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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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Prague, 2024

DECLARATION STATEMENT

I declare that I have prepared my thesis independently and that I have properly listed and cited all sources and literature used. I also declare that the thesis has not been used to obtain another or the same degree. I agree to the permanent storage of the electronic version of my thesis in the database of the inter-university project Theses.cz for the purpose of continuous checking of the similarity of qualifying theses.

Prague, June 15, 2024 **MUDr. Azzat Al-Redouan**

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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

ABSTRAKT

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 u stenóza 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 byl částečně zakryto úponem *musculus omohyoideus* svalem 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.

LIST OF ABBREVIATIONS

IFSM – infraspinatus muscle

INFF – infraspinous fossa

OMHM – omohyoid muscle

SA – suprascapular artery

SGF – spinoglenoid fossa

SGL – spinoglenoid ligament

SGN – spinoglenoid notch

SN – suprascapular nerve

SNE – suprascapular nerve entrapment

SPM – subclavius posticus muscle

SSC – suprascapular canal

SSL – suprascapular ligament

SSN – suprascapular notch

SUBF – subscapular fossa

SUBM – subscapularis muscle

SUPF – supraspinous fossa

SUPM – supraspinatus muscle

SV – suprascapular vein

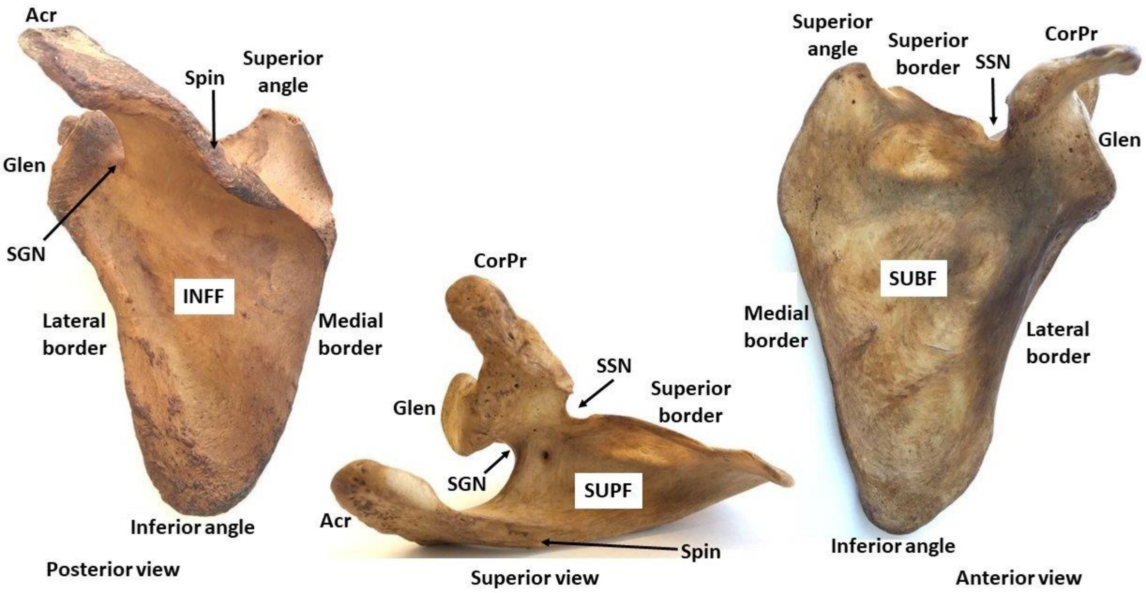
TA – Terminologia Anatomica

CONTENTS

1. INTRODUCTORY SURVEY

The scapula is a flat bone (Figure 1) anchoring the shoulder onto the dorsal aspect of the trunk via muscular attachments on its medial border, superior angle and spine of the scapula and thus forming a unique "muscular joint" in the human body (thoracoscapular joint) (Paine and Voight, 1993; Williams et al., 1999; Halder et al., 2000; Frank et al., 2013; Osias et al., 2018). On the other aspect, it forms the shoulder girdle along with the humerus and clavicle where its glenoid fossa articulates with the head of the humerus forming the glenohumeral (shoulder) joint and its acromion articulates with the acromial (lateral) end of the clavicle forming the acromioclavicular joint. From the anterior (costal) and posterior surfaces as well as the lateral margin of the scapula originate muscles involved in the shoulder movements alongside other muscles (Culham E, Peat, 1993; Paine and Voight, 1993; Williams et al., 1999; Halder et al., 2000; von Schroeder et al., 2001; Lambert, 2016; Osias et al., 2018).

Figure 1. The scapula – main structures overview.



Legend: Arc – acromion, CorP – coracoid process, Glen – glenoid, INFF – infraspinous fossa, SGN – spinoglenoid notch, Spi – spine of scapula, SSN – suprascapular notch, SUBF – subscapular fossa, SUPF – supraspinous fossa.

The scapula contains complex structures (Figure 1) on its lateral angle, namely the glenoid, coracoid process and acromion. The spine of the scapula divides its posterior surface into supraspinous fossa (SUPF) and infraspinous fossa (INFF) where two of the four rotator cuff muscles, supraspinatus muscle (SUPM) and infraspinatus muscle (INFM), originate. On the opposite side, the scapula exhibits a concave anterior (costal) surface forming the subscapular fossa (SUBF) where the rotator cuff subscapularis muscle (SUBM) originates occupying the entire SUBF (Mallon et al., 1992; Paine and Voight, 1993; von Schroeder et al., 2001; Lambert, 2016). The SUPF is a central focus of this investigation. It contains the suprascapular notch (SSN) which is an indentation on the superior border of the scapula, enclosed in most cases by the suprascapular ligament (SSL), while in other cases it can have the shape of a foramen enclosed by an ossified SSL (Ward, 2016). Inferiorly, the SUPF communicates with the INFF via the spinoglenoid notch (SGN) which resides underneath the margin of the spine of the scapula and is enclosed by the spinoglenoid ligament (SGL). The nerve of our focus, the suprascapular nerve (SN), courses between these two notches underneath the SUPM to reach its target of innervation. It innervates the SUPM and the INFM, as well as two-thirds of the shoulder joint capsule (Lambert, 2016; Vorster et al., 2008; Shin et al., 2010; Ebraheim et al., 2011; Hermenegildo et al., 2014; Laumonerie et al., 2019a). This forms a topographical space composed of morphologically variable structures. The course of the vessels running in this area can be substantially different. Thesuprascapular artery (SA) and suprascapular vein (SV) vary in number as well as their course at the SSN (Rengachary et al., 1979b; Demirhan et al., 1998; Avery et al., 2002; Dargaud et al., 2002; Bayramoglu et al., 2003; Demirkan et al., 2003; Urgüden et al., 2004; Duparc et al., 2010; Ebraheim et al., 2010; Chen and Adds, 2011; Polguj et al., 2011a; Polguj et al., 2011b; Yang et al., 2012; Polguj et al., 2013a; Polguj et al., 2013b; Polguj et al., 2013c; Tubbs et al., 2013; Inoue et al., 2014; Kumar et al., 2014; Polguj et al., 2014a; Polguj et al., 2014b; Won et al., 2014; Podgórski et al., 2015; Ward, 2016; Labetowicz et al., 2017; Yang et al., 2019; Zhang et al., 2019; Bagoji et al., 2020). The SSN exhibits diverse shapes and contents. As the SN runs through the aforementioned topographical sites it passes through varying narrow anatomical spaces causing it to be vulnerable to anatomical compression at multiple sites (Ringel et al., 1990; Post and Grinblat, 1992; Cummins et al., 2000; Zehetgruber et al., 2002; Ravindran, 2003; Duparc et al., 2010; Nakazawa et al., 2011; Moen et al., 2012; Waldman, 2014; Tasaki et al., 2015; Yamakado, 2016; Kostretzis et al., 2017; Labetowicz et al., 2017).

Suprascapular nerve entrapment (SNE) is a rather common lesion with a prevalence of 2% (Zehetgruber et al., 2002). It affects two distinctive demographical groups, one being the elderly due to generalized shoulder aging and weakness, and the other group are athletes playing certain types of sports that exhort overhand strenuous motion, such as volleyball players and swimmers (Ravindran, 2003; Moen et al., 2012; Shi et al., 2012; Paine and Voight, 1993; Memon et al., 2019; Garrison et al., 2021). The SNE manifests as vague pain radiating over the shoulder joint stemming from the SN somatosensory area, and muscular atrophy associated with weakness of the supraspinatus and infraspinatus muscles as a manifestation of the compromised somatomotor supply (Curnow, 1873; Wang et al., 1996; Zehetgruber et al., 2002; Leschingera et al., 2017; Kostretzis al., 2017; Fabis-Strobin et al., 2018; Rubin, 2020).

1.1. Survey of literature and overview of the problem – History of investigation

The anatomical passage where the SN courses between the SSN and the 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). It appeared first in the literature by Cummins et al., 2000 and documented later on by Tasaki et al., 2015. Duparc et al., 2010 had described it in a cadaveric study as an osteofibrous canal with emphasis on the role of the SUPM fascia in pathological conditions causing SN entrapments by adhesive fibrous tissue. However, the term "osteofibrous canal" addressed by Duparc et al., 2010 has been neither codified as a designated official term nor incorporated into the Terminologia Anatomica (TA) (FIPAT, 2019). The described boundaries by the aforementioned authors addressing a passage between the SSN and SGN covered by the SUPS do not offer a sufficient description of its full morphological topography as well as a solidified description of its contents.

The SSN received more attention throughout the literature with controversial findings and descriptions in regard to its shape and type classifications (Hrdlicka, 1942; Rengachary et al., 1979a; Urgüden et al., 2004; Natsis et al., 2007; Sinkeet et al., 2010; Iqbal et al., 2011; Polguj et al., 2011a; Albino et al., 2013; Inoue et al., 2014; Kannan et al., 2014; Kumar et al., 2014; Agrawal et al., 2015; Jezierski et al., 2017; Zhang et al., 2019; Bagoji et al., 2020; Inoue et al., 2021) as well as its contents (Demirhan et al., 1998; Avery et al., 2002; Dargaud et al., 2002; Bayramoglu et al., 2003; Urgüden et al., 2004; Chen and Adds, 2011; Polguj et al., 2012a; Polguj et al., 2012b; Yang et al., 2012; Polguj et al., 2013a; Polguj et al., 2013b; Polguj et al., 2013c; Tubbs et al., 2013; Polguj et al., 2014a; Polguj et al., 2014b; Podgórski et al., 2015; Polguj et al., 2015; Polguj et al., 2016; Labetowicz et al., 2017; Zhang et al., 2019). On the other side, the SGN was described in a sufficient matter with more concurrent findings (Demirkan et al., 2003; Duparc et al., 2010; Ebraheim et al., 2010; Yang et al., 2019; Won et al., 2014). The SN entrapment at the SGN is more understood than at the SSN (Ringel et al., 1990; Post and Grinblat, 1992; Demirhan et al., 1998; Cummins et al., 2000; Zehetgruber et al., 2002; Demirkan et al., 2003; Ravindran, 2003; Duparc et al., 2010; Moen et al., 2012; Waldman, 2014; Won et al., 2014; Tasaki et al., 2015; Kostretzis et al., 2017; Labetowicz et al., 2017; Yang et al., 2019).

1.1.1. The course of the suprascapular nerve

The SN originates from C5-C6 segments of the spinal cord and belongs to the supraclavicular part of the brachial plexus. It takes a ramping course deep in the omoclavicular triangle running in a retroclavicular direction to enter the SSN under the SSL. Here, it takes a dorsolateral acute turn within the SUPF to run through the SGN under the SGL (Lambert, 2016). This passage between the SSN and SGN was not well elaborated on in the literature (Cummins et al., 2000; Duparc et al., 2010; Tasaki et al., 2015) as mentioned above in Section 1.1.

1.1.2. The morphology of the suprascapular notch

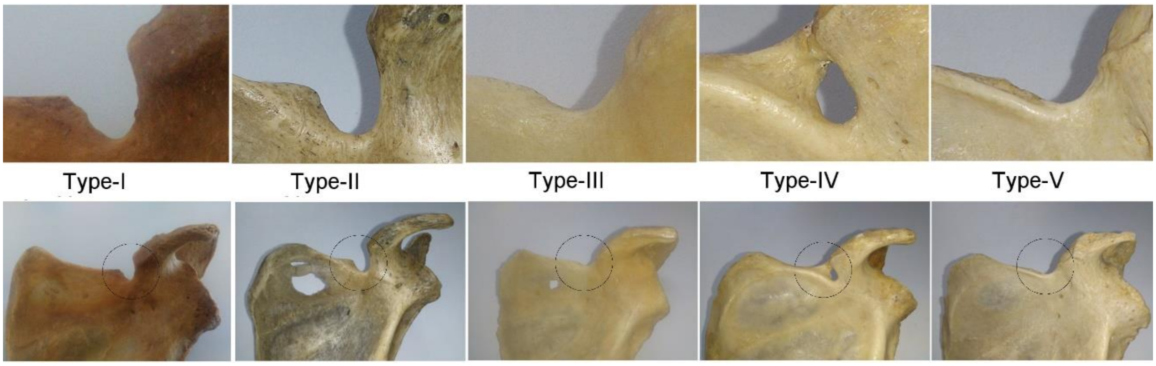
As aforementioned in the Introduction, the SSN is enclosed by the SSL in most cases and enclosed by ossified tissue in other cases forming a foramen. A SSN foramen has been regarded as an anatomical variant rather than a type in major anatomy textbook references (Lambert, 2016; Ward, 2016). It is rather a common variant which should be considered as major type (Hrdlicka, 1942; Rengachary et al., 1979a; Rengachary et al., 1979b; Urgüden et al., 2004; Natsis et al., 2007; Sinkeet et al., 2010; Iqbal et al., 2011; Polguj et al., 2011a; Albino et al., 2013; Inoue et al., 2014; Kannan et al., 2014; Kumar et al., 2014; Agrawal et al., 2015; Jezierski et al., 2017; Zhang et al., 2019; Bagoji et al., 2020).

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., 2011a; Iqbal et al., 2011; Kumar et al., 2014; Jezierski et al., 2017) and the other one is based on subjective observation of the SSN shape (Hrdlicka, 1942; Rengachary et al., 1979a; Urgüden et al., 2004; Sinkeet et al., 2010; Albino et al., 2013; Inoue et al., 2014; Kannan et al., 2014; Agrawal et al., 2015; Zhang et al., 2019).

The morphometric system: The first method of measuring the SSN parameters was introduced by Natsis et al. (2007) where the classification was based on the SSN depth versus its width. Later on, Polguj et al. (2011a) proposed a modified classification system based also on the depth of the SSN but versus its superior width rather than the internal width suggested before by Natsis et al. (2007). Polguj et al. (2011a) categorized the SSN into five types as shown in Figure 2. These types are:

- 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 is opposite to Type-I 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.

Figure 2. Five recognized types of the suprascapular notch based on the morphometric system according to Polguj et al. (2011a)



Legend: Type-I (depth > superior width); Type-II (depth = superior width); Type-III (depth < superior width); Type-IV (foramen); Type-V (discrete).

The shape descriptive system: This system preceded the morphometric system and was first introduced by Hrdicka in 1942, describing the differing shapes of the SSN without categorizations into classes. Partial or complete SSL ossification is considered in this approach. Rengachary et al. (1979a) proposed the first SSN classification system based on visual observation featuring six types:

- Type-I describes a discrete SSN using the term “absent notch”.
- Type-II describes a blunted V-shape SSN.

- Type-III describes a U-shaped SSN with parallel margins.
- Type-IV describes a V-shaped SSN but is smaller in size compared to Type-II.
- Type-V describes a U-shaped SSN with a partially ossified SSL.
- Type-VI describes a U-shaped SSN with a completely ossified SLL exhibiting a foramen.

Type-V and VI focus on the gross appearance of the SSL ossification. However, a study by Bagoji et al. (2020) introduced an additional SSN type, described as a J-shaped SSN.

The morphometric approach is reproducible with less discrepancy than its counter method of visual observation. The proposed system by Polguj et al. (2011a) gained more popularity than the preceded system by Natsis et al. (2007) and is used in the literature with some modifications (Iqbal et al., 2011; Kumar et al., 2014; Jezierski et al., 2017). On the other hand, the non-morphometric approach proposed by Rengachary et al. (1979a) is widely used until today more than the morphometric system. The studies utilized the Rengachary's system showed a high discrepancy in data (Hrdlicka, 1942; Rengachary et al., 1979a; Urgüden et al., 2004; Sinkeet et al., 2010; Albino et al., 2013; Inoue et al., 2014; Kannan et al., 2014; Agrawal et al., 2015; Zhang et al., 2019). The term "absent SSN" describing a discrete SSN in this system is rather misleading and gives the notion of a non-existing notch. An absent SSN had been claimed in several studies (Ofusori et al., 2008; Pawar et al., 2015; Yun et al., 2018; Hegazy and Hegazy, 2020). An additional difference between these two systems is the consideration of the SSL ossification pattern. Partial or complete ossification of the SSL is a part of the Rengachary's classification system (Rengachary et al., 1979a). On the contrary, only a complete SSL ossification is considered in the morphometric classification system by Polguj et al. (2011a) and a partial ossification of the SSL does not change the SSN type. This strongly recalls the standardization of a practical SSN classification system.

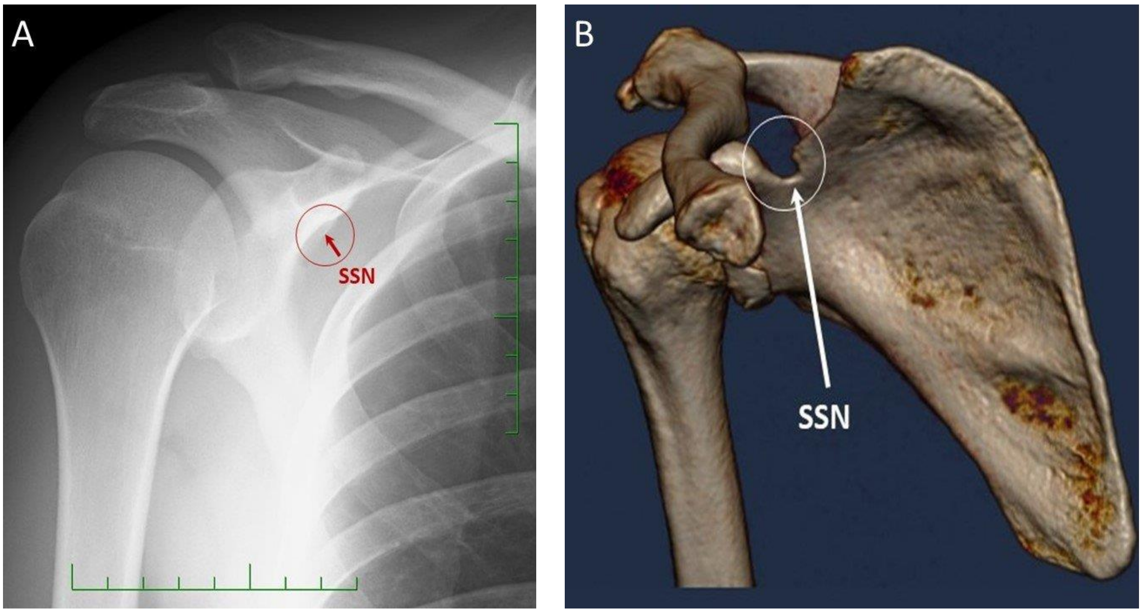
The understanding of the morphological influence of each SSN type on the risk of SNE has not been reached prior to this dissertation thesis (Al-Redouan et al., 2021b). Multiple contradictory hypotheses exist but have been neither confirmed nor reached an agreement (Bayramoglu et al., 2003; Urgüden et al., 2004; Polguj et al., 2013a; Polguj et al., 2014a; Tubbs et al., 2013). An in-depth redefinition of parameters is needed to analyze the internal space capacity of the SSN to accommodate the passing SN. Cadaveric dissections and observations have been done extensively but they lack precision of clinical implication in non-diseased cases (Avery et al., 2002; Bayramoglu et al., 2003; Demirkan et al., 2003; Duparc et al., 2010; Chen and Adds, 2011; Yang et al., 2012; Polguj et al., 2014b).

