



Verification of intramuscular electromyography electrode placement for neuromuscular partitions of infraspinatus



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ABSTRACT

The infraspinatus muscle is composed of three neuromuscular partitions: superior, middle and inferior. Although methods for fine-wire EMG electrode insertion into these partitions have been developed and used, it has yet to be verified. The purpose of this cadaveric EMG needle placement study was to assess the accuracy and reproducibility of a protocol used to target the three partitions of infraspinatus. On seven shoulder specimens, two investigators inserted needles into each superior, middle and inferior partition according to a previously developed protocol. Each was blinded to the other's insertion sites. The specimens were dissected and the location of each needle was digitized and modeled in 3D. Of the 42 needles that were inserted, 32 were placed in the targeted partition. The highest accuracy rate occurred for the middle partition (100%), followed by the inferior (71.4%) and then the superior (57.1%). When the needles were not placed in the targeted partition, they were located in the neighboring partition within infraspinatus or the teres minor muscle. The current study showed the middle partition could be targeted accurately, whereas the superior and inferior partitions were more challenging. Ultrasound guidance may be necessary to ensure accurate placement into all parts of infraspinatus.

1. Introduction

Targeted training of the infraspinatus muscle (IS) is an important component of conservative management and post-operative rehabilitation protocols for rotator cuff pathologies, such as tendon tears (Kuhn et al., 2013). Together with the other rotator cuff muscles, IS is essential for stabilizing the humeral head in the glenoid fossa through generating compressive joint force (Wilk et al., 1997; Wuelker, 1998). Optimal training of IS depends on a thorough understanding of its structure and related function. Until recently, its functional description may have been oversimplified.

Despite the functional importance of IS, most anatomical and EMG studies regarded the IS as a whole unit (Ryan et al., 2018; Sasaki et al., 2019; Reinold et al., 2004; Townsend et al., 1991), despite recent contrary evidence. Recently Hermenegildo et al. (2013) and Ko et al. (2013) in a 3D digitization and modeling study defined three neuromuscular partitions of IS: superior, middle and inferior. Partition distinctions relied on distinct fibre bundle architecture and innervation patterns. The superior region comprised approximately 15% of the total IS volume, the middle region 50% and the inferior region 35%. Fiber

bundle orientation differed between the three partitions. The superior partition consisted of horizontally oriented fiber bundles, whereas the fiber bundles of the middle and inferior partitions were more obliquely oriented and directed superolaterally. Distinct primary branches of the suprascapular nerve correlated with these distinct partitions.

Similar to the generalizations made in previous anatomical studies, conventional electromyography (EMG) studies of IS have most commonly placed electrodes in the center of the muscle, implicitly assuming IS acts as one functional unit (Reinold et al., 2004; Townsend et al., 1991). More recently, fine-wire EMG studies have investigated the activations of the partitions of IS during maximal voluntary contractions and varying functional activities (Alenabi et al., 2018; Alenabi et al., 2019; Joseph et al., 2018; Calver et al., 2019). These studies have demonstrated activation levels between the partitions of IS differ and are dependent on arm position and the type of shoulder task. For example, during isometric arm elevation to 90°, the superior partition of IS was more highly activated than the middle (Alenabi et al., 2019). Similarly, during different dynamic shoulder tasks, differences in activation levels were found between partitions of IS. For example during external rotation, the relative activation of the superior partition of IS was greater

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than the middle compared to when the shoulder was dynamically flexed or abducted (Calver et al., 2019).

The EMG protocol used in these studies applied the anatomical findings of Hermenegildo et al. (2013) and Ko et al. (2013); however, the accuracy of fine-wire electrode placement into the three partitions of IS lacks evaluation. Validating the accuracy of EMG electrode placement into the three neuromuscular partitions of IS *in vivo* critically relates to ensuring consistency and reproducibility of findings. Therefore, the purpose of this cadaveric EMG needle placement study was to assess the accuracy and reproducibility of the protocol to target the superior, middle and inferior partitions of IS.

