HUMAN ANATOMY

Anatomical structure and nerve branching pattern of the human infraspinatus muscle

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Summary The function of the infraspinatus muscle, critical to rotator cuff function, is dependent upon the muscle’s structure and innervation pattern. The morphology of the infraspinatus muscle has been inconsistently described in the literature. Additionally, the branching pattern of the suprascapular nerve in the infraspinous fossa has not been addressed in the literature. The purposes of this study were to determine: the arrangement of the infraspinatus muscle bellies; the branching patterns of the suprascapular nerve to the infraspinatus muscle; if the infraspinatus muscle was composed the neuromuscular compartments. Forty-eight infraspinatus muscles from 24 embalmed cadavers were studied using standard dissection techniques to determine morphological characteristics and innervation patterns. Results demonstrated that the infraspinatus muscles were comprised of three separate muscular partitions with each partition residing in a thin fascial compartment but all residing deep to the posterior scapular fascia. A first order suprascapular nerve branch was present in 91.6% of superior, 100% of middle, and 70.8% of inferior partitions. A first order nerve was present in all 3 muscular compartments of the same infraspinatus muscle in 62.5% of cases. Second order nerve branches were present in 8.3% of superior, 0% of middle, and 29.2% of inferior partitions. These findings help to determine a more complete and accurate understanding of the structure of the infraspinatus muscle. A better understanding of its structure could lead to a better understanding of the function of the muscle. Such information will enable more effective rehabilitation strategies for injuries involving the infraspinatus component of the rotator cuff.

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Introduction

The gross anatomical structure of the infraspinatus muscle has been inconsistently described in the literature. Further, there are no reports in the literature that describe the branching pattern of the suprascapular nerve in the infraspinous fossa. Accurate descriptions of muscle morphology and motor innervation patterns can lead to a more accurate understanding of a muscle’s function (Segal et al., 1991, 2002; English et al., 1993). However, there is a lack of consensus regarding the structure of the infraspinatus muscle and the motor innervation pattern has not been fully described for the infraspinatus muscle.

Current literature describes the gross anatomical appearance of the infraspinatus muscle as multipennate, bipennate, or being partitioned into two separate compartments (Keating et al., 1993; Johnson and Pedowitz, 2006; Bigliani and Flatow, 2005; Standring, 2008; Moore et al., 2010; Kato et al., 2011). The infraspinatus muscle has been described as being inseparably blended with the teres minor muscle and inserting together with the teres minor muscle on the posterior aspect of the greater tuberosity of the humerus (Kato et al., 2011). The infraspinatus muscle has been described as consisting of two bellies connected by a central raphe where the superior muscle belly represents the infraspinatus muscle while the inferior belly represents the teres minor muscle (Gray and Lewis, 1918). This fibrous septum arises from "an elevated ridge located along the lateral border of the dorsal surface of the scapula, which runs from the lower part of the glenoid cavity to the vertebral border and 2.5 inches above the inferior angle" (Gray and Lewis, 1918). The infraspinatus muscle has also been described as having two bellies connected by a central raphe where the superior muscle belly represents the infraspinatus muscle while the inferior belly represents the teres minor muscle (Bigliani and Flatow, 2005; Johnson and Pedowitz, 2006; Heisler, 1920). Bigliani and Flatow described the infraspinatus muscle as "bipennate and when three groups of muscle fibers can be seen, the upper two represent the infraspinatus muscle and the lower separation represents the teres minor muscle" (Bigliani and Flatow, 2005). The authors further distinguish the two muscles according to their distal attachments with the infraspinatus muscle inserting on the middle facet of the greater tuberosity of the humerus and the teres minor muscle inserting on a distinct smaller facet, which is inferior and typically palpable (Bigliani and Flatow, 2005). Heisler also reported that the infraspinatus muscle can sometimes be divided into upper and lower portions (Heisler, 1920). Dwight et al. described the infraspinatus muscle as arising from the infraspinous fossa and infraspinatus fascia. Further, a variation of the infraspinatus muscle was described, where the upper portion of the muscle may be distinctly separated from the rest of the muscle and termed it the "infra-spinatus minor" muscle (Dwight et al., 1907). Recently, the infraspinatus muscle has been described as consisting of two parts, an oblique portion and a transverse portion (Kato et al., 2011). Kato et al. described the transverse portion as arising from the scapular spine and attaching into a common tendon while the oblique portion was depicted as arising from the infraspinous fossa and attaching distally to the greater tuberosity of the humerus (Kato et al., 2011).