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., 2023a). Interestingly, the SSN can contain internal ligaments according to several reports in the literature (Avery et al., 2002; Polguj et al., 2013b; Gürses et al., 2015; Podgórski et al., 2015; Polguj et al., 2016). A misconception in the literature exists considering the 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. However, the foramina in other anatomical regions do not entrap the passing structures if not associated with localized stenosis. Even though, the SSL can impinge on the underlying SN (Rengachary et al., 1979a; Rengachary et al., 1979b; Avery et al., 2002; Zehetgruber et al., 2002; Duparc et al., 2010; Moen et al., 2012; Tubbs et al., 2013; Polguj et al., 2014b; Tasaki et al., 2015; Kostretzis et al., 2017), it is not the sole etiology. Therefore, the commonly used surgical approach of SSL release does not relieve the compression of the SN at the SSN in all cases (Rengachary et al., 1979b; Lafosse et al., 2007; Tasaki et al., 2015; Kostretzis et al., 2017; Zlotolow et al., 2019; Cano-Martínez et al., 2021). Apart from the osteofibrous composition of the SSN, the literature also reports variations in the contents of the SSN (Ringel et al., 1990; Yang et al., 2012; Polguj et al., 2014a; Labetowicz et al., 2017). The SA has been speculated whether it causes entrapment or it serves as a cushion to the SN when accompanying the SN in its course through the SSN underneath the SSL (Ringel et al., 1990; Labetowicz et al., 2017).

1.1.3. 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 as illustrated in Figure 3A.

Figure 3. Radiological imaging of the suprascapular notch. A) Anterior-posterior plain X-ray of a right shoulder. B) 3D reconstruction of a right shoulder CT.

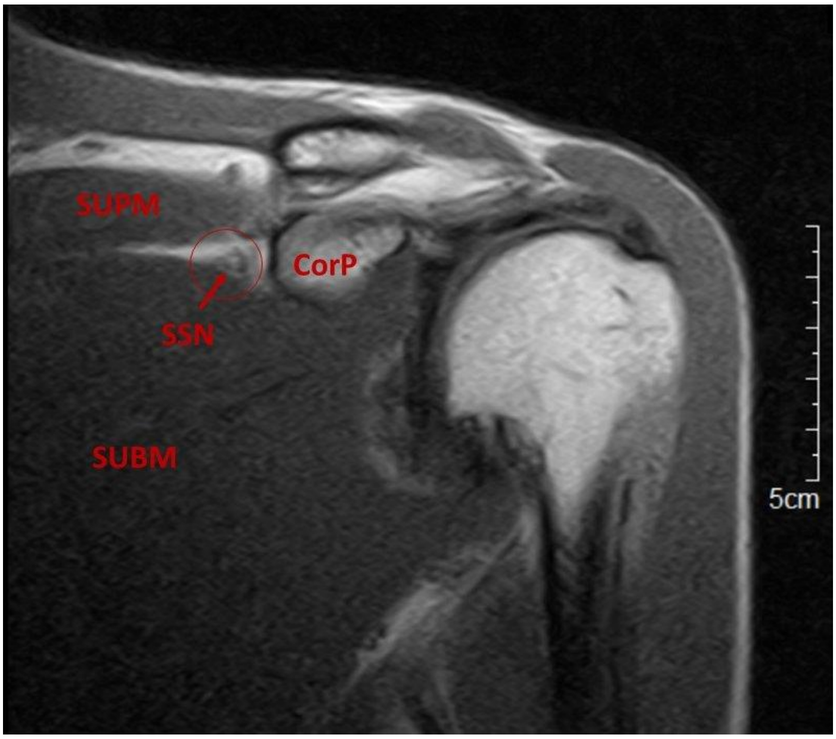


Legend: SSN – suprascapular notch

However, 3D-CT (three-dimensional computed tomography) reconstructions (Figure 3B) gives clear boundaries of the SSN resembling what can be seen on dry bones. Even though this imaging method gives an excellent visibility of the SSN, it has its limitation in regard to visualizing the passing SN with no interventional radiological methods such as fluoroscopy (Peng et al., 2010; Leider et al., 2012).

Even though the SSN is visible on magnetic resonance image (MRI), its borders cannot be captured on MRI sections since they do not align with the standardized MRI sectioning planes (Figure 4), that is why the suprascapular canal (SSC) and the SSN can be misinterpreted in MRI examinations (Wu et al., 2018).

Figure 4. Frontal section of a left shoulder T1-weighted magnetic resonance image (MRI).



Legend: CorP – coracoid process, SSN – suprascapular notch, SUBM – subscapularis muscle, SUPM – suprascapular muscle.

This applies to CT images as well. A misconception about labeling the SSN at an anatomically inaccurate site has been encountered in some articles (Park et al., 2022). Even though ultrasound examination gives the advantage of probe manual rotation to align the beam to transduce through the SSN vicinity, it still carries its obstacles (Chan and Pang, 2011; Fernandes et al., 2012; Yamakado, 2015; Laumonerie et al., 2017; Laumonerie et al., 2018; Kamal et al., 2018). These obstacles include the skills of the observer and the variability of the SSN contents adds more challenge to its visualization.

1.1.4. 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 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 (Post and Grinblat, 1992; Rengachary et al., 1979a; Rengachary et al., 1979b; Avery et al., 2002; Bayramoglu et al., 2003; Ofusori et al., 2008; Duparc et al., 2010; Ebraheim et al., 2010; Polguj et al., 2011a; Polguj et al., 2011b; Polguj et al., 2012a; Polguj et al., 2012b; Polguj et al., 2013a; Polguj et al., 2013b; Polguj et al., 2013c; Tubbs et al., 2013; Kumar et al., 2014; Podgórski et al., 2014; Polguj et al., 2012a; Polguj et al., 2014b; Sangam and Devi, 2014; Waldman, 2014; Podgórski et al., 2015; Polguj et al., 2015; Polguj et al., 2016; Labetowicz et al., 2017; Leschingera et al., 2017; Bagoji et al., 2020; Bagoji et al., 2021). It was a major interest in this thesis to localize those anatomical sites and describe the morphological patterns and correlations of structures. Visualizing the SN remains a challengeable task by ultrasound and MRI (Peng et al., 2010; Laumonerie et al., 2017; Kamal et al., 2018; Laumonerie et al., 2018; Ulusoy et al., 2018; Katsuura et al., 2019; Laumonerie et al., 2019b; Laumonerie et al., 2019b; Podgórski et al., 2019; Yildizgören, 2020; Park et al., 2022; Prenaud et al., 2021). This generates an obstacle in diagnosing the anatomical entrapment when the boundaries are not projected on the image.

The SNE is commonly treated by nerve blocks yielding temporary relief (Schneider-Kolsky et al., 2004; Peng et al., 2010; Chan and Peng, 2011; Fernandes et al., 2012; Hill et al., 2014; Laumonerie et al., 2017; Laumonerie et al., 2018; Kamal et al., 2018; Laumonerie et al., 2019a; Laumonerie et al., 2019b) or surgically by SSL resection releasing the entrapped SN (Barwood et al., 2007; Lafosse et al., 2007; Barber, 2008; Memon et al., 2018; Zlotolow et al., 2019; Cano-Martínez 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., 2019a), 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. OUTLINE OF OBJECTIVES

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

This research will provide evidence of SSN variations with frequency of occurrence (Al-Redouan et al., 2021b). It will further contribute with detailed insight into the morphology of the scapular region and refine the understanding of the SN course topographically (Al-Redouan et al., 2021a). It aimed to define the morphological pattern of each site that carries a potential risk of anatomical stenosis and entrapment with emphasis on the SSN space parametric variation and its correlation to accommodate the passing SN. Ultimately, we provide a sonographic stepwise approach to evaluate the SSN stenosis with more precision.

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. DESCRIPTION OF THE EXPERIMENTAL METHODS

The project consisted of three phases as stated above in Section 2 and detailed below. First, dry bones were observed with parametric measurements; second, cadaveric dissections were performed and their observations were documented; third, MRI and ultrasound images were evaluated and described.

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. The observed material

3.1.1. Osteology observation

At the osteology level, the morphometric variations of the SSN were investigated on 333 unpaired dry scapulae of unknown age and sex from the anatomical specimens' collections of the Institute of Anatomy, First Faculty of Medicine, Charles University, Prague, Czech Republic; and 180 paired dry scapulae with recorded age and sex from a documented collection (Pachner, 1937) maintained and administered by the Department of Anthropology, National Museum, Prague, Czech Republic.

3.1.2. Cadaveric dissections and observation

The SSC was dissected and observed in 30 free limbs (15 right, 15 left) of unknown age and sex of cadaveric donors of the Institute of Anatomy, First Faculty of Medicine, Charles University, Prague, Czech Republic. The topographical relationships were described and documented with images. The vicinity and contents of the SSN were dissected and observed in 159 SSN cadaveric specimens (69 males: 55 bilateral SSNs, nine unilateral right SSNs, five unilateral left SSNs; 33 females: 23 bilateral SSNs, six unilateral right SSNs, four unilateral left SSNs; 57 unilateral free limbs: 31 right, 26 left) of the Institute of Anatomy, First Faculty of Medicine, Charles University, Prague, Czech Republic; the Department of Anatomy, Second Faculty of Medicine, Charles University, Prague, Czech Republic; and the Department of Anatomy, Third Faculty of Medicine, Charles University, Prague, Czech Republic. In addition, 115 SSN (48 males: 38 bilateral SSNs, six unilateral right SSNs, four unilateral left SSNs; 34 females: 26 bilateral SSNs, five unilateral right SSNs, three unilateral left SSNs; 34 unilateral free limbs: 16 right, 17 left) were dissected and observed in cadaveric specimens of the Institute of Anatomy, First Faculty of Medicine, Charles University, Prague, Czech Republic; and the Department of Anatomy, Second Faculty of Medicine, Charles University, Prague, Czech Republic, to study the adjacent muscles' relationship to the SSN boundaries. All the aforementioned specimens belonged to denoted cadavers of Central European origin, fixed with the classical formaldehyde method of unknown age and recorded sex in cases of full body cadavers. To be noted, the total number of observed specimens reflects the quantity of the SSNs and not the cadavers as a body count.

3.1.3. Imaging anatomical evaluation

The imaging evaluation 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) patients' database of the Department of Orthopaedic and Traumatology, Second Faculty of Medicine, Charles University and Motol University Hospital, Prague, Czech Republic. In addition, three CTs (adult males who suffered traffic accidents, ages 19, 23, and 47) were evaluated and twenty bilateral 3D-CT reconstructions (10 females and 10 males, age 19 to 67 (average ±43 age)) were observed. Further, two encountered dry scapulae carrying an ossified SSC variant were X-rayed and the internal interval of the SSC was evaluated by CT sections and published as case report series (Al-Redouan et al., 2023). These two cases were from the documented collection mentioned in Section 3.1.1. (Pachner, 1937) maintained and administered by the Department of Anthropology, National Museum, Prague, Czech Republic. One case belonged to a deceased 65 years-old male with an estimated height of 160 cm, and the second case belonged to a deceased 77 years-old male with an estimated height of 171 cm. 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. Both the CTs and MRIs were accessed from the patients' database of the Department of Orthopaedic and Traumatology, Second Faculty of Medicine, Charles University and Motol University Hospital, Prague, Czech Republic. All the above-mentioned samples were collected retrospectively from patients' records with a note on the diagnosed disorder, all patients' confidentiality was maintained and kept anonymous. Using the ultrasound imaging, the superior of the shoulder region was examined bilaterally in 20 young healthy volunteers (12 females and 8 males; average age ±21), with prior written consent.

3.1.4. Literature review and analysis

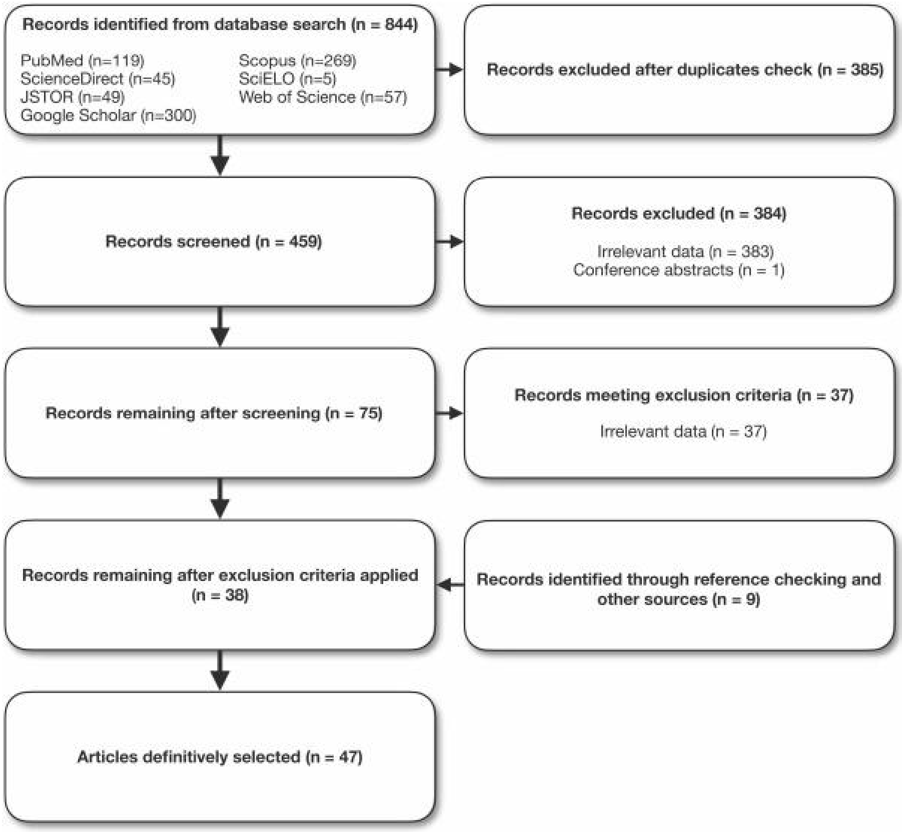
The literature review was conducted twice.

First, **a narrative review** was conducted to survey the reported SNE in the literature to investigate the described etiologies and study the potential anatomical related sites. The aim was to match incidences with the corresponding SSC site. 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), found in cadaveric as well as MRI studies (Macalister, 1871; Humphry, 1873; Curnow, 1873; Reid and Taylor, 1879; Knott, 1883; Mori, 1964; Wood, 1868; Anderson, 1982; Akita et al., 1996; Akita et al., 2000; Forcada et al., 2001; Kutoglu et al., 2005; Shetty et al., 2006; Martin et al., 2008; Rabi et al., 2008; Singhal et al., 2008; Kolpattil et al., 2009; Ozçakar et al., 2010; Piyawinijwong and Sirisathira, 2010; Smayra et al., 2014; Cogar et al., 2015; Muellner et al., 2015; Ciampi et al., 2017; Yun et al., 2017; Grigoriță et al., 2018; Liu et al., 2018; Moyano et al., 2018; Ulusoy et al., 2018; Erdogan et al., 2019; Pajaj et al., 2020; Bhavya et al., 2021; Diwan et al., 2022).

The scoping study was performed by the method proposed by Arksey and O'Malley (2005). This method entitles stepwise searching and exclusion criteria which assures reproducibility of results. The relevant keywords were generated according to the Medical Subject Headings (MeSH) terms indexing metrics (Rogers, 1963). These terms were then searched inall scientific databases, including PubMed, Scopus, ScienceDirect, SciELO, JSTOR, Web of Science, and Google Scholar (first 200 hits). The flow diagram in Figure 5 shows the stepwise process of screening and inclusion of the relevant literature.

Figure 5. Flow diagram of the literature selection process.



*Modified image, source: (*Al-Redouan et al., 2023)*.

The meta-analytic techniques were used to calculate the pooled prevalence estimates from the identified cohort studies as applicable. The meta-analysis was conducted with R programming language (*R Project for Statistical Computing, Austria*) using the package "meta" (Henry et al., 2015; Balduzzi et al., 2019) and in accordance to the PRISMA Extension for Scoping Reviews (PRISMA-ScR) issued by Tricco et al. (2018).

The work was published as a review article explaining the anatomy of the SPM and its involvement in neurogenic thoracic outlet syndrome in the scapular region (Al-Redouan et al., 2023).

3.1.5. Consensus method of Delphi

There were 16 encountered scapular structures with previously unidentified terminology and 13 with non-unified designated terms used controversially throughout the literature.

This called for a parallel study (Al-Redouan and Kachlik, 2022b) to redefine these structures and propose a less ambiguous terms. Among those terms, nine terms (Table 1) concerned the SSC (Figure 6) of which five are new terms described and proposed as part of this project, and four are revised terms that lack unity in terminology usage.

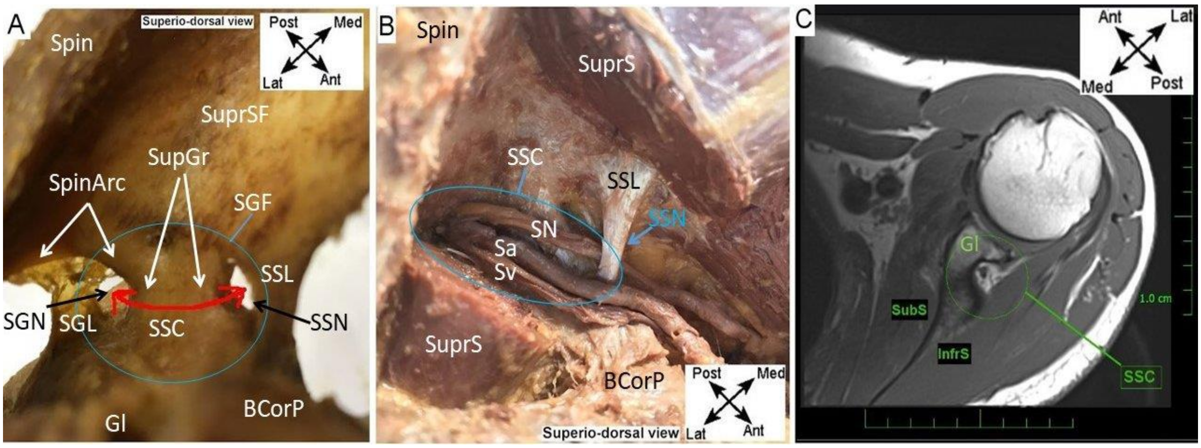
Table 1. Summary of the proposed terms with definitions and significance of use.

New Terms		
Suprascapular canal	***canalis suprascapularis***	A passage tunnel defined by its entrance site at the SSN and its exit site at the SGN. A core finding in this thesis.
Spinoglenoid fossa	***fossa spinoglenoidalis***	The fossa between the glenoid and the spine of the scapula where the SUPM is not in direct contact with the bone. It serves as the floor of the SSC.
Suprascapular groove	***sulcus suprascapularis***	A groove on the bone lying within the SGF extending between the SSN and the SGN where the neurovascular bundle resides.
Spinoacromial arch	***arcus spinoacromialis***	The transitional part interconnecting the spine of the scapula and the acromion. It serves as one of the SGN borders.
Base of coracoid process	***basis processus coracoidei***	The beginning of the coracoid process as it projects from the lamina of the scapula. It serves as the lateral bored of the SSN.
Revised Terms		
Suprascapular ligament	***ligamentum suprascapulare***	A fibrous, relatively thin ligament connecting the medial and lateral peaks of the SSN enclosing its vicinity (Lambert, 2016). The term "superior transverse scapular ligament" is used more commonly in classical textbooks and literature. However, the term "suprascapular ligament" is emerging in recent literature (Davis et al., 2019; Zlotolow et al., 2019) and matches the term for the suprascapular notch.
Suprascapular foramen	***foramen suprascapulare***	A varying morphological form of the SSN arises due to an ossified SSL (Polguj et al., 2011a). Defining this designated SSN type would eliminate possible confusion with other uncommon variants.
Spinoglenoid notch	***incisura spinoglenoidalis***	Bordered by the spinoacromial arch (proposed to be defined above) and the glenoid. It is enclosed by the SGL (officially termed inferior transverse ligament) superolaterally (Kachlik et al., 2016; Kachlik et al., 2017). A passage between the SUPF and INFF, where the SN and vessels travel distally.