2. Methods

2.1. Specimens

This proof of concept study used seven formalin-embalmed male shoulder specimens with mean age of 83.8 ± 4.4 years. Specimens with evidence of musculoskeletal pathologies, deformities, previous surgeries, or trauma were excluded. Ethics approval was obtained from the University of Toronto Health Sciences Research Ethics Board (#27210).

2.2. Research design

Two investigators (A and B), each with more than 2 years of shoulder fine-wire EMG experience (i.e. each performed more than 80 needle placements within IS on research participants) placed the needles (25 gauge, 1.5"). Investigators A and B each inserted one needle into the superior, middle and inferior partitions of 3 right and 4 left IS according to the protocol defined by Alenabi et al. (2018). The investigators were blinded to each other's insertion sites as the needles were clipped so that their ends were not visible from the skin surface. Prior to clipping the needle, its entry point on the skin was digitized using a Microscribe™ G2X® digitizer. This provided a permanent record of the Cartesian coordinates of each needle entry point.

2.3. Needling protocol

Cadavers were positioned in prone with the elbow flexed (approximately 45°) and the dorsum of the hand resting on the lumbar region to simulate the clinical protocol outlined by Alenabi et al (2018). To enable reconstruction of the digitized data, three reference points, lateral aspect of acromion, spinous process of T3 and base of the occiput were demarcated with screws. The spine, acromion, medial and lateral borders of the scapula were outlined using a skin marker. To assist with needle placement, the following lines were demarcated on the skin: (1) vertical lines separating the lateral, middle and medial thirds of the scapular spine and (2) a horizontal line connecting the mid-points of lateral and medial borders of scapula. These landmarks were identified and demarcated in 3 specimens by Investigator A and in the other 4 specimens by Investigator B. See Fig. 1.

To target each of the three partitions, the EMG needle was inserted into IS using the protocol below:

- Superior partition. First, a point in the lateral half of the middle third of the spine was identified. The needle was inserted vertically at this point just inferior (5 mm) to the spine of the scapula (Fig. 1).
- Middle partition. The needle was inserted vertically at the intersection of the line connecting the mid-points of the lateral and medial borders of the scapula with the line between the medial and middle thirds of the spine of scapula (Fig. 1).
- Inferior partition. The needle was inserted at the intersection of the line connecting the mid-points of the lateral and medial borders of the scapula with the line between the middle and lateral thirds of the spine of scapula. The needle was angled 30° toward the inferior

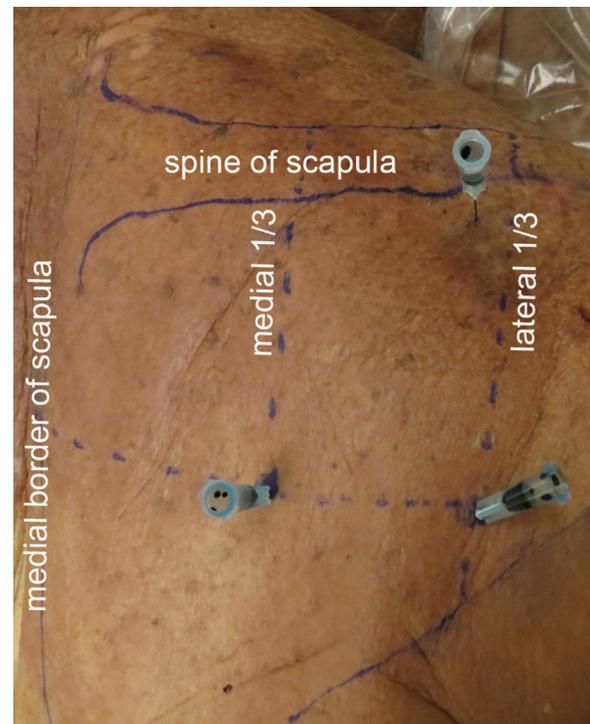


Fig. 1. Right shoulder specimen with landmarks outlined and needles insertions by investigator A into partitions of IS.

angle of scapula (Fig. 1).

2.4. Digitization, 3D modeling and data analysis

The needle entry point into the superior, middle and inferior partitions of the first investigator was digitized immediately after placement as described above. After the second investigator placed the needles, the skin entry points were digitized. Next, the needles were lightly tapped with a mallet to ensure the needle tips were anchored in the scapula, preventing needle displacement during dissection. The skin, subcutaneous tissue, and fascia were removed to expose the IS muscle belly, the three needles, and bony landmarks including the spine of scapula, acromion, medial and lateral borders and inferior angle (Fig. 2i). Next, the surface and boundaries of the superior, middle and inferior partitions were identified. This was followed by digitization of the: (1) the perimeter of the superior, middle and inferior partitions; (2) needle; and (3) bony landmarks of scapula: spine, acromion, medial border, lateral border, and inferior angle (Fig. 2ii). Digitized data from each specimen was exported into Autodesk™ Maya® (enhanced with plug-ins developed in our laboratory) for 3D modeling. The 3D models were used to assess needle placement into the superior, middle, and inferior partitions of IS by Investigator A and B (Fig. 3). Needle placement was characterized by determining the: (1) frequency of successful/unsuccessful needle placement into the targeted partition, (2) frequency of needle placement into each quadrant of the targeted partition, and (3) the location of the needle within each partition with respect to the perpendicular distances to two bony landmarks: inferior border of spine of scapula and medial border of scapula. The distances to these landmarks were summarized with descriptive statistics (means, standard deviations, range).

3. Results

Of the 42 needle insertions, 32 were placed in the targeted partition. When the needles were not placed in the targeted partition, they were located inferiorly in either the neighboring partition within IS or a

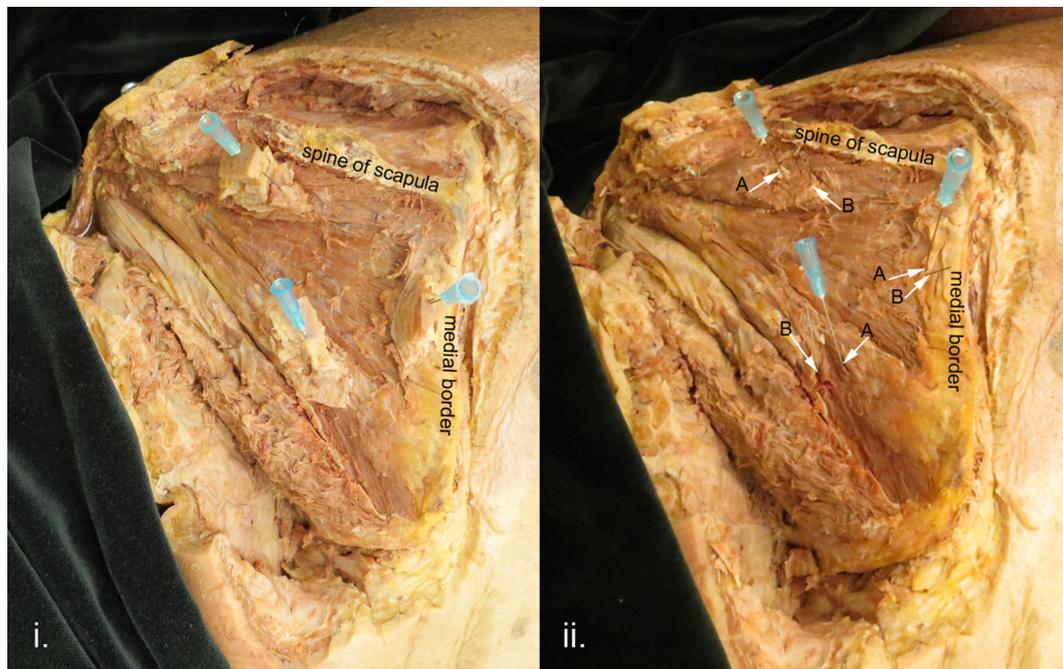


Fig. 2. Left shoulder specimen. (i) Initial dissection leaving needles embedded in skin and subcutaneous tissue, (ii) Complete dissection with needles of Investigator A and B in their respective sites. Arrow heads show location of needle tip.