The course and number of primary nerve branches arising from the suprascapular nerve and innervating the infraspinatus muscle have not been clearly addressed in the literature. The suprascapular nerve typically passes into the supraspinous fossa by passing superior to the scapular notch, inferior to the superior transverse scapular liga-
ment. As it passes through the supraspinous fossa the suprascapular nerve supplies two motor branches to the supraspinatus muscle (Warner et al., 1992). The suprascapular nerve leaves the supraspinous fossa by passing through the spinoglenoid notch, enters the infraspinous fossa and distributes branches to the infraspinatus muscle. The specific branching pattern of the suprascapular nerve to the infraspinatus muscle has been inconsistently described as two motor branches (Ozer et al., 1995; Standring, 2008) or three to four motor branches (Warner et al., 1992).

One way of examining the gross morphology and motor innervation pattern of a muscle is to determine the neuromuscular partitioning of the muscle. Neuromuscular partitioning is defined by two criteria. One criterion is the specific architectural characteristics of the muscle such as muscle fiber angle and direction and the existence of tendinous boundaries within the muscle. The second criterion is that the innervation to the partitioned regions of the muscle is from a primary nerve branch (English et al., 1993; Segal et al., 2002).

Neuromuscular partitioning has been demonstrated in some upper and lower extremity human skeletal muscles (Romeny et al., 1984; Segal et al., 1991, 2002; Wolf et al., 1992). The results of work by Romeny et al. indicate that there is a correlation between neuromuscular compart-
ments in the biceps brachii muscle and the motions of elbow flexion and supination (Romeny et al., 1984). The lateral compartment of the biceps brachii muscle showed more electrical activity during elbow flexion, while the medial compartment showed electrical activity during forearm supination or during the linear combination of elbow flexion and forearm supination (Romeny et al., 1984). The central part of the muscle showed more electrical activity during the nonlinear combination of elbow flexion and forearm supination than in any other motions monitored in the study (Romeny et al., 1984). A consistent pattern neuromuscular compartmentalization was described for the flexor carpi radialis muscle (FCR) and the extensor carpi radialis longus muscle (ECRL) (Segal et al., 1991). The pattern of motor innervation of the FCR di-
vides the muscle into three neuromuscular compartments. The proximal division of the primary motor branch innervates the lateral and intermediate fibers of the FCR, and the distal division of the primary motor branch innervates the medial fibers of the FCR. Similar discrete partitioning was also shown to occur in the ECRL. The superficial head of the ECRL is supplied by the distal division of the primary motor branch, and the deep head by the proximal division of the primary motor branch (Segal et al., 1991). Wolf, Segal and English were able to selectively activate the lateral head of the human gastrocnemius muscle while the subjects performed functional tasks (Wolf et al., 1992). Their research suggested that partitions within the gastrocnemius, a two joint muscle, displays selectively different levels of muscle activity depending on the motor
task. Segal et al. demonstrated neuromuscular partitioning of human extensor carpi ulnaris (ECU), flexor carpi ulnaris (FCU), and flexor digitorum profundus (FDP) muscles (Segal et al., 2002). Each muscle was shown to have specific architectural characteristics such as fiber arrangement and orientation within fascia bounded subregions that were served by primary nerve branches consistent with neuromuscular partitioning (Segal et al., 2002).

The morphology, innervation pattern and existence or absence of partitions has not been described for the infraspinatus muscle. Further, the branching pattern of the suprascapular nerve has not been clearly described in the infraspinous fossa. The lack of understanding of the neuromuscular partitioning of the infraspinatus muscle is compounded by the lack of consensus on the anatomical description of the muscle. The purposes of this study were: to determine, on a gross anatomical level, the arrangement of the infraspinatus muscle bