The Second Faculty/Motol Scientific Conference; Nov 2/2023. 2023 Prague, Czech Republic.

7. **Al-Redouan, Azzat**; Benes, Michal; Theodorakioglou, Aimilia; Sadat, Mehdi; Kunc, Vojtech; Kachlik, David. **Suprascapular notch muscular variations intervening with arthroscopic feasibility in Suprascapular Nerve Decompression**. The 53rd International Congress of the Czech Anatomical Society; Sep 11/2022. Morphology 2022 Hradec Kralove, Czech Republic.
8. **Al-Redouan, Azzat**; Benes, Michal; Sadat, Mehdi; Theodorakioglou, Aimilia; Abbaspour, Ehsan; Kunc, Vojtech; Kachlik, David. **Prevalence and anatomy of the variant subclavius posticus muscle and its clinical implications**. The 53rd International Congress of the Czech Anatomical Society; Sep 11/2022. Morphology 2022 Hradec Kralove, Czech Republic.
9. **Al-Redouan, Azzat**; Sadat, Mehdi; Theodorakioglou, Aimilia; Holding, Keiv; Belbl, Miroslav; Naňka, Ondřej; Kachlik, David. **Mapping the suprascapular notch topographical variations as a guidance to ultrasound imaging.** The 52nd International Congress of the Czech Anatomical Society; Sep 10/2021. Morphology 2021 Prague, Czech Republic.
10. **Al-Redouan, Azzat**; Salavova, Šarka; Theodorakioglou, Aimilia; Čvrcek, Jan; Velemínská, Jana; Velemínský, Petr; Kachlik, David. **Suprascapular osseous canal enclosing the passage between the suprascapular and spinoglenoid notches would hinder suprascapular nerve block and posterior surgical approach: Case report.** The 52nd International Congress of the Czech Anatomical Society; Sep 10/2021. Morphology 2021 Prague, Czech Republic.
11. **Al-Redouan, Azzat**; Holding, Keiv; Ondrej Nanka; Kachlik, David. **Mapping the suprascapular notch topographical variations as a guidance to ultrasound imaging.** The Second Faculty/Motol Scientific Conference; Oct 2/2020. 2020 Prague, Czech Republic.

12. **Al-Redouan, Azzat**; Kachlik, David. **Scapula- New anatomical terms of not yet described structures: A modified Delphi approach**. The 45th International Congress of the Slovak Anatomical Society; Sep 6/2019. Morphology 2019 Štrbské Pleso, Slovakia.
13. **Al-Redouan, Azzat**; Hudak, Radovan; Kachlik, David. **Morphological stenosis pattern of the suprascapular notch and potential risk of the suprascapular nerve anatomical entrapment according to its variant types.** The Second Faculty/Motol Scientific Conference; Apr 22/2019. 2019 Prague, Czech Republic.