Spinoglenoid ligament	***ligamentum spinoglenoidale***	A membranous bundle spanning from the lateral margin of the spine of the scapula to the glenoid limbus (Lambert, 2016) It encloses the SGN, a potential entrapment site of the SN. The term "spinoglenoid ligament" is used quite often in the literature (Demirkan et al., 2003; Duparc et al., 2010; Ebraheim et al., 2010; Yang et al., 2019; Won et al., 2014).

Legends: INFF – infraspinous fossa, SGF spinoglenoid fossa, SGN, spinoglenoid notch, SN – suprascapular nerve, SSC – suprascapular canal, SSN – suprascapular notch, SUPF – supraspinous fossa.

Figure 6. Illustration of the new and revised terms concerning the suprascapular canal.
A) Supero-posterior view of a right wet scapula. B) Supero-posterior view of a left shoulder cadaveric specimen. C) Transverse cross-section of a left shoulder T1-weighted magnetic resonance image.



Legend: BCorP – base of coracoid process, Gl – glenoid, Spin – spine of scapula, InfrS – infraspinatus muscle, Sa – suprascapular artery, SGF – spinoglenoid fosss, SGL – spinoglenoid ligament, SGN – spinoglenoid notch, SN – suprascapular nerve, SpinArc – spinoacromial arch, SSC – suprascapular canal (containing neurovascular bundle), SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupGr – suprascapular groove, SuprSF – supraspinous fossa, SupS – supraspinatus muscle, Sv – suprascapular vein.
Ant – anterior, Lat – lateral, Med – medial, Post – posterior.
*Modified image, source: A) (*Al-Redouan and Kachlik, 2022b)*; B and C) (*Al-Redouan et al., 2021a)*.

The peer consensus of the above-mentioned terms was obtained by applying the Delphi method in an electronic Google survey form composed of two rounds (Cantrill et al., 1996; Fink et al., 1984; McMillan et al., 2016; Humphrey-Murto et al., 2017). First, taxonomy panels and etymology of anatomical terminology were considered in generating the proposed terms (Table 1). Then, 21 nominees were selected based on the recommendation by Fink et al., 1984 to be within the range of 15 to 27 participants. The list of nominees was composed of recognized anatomy experts in medical schools' anatomy education, orthopedic clinicians and radiologists with teaching experience, and researchers with published and acknowledged work on the scapula. The nominees voted and commented on the proposed terms in the first round of the survey. The nominees then voted on re-adjusted terms in compliance with their previous expert feedback and recommendations. The level of consensus of each term was calculated from the second round results based on a scale from 1 to 7, and the outcome results were finally published (Al-Redouan and Kachlik, 2022b).

3.2. The experimentation design

The study consisted of an initial gross anatomical description of the dissected SSC aided by the reported cases in the literature. Based on our observation, the focus shifted to the SSN to investigate its anatomical correlation to the SNE, and further on we derived its clinical application in diagnostics and influence on its surgical release approaches. In addition, different radiographic modalities (X-rays, CT, MRI, ultrasound) were evaluated to assess the visibility of the SSC components with a focus on the SSN.

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

This area of interest was dissected and observed in two parallel approaches: a dorsal aspect to expose the SSC, and a frontal aspect to examine the SSN morphology and contents.

The suprascapular canal dissection

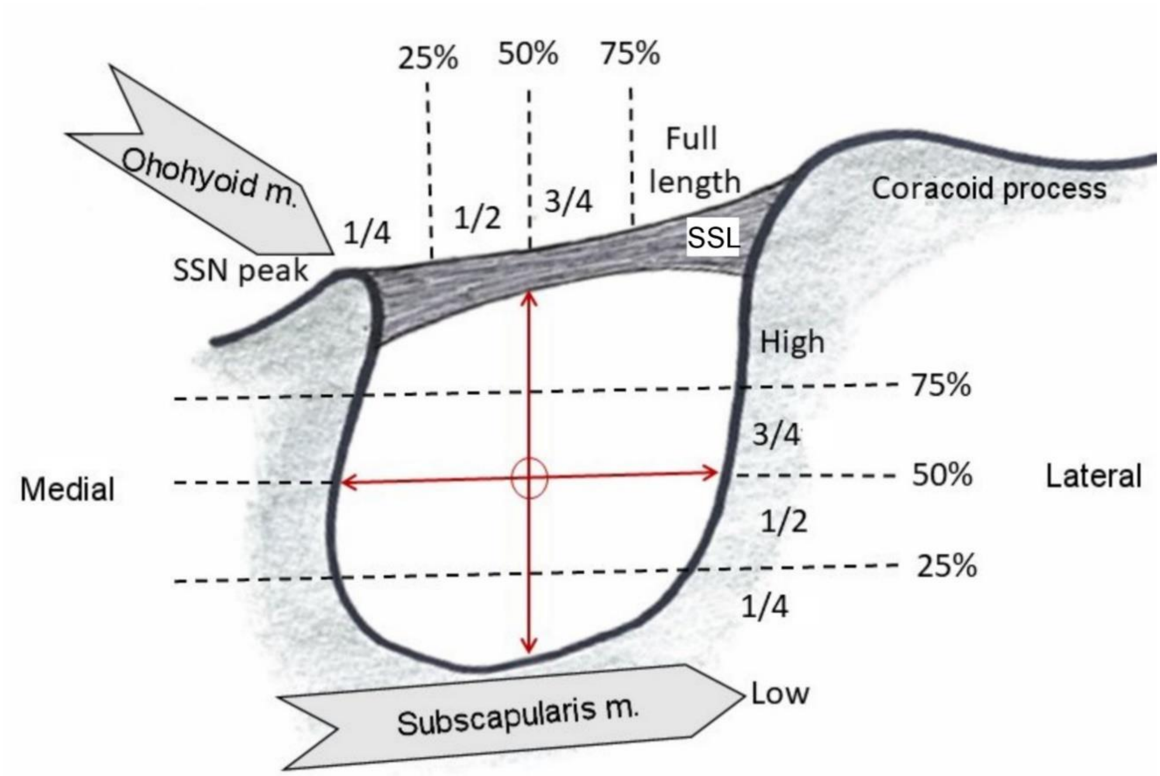
The dorsal aspect of the free limbs aforementioned in Section 3.2.1. was prepared first by reflecting the masking large muscles to reveal the underlying layer of interest where the SUPM and INFM are situated. The trapezius muscle was reflected medially by making an incision through its full insertion at the margin of the spine of the scapula, the acromion and the acromial end of the clavicle. The latissimus dorsi muscle was reflected laterally as it was freed prior to the dissection from its origin site. The SUPM was released from its origin by scrubbing its fibers from the surface of the SUPF and was carefully lifted to examine its underlying area which is the SGF including its contents. As we reflected the SUPM laterally towards its insertion, the full length of the SSC between the SSN and the SGN was exposed and all contents were made visible. However, different incision approach was performed in two selected specimens to maintain the SUPM origin and insertion while exposing only the SGF keeping the SUPF and subacromial space intact. In this approach, the roof of the SSC formed by the SUPM was removed by making two parallel incisions in a perpendicular plane to the muscle fibers of the SUPM, and the result of this view is shown in Figure 6B in Section 3.1.5. The neurovascular bundle was dissected and the passing suprascapular vessels running alongside the SN were quantified and measured. The relationship between the neurovascular bundles and the SSL were documented. The length of the full canal was measured in millimeters and rounded to the nearest first fraction of ±0.5 mm. The width of the canal was measured at three intervals: at the beginning of the SSC (post-the SSN), the widest midpoint, and at the end of the SSC (pre-SGN). The height and width of both the SSN and SGN were measured with the same numerical rounding to the nearest ±0.5 mm. Also, the same method of measurement was performed in measuring the length and width of the SSL and SGL. These aforementioned parametric measurements were taken by a *Vernier* caliper (size 150 mm) with an estimated ±0.2 mm range of accuracy, specified by the manufacturer (*Anyi Instrument Co. Guilin, China*).

The suprascapular notch dissection

The SSN frontal 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 tough sternoclavicular joint capsule and reflected laterally. The adipose tissue around the SSN was cleaned out ensuring clear visibility of the SSN boundaries and surrounding structures as well as its contents. Any SSN with accidentally damaged or lost structures was excluded. All structures were documented either schematically or photographed. Contents were described with notes on their relationships to each other with emphasis on how the suprascapular vessels pass in relation to the SN and to the SSL. The SA and SV were first quantified and their calibers at the SSN were measured by the same above described measuring tool and method. The vicinity of the SSN was measured by two major parameters: depth versus superior width. The SSL length, its lateral and medial widths were all measured as well.

The muscles surrounding the SSN were described as well. The omohyoid muscle (OMHM) and SUBM were specifically focused on since they have been noticed to intervene with the SSN vicinity which was evaluated by the illustrated diagram shown in Figure 7 and explained in the proceeding paragraph.

Figure 7. Illustration of the evaluated 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.

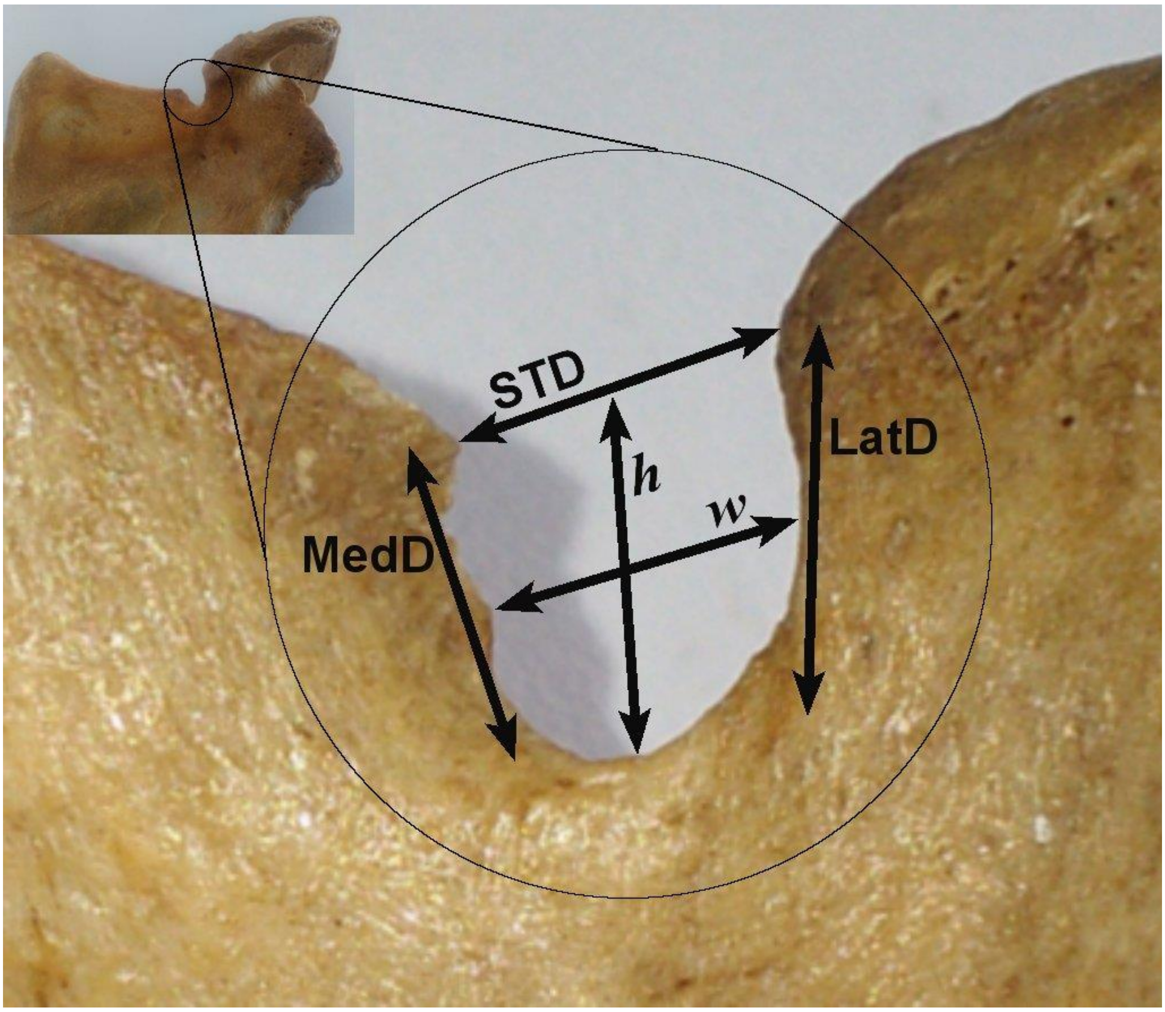
The intervals by quadrant ratio from zero to full extent (0, 25%, 50%, 75%, and 100%) were used instead of the standard measurement in millimeters and the reasoning behind this approach is discussed in the following paragraph. The level of how much does the SUBM masks the anterior vicinity of the SSN was assessed by first measuring (by the same digital caliper) the height of the SSN and then dividing the obtained number by four, the level of the superior margin of the SUBM was approximated to the five obtained quadrated levels from zero to full height. The extent of the OMHM insertion onto the SSL was measured similarly (by the same digital caliper) from the beginning of the medial attachment of the SSL to the most prominent end point of muscle fibers mass along the SSL towards its lateral attachment. To be noted, the delicate fibers extending further beyond the aforementioned prominent attachment were not counted in the measurements as they most probably reflect an artifact of the dissection arisen during soft tissue cleaning. In a similar way, the obtained number was divided by four and the length of the SSL covered by the OMHM was estimated by the same scale from zero to full length.

The reasoning behind using this alternative measuring method was as follows: The muscles by its nature exhibit a rounded and not a demarcated flat line. The OMHM inserts on the medial peak of the SSN and in variable length its fibers crawl around to inserts over the SSL in a non-unified pattern around the SSL margins (Anderson, 1982). The SUBM runs in adjacent plane anteriorly to the SSN with neither intimate contact nor any insertional point on any of the SSN borders. Therefore, it is neither practical nor accurate to measure the designated parameters by the routinely done caliper numbers. Also, taking into account the mobility of muscles adds-up to the above-mentioned obstacles. This implemented method yielded more practical results that served our purpose in this descriptive study. The reducibility of this method was tested on 20 specimens. Both inter- and intra-rater reliability were tested for both methods, the data measured by the digital caliper numerically versus the data gained by the in ratio alternative method. In our specific case, the caliper method without ratio estimation was found to be non-reliable and was not the optimum fit to our descriptive study. On the other hand, this constructed method showed a significantly higher level of data agreement between two independent observers.

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

The SSN was grouped according to the classification system (detailed in Section 1.1.2.) proposed by Polguj et al., (2011a) into five basic types based on depth versus superior width parameter measurements performed on the dry bones specimens listed in Section 3.1.1. This was evaluated by measuring the vertical parameters as a set of SSN height, SSN medial margin, and SSN lateral margin; and the horizontal parameters as another set of SSN superior-width and SSN middle-width (Figure 8).

Figure 8. 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*).

Statistical analysis was performed using *Microsoft Excel, Arcus Quickstat Biomedical 1.1.*, and *GraphPad Prism statistical software package (version 10.0.3 (275)*, to predict the prevalence of each type of the SSN and the incidence of SSN stenosis was indicated by below 3 mm parametric value. The pattern of stenosis of each SSN was described, assessed and accordingly categorized into horizontal versus vertical parametric in value reduction. The SSN of a foramen type was examined to test the literature hypothesis addressing it as the cause of SNE. This experimental design and its results were published (Al-Redouan et al., 2021b).

3.2.3. Imaging evaluation of the suprascapular canal and notch

All the material addressed in Section 3.1.3. were evaluated with emphasis on comparing the visibility of all SSN borders coming into the view at once.

First, the plain X-rays were screened to subjectively evaluate the visibility of the SSN, which turned out to be masked by the surrounding bone dense projections (Figure 3). Second, the appearance of the SSN in 3D-CT reconstruction of retrospective shoulder images was compared to dry bones scapulae. Third, MRI in frontal, sagittal, and transversal planes were examined to navigate throughout the SCC in addition to observing the visibility of the SSN as the main focus of attention. Ultrasound imaging was experimented on volunteers with prior written consent to find the optimum probe angles for localization and visualization of the SSN.

The ultrasound scanning practice had achieved images of a fit quality to our intended goal of SSN visibility. The SSC was captured in a sagittal section extending its full length from the SSN to the SGN as described in detail in the Results section. The SSN was captured in a posterior probe projection through the SUPF by testing different published protocols (Jezierski et al., 2017; Jezierski et al., 2018; Laumonerie et al., 2018), in which were applied with modifications. The SSN was captured in an anterior probe projection below the clavicle by a protocol we created and tested as described stepwise below and in both the Results (Section 4.4.2.) and Discussion (Section 5.3.3.) sections. Therefore, additional experimentation was performed, including applying the stated in the hypothesis (Section 2.1.) parametric measurements as a diagnostic algorithm in detecting SSN stenosis. These parameters include: SN vertical and horizontal parameters; superior width, middle-width, and depth of the SSN.

The sagittal ultrasound probe approach: The probe was oriented above the SGF utilizing the palpable acromion and spine of the scapula as anatomical landmarks. The probe was tilted laterally at approximately 10° degrees. Then, the probe was adjusted while performing an arm abduction maneuver until optimum screen image was reached.

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 corner 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, in a diagonal plane. After this, the probe was navigated in sliding and tilting motion towards the SSN until the full length of the SSL came to the screen view. The tilt of the probe at this optimum location was toned to refine a clear cross-sectional visibility of the SN.

The anterior below the clavicle ultrasound probe approach: To our current best knowledge of the available literature, this projection has not been presented before. We experimented scanning the anterior area of the shoulder from differing angles. Different shoulder maneuvers were attempted in seated and lying positions. The selected maneuvers were in an attempt to move away the masking structures preventing the projection of the transducer to our target of interest, the SSN. This was achieved by a not yet published four steps' shoulder maneuver protocol in lying position:

1) Arm abduction in approximately 45° degrees, lifting up both the SUPSM 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, 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 to the opposite side until seen stretched on the screen.

The image considered optimum when the SSL full extent was visible and the inferior border of the SSN was noticeable. The SN was then identified and measured besides the length of the SSL, middle width and depth of the SSN.

3.2.4. The experimentation and testing

The influence of the SSN morphology on the potential SNE was the main investigation with an aim to optimize the SN release surgical management and its imaging diagnostics modality.

Space capacity of each of the five classified SSN types was investigated by parametric analysis. The role of the SSL versus bone tissue in the reduction of the SSN space capacity was investigated. 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, which is not enough to accommodate a cross-sectional diameter of 2-3 mm SN.

This described vertical oriented SSN stenosis 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. This theoretically explains when ligamentectomy may fail to relieve the SN, and elucidates the necessity of SSN osteoplasty in certain cases. This hypothesis was confirmed and published (Al-Redouan et al., 2021b).

The documented morphology of the SSN as a part of the SSC has served in understanding the reported SNE cases. From the literature reviews, the etiologies could be categorized and cross-linked with each narrow defined site within the SSC. This work has been published as well (Al-Redouan et al., 2021a). This part of the thesis was rather a descriptive study to supplement our understanding of the SNE pathoanatomical mechanisms.

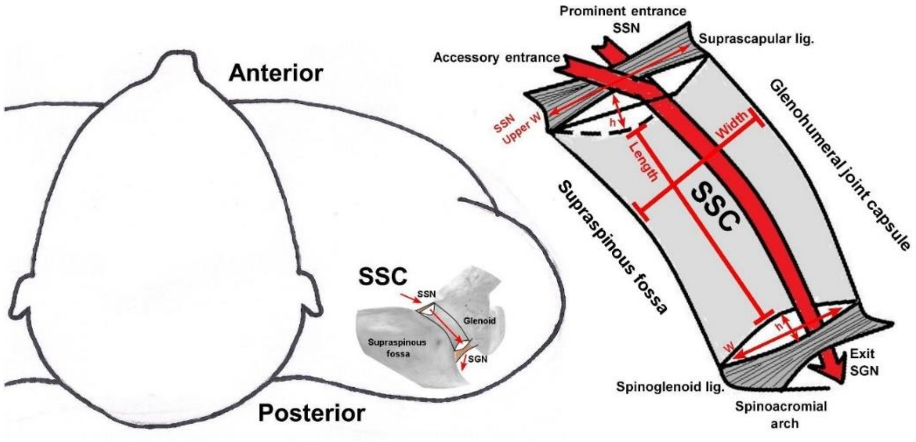
The obtained data revealed what is the minimal morphological ultrasound appearance required for efficient application. This served as the basis in optimizing the ultrasound transducer techniques. The critical parametric measurements were found in the osteological investigation and could be applied as an algorithm to evaluate *in vivo* the SSN as a diagnostic tool to detect SSN stenosis in clinical practice.

4. SURVEY RESULTS

4.1. The suprascapular canal

We have studied this topographical space and identified it as the suprascapular canal (SSC) with elaboration on its clinical significance in SNE (Al-Redouan et al., 2021a), (Figure 9).

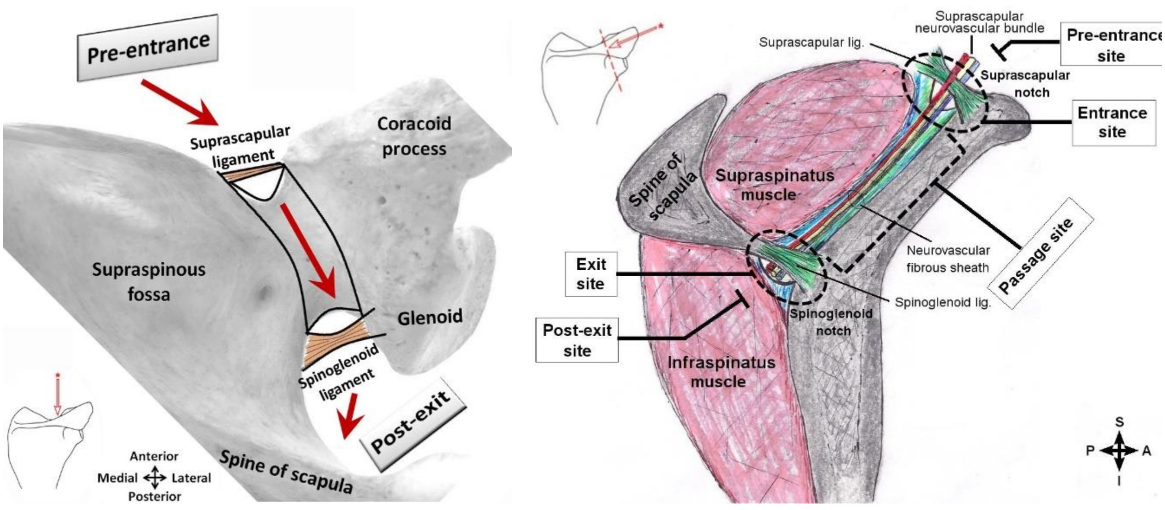
Figure 9. Schematic presentation of the suprascapular canal illustrating its spatial orientation.



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

In this work, 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 (Figure 10). Through this passage travels the neurovascular bundle containing the SN, SA and SV.

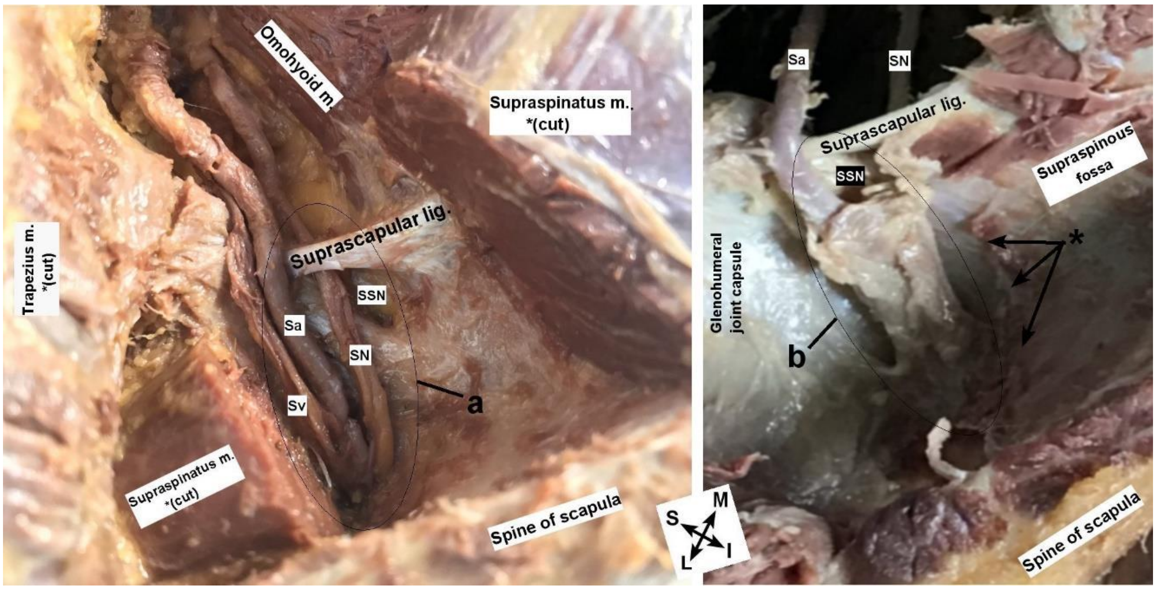
Figure 10. Schematic presentation of the suprascapular canal.



*Modified 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 (Figure 11).

Figure 11. 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*).

The roof of the SSC is composed of the SUPM. The corresponding muscular fascia seems thicker at this area than on its opposite superficial side. 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 (Figure 11).

4.1.1. The outcome of the relevant proposed terms consensus

The level of consensus of the proposed terms concerning the SSC structures are listed below in Table 2 (Al-Redouan and Kachlik, 2022b).

Table 2. 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%

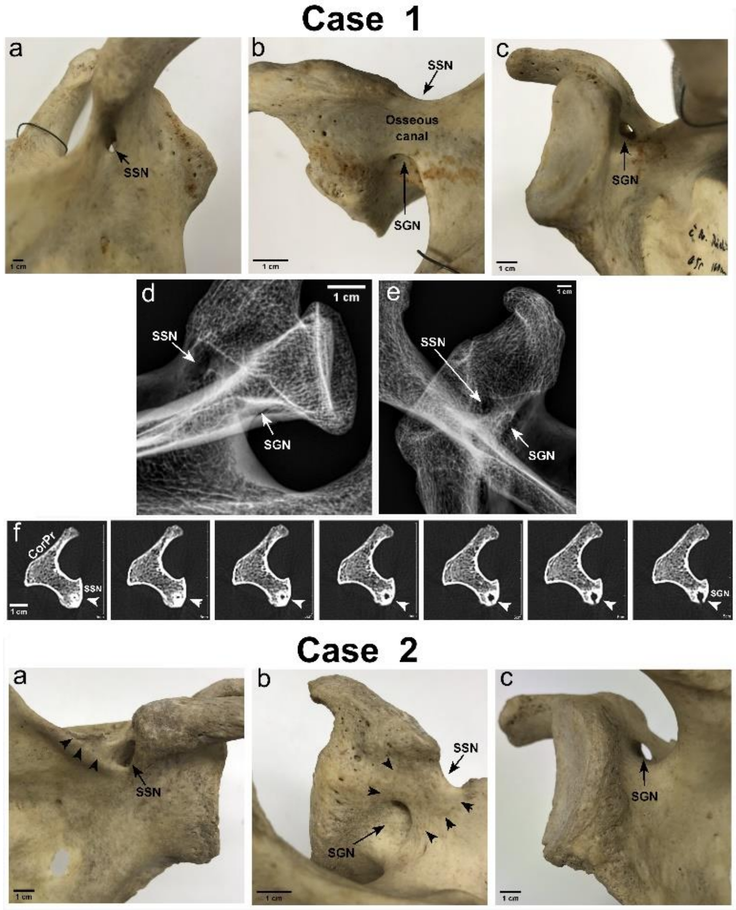
*Modified table, source: (*Al-Redouan and Kachlik, 2022b).*

The level of the peer consensus in regard to the above-mentioned terms were all above the threshold (57.16%) of acceptable range of agreement. Therefore, they were used in this thesis regardless of its current state of not yet incorporated into the Terminologia Anatomica (TA) (FIPAT, 2019).

4.1.2. Encountered cases of the osseous suprascapular canal

Two atypical dry scapulae exhibiting a unilateral completely ossified roof of the SSC were encountered during our study (Figure 12). The sample size reflects all the listed specimens in the material section (section 3.1.), which was collectively 768 pieces including dry and wet specimens as well as 3D-CT reconstructions. The biographic data of these two cases are detailed in section 3.1.3. They differed slightly in the gross appearance of the bone tissue as described below.

Figure 12. Osseous suprascapular canal cases.



Legend: SSN – suprascapular notch, SGN – spinoglenoid notch, arrows - traces of line-streaks.

*Modified image: source (*Al-Redouan et al., 2022d*).

Case 1: An osseous canal.

It did not appear as an ossified soft tissue in comparison to the other case. It seemed to be formed by bone tissue with no traces of ossification landmarks. The scapula was X-rayed in three standard anthropology planes: frontal, superior, and tangent. Figure 12-d and e illustrate the internal meshwork of a radiological bone appearance. The continuity of the canal is demonstrated by CT sections in Figure 12-f.

Case 2: An ossified canal.

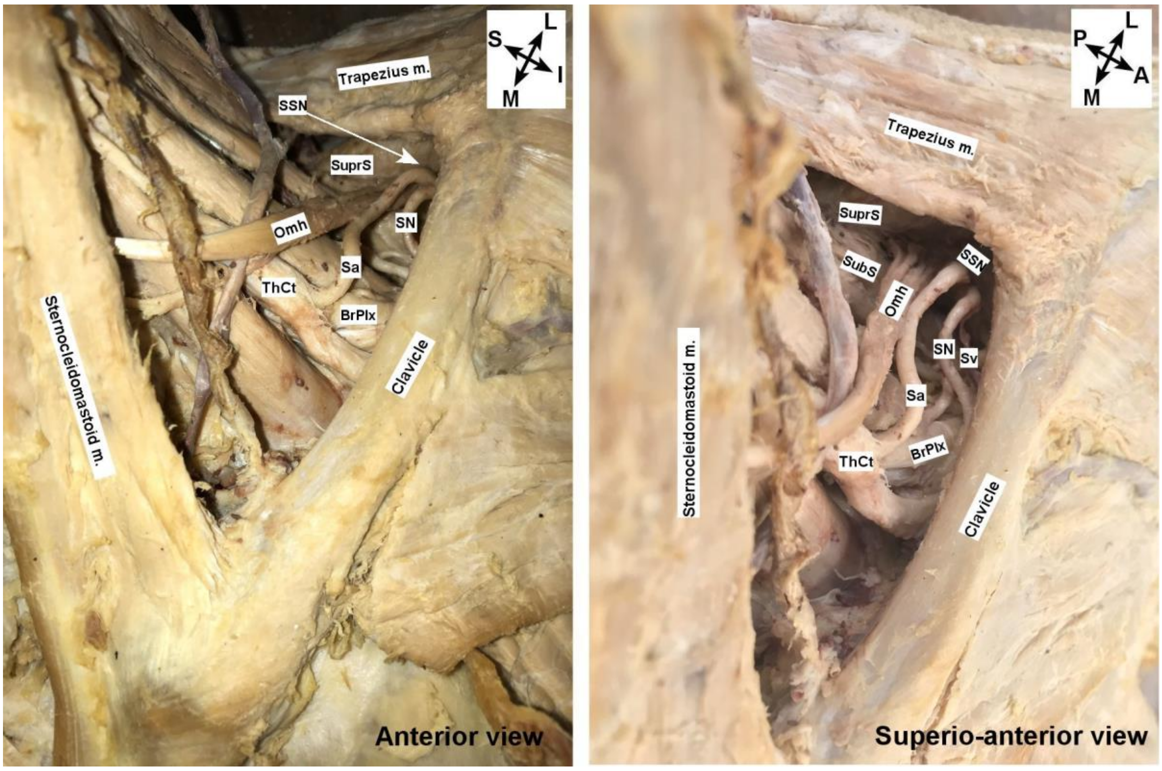
Traces of marks resembling line-streaks are grossly evident on the medial and lateral margins of the ossified roof of the SSC (Figure 12). This indicates a soft tissue ossification and not a bone by origin as observed in the first case.

These two cases were published as case report series (Al-Redouan et al., 2022d). Nevertheless, two similar cases had been reported and were prevailed in our literature review pooled dada (section 3.1.4). On the contrary to our description, the authors reported their finding describing it as an ossified SSL forming a SSN (Kharay et al., 2016; Voisin et al., 2016).

4.2. The suprascapular notch topography and morphology

The SSN is impeded deep in the lateral corner of the omoclavicular triangle (Figure 13). 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 (Figure 13). The clavicle masks the SSN anterior visibility. Further details of the SSN composition are described in the proceeding sections.

Figure 13. Suprascapular notch topography.



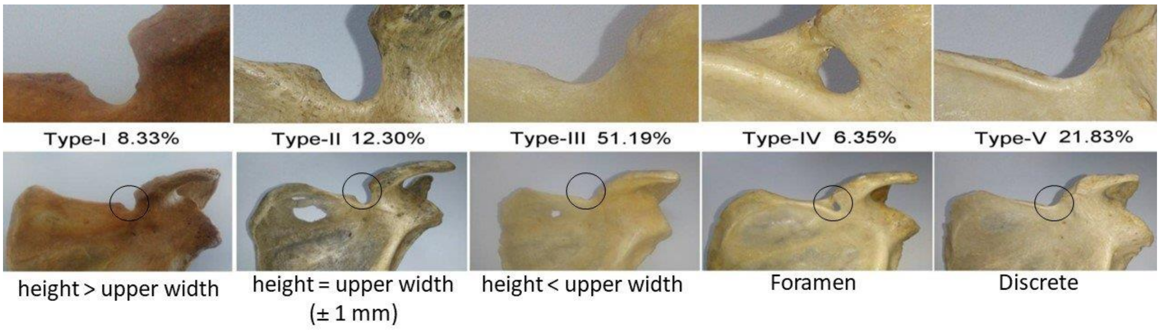
Legend: BrPlx – brachial plexus, Omh – omohyoid muscle, Sa – suprascapular artery, SN – suprascapular nerve, SSN – suprascapular notch, SubS – subscapularis muscle, SuprS – supraspinatus muscle, Sv – suprascapular vein, ThCt – thyrocervicak trunk.

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

4.2.1. Suprascapular notch type classification

Figure 14 illustrates the five types of the SSN completed with percentage in the 693 observed dry bone scapulae. Type-III was the most common accounting for approximately half of the cases. A SSN foramen, even though was the least common, had a relatively similar prevalence to Type-I SSN.

Figure 14. Suprascapular notch types

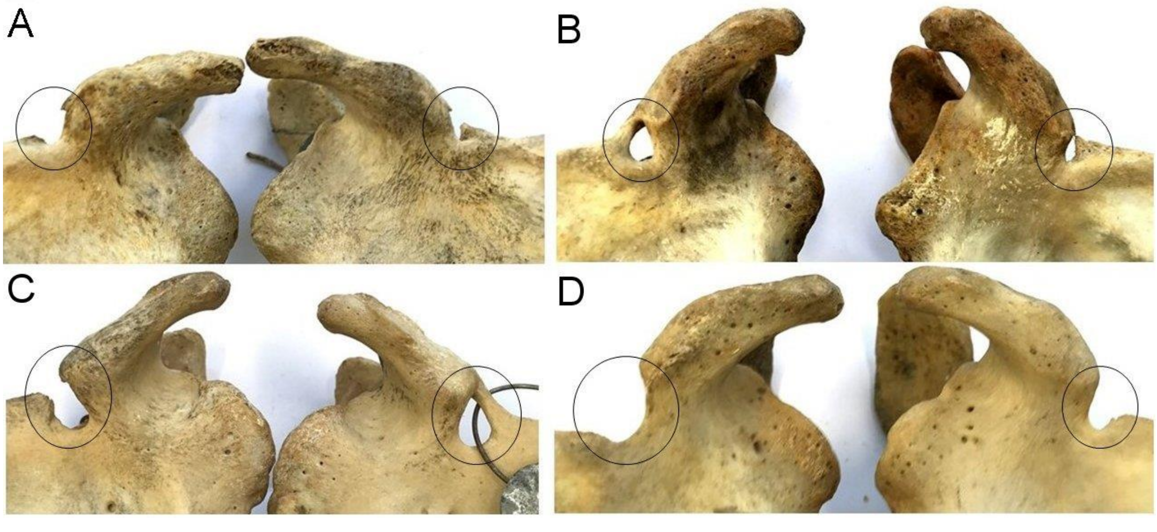


*Modified Image – source: (*Al-Redouan et al., 2021b*).

The analysis of the180 paired scapulae showed significant asymmetry in the type of the SSN (Figure 15). This indicates that the SSN bone development forming its depth is independent of genetic factors.

Figure 15. Examples of asymmetric suprascapular notch types.

A) Type-III/Type-III, differing in size. B) Type-IV (foramen)/Type-I. C) Type-I/Type-IV (foramen). D) Type-III/Type-II.



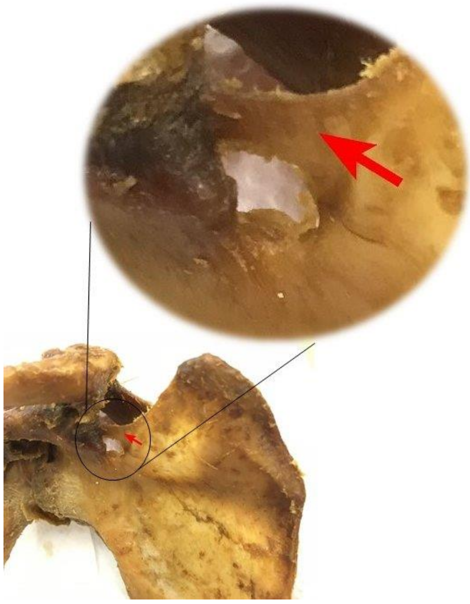
4.2.2. Suprascapular notch osteofibrous structure

The SSN is composed of bony and ligamentous tissues. There are three grossly distinctive appearances at its osteology level: smooth curved margined bone, sharped angulated margined bone, and fully surrounded by bone in the shape of a foramen (Figure 16).

Figure 16. The three shapes of margins of the suprascapular notch (SSN).
A) Smooth margined SSN. B) Sharp margined SSN. C) SSN fully enclosed by bone margins.

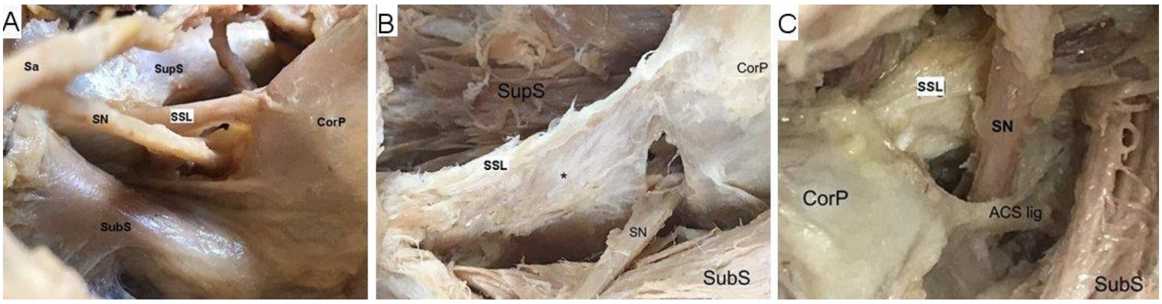
The typical SSN is enclosed by the SSL (Figure 17). This was observed in all the SSN types with the exception of Type-IV (foramen).

Figure 17. The typical suprascapular notch enclosed by the suprascapular ligament.



The SSL varied in shape (Figure 18). It was found to be thin-rounded in 8 out of 63 (12.7%) specimens (Figure 18A), flat in 39 out of 63 (61.9%) specimens (Figure 18B), and fanned (narrowing from medial to lateral) in 16 out of 63 (25.4%) specimens (Figure 18C). The 63 specimens reflect the number of non-ossified SSL (59 out of 159 SSL showed grossly noticeable partial ossification). The SSL had 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). However, the fanned SSL type had unequal width at its attachments of a 3 to 7 mm medial width (average ± 6.1 mm) and a 1 to 5 mm lateral width (average ±4.6 mm), in which the medial width was always larger. 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%) (Figure 18C) 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. Moreover, it was found to be duplicated in two specimens. It was always running underneath the SN in all the observed cases.

Figure 18. Distinctively observed suprascapular ligament variations.
A) Typical gross appearance. B) Fibrous appearance with a radiating thin membrane covering the SSN vicinity pierced by the SN. C) Additional internal variant ligament (anterior coracoscapular ligament).

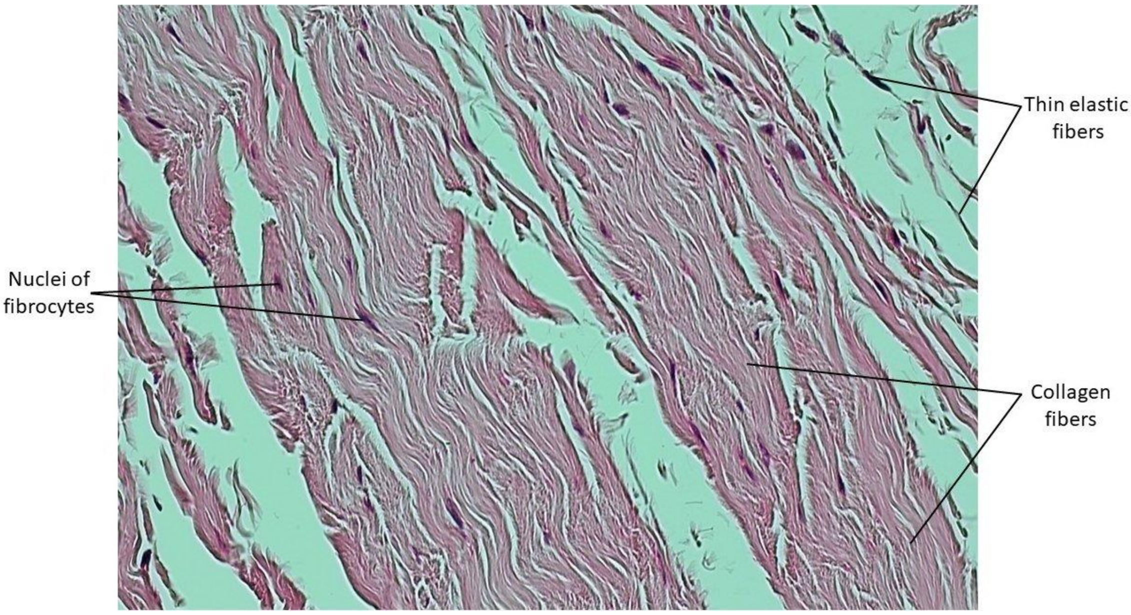


Legend: ACS lig – anterior coracoscapular ligament, CorP – coracoid process, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein.

A membrane was noticeable in seven SSNs composed of delicate fibers, extending inferiorly as it originates from the SSL, covering the area of the SSN. This membrane was pierced by the passing SN as shown in (Figure 18B). Nevertheless, a note must be mentioned concerning the accuracy of the aforementioned description of this membrane. The membrane may had been artificially lost during some of the dissections in which the membrane was subjected to a potential artificial loss during soft tissue resections, in which this membrane if existed could have been pulled out with the adipose tissue even though the dissection was performed with forceps by a blunt dissection technique.

The SSL was composed of dense collagen fibers of a typical ligament with additional elastic fibers (Figure 19). Immunohistochemistry was not performed as it was expected to not work sufficiently after fixation in formalin.

Figure 19. Typical histological appearance of the suprascapular ligament.

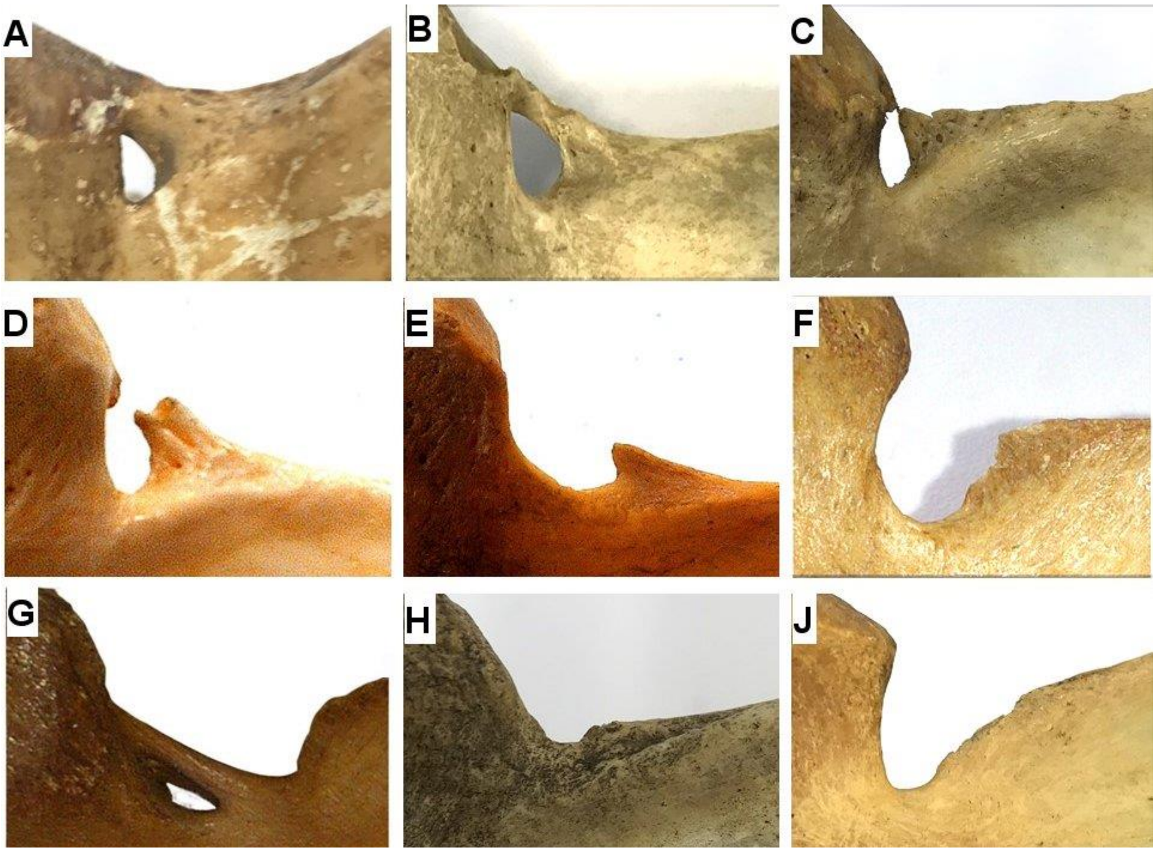


* Hematoxylin and eosin staining (40x magnification).

The SSL was found to be ossified in a differing pattern (Figure 20). Two forms of a suprascapular foramen were observed: (1) the SSN exhibiting bone tissue with no traces of ossified connective tissue (Figure 20A), and (2) the SSN exhibiting traces of streak marks of ossification (Figure 20B). This suggests that the occurrence of a suprascapular foramen can appear either during fetal period or later postnatally by complete SSL ossification. An evidence of the intermediate phase of forming a suprascapular foramen can be seen in Figure 20C presenting a bridging of the ossification sites merging to meet midway along the plane of the SSL. The growth of the aforementioned bridging was observed at a varying extent (Figure 20C-F). Ossification of the internal variant anterior coracoscapular ligament was observed in two dry bone specimens (Figure 20G). Further, internal ossification extending from the SSN bone margins and not from the SSL was also observed (Figure 20H-J).

Figure 20. The observed differing ossification patterns of the suprascapular notch.

A) Cross-sectional appearance of an osseous SSL. B) Ossified SSL with a streak line. C) Complete (united) bridging of an ossified SSL. D) Incomplete (non-united) bridging of an ossified SSL. E) Partial ossification of the SSL. F) Sharped margin of the SSN caused by SSL ossification at its medial attachment site. G) Internal variant osseous structure dividing the SSN into a foramen imposed by a notch above. H) Ossification growth of the SSN margins. J) Sharped margins of the SSN along its medial border.



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

4.2.3. Suprascapular notch surrounding muscles

The surrounding muscles at the SSN were categorized into four groups based on their topographical relationship to the SSN concerning the arthroscopic feasibility to the SSN.

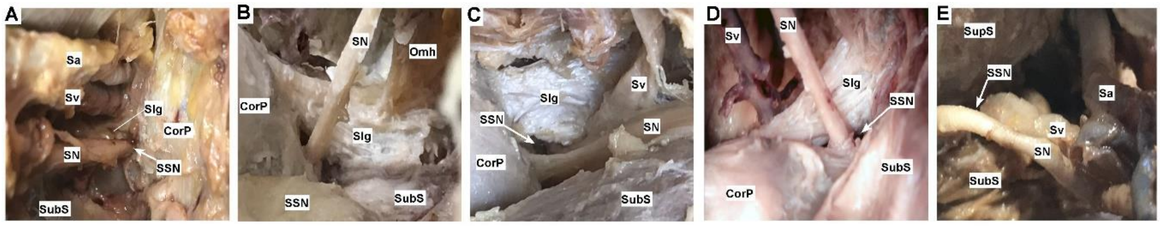
I) Constant muscles not intervening with the SSN space – Supraspinatus muscle.

In all cases, the SUPM was running parallel to the SSL above the SSN. Therefore, it does not intervene with the vicinity of the SSN.

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

The superior margin of the SUBM ran antero-inferiorly in a parallel direction to the SSL. However, the height of the superior margin of the SUBM varied in relation to the SSN anterior vicinity (Figure 21). It was encountered to be coursing low, further 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 (Figure 21A). Also, it was observed to gradually extend upward by approximately 25% of the SSN height in 19 (16.5%) (Figure 21B), by approximately 50% of the SSN height in 15 (13.0%) (Figure 21C), and by approximately 75% of the SSN height in 10 (8.7%) specimens (Figure 21D), respectively. It was noticed to fully cover the visibility of the SSN anterior vicinity in four out of the 115 (3.5%) specimens (Figure 21E). Therefore, the SUBM can impinge on the SN causing dynamic SNE.

Figure 21. 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.



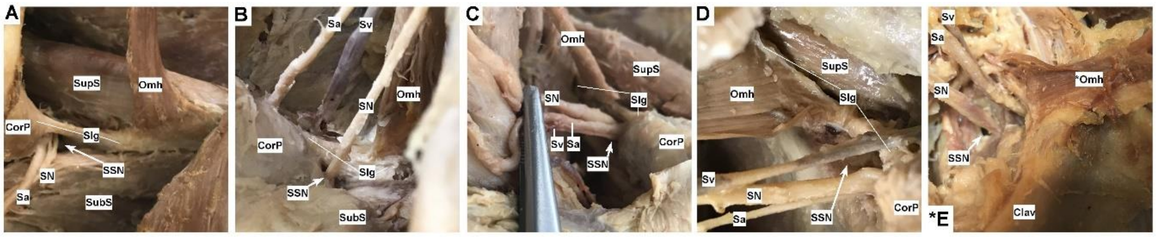
Legend: CorP – coracoid process, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein.

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

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 (Figure 22A). 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 (Figure 22). The insertion on the SSL was varying in length. It was found to cover approximately 25% of the SSL margin in 23 (20.0%) (Figure 22B), approximately 50% of the SSL in eight (7.0%) (Figure 22C), and approximately 75% of the SSL in three (2.6%) specimens (Figure 22D), respectively. However, the full length of the SSL was never seen to be fully occupied by the OMHM. Interestingly, the OMHM was encountered inserting onto the clavicle in two cases (1.7%) (Figure 22E) with no insertional point on the SSN. This study elucidates the necessity to assess and secure OMHM attachment on the SSL in SN surgical decompression ligamentectomy.

Figure 22. 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. E) Rare variant of OMHM inserting on the clavicle.

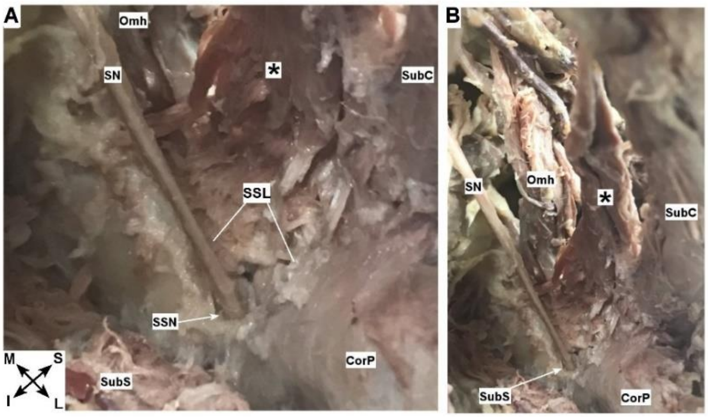


Legend: CorP – coracoid process, Omh – omohyoid muscle, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein.

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

Two rare variants were observed with topographical relationship to the SSN. 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 (Figure 23). It is an auxiliary muscle and was seen to run impinging on the brachial plexus and was regarded as a cause of neurogenic outlet syndrome (Al-Redouan et al., 2023).

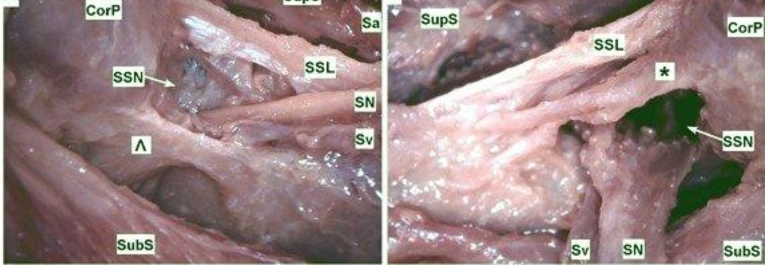
Figure 23. The variant subclavius posticus muscle.



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

The other variant muscle has to our best knowledge never been reported before. It was found unilaterally on the left side (Figure 24), running parallel to the SSL antero-inferiorly and sharing the same attachment points on the SSL. We had proposed the term "coracoscapularis muscle" based on its attachment sites at the medial peak of the SSN medially and laterally at the base of the coracoid process (Figure 24). It seems to be an auxiliary muscle and its resection during arthroscopic procedures will probably not cause any complications. It did not reduce the space capacity of the SSN, and therefore causing SNE was not suspected neither confirmed in this observation.

Figure 24. The unilateral variant coracoscapularis muscle.
A) Right SSN exhibiting a variant anterior coracoscapular ligament. B) Left SSN exhibiting the variant coracoscapularis muscle.

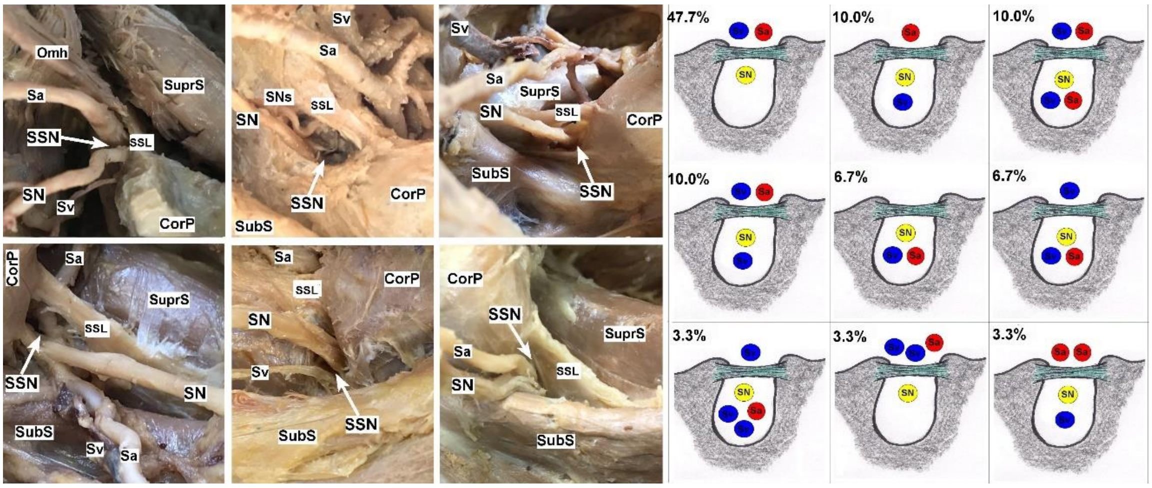


Legend: CorP – coracoid process, Sa – suprascapular artery, SN – suprascapular nerve, SSL – suprascapular ligament, SSN – suprascapular notch, SubS – subscapularis muscle, SupS – supraspinatus muscle, Sv – suprascapular vein, ʌ – anterior coracoscapular ligament, * – coracoscapularis muscle.

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. However, nine differing patterns of how the SA and SV pass at the SSN were observed and documented (Al-Redouan et al., 2021a), (Figure 25).

Figure 25. 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. In contrast to the popular believe, suprascapular vessels passed through the SSN underneath the SSL in 49.0% (Figure 25). In addition, a SN accompanied by a single SA and a single SV was found only in 64.4%. This observation shows that more than one artery or vein can exist at the SSN with varying diameters (Table 3).

Table 3. Numbers and diameter range of the vessels passing at the suprascapular notch.

Suprascapular artery (0–2 found around the SSN)				
	Passing only inside SSN (0–1 SA)	Passing only outside SSN (0–2 SA)	Passing both inside and outside the SSN	Absent
SA diameter	1–4 mm	1–5 mm		
Number of cases	17	55	3	6
Suprascapular vein (1–3 found around the SSN)				
	Passing only inside SSN (0–2 SV)	Passing only outside SSN (0–2 SV)	Passing both inside & outside the SSN	Absent
SV diameter	0.5–5 mm	1–7 mm		
Number of cases	12	47	19	0
No. 159 SSN				

Legends: SA – suprascapular artery, SV – suprascapular vein, SSN – suprascapular notch.

4.3. Suprascapular nerve anatomical entrapments

The underlying anatomical reasons were revealed in two of our published studies (Al-Redouan et al., 2021a; Al-Redouan et al., 2023). Table 4 below lists the etiologies concerning SNE at the SSN.

Table 4. 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

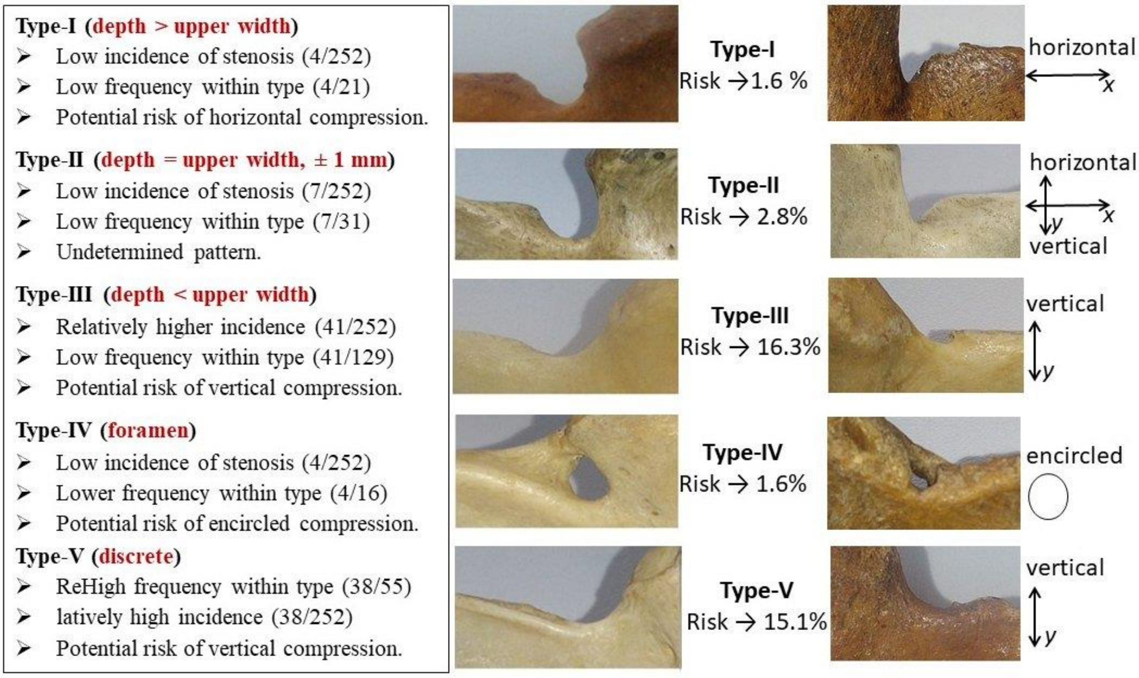
Legend: SSN – suprascapular notch.

*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. The incidence by type was reported in a published work (Al-Redouan et al., 2021b) and listed in the figure below (Figure 26).

Figure 26. Suprascapular notch stenosis pattern and prevalence.



*Modified source of published work: (*Al-Redouan et al., 2021b*).

The analysis of the reduced in size parameters revealed three distinctive patterns of SSN stenosis (Al-Redouan et al., 2021b):

(1) SSN stenosis with a vertically oriented compression. This form showed higher incidence (Figure 27). In this pattern, the SN is at risk of being compressed by the SSL against the inferior margin of the SSN.

(2) SSN stenosis with a horizontally oriented compression. This form showed lower incidence (Figure 27). In this pattern, the SN is at risk of being compressed between two SSN bone margins.

(3) SSN stenosis with a combined horizontal and vertical orientation. This form showed higher incidence than the horizontal pattern (Figure 27).

This study suggests a consideration of surgical decompression by osteoplasty when the SN is compressed between bone margins. Theoretically, the routinely performed surgical ligamentectomy of the SSL would not release the entrapped SN in Type-I SSN and may fail in Type-II SSN (Al-Redouan et al., 2021b).

Figure 27. Suprascapular notch stenosis pattern by type.

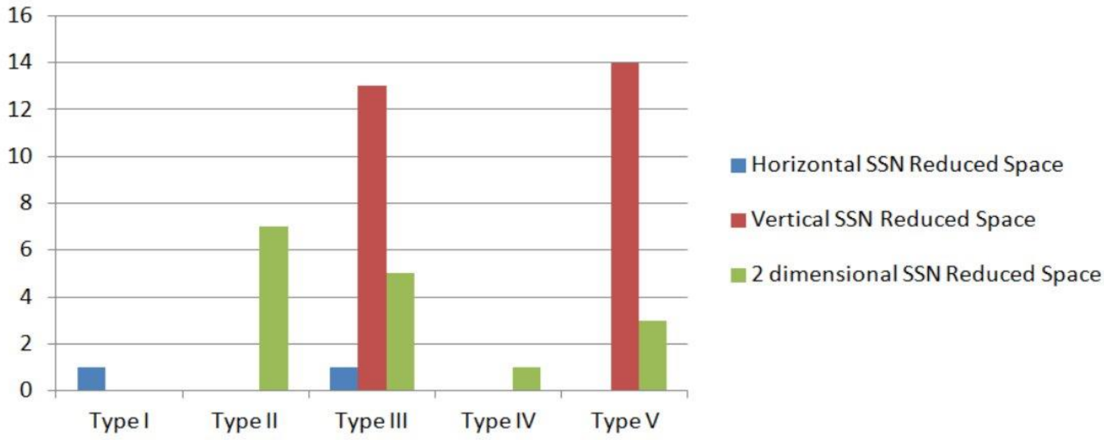


*Image source: (*Al-Redouan et al., 2021b*).

The statistical analysis illustrated graphically in Figure 28 shows the relative risk of SSN stenosis by type (Al-Redouan et al., 2021b). Type-V SSN had the highest incidence of stenosis. On the other hand, Type-III was the most common type which had an equal incidence in the overall sample (Figure 28A). The height and the width of the SSN are the two key parameters in detecting SSN stenosis, driven from this analysis (Figure 28B).

Figure 28. Graphical representation of the suprascapular notch stenosis by ratios.
A) The overall prevalence was high in Type-V. B) The overall prevalence within each type was high in Type-III and Type-V populations.

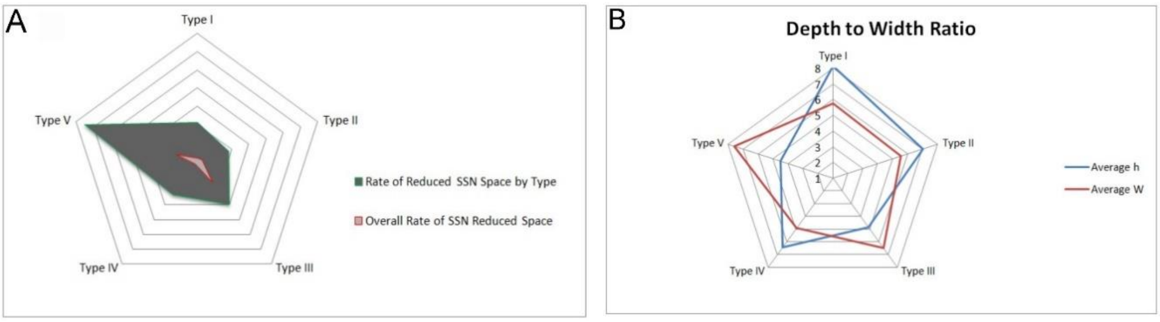
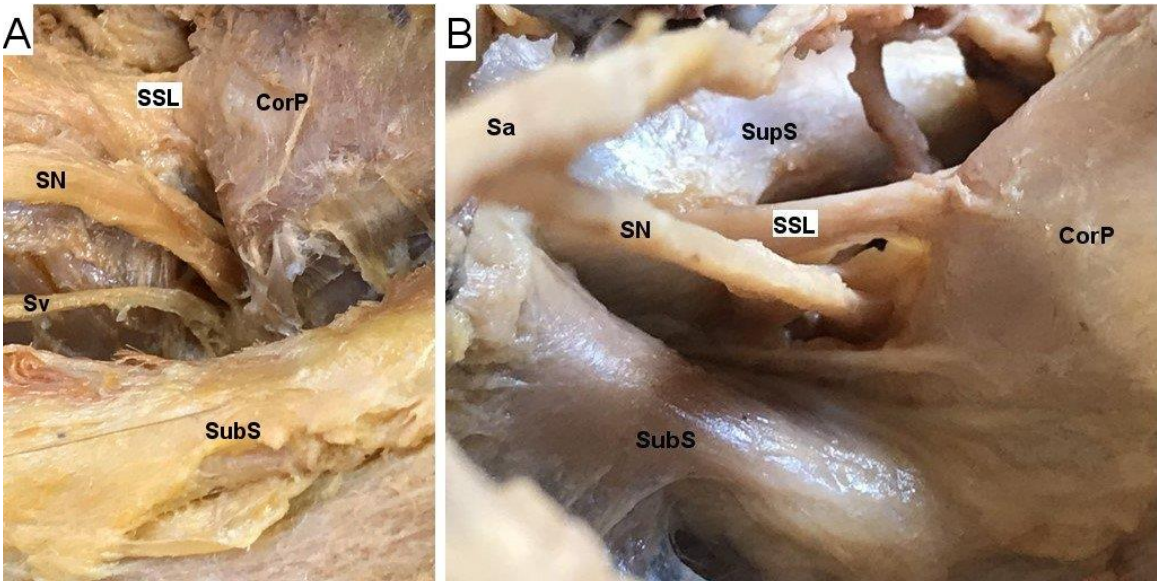


*Image source: (*Al-Redouan et al., 2021b*).

An example of Type-I SSN stenosis encountered during the cadaveric dissections (Figure 29A) in comparison to a non-stenosed SSN (Figure 29B) is shown below.

Figure 29. A suprascapular notch stenosis cadaveric specimens (A) in comparison to typical suprascapular notch size (B)
A) Stenosed Type-I SSN. B) Non-stenosed Type-III SSN.



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

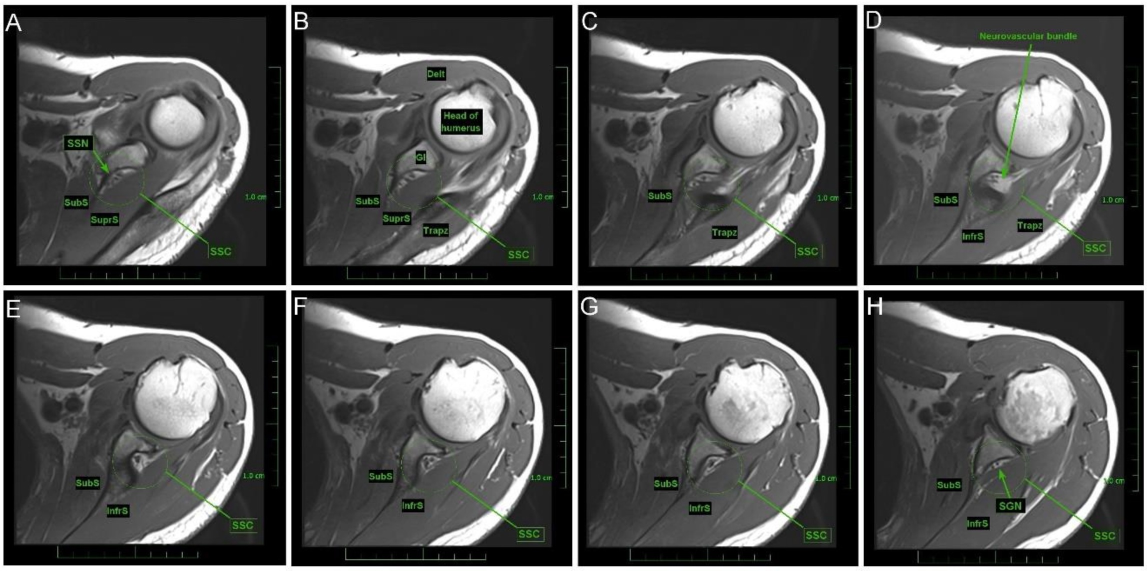
4.4. Suprascapular canal and notch imaging

The intervals of the SSC were navigated sequentially on MRI cross-sections. However, the borders of the intervals at the SSN, SSC passage, and the SGN were not captured in a given image by MRI.

4.4.1. Suprascapular canal MRI anatomy

The figures below show the sequential anatomy of the SSC in transverse cross-sections (Figure 30), sagittal in cross-sections (Figure 31), and in frontal cross-sections (Figure 32).

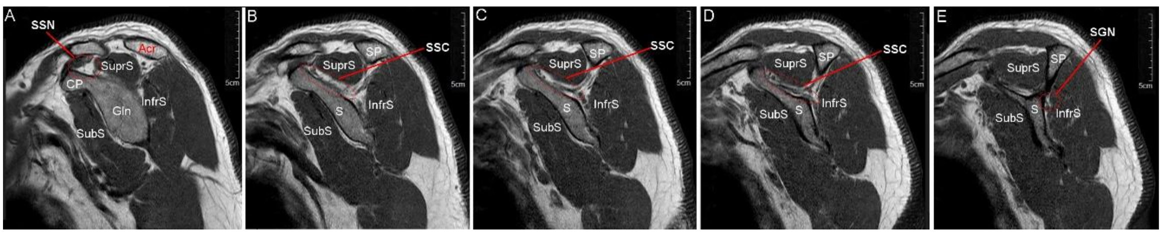
Figure 30. Transverse T1-weighted magnetic resonance image (MRI) sections of a left shoulder navigating through the suprascapular canal.



Legend: Gl – glenoid, InfrS – infraspinatus muscle, SGN – spinoglenoid notch, SSC – suprascapular canal, SSN – suprascapular notch, SubS – subscapularis muscle, SuprS – supraspinatus muscle, Trapz – trapezius muscle.

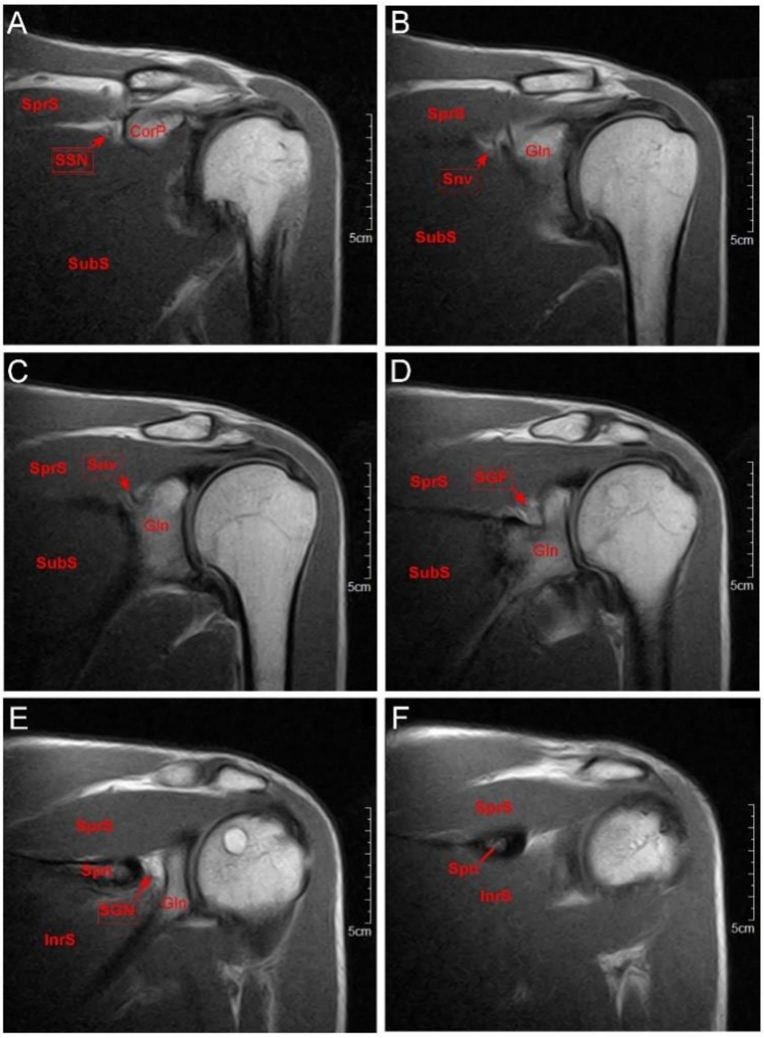
*Image source: (*Al-Redouan et al., 2021a*).

Figure 31. Sagittal T1-weighted magnetic resonance image (MRI) sections of a left shoulder navigating through the suprascapular canal.



Legend: Gl – glenoid, InfrS – infraspinatus muscle, SSN – suprascapular notch, SubS – subscapularis muscle, SuprS – supraspinatus muscle, Trapz – trapezius muscle.

Figure 32. Frontal T1-weighted magnetic resonance image (MRI) sections of a left shoulder navigating through the suprascapular canal.



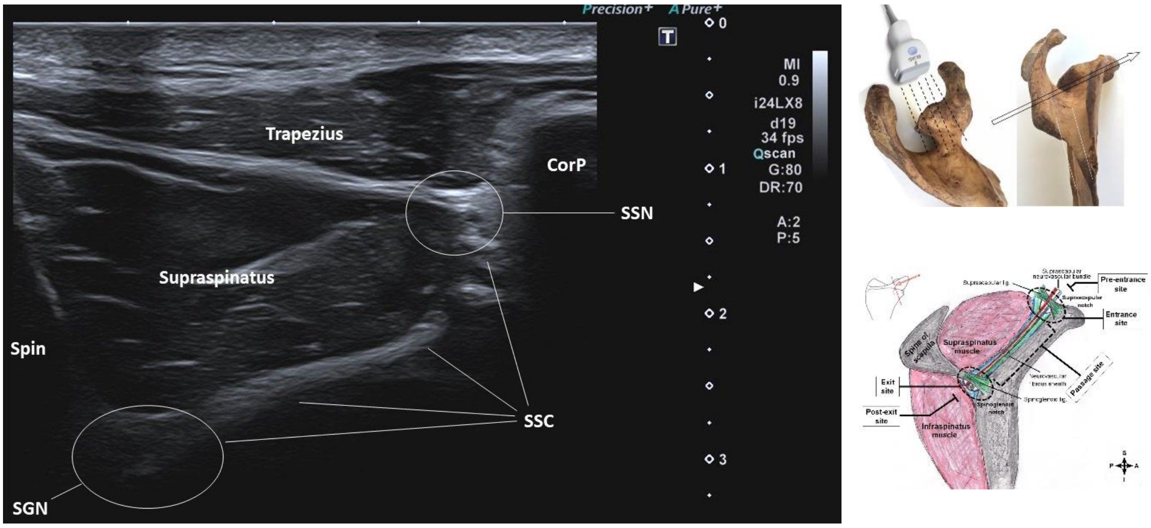
Legend: Gln – glenoid, InfrS – infraspinatus muscle, SGF – spinoglenoid fossa, SGN – spinoglenoid notch, Snv – suprascapular neurovascular bundle, spin – spine of scapula, SSC – suprascapular canal, SSN – suprascapular notch, SubS – subscapularis muscle, SuprS – supraspinatus muscle.

*Image source: (*Al-Redouan and Kachlik, 2022c*).

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 (Figure 33). The surface anatomical landmarks are the spine of the scapula at the base of the acromion, where the probe was placed anterior to this palpable landmark.

