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CLINICAL IMPLICATIONS OF BASIC RESEARCH

Neuromuscular Partitioning of Subscapularis Based on Intramuscular Nerve Distribution Patterns: Implications for Botulinum Toxin Injections

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Abstract

Subscapularis muscle spasticity is commonly treated with botulinum toxin injections; however, there are challenges in determining optimal injection sites within the muscle. The purpose of this study was to document the intramuscular innervation patterns of the subscapularis (1) to determine how the muscle is neuromuscularly partitioned and (2) to identify a strategy for botulinum toxin injection based on neuromuscular partitioning. In 50 formalin-embalmed cadaveric specimens, the extramuscular and intramuscular innervation was (1) serially dissected, digitized, and reconstructed in 3 dimensions (n=7); or (2) serially dissected and photographed (n=43). Intramuscular innervation patterns were compared among specimens to identify neuromuscular partitions. Variation was observed in the number (2–5) and origin of extramuscular nerve branches to the subscapularis. Despite variation in extramuscular innervation, the intramuscular innervation was consistent. Based on intramuscular innervation patterns, the subscapularis had 3 neuromuscular partitions (superior, middle, inferior) in 78% of specimens, and 2 partitions (superior, inferior) in 22% of specimens. The superior and middle partitions were most commonly innervated by branch(es) from the posterior cord, and the inferior partition by branch(es) from the axillary nerve. Injection of botulinum toxin into each partition may help to optimize results in the treatment of shoulder spasticity, and may be achieved by a combination of medial and inferior approaches. Clinical studies are required to determine whether the combination approach is more effective than any single approach and whether the number of partitions injected correlates with clinical outcomes.

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Upper limb spasticity, a velocity-dependent increase in muscle tone,[1] is a common complication of central nervous system disorders such as stroke[2] and cervical spinal cord injury.[3] Spasticity of the subscapularis (SSC) and the relative weakness of the remaining rotator cuff muscles may lead to excessive and/or sustained adduction and internal rotation of the shoulder with associated subluxation of the humeral head.[4] The resulting shoulder pain and limited range of motion can have a significant impact on quality of life.[5]

In an international consensus statement regarding the clinical use of botulinum toxin A (BoNT-A) for upper limb spasticity in adults, Sheean et al[6] recommended that injections into the shoulder girdle muscles be considered as a treatment option to decrease poststroke shoulder pain. In a literature review of clinical studies investigating SSC injection with BoNT-A poststroke, 4 studies were found. These studies included 3 randomized controlled trials[7-9] and 1 case series.[10] The injection approaches, number of injection sites, and dosage per site are compared in table 1.

Injection of SSC is challenging because of its location in the subscapular fossa and proximity to vital neurovascular structures.[4,11] Many approaches, including medial, lateral, superior,

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Table 1 Approaches of BoNT-A injections of SSC

Approach	Authors	Type (n)	Sites	Dosage per Site
Medial	Yelnik et al,[7] 2007	RCT (20)	1	500U*
	de Boer et al,[8] 2008	RCT (22)	2	50U
Inferior	Unlu et al,[10] 2010	Cases (5)	NR	30–50U
NR	Lim et al,[9] 2008	RCT (29)	2	Up to 25U

Abbreviations: NR, not reported; RCT, randomized controlled trial.
* Speywood units.

Table 2 Injection of SSC: cadaveric studies

Authors	Approach	% (n) in SSC	Other Injected Sites
Chiodo et al,[4] 2005	Lateral	78 (7/9)	Teres major, Latissimus dorsi
	Medial	33 (3/9)	NR
	Superior	0 (0/9)	Supraspinatus, Trapezius, Levator scapulae
Unlu et al,[11] 2008	Inferior	96 (23/24)	Infraspinatus

Abbreviation: NR, not reported.

and inferior, have been developed for SSC injection. Two cadaveric studies were found that evaluated the accuracy of needle placement using these approaches (table 2). Chiodo et al[4] found that the lateral approach was more effective than the medial and superior approaches. In contrast, Unlu et al,[11] using the inferior approach, reported successful injection of SSC in 96% of specimens, with injection into the thickest, inferolateral portion of the muscle in 92%.