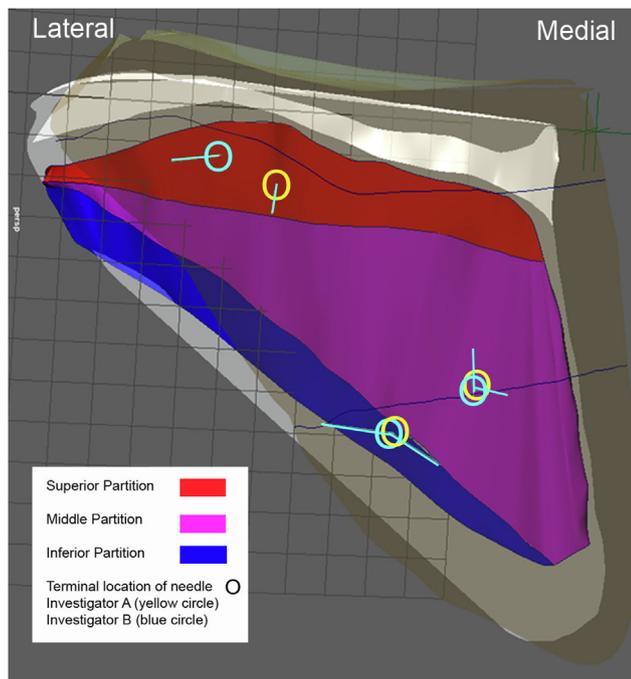


Fig. 3. 3D model of left shoulder used to determine needle placement in partitions of IS. Posterior view.

different muscle belly. The highest accuracy rate occurred for the middle partition, followed by the inferior and superior partitions (Table 1).

Needles targeted for the superior partition were placed accurately in 57.1% of the 14 specimens. The needle was most commonly located in the lower lateral quadrant (LLQ) of the superior partition. Investigator A had a success rate of 71.4% (5/7 specimens) and Investigator B 42.9% (3/7 specimens). When a needle was incorrectly placed, it was most often found in the upper lateral quadrant (ULQ) of the middle partition (5/6 specimens) of IS (Fig. 4A). In one case, the needle was placed in

the upper medial quadrant (UMQ) of the middle partition of IS. Mean distance (SD) of the needle from the spine of scapula, when the needle was accurately placed, was 13.9 ± 6.4 mm, but 28.1 ± 8.3 mm when inaccurately placed. Mean distance of the needle from the medial border of scapula when the needle was accurately placed was 63.8 ± 14.1 mm but 60.6 ± 8.3 mm when inaccurately placed (Table 2).

For the middle partition, needles were placed accurately in all specimens; in nine specimens (64.3%), the needle was located in the lower medial quadrant (LMQ) (Fig. 4A), and in five specimens (35.7%) in the UMQ (Table 1). Mean distance (SD) of the needle to the spine of scapula was 47.7 ± 9.6 mm and 22.3 ± 6.7 mm from the medial border (Table 2).

Needles targeted for the inferior partition were placed accurately in 71.4% of specimens (Table 1). Both investigator A and B had the same rate of success (5/7 specimens). In six specimens (42.9%), the needle was located in the lateral medial quadrant (LMQ) and in four specimens (29%) in the UMQ (Fig. 4A). In the incorrect attempts, the needle was placed in the teres minor (Fig. 4B). Mean distance (SD) of needle from the spine of scapula was 71.5 ± 5.9 mm when the needle was accurately placed, however when inaccurately placed the mean distance was 76.9 ± 5.1 mm. Mean distance of the needle from the medial border of the scapula was 45.6 ± 7.3 mm when the needle was accurately placed but 50.1 ± 3.9 mm when not in the targeted partition (Table 2).

4. Discussion

Anatomical investigations have defined three distinct neuromuscular partitions of IS: superior, middle and inferior (Hermenegildo et al., 2013; Ko et al., 2013; Fabrizio et al., 2014). Novel fine-wire EMG studies, based on these anatomical findings, have investigated muscle activation of each partition (Alenabi et al., 2018; Alenabi et al., 2019; Joseph et al., 2018; Calver et al., 2019). Traditionally, the location of EMG electrodes in a targeted muscle is confirmed with manual muscle testing, where expected muscle activation with a defined movement is used to confirm placement (Kibler et al., 2007). However, when fine-wire electrodes are placed in multiple partitions within a single muscle where unique activation patterns may be present but are not well

Table 1
Summary of successful/unsuccessful needle placement into targeted partitions and location with respect to quadrants of the partition.