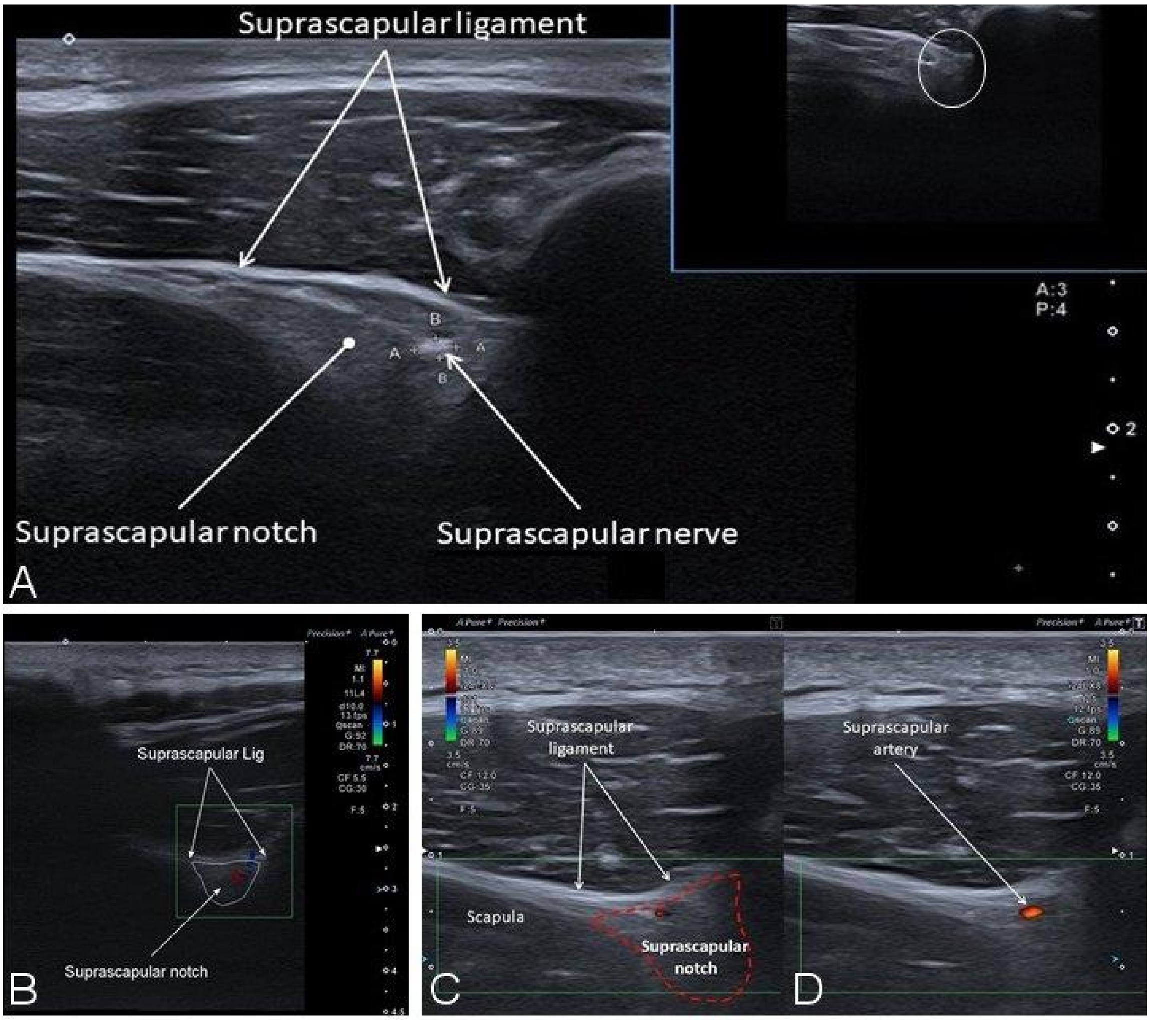
Figure 33. Diagonal sonographic section of a left shoulder through the suprascapular canal.



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

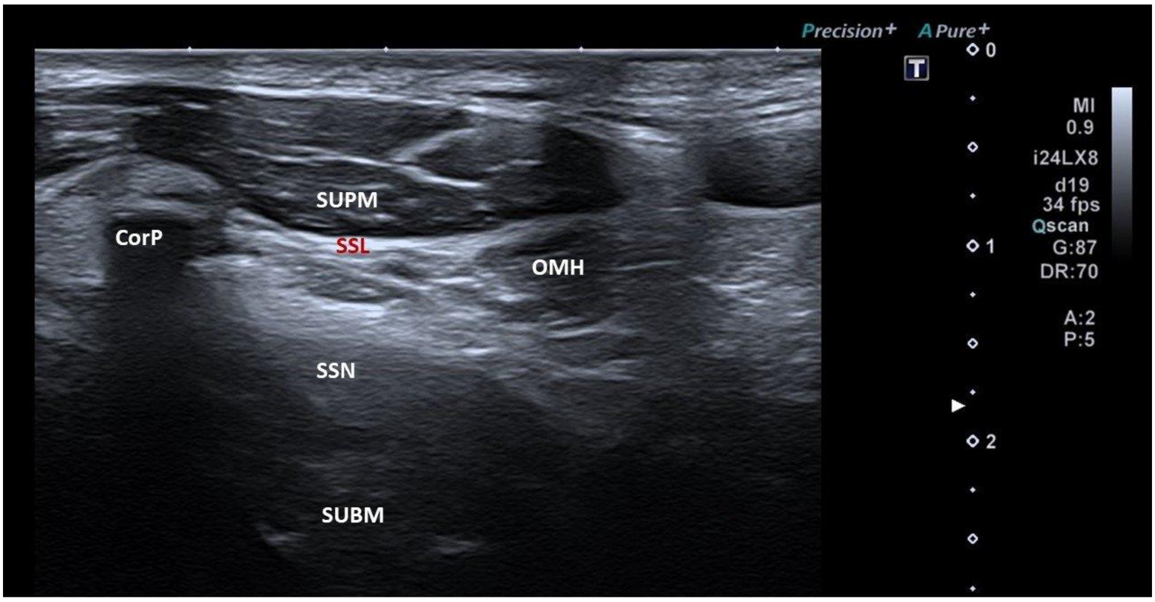
The SSN was visualized in a posterior view (routinely performed view in the clinical practice) by aligning the probe horizontally above the SSN with an internal tilt facing medially simultaneously with a frontal tilt. The ultrasound array was oriented in a posterio-inferior-medial direction to the body plane. The SSN borders were visible on one image (Figure 34) and the SN was detectable (Figure 34A). However, the sensitivity of the ultrasound Doppler mode was low and did not detect the vessels in all the cases. The SA and SV were detected by ultrasound Doppler mode in seven out of the 20 volunteers Figures 34B-D.

Figure 34. Ultrasound image of the suprascapular notch (right shoulder, superior-posterior transducer approach).



The SSN was captured in an anterior view (a novel approach described stepwise in section 3.2.3.). The SSN anatomy on an anterior ultrasound view is described below (Figure 35). The advantage of the ultrasound anterior view (Figure 35) was the ability to visualize the SUBM and OMHM. These are the two topographically relevant structures to the SSN that cannot be seen in the ultrasound posterior view (Figure 34).

Figure 35. Ultrasound image of the suprascapular notch (right shoulder, anterior transducer approach).

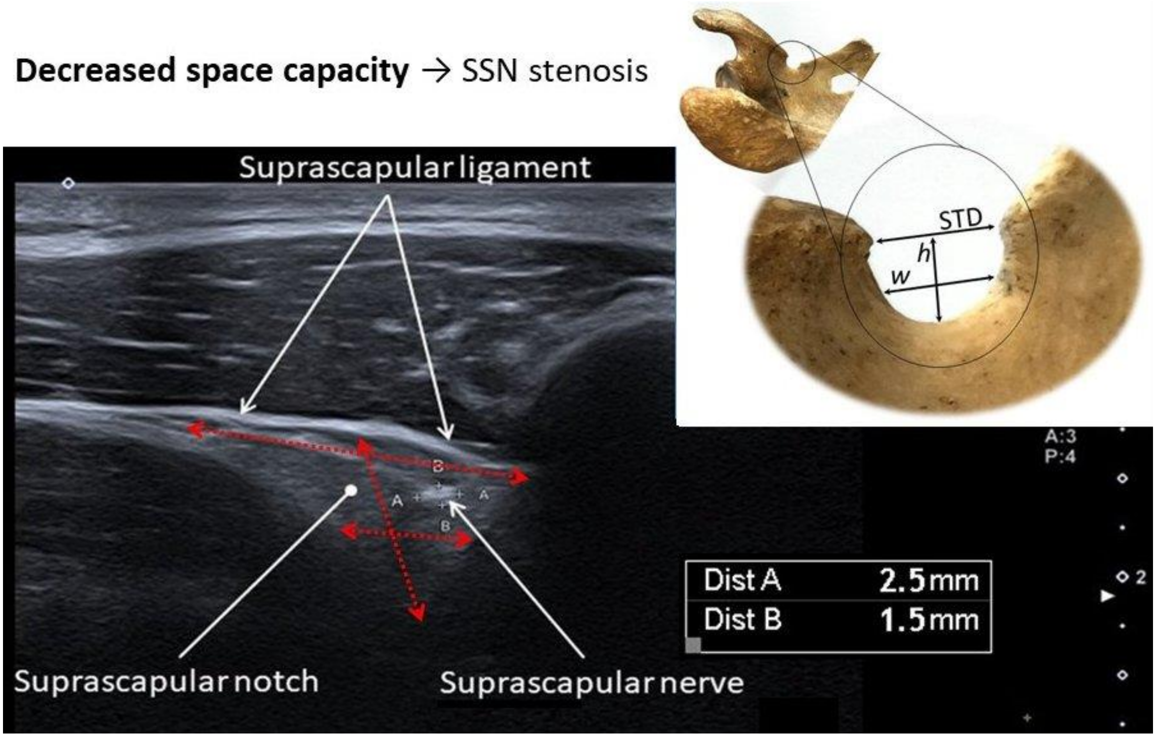


Legend: SSN – suprascapular notch, SSL – suprascapular ligament, SUPM – supraspinatus muscle, SUBM – subscapularis muscle, OMH – omohyoid muscle, CorP – coracoid process.

4.4.3. Suprascapular notch stenosis ultrasound diagnostic algorithm

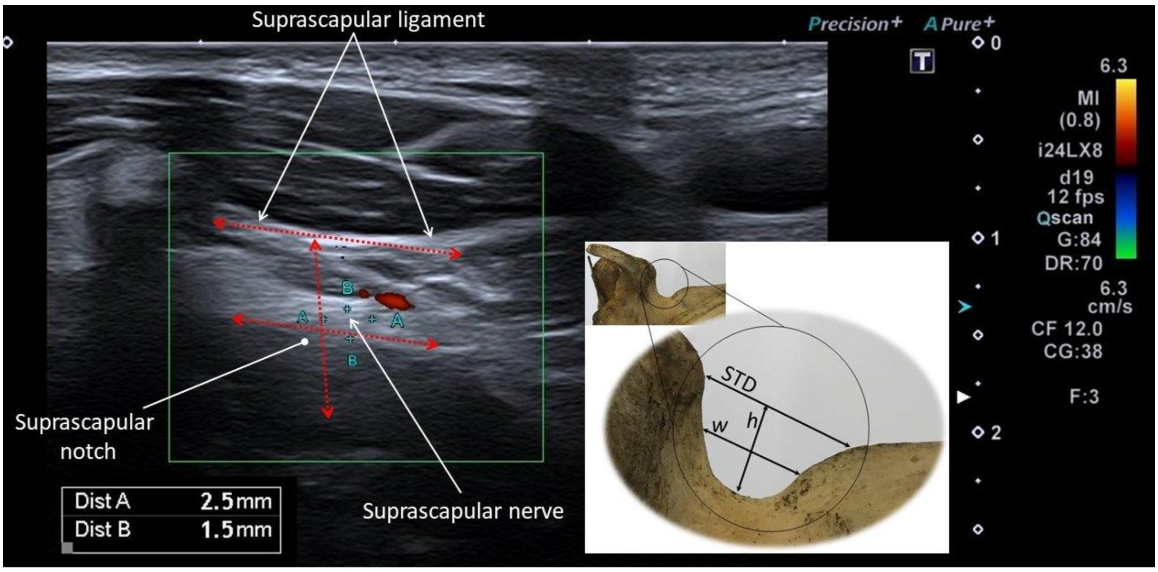
A suspected SSN stenosis can be assessed by measuring the space determining parameters on an ultrasound examination using the posterior (Figure 36) and anterior (Figure 37) ultrasound views. The SSN space capacity is assessed by measuring its superior width, its internal width, and its height. Then, the cross-sectional size of the residing SN is assessed by measuring its vertical and horizontal diameters. The diameter of the SN was found to be 2–3 mm. SSN height or widths below 3 mm are considered critical values indicating a SSN anatomical stenosis. Assessing the SSN on the ultrasound anterior view (Figure 37) adds confirmation to the values obtained from the ultrasound posterior view (Figure 36). In addition, the anatomy of the OMHM and SUBM is examined. Specifically, this 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 *in vivo*.

Figure 36. Ultrasound algorithm in detecting suprascapular notch stenosis (right shoulder, posterior transducer approach).



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

Figure 37. Ultrasound algorithm in detecting suprascapular notch stenosis (right shoulder, frontal transducer approach).



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

5. DISCUSSION OF METHODOLOGICAL PROCEDURES AND RESULTS

The methodological procedure consisted of three phases: osteological, cadaveric and imaging observations of the spaces where the SN passes through. These procedures lead us to define the topographical space and elaborate on its specific anatomical sites involving the risk of SNE. Furthermore, imaging modalities were assessed to enhance optimal visualization of those sites. The presented work aimed to provide imaging anatomy-based detection of a suspected SNE and insights on its surgical approaches.

5.1. The suprascapular canal defined as a topographical site

The osteo-musculo-fibrous topographical space between the SSN and the SGN was addressed in the literature superficially (Cummins et al., 2000; Duparc et al., 2010; Tasaki et al., 2015) as stated in Section 1.1. We had dissected and studied this topographical space in detail. Consequently, we had identified this topographical space as the "suprascapular canal" (Al-Redouan et al., 2021a). The SSC was revealed (Figure 6) through the dissections (Figure 11 and 13) and evaluated by MRI (Figure 30, 31, and 32) and ultrasound imaging methods (Figure 33). The SSC is enclosed by the supraspinatus fascia which attaches on the margins of the SGF. The specific attachment sites are the neck of the glenoid laterally, a visible muscular attachment line within the SUPF medially, and the spinoachromial arch distally (Al-Redouan et al., 2021a). The supraspinatus fascia was relatively thicker at the site where it covers the SSC than its other medial and lateral surfaces. However, there were some limitations in studying formaldehyde-fixed cadaveric fasciae. First, observing its variations and thickness is not reliable due to the fixation-caused artifacts and adhesions; and second, its biomechanical mobility during SUPM contraction cannot be examined in this method of cadaveric fixation. The SSN was found to be highly variable (Figure 18, 21, 22 and 25) in contrast to the SGN. The observed variations of the SSN morphology were in concordance with the literature reports (Rengachary et al., 1979b; Demirhan et al., 1998; Avery et al., 2002; Dargaud et al., 2002; Bayramoglu et al., 2003; Demirkan et al., 2003; Urgüden et al., 2004; Duparc et al., 2010; Ebraheim et al., 2010; Chen and Adds, 2011; Polguj et al., 2011a; Yang et al., 2012; Polguj et al., 2013a; Polguj et al., 2013b; Tubbs et al., 2013; Inoue et al., 2014; Kumar et al., 2014; Polguj et al., 2014a; Polguj et al., 2014b; Sangam and Devi, 2014 ; Podgórski et al., 2015; Won et al., 2014; Labetowicz et al., 2017; Podgórski et al., 2018 ; Yang et al., 2019; Zhang et al., 2019 ; Inoue et al., 2021; Ravikumar and Siri, 2022). We had documented more detailed observations of the SSN morphological structure and variations as listed below in Section 5.2.

The MRI imaging method exposes the SSC cross-sections in the standardized transverse, sagittal, and frontal body planes (Figure 30, 31, and 32). Thus, MRI is a good imaging method to expose the SSC soft tissue structures. However, the SSN and the SGN full boundaries do not align into a single captured section at once and require more sectional navigations (Al-Redouan and Kachlik, 2022c). On the other hand, ultrasound imaging of the SSC had showed better topographical exposure of the SSC as a whole. The full length of the SSC passage running between the SSN and SGN was captured sonographically in oblique ultrasound probe orientation (Figure 33). The SSN was captured in both the posterior (Figure 34) and anterior views (Figure 35). The posterior view is commonly practiced in the clinical practice (Schneider-Kolsky et al., 2004; Peng et al., 2010; Chan and Peng, 2011; Fernandes et al., 2012; Hill et al., 2014; Laumonerie et al., 2017; Laumonerie et al., 2018; Kamal et al., 2018; Laumonerie et al., 2019a; Laumonerie et al., 2019b) as well as in the experimental research (Peng et al., 2010; Laumonerie et al., 2017; Kamal et al., 2018; Laumonerie et al., 2018; Ulusoy et al., 2018; Katsuura et al., 2019; Laumonerie et al., 2019a; Laumonerie et al., 2019b; Podgórski et al., 2019; Yildizgören, 2020; Park et al., 2022; Prenaud et al., 2021). The accuracy of the method was questioned in the literature (Taskaynatan et al., 2012; Keles et al., 2018, Jezierski et al., 2018, Yildizhan et al., 2024). In this thesis, we assured capturing the correct view by navigating through the SSC ensuring a proper reach to the SSN with emphases on localizing the SSL (with full visibility of its full length) beside the bony margins of the SSN (Figure 34). The clarity of ultrasound images seemed to be affected by both the skill of the examiner and the musculature size of the subject in contrary to what had been stated by some authors in the literature who claimed a no BMI influence (Jezierski et al., 2018). Furthermore, the ultrasound Doppler sensitivity of the suprascapular vessels was low and cannot be reliable. We had illustrated a case where the SA running under the SSL and the SV above the SSL in Figure 34 by ultrasound Doppler. However, the SV was not detected in nine cases and the SA was not detected in four cases out of the 20 examined cases. Therefore, ultrasound even though being a reliable imaging method in evaluating the SSN and the SN, it is not reliable concerning the evaluation of the suprascapular vessels.

5.1.1. The newly identified and proposed terms

The "suprascapular canal" as a term as well as some additional descriptive terms of structures forming the SSC are not listed in TA (FIPAT, 1998; 2019). The shortage of anatomical terms concerning the upper limb was addressed in the literature (Kachlik et al., 2017). Therefore, the consensus method of Delphi addressed in Section 3.1.5. (Cantrill et al., 1996; Fink et al., 1984; McMillan et al. 2016; Humphrey-Murto et al., 2017) was applied to solve the shortage of this concerned terminology and nomenclature (Al-Redouan and Kachlik, 2022b). The overall level of consensus of the nine terms was high (Table 1). 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". The proposed "suprascapular ligament" term suits in our opinion better within the context of the SSC. Ambiguity and discrepancy in terminology persists in the literature (Kachlik et al., 2008; Kachlik et al., 2009; Vogl, 2009; Kachlik et al., 2015; Kachlik et al., 2016; Loukas et al., 2016; Strzelec et al., 2017; Chmielewski, 2020; Chmielewski and Strzelec, 2020; Chmielewski & Strzelec, 2020). Although the Delphi consensus method is an objective voting system with limited potentials to bring agreement among experts on a particular term (Fink et al., 1984; Yammine, 2014; McMillan et al., 2016; Humphrey-Murto et al., 2017), it is nonetheless the best acceptable method.

5.2. Suprascapular notch variation

Profiling the SSN morphological variation is better understood when dividing it into the following components: the osteology of the SSN, and the topography of the SSN.

5.2.1. Suprascapular notch classification systems

The SSN shape variability was established and classified based on the osteological observations by morphometric measurements. The stenosis pattern of the SSN was established in each morphological type. This finding was driven from analyzing the reduction in the parametric measurements addressed in Section 3.2.2. (Figure 26) and the results were published (Al-Redouan et al., 2021b). The SSN takes five forms based on depth versus superior width length. The SSN with a discrete notch (Type-V) and with a reduced depth (Type-III) are at higher risk of stenosis. An osteoplasty is necessary when the SN is compressed at the SSN by bone margins, specifically in Type-I SSN (Al-Redouan et al., 2021b). Our morphometric classification system is in concordance with the proposed classification system by Polguj et al. (2011a) 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 observed differences in prevalence is probably influenced by the sample sizes and its demography in each study. A confusion in describing the discrete type of the SSN had been encountered in the literature (Al-Redouan and Kachlik, 2021c; Al-Redouan and Kachlik, 2021d; Al-Redouan and Kachlik, 2022a). The discussion and debate of classifying the SSN shape is persisting throughout the literature. A meta-analytic study was presented by Tsakotos et al. (2024) sorting and elaborating on the reported SSN classification studies. However, their review demonstrated the lack of coherence in the SSN typing systems (Hrdlicka, 1942; Rengachary et al., 1979a; Urgüden et al., 2004; Natsis et al., 2007; Sinkeet et al., 2010; Iqbal et al., 2011; Polguj et al., 2011a; Albino et al., 2013; Inoue et al., 2014; Kannan et al., 2014; Kumar et al., 2014; Agrawal et al., 2015; Jezierski et al., 2017; Zhang et al., 2019; Bagoji et al., 2020). 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 (Al-Redouan et al., 2021b).