BoNT-A blocks release of acetylcholine at the neuromuscular junction, leading to a temporary decrease in muscle tone.[2,12] Knowledge of the intramuscular innervation pattern can help guide the selection of injection sites, as the nerve branches terminate at the neuromuscular junction. Previous innervation studies of SSC have focused primarily on extramuscular innervation and have found variation in both the number and origin of the branches constituting the upper subscapular (table 3) and lower subscapular (table 4) nerve complexes.

The upper subscapular nerve(s), which innervate the superior portion of SSC, have been reported to originate from a wide variety of sources, most commonly from the posterior cord (12/13 studies) or posterior divisions of the superior and middle trunks (5/13 studies). The thoracodorsal and axillary nerves were identified as sources of innervation in 2 studies. In the literature, the total number of upper subscapular nerves to the superior portion of SSC ranged from 1 to 5. In contrast, 1 to 3 lower subscapular nerve(s) have been found to innervate the inferior portion of SSC and teres major. The frequency of origin of the lower subscapular nerve(s) was from the posterior cord in all 13 studies, the axillary nerve in 10 studies, and the thoracodorsal nerve in 6 studies.

The intramuscular innervation of SSC was found to be described in 2 cadaveric studies.[15,19] In both studies, the results were documented using 2-dimensional line illustrations, rather than volumetrically. Based on the intramuscular innervation pattern, Frohse and Fränkel[15] described 2 portions of SSC, thoracic and axillary, whereas Kato[19] identified 3 portions, upper, middle and lower/axillary.

Electromyographic studies have found that the upper and lower portions of SSC were selectively recruited during a variety of shoulder movements, shoulder-strengthening exercises, and pitching (table 5). The intramuscular wire electrodes were inserted using medial or lateral approaches. This differential recruitment of the upper and lower portions of SSC suggests that SSC may be neuromuscularly partitioned based on innervation pattern.

List of abbreviations:

BoNT-A botulinum toxin A
3D 3-dimensional
SSC subscapularis muscle

Since SSC is a large multipennate muscle with numerous intramuscular tendons, and given that fascia has been shown to reduce intramuscular diffusion of BoNT-A by 23%,[32] targeting SSC with a single injection may be insufficient. Detailed knowledge of neuromuscular partitioning of SSC could be used to understand the coverage of the muscle belly using current injection techniques and to identify other options for injection. To date, the intramuscular innervation pattern of SSC has not been studied in 3 dimensions throughout the muscle volume. Recent studies[33,34] from our laboratory have shown that detailed patterns of intramuscular nerve distribution can be analyzed using 3-dimensional (3D) modeling to determine the presence of neuromuscular partitioning. Therefore, the purpose of this study was to document the extra- and intramuscular innervation patterns of SSC throughout the muscle volume using dissection, digitization, and 3D modeling.

Methods

Fifty formalin-embalmed cadaveric specimens (mean age, 79.5±12.4y) were studied (29 men, 21 women). Ethics approval was obtained from the University of Toronto Health Sciences Research Ethics Board (protocol no. 27210). Exclusion criteria

Table 3 Number and origin of upper subscapular nerves

			Origin (%)			
Studies	n	No. of Br	PD	PC	TD	AX
Walsh,[13] 1877	350	1–2	✓			
Herringham,[14] 1887	55	2–3		✓		
Frohse and Fränkel,[15] 1908	NR	3		✓		
Kerr,[16,*] 1918	157	1–3	64	14	<1	<1
Bryce,[17] 1923	NR	2		✓		
Brash,[18] 1955	29	2–3		✓		
Kato,[19] 1989	40	1–5	✓	✓		
McCann et al,[20] 1994	50	1–2	✓	✓		
Yung et al,[21] 1996	11	1–2		✓		
Tubbs et al,[22] 2007	62	1–3		97		3
Kasper et al,[23] 2008	20	1–2		✓		
Saleh et al,[24] 2012	33	1–3		97	3	
Chen et al,[25] 2013	33	1–3	✓	✓		

Abbreviations: AX, axillary nerve; Br, branches; NR, not reported; PC, posterior cord; PD, posterior division(s) of trunk(s); TD, thoracodorsal nerve; ✓, present (not quantified).
* In <2%: anterior ramus C5, superior/middle trunk, anterior division of superior/middle trunk, lateral cord and/or suprascapular/radial nerves.