Specimen	Superior partition				Middle partition				Inferior partition			
	A	Location	B	Location	A	Location	B	Location	A	Location	B	Location
1	✓	LLQ	✗	ULQ of middle	✓	UMQ	✓	LMQ	✓	LMQ	✓	UMQ
2	✗	ULQ of middle	✗	ULQ of middle	✓	LMQ	✓	LMQ	✓	LMQ	✓	LMQ
3	✓	LLQ	✗	ULQ of middle	✓	LMQ	✓	UMQ	✗	UMQ of teres minor	✗	UMQ of teres minor
4	✓	ULQ	✓	LMQ	✓	UMQ	✓	UMQ	✓	LMQ	✓	LMQ
5	✓	UMQ	✓	LMQ	✓	LMQ	✓	LMQ	✓	UMQ	✓	LMQ
6	✓	ULQ	✓	LLQ	✓	LMQ	✓	LMQ	✓	UMQ	✓	UMQ
7	✗	UMQ of middle	✗	ULQ of middle	✓	LMQ	✓	UMQ	✗	UMQ of teres minor	✗	UMQ of teres minor

A: investigator A; B: investigator B; ✓ = inserted into targeted partition; ✗ = not inserted into targeted partition; ULQ = upper lateral quadrant; UMQ = upper medial quadrant; LLQ = lower lateral quadrant; LMQ = lower medial quadrant.

defined, confirmation of needle placement can be challenging. In this novel cadaveric study investigating the accuracy of EMG needle placement in the superior, middle and inferior partitions of IS, we demonstrated that the accuracy was not consistent between partitions.

4.1. Superior partition

In the present study, the mean distance of the needle from the scapular spine was consistently greater than the 5 mm stated in the protocol. When the needle was accurately placed in the ULQ of the superior partition, the mean distance from the spine of scapula was approximately 14 mm; however, when the needle was inaccurately placed, this distance increased five-fold to approximately 28 mm. It should be noted that needles were incorrectly placed by both investigators in the same specimen on two occasions. Difficulty palpating and outlining the inferior border of the spine of scapula may have contributed to this issue. In addition, anthropometric differences between the specimens may have played a role in incorrect placements. Since the superior partition is smallest of the three partitions of IS, accounting for only approximately 15% of the muscle volume (Hermenegildo et al., 2013; Ko et al., 2013), the margin for error is small. By using a fixed distance from the spine of scapula (i.e. 5 mm) as stated in the protocol, size differences between individuals are not

accounted for. Instead, calculating a percentage of the vertical distance from the spine of scapula, at the stated point along the length of spine of scapula to the inferior border of the scapula may improve insertion accuracy. For example, if the vertical distance is 80 mm, using a point 95% of that distance would allow for consistency in placement despite the size of the individual. In addition to implementing a method that accounts for anthropometric differences between individuals, ultrasound imaging may also mitigate inaccurate placement of the EMG electrode. To correctly identify the inferior border of the spine of scapula, the ultrasound probe can be positioned perpendicular to the spine of scapula. The interface between the bone and superior partition can be easily identified. Alternatively, viewing the needle placement directly with ultrasound imaging may also prevent incorrect placement into the middle partition. This may be achieved by altering the needle insertion point to just inferior to the spine of scapula, at the junction of its medial and middle thirds. The needle would then be directed superolaterally parallel to the spine of scapula, at approximately a 30° angle to the skin. With the probe placed just inferior to the needle and parallel to the spine of scapula, needle advancement could be tracked.

