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ARTICLE

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

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ABSTRACT

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

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

Introduction

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

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

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

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

Basic anatomy

Spinal accessory nerve anatomy

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

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Suprascapular nerve anatomy

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

Material and methods

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

Spinal accessory nerve course and length

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

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

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

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

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

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

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

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

Spinal accessory to infraspinatus branch of suprascapular nerve transfer technique

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

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

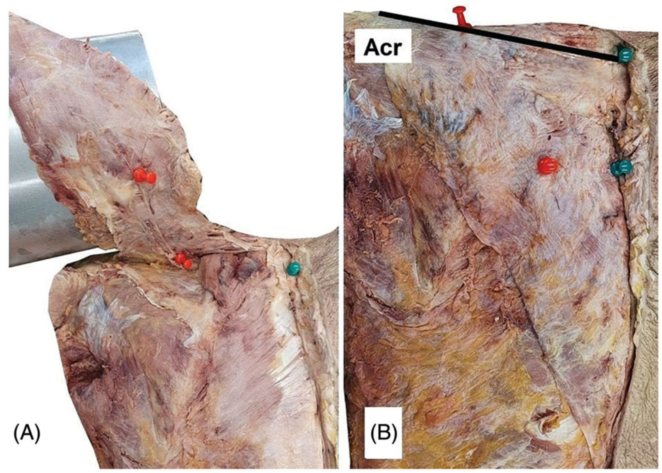

Figure 1. The technique of morphological mapping of the SAN. (A) Trapezius muscle was detached from the spinous processes and the scapular spine and rotated cranio-laterally. The SAN was dissected from its entry into the trapezius muscle to the terminal branches. It was then marked by upper red pushpin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

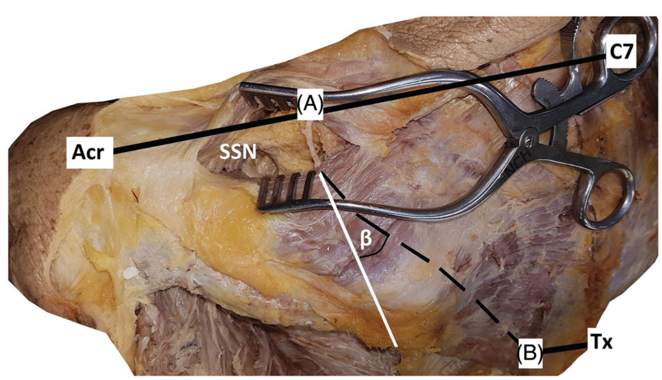

Figure 2. The position of (A) the entry point of the SAN into the trapezius muscle on the line between acromion (Acr) and C7 spinous process and (B) the most caudal part of the nerve with minimal 2 mm of diameter. Distance 1 measured between the points A and C7, Distance 2 between B and corresponding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

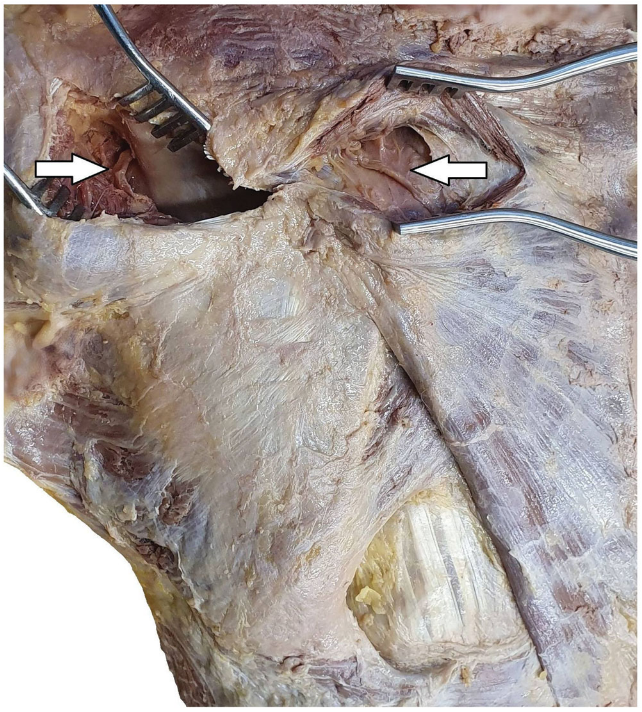

Figure 3. Anatomical situation after separation of the infraspinatus muscle from the spine of scapula and floor of the infraspinous fossa and dissection of the SAN between the muscle fibres of the trapezius muscle. Left arrow – IB-SSN, right arrow – SAN.

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

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

Results

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

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

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

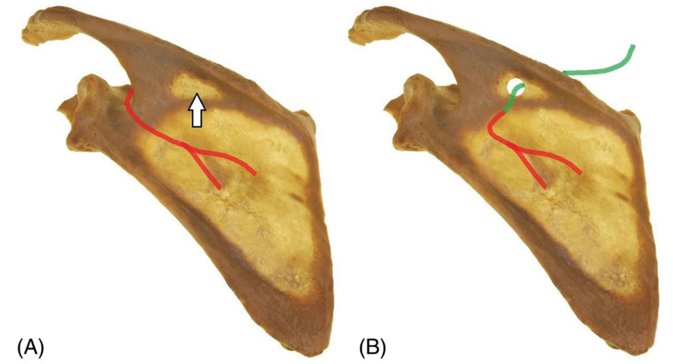

Figure 4. Transilluminated scapula, postero-inferior view [23]. A. SSN (red) passes through the spinoglenoid notch, arrow – central weakened area. B. Schematic drawing of the SAN (green) to SSN (red) transfer. SAN running through the bony canal in the weakened area under the spine of the scapula.

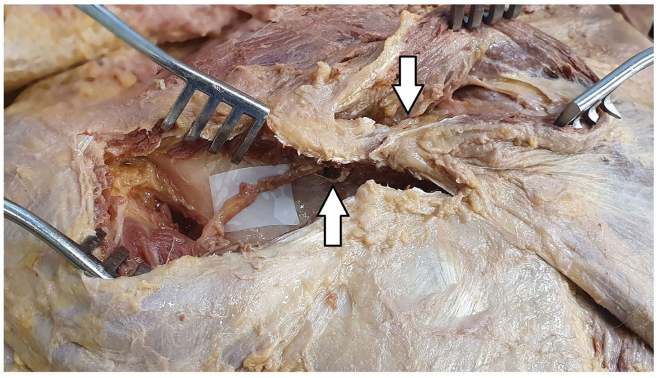

Figure 5. Direct SAN to IB-SSN transfer. Left arrow – SAN transferred through the bony canal performed in the central weakened area of the scapular spine, right arrow – proximal part of the SAN.

Discussion

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

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

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

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

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

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

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

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

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

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

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

Limitations

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

Conclusion

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

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Disclosure statement

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

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