5.2.2. Suprascapular notch content

The SSL was found to vary morphologically (Figure 18) as addressed in the literature (Avery et al., 2002; Tubbs et al., 2013; Polguj et al., 2012a; Polguj et al., 2013b; Polguj et al., 2014b; Gürses et al., 2015; Podgórski et al., 2015; Kaledzera et al., 2022; Kumar et al., 2023a). The observation of the SSL was subjected to dissection artifacts in many of the cases. The SSN can contain a membrane as illustrated in some of our observed cases (Figure 19B). However, this membrane is delicate and can be lost during the dissection while cleaning the connective and adipose tissues occupying the SSN vicinity. In addition, the variant anterior coracoscapular ligament (Figure 19C) is also very delicate with an average size of one millimeter and can be easily lost during dissection. To assure an accurate report of its prevalence, only 63 specimens were included. The exclusion criteria were: prosected SSN specimens that seemed to be not well dissected, and any SSN containing adhesive connective tissue when it was inevitable to be resected by sharp dissection. Therefore, the reported prevalence of 15.9% reflects ten out of the reliable 63 SSN specimens concerning the aforementioned variant anterior coracoscapular ligament. There is a discrepancy throughout the literature in the reported prevalence of the anterior coracoscapular ligament (Avery et al., 2002; Bayramoglu et al., 2003; Piyawinijwong and Tantipoon, 2012; Polguj et al., 2013b; Gürses et al., 2015; Podgórski et al., 2015; Polguj et al., 2016). 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. Nevertheless, our observation was mainly from free limbs and therefore the laterality of the anterior coracoscapular ligament could have not been assessed. The histological evaluation of the SSL in this thesis was limited due to the formalin-fixed cadavers. Immunohistochemistry was not performed as stated in Section 4.2.2. As aforementioned, the SSL was composed of dense collagen fibers of a typical ligament with an admixture of elastic fibers (Figure 20). Currently, there is no comprehensive histological study concerning the SSL microscopic structure available in the literature.

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, our study shows strong opposing evidence. 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 (Figure 25) (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% of cases, 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). Both our study (Al-Redouan et al., 2021a) and the literature reports are in agreement with the variability of the vessels' course but with a discrepancy in the prevalence. The course of the vessels in relation to the SSN is overlooked by many anatomists (Al-Redouan and Kachlik, 2021d). 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 (Figure 25) (Al-Redouan et al., 2021a). A duplicated SV was found in 30.0%, while a tripled SV in 3.3% of cases (Al-Redouan et al., 2021a). However, the SA was less likely to be duplicated and was found only in 3.3% of cases (Figure 25) (Al-Redouan et al., 2021a). In fact, the variation in course and quantity of the SA and SV is well documented in the modern literature (Rengachary et al., 1979b; Demirhan et al., 1998; Avery et al., 2002; Dargaud et al., 2002; Bayramoglu et al., 2003; Urgüden et al., 2004; Chen and Adds, 2011; Polguj et al., 2011a; Yang et al., 2012; Polguj et al., 2013a; Polguj et al., 2013b; Tubbs et al., 2013; Inoue et al., 2014; Kumar et al., 2014; Polguj et al., 2014c; Polguj et al., 2015; Podgórski et al., 2015; Labetowicz et al., 2017; Zhang et al., 2019). The variations of the vessels within the SSN cannot be observed *in vivo* with reliability by ultrasound Doppler as stated in Section 5.1.

The topographical variations of muscles in relation to the SSN has not been to our best knowledge studied before with the exception of the OMHM. The insertion of the OMHM was repetitively reported (Brown, 1980; Anderson, 1982; Bayramoglu et al., 2003; Buntine et al., 1970; Bhat et al., 2018; Singh et al., 2018; Kumar et al., 2023b; Verma et al., 2016). It is a well-established fact that the OMHM inserts on both the medial peak of the SSN and the SSL (Lambert, 2016) with some documented variation of its attachment sites (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 cadaveric specimens. Only in 29.6%, the SSL was involved as an insertion site for the OMHM (Figure 23). The observed variability of the SSL involvement as an attachment site was document previously in the literature (Buntine et al., 1970, Bayramoglu et al., 2003; Verma et al., 2016; Bhat et al., 2018; Singh et al., 2018; Kumar et al., 2023a). 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 as stated in Section 4.2.3. The anterior coracoscapular muscle has never been to our best knowledge 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) and it was encountered only twice unilaterally in our study. The superior margin of the SUBM can run more cranially covering the anterior surface of the SSN as illustrated in Section 4.2.3. (Figure 21). This can cause impingement on the SN leading to SNE (Al-Redouan et al., 2021a) as discussed further below in Section 5.3. 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). Our observation of muscles in our cadaveric study was limited. The functional outcome of the OMHM variable insertion could not be examined. As we had stated in Section 4.2.3., evaluating the OMHM attachment onto the SSL should be put into consideration in cases of surgical resection of the SSL. However, the pathological effect of the OMHM iatrogenic loss of attachment could not be assessed in a formalin-fixed cadaveric study. 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), but could not have been verified in our cadaveric study.

5.3. Suprascapular nerve entrapment at the suprascapular notch

The SNE anatomical causes at the SSN are listed in Table 4 (Al-Redouan et al., 2021a; Al-Redouan et al., 2023). These etiologies reflect collective reports from the literature (Post and Grinblat, 1992; Rengachary et al., 1979a; Rengachary et al., 1979b; Ringel et al., 1990; Berry et al., 1995; Avery et al., 2002; Zehetgruber et al., 2002; Bayramoglu et al., 2003; Ravindran, 2003; Bodily et al., 2005; Spinner et al., 2006 ; Ofusori et al., 2008; Duparc et al., 2010; Ebraheim et al., 2010; Parvizi and Kim, 2010; Shin et al., 2010; Economides et al., 2011; Kang et al., 2012a; Moen et al., 2012; Polguj et al., 2012a; Polguj et al., 201b; Shi et al., 2012; Polguj et al., 2013c; Tubbs et al., 2013; Kumar et al., 2014; Podgórski et al., 2014; Waldman, 2014; Czihal et al., 2015; Podgórski et al., 2015; Polguj et al., 2015; Tasaki et al., 2015; Kostretzis, 2017; Labetowicz et al., 2017; Leschingera et al., 2017; Katsuura et al., 2019; Memon et al., 2019; Bagoji et al., 2020; Rubin, 2020; Bagoji et al., 2021; Leider et al., 2021; Patetta et al., 2021; Cummins et al., 2022; Vij et al., 2022).

5.3.1. Mechanism of suprascapular nerve entrapment at the suprascapular notch

A decrease in space capacity within the SSN below a critical point of 3 mm will predispose to SSN stenosis (Al-Redouan et al., 2021a; Al-Redouan et al., 2021b). Consequently, the SN will 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; Yamakado, 2016; 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 can occur with an incidence of 15% (Al-Redouan et al., 2021b) due to ossification of the SSN margins as illustrated in some examples in Figure 20 in Section 4.2.2. This form of stenosis can take three distinctive patterns as addressed in Figure 26. A horizontal pattern where the SN is compressed between two bone margins (Figure 29A), 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. This finding is novel in this thesis and has not been addressed prior to our published study (Al-Redouan et al., 2021b). 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). This could be a variant structure such as the anterior coracoscapular ligament (Figure 18C), running underneath the SN in a transverse plane dividing the SSN into two internal compartments (Avery et al., 2002; Bayramoglu et al., 2003; Piyawinijwong and Tantipoon, 2012; Polguj et al., 2013b; Gürses et al., 2015; Podgórski et al., 2015). It had been addressed in the literature as a potential cause of the SNE (Polguj et al., 2013b). However, other authors argued that it could give protective mechanism serving in lifting up the SN away from the inferior sharp margin of the SSN (Podgórski et al., 2015). The key concept relies in the extent of how much of space does the structure occupy versus how much of a space is left to accommodate the residing SN featuring 2–3 mm in diameter. Other space occupying structures are the suprascapular vessels if they are passing within the SSN under the SSL, depending on their number and calibers. It was also speculated that the SV could serve as a protective cushion for the SN (Podgórski et al., 2015; Łabętowicz et al., 2017).

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 (Figure 21) 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. Etiologies of the suprascapular nerve entrapment at the suprascapular notch

In addition to the aforementioned space occupying variant structures (Section 5.3.1.), the variant SPM can compress the SN before it enters through the SSN (Al-Redouan et al., 2023). Tortuous and dilated (varicose) veins can lead to both stenosis and vascular dynamic compression (Katsuura et al., 2019). Pathological conditions such as SN neuroma can increase the SN diameter to a point where it can gets entrapped and becomes compressed (Berry et al., 1995; Bodily et al., 2005). In general, a ganglion cyst is a common reported etiology (Chochole et al., 1997; Ticker et al., 1998; Spinner et al., 2006; Lee et al., 2007; Pillai et al., 2007; Tan et al., 2012; Mahjoub et al., 2018; Yildizgören et al., 2020). A post-fracture inflammatory process can result in adhesions and entrapment of the SN (Kang et al., 2012a; Moen et al., 2012; Kostretzis et al., 2017). A post-inflammatory process in soft tissue lesions of the SUPM or its fascia can lead to adhesions that can entrap of the SN as well. Patients with history of rotator cuff damage affecting the central tendon of the SUPM are at risk of SNE (Massimini et al., 2013; Fabis-Strobin et al., 2018; Katsuura et al., 2019). In addition to the above-mentioned dynamic causes (Section 5.3.1.), a retroclavicular tension such as chronic heavy loads (bags' belt) can cause compression and occlusion of the SN vasa nervorum leading to a microembolic damage (Waldman, 2014). In pediatric patients, a shoulder dystonia can also cause SNE by shear damage (Parvizi and Kim, 2010; Mandal et al., 2019). The etiologies leading to SSN stenosis were invistigated in our study on dry bones and cadaveric specimens (Al-Redouan et al., 2021a; Al-Redouan et al., 2021b). However, the dynamic forms of compression are a limitation in our methodology of investigation and the relevant information is solely based on literature reviews.

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

Two basic imaging modalities that can be utilized in detecting SNE and each carry its own limitations.

MRI (Figure 30–32) is useful to search for soft tissue pathologies (Katsuura et al., 2019; Rubin, 2020) within the SSC intervals (Al-Redouan et al., 2021a). It has 95% sensitivity and specificity in detecting ganglionic cysts (Leider et al., 2021). 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. However, as stated in Section 4.4., it does not give a clear visualization to detect SSN stenosis (Al-Redouan and Kachlik, 2022c).

Ultrasound is an instant and non-invasive low-cost method for fast screening of the SSN surrounding soft tissue (Al-Redouan and Kachlik, 2022c). It is an excellent tool for fellow-ups screening (Kim et al., 2009; Leider et al., 2021). The SN can be localized and traced sonographically as well with challenge (Peng et al., 2010; Laumonerie et al., 2017; Kamal et al., 2018; Laumonerie et al., 2018; Ulusoy et al., 2018; Katsuura et al., 2019; Laumonerie et al., 2019b; Laumonerie et al., 2019c; Podgórski et al., 2019; Yildizgören, 2020; Park et al., 2022; Prenaud et al., 2021). The SSN stenosis can be assessed in two views, posterior (Figure 36) and anterior views (Figure 37), as stated in Section 4.4.3. Through this thesis, we show a novel approach to evaluate a suspected SSN by ultrasound assessment. The SSN internal size is evaluated by two sets of measurements. 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 (Figure 14) (Al-Redouan et al., 2021b). 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).

Other sophisticated and invasive imaging modalities can contribute to the detection of a SNE. The 3D-CT reconstruction does expose the SSN osteology type with high resolution and precision, but does nor the SSL neither the SN (Moen et al., 2012; Leider et al., 2021). Its sensitivity to detect the SA and SV depends on software technicality. Fluoroscopy gives a clear SSN anterior view visibility (Kang et al., 2012b), but it loads the patient with a high radiation dose in one setting. Arthroscopy is the ultimate imaging method that gives a direct view of the whole SSN topography (Barwood et al., 2007; Lubowitz et al., 2009; Prenaud et al., 2021). However, it is an invasive method and requires surgical indications (Lubowitz et al., 2012). Furthermore, Shimokobe et al. (2013) reported two cases where a ganglion cyst located in the SUPF was not detected during arthroscopic procedures and required full exposure of the SN through more soft tissue resection along its course.

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

Surgical treatment of the SNE is indicated when a conservative treatment fails to relieve the pain (Strauss et al., 2020; Leider et al., 2021). However, from our findings in this thesis, it is essential to first assess and confirm the degree of any potentially existing anatomical compression. The rationale is if the SN remains compressed regardless of the relief of pain, it will continue to be damaged and may gradually lose its function. A systematic review by von Knoch et al. (2021) showed that motor recovery after conservative treatments was not pertained in 60% of the reported cases.

Conservative and minimally invasive treatment methods are favored (Strauss et al., 2020; Leider et al., 2021). The SN anesthetic block brings a quick short-term pain relief (Chan and Peng, 2011; Fernandes et al., 2012). Chan and Peng (2011) published a narrative review on the SN block and according to their study, 85.3% of the acute SN pain was relieved by this procedure. They also elaborated on the use of catheter tunneled into the SSC for chronic SN pain relief with no case reports available in the literature in regard to its long-term outcome (Chan and Peng, 2011). The efficacy of this method may be influenced by the anatomical extension into the SN vicinity (Al-Redouan et al., 2022d). 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 shown more aggressive types of post-procedure complications with recurrent higher intensity pain (Chang et al., 2015; Vij et al., 2022). On the contrary, a study by Ergönenç and Beyaz (2018) showed that a repeated interval of pulsed radiofrequency could manage the pain within six months, but with poor SUPM and INFM functional recovery. 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). However, this method is relatively recent and further randomized trials are needed to assess its long-term efficacy and complications. Another recently introduced method in treating SN neuropathy is SN cryoneurolysis (Gabriel et al., 2019; Leider et al., 2021). According to Leider et al. (2021), this method showed an excellent pain relief due to the somatosensory fibers ablation. However, the SUPM and INFM showed atrophy due to the loss of somatomotor fibers carried within the SN (Wang et al., 1996; Fabis-Strobin et al., 2018; Gabriel et al., 2019; Leider et al., 2021). These methods are enhanced when performed under imaging modality-guidance (Schneider-Kolsky et al., 2004; Peng et al., 2010; Chan and Peng, 2011; Fernandes et al., 2012; Hill et al., 2014; Chang et al., 2015; Laumonerie et al., 2017; Ergönenç and Beyaz, 2018; Laumonerie et al., 2018; Kamal et al., 2018; Gabriel et al., 2019; Ilfeld et al., 2019; Laumonerie et al., 2019a; Laumonerie et al., 2019b; Yildizgören, 2020; Leider et al., 2021; Prenaud et al., 2021; von Knoch et al., 2021; Vij et al., 2022). Our introduced protocol for the SSN ultrasound examination could contribute to enhance the SN targeting in these types of procedures. The anatomical access to the SN in these aforementioned procedures includes posterior and anterior approaches (Chan and Peng, 2011; Fernandes et al., 2012; Laumonerie et al., 2017; Laumonerie et al., 2018; Laumonerie et al., 2019a; Laumonerie et al., 2019b; Laumonerie et al., 2019c; Leider et al., 2021; Al-Redouan et al., 2022d). 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; Al-Redouan et al., 2022d) 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; Al-Redouan et al., 2022d). Further, our detailed SSC topographical description (Al-Redouan et al., 2021a) could contribute to the topographical access to the SN and to raise awareness of the potential variant structural contents.

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). Open surgical compression becoming less practiced even though it had showed good outcome (Tender et al., 2006; Lafosse et al., 2007; Strauss et al., 2020; Leider et al., 2021). Less invasive surgical methods became the primary choice under imaging modality guidance (Peng et al., 2010; Chan and Peng, 2011; Kamal et al., 2018; Laumonerie et al., 2019a; Laumonerie et al., 2019b; Leider et al., 2021; Al-Redouan et al., 2022d; Al-Redouan et al., 2023). Two main imaging-guided procedures fall into this category: (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 (Chen et al., 2003; Millett et al., 2006; Lafosse et al., 2007; Chan and Peng, 2011; Momaya et al., 2018; Davis et al., 2020; Strauss et al., 2020; Cano-Martínez et al., 2021; Leider et al., 2021; Nolte et al., 2021). Currently, there are multiple surgical approaches in SNE decompression procedures. Two surgical approaches are performed in open surgical decompression (Leider et al., 2021). The posterior surgical approach is through the SUPF by splitting the trapezius muscle and the SUPM (Lafosse et al., 2007; Pruksakorn et al., 2007; Tubbs et al., 2007; Leider et al., 2021; Maurya et al., 2021) which gives access to the SSL for its decompression by ligamentectomy (Al-Redouan et al., 2021a; Al-Redouan et al., 2021ba). 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 (Al-Redouan et al., 2021a; Leider et al., 2021; Al-Redouan et al., 2023). The arthroscopic surgical approaches require more precise topographical portal insertions. The modern arthroscopic approach utilizes multiple portals (Leider et al., 2021). The posterior portal is placed under the base of the acromion for initial inspection. The lateral subacromial portal is then placed for visualization and guidance through the structures (Romeo et al., 2010; Davis et al., 2020; Leider et al., 2021). The anterolateral portal is placed to perform a bursectomy and navigate through the structures to the base of the coracoid process (Romeo et al., 2010; Leider et al., 2021). The Neviaser's portal, which is a superior medial portal inserted underneath the acromioclavicular joint, is placed to bluntly dissect the soft tissue reaching to the target and to transect the compressing structures (Lafosse et al., 2007; Leider et al., 2021). The SN portal is utilized to verify the mobility of the released nerve (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 FINDINGS

7.1. Suprascapular notch morphology

The suprascapular notch (SSN) was classified into five SSN types based on its morphometric measurements (Figure 14): 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, orfanned 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 (Figure 25): (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 (Figure 10). 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 (Figure 26): (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 (Figure 36 and 37). 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 (Figure 33); (2) posterior-frontal view projecting the SSN space from its posterior surface (Figure 34); and (3) anterior-frontal view projecting the SSN space from its anterior surface (Figure 35).

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 FINDINGS IN CZECH

8.1. Morfologie *incisura scapulae*

Incisura scapulae (SSN) byla na základě morfometrických měření klasifikována do pěti typů (Obrázek 14): 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 pokryto 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 (Obrázek 25): (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 (Obrázek 10). 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 zvýšený setrvalý tlak svým tepem. V prostoru po výstupu z SSN: (1) vazivové srůsty fascie v důsledku poškození SUPM; (2) přetažení SN u natržení rotátorové manžety a sportovních zranění; (3) dynamický útlak v důsledku trvalého 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 (Obrázek 26): (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 (Obrázek 36 a 37). 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 (Obrázek 33); (2) zadní a frontální přístup poskytující pohled na prostor SSN z jeho zadní strany (Obrázek 34); a (3) přední a frontální přístup poskytující pohled na prostor SSN z jeho přední strany (Obrázek 35).

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.

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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)

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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.
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5. **Al-Redouan, Azzat**; Sadat, Mehdi S.; Theodorakioglou, Aimilia; Benes, Michal; Holding, Keiv; Zhauyrova, Madina; Nesterenko, Polina; Kunc, Vojtech; Salavova,

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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.
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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.