4.2. Middle partition

High success rates and consistency of needle placement into the

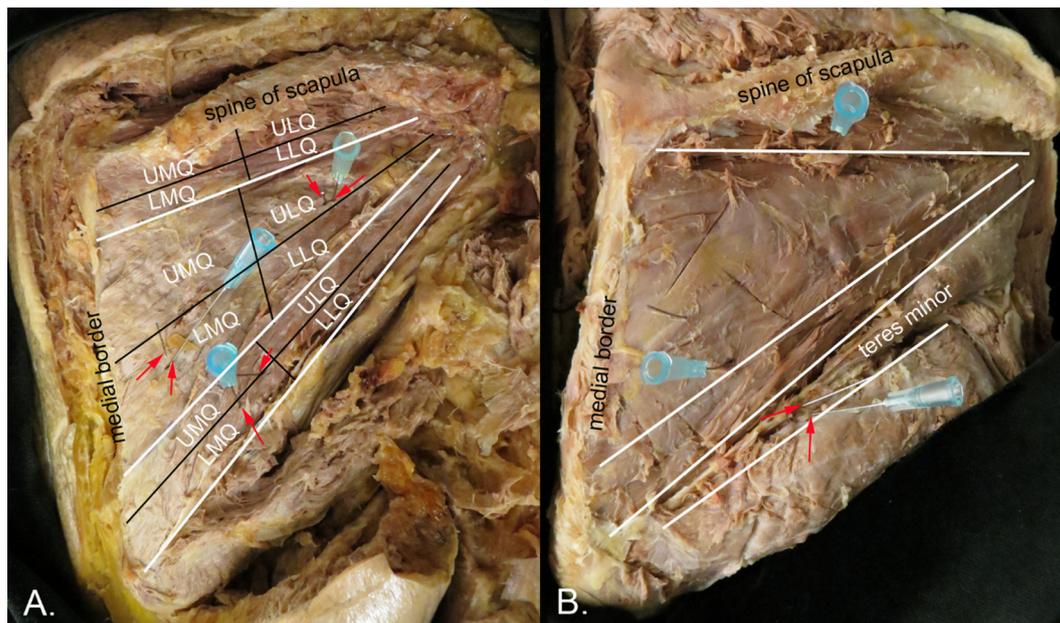


Fig. 4. Right shoulder specimens. (A) Quadrants of each region of IS are shown. Needles targeted for the superior region were inaccurately placed into the upper lateral quadrant (ULQ) of the middle region by both investigators. Needles targeted for the middle region were accurately placed and placed in the lower medial quadrant (LMQ). Needles targeted for the inferior region were accurately placed and located in either the upper medial quadrant (UMQ) or lower medial quadrant (LMQ). (B) Needles targeted for the inferior region of IS were inaccurately placed and located in the teres minor. Arrows show location of needle tips.

Table 2
Needle tip distance from major bony landmarks (mm).

Specimen	Scapular Spine Investigator		Medial Border of Scapula Investigator	
	A	B	A	B
<i>A. Superior Partition</i>				
1	23.86	30.74	79.1	62.1
2	36.63	37.18	69.1	66.5
3	16.93	20.75	82.7	63.0
4	8.93	3.11	64.5	55.7
5	16.29	10.46	48.9	44.0
6	18.4	13.45	61.3	74.3
7	16.8	26.33	46.0	56.9
Mean (SD), range for correctly placed	13.9 (6.4) 3.11–23.86		63.8 (14.1) 44.0–82.7	
Mean (SD), range for incorrectly placed	28.1 (8.3) 16.8–37.18		60.6 (8.3) 46.0–69.1	
<i>B. Middle Partition</i>				
1	42.7	40.6	19.3	17.0
2	61.6	56.8	18.9	19.4
3	48.3	43.8	16.9	21.2
4	30.8	29.7	13.7	16.7
5	52.3	58.0	25.3	38.6
6	47.5	50.3	26.8	26.7
7	57.4	47.5	31.0	20.8
Mean (SD), range	47.7 (9.6) 29.7–61.6		22.3 (6.7) 13.7–38.6	
<i>C. Inferior Partition</i>				
1	60.5	73.5	43.6	37.2
2	74.7	68.8	37.4	44.5
3	83.5	77.9	48.4	45.3
4	75.9	67.0	46.1	53.4
5	74.9	81.3	57.3	52.5
6	66.3	72.1	47.6	36.5
7	74.4	71.7	53.1	53.5
Mean (SD), range for correctly placed	71.5 (5.9) 60.5–81.3		45.6(7.3) 36.5–57.3	
Mean (SD), range for incorrectly placed	76.9 (5.1) 71.7–83.5		50.1 (3.9) 45.3–53.5	

Standard Deviation (SD); bold italicized numbers indicate specimens where needles were not in the targeted partition.

medial quadrants of the middle partition are likely due to the large size and easy accessibility of this partition in comparison to the superior and inferior partitions. Also, by positioning the hand behind the back, the scapula was internally rotated and the medial border elevated from the rib cage, facilitating palpation of the medial border. Palpation of the bony landmarks for needle insertion into this partition seem adequate; although ultrasound guidance could be useful for enhancing confidence of a novice investigator.

4.3. Inferior partition

The inferior partition was targeted more accurately than the superior, with a miss rate of 28.6% and 42.8% respectively. The slightly larger cross sectional area of the inferior partition compared to the superior may have attributed to the higher accuracy levels (Hermenegildo et al., 2013; Ko et al., 2013). Interestingly, the difference between the mean distance of the needle to spine of scapula on successful and unsuccessful attempts was about 5 mm (71.5 mm versus 76.9 mm), a much smaller distance than that found in the superior partition.

Investigators A and B, both incorrectly placed needles targeted for the inferior partition into the teres minor, in the same two specimens. To improve accuracy, ultrasound guidance could be used to visualize the fascial plane separating the inferior partition of IS and teres minor

by placing the probe vertically and scanning medially and laterally to identify the extent and location of this plane. Ultrasound imaging could also ensure the needle was placed into the center of the muscle belly, reducing the risk of electrode displacement (Alenabi et al., 2018). Additionally, the use of ultrasound guidance was also suggested in an EMG needle placement study where fine-wire electrodes targeted for teres minor were found in the inferior part of IS in three of four specimens (Rathi et al., 2015).

A limitation of this study is the small sample size. However, dissection, digitization and modeling are very time consuming. The current study, as a proof of concept, provides a basis for clinical evaluation of fine-wire EMG needle placement using ultrasound guidance. Like all anatomical studies, tissue properties of embalmed specimens may have increased the difficulty of palpating landmarks and the mean age of specimens may not be representative of target populations for future fine wire EMG studies. Since there is generally a decrease in muscle cross sectional area with aging (Frontera et al., 1985), the needle insertion angle used to target the superior and inferior partitions may need to be adjusted in younger individuals with thicker muscles to ensure an appropriate needle depth within the muscle belly is achieved. Finally, individual differences between volume and physiological cross sectional area of each partition may have influenced success rates of electrode placement.

5. Conclusion

Accurate placement of EMG electrodes into the superior, middle and inferior partitions of IS is essential to obtain high fidelity muscle activity data. The current study showed that the middle partition could be targeted accurately, whereas the superior and inferior partitions were more difficult to target. Thus, ultrasound guidance may be necessary to ensure sufficiently accurate placement into all parts of IS. The results of comprehensive EMG studies at the muscle partition level can provide new evidence for novel treatment protocols to rehabilitate shoulder injuries and pathologies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Alenabi, T., Whittaker, R., Kim, S.Y., Dickerson, C.R., 2019. Arm posture influences on regional supraspinatus and infraspinatus activation in isometric arm elevation efforts. *J. Electromyog. Kinesiol.* 44, 108–116.
- Alenabi, T., Whittaker, R., Kim, S.Y., Dickerson, C.R., 2018. Maximal voluntary isometric contraction tests for normalizing electromyographic data from different regions of supraspinatus and infraspinatus muscles: Identifying reliable combinations. *J. Electromyog. Kinesiol.* 41, 19–26.
- Calver, R., Alenabi, T., Cudlip, A., Dickerson, C.R., Mondal, P., Kim, S.Y., 2019. Regional activation of supraspinatus and infraspinatus sub-regions during dynamic tasks performed with free weights. *J. Electromyog. Kinesiol.* <https://doi.org/10.1016/j.jelekin.2019.05.009>.
- Fabrizio, P., Clemente, R., 2014. Anatomical structure and nerve branching pattern of the human infraspinatus muscle. *J. Bodyw. Mov. Ther.* 18, 228–232.
- Frontera, W.R., Hughes, V.A., Fielding, R.A., Fiatarone, M.A., Evans, W.J., Roubenoff, R., 1985. Aging of skeletal muscle: a 12-yr longitudinal study 2000. *J. Appl. Physiol.* 88 (4), 1321–1326.
- Hermenegildo, J.A., Ko, D.M., Li, Z., Johnson, M., Merrifield, P.A., Agur, A.M., 2013. Prototype 3-D model of the musculotendinous architecture of infraspinatus. *FASEB Journal* 27, 749.5. American Association of Anatomists Annual Meeting at Experimental Biology 2013. Boston Convention and Exhibition Center, Boston,

- Massachusetts, USA. April 20-24, 2013. Abstract/Poster.
- Joseph, R., Alenabi, T., Lulic, T., Dickerson, C.R., 2018. Activation of supraspinatus and infraspinatus partitions and pericapsular musculature during rehabilitative elastic resistance exercises. *Am. J. Phys. Med.* <https://doi.org/10.1016/j.jelekin.2019.05.009>.
- Kibler, W.B., Chandler, T.J., Shapiro, R., Conuel, M., 2007. Muscle activation coupled scapulohumeral motions in high performance tennis serv. *Br. J. Sport Med.* 41, 745–749.
- Ko, D., Hermenegildo, J.A., Li, Z., Arfeen, S., Agur, A.M., 2013. Architectural partitioning of infraspinatus: a 3D analysis. *Clinical Anatomy* 26, 1047. American Association of Clinical Anatomists Meeting, Denver, Colorado, July 9-13, 2013. Abstract/Poster.
- Kuhn, J., Dunn, W., Sanders, R., An, Q., Baumgarten, K., Bishop, J., Brophy, R., Carey, J., Holloway, B., Jones, G., Ma, B., Marx, R., McCarty, E., Poddar, S., Smith, M., Spencer, E., Vidal, A., Wolf, B., Wright, R., 2013. Effectiveness of physical therapy in treating atraumatic full-thickness rotator cuff tears: a multicenter prospective cohort study. *J. Shoulder Elbow Surg.* 22, 1371–1379.
- Rathi, S., Zacharias, A., Green, R.A., 2015. Verification of a standardized method for inserting intramuscular electromyography electrodes into teres minor using ultrasound. *Clin. Anat.* 28, 780–785.
- Reinold, M.M., Wilk, K.E., Fleisig, G.S., Zheng, N., Barrentine, S.W., Chmielewski, T., Cody, R.C., Jameson, G.G., Andrews, J.R., 2004. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. *J. Orthop. Sports Phys. Ther.* 34 (7), 385–394.
- Ryan, G., Johnston, H., Moreside, J., 2018. Infraspinatus isolation during external rotation exercise at varying degrees of abduction. *J. Sport Rehabil.* 27 (4), 334–339.
- Sasaki, S., Kenmoku, T., Otera, A., Miyamjima, G., Nagura, N., Nakawaki, M., Nakazawa, T., Takaso, M., Fukuda, M., Takahira, N., 2019. Electromyographic analysis of infraspinatus and subscapular muscle during external shoulder rotation with different weight loads and positions. *J. Orthop Sci.* 24 (1), 75–80.
- Townsend, H., Jobe, F.W., Pink, M., Perry, J., 1991. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. *Am. J. Sports Med.* 19 (3), 264–272.
- Wilk, K.E., Andrews, J.R., Arrigo, C.A., 1997. The physical examination of the glenohumeral joint: emphasis on the stabilizing structures. *J. Orthop. Sports Phys. Ther.* 25 (6), 380–389.
- Wuelker, N., 1998. Korell M, Thren K, Dynamic glenohumeral joint stability. *J. Shoulder Elbow Surg.* 7 (1), 43–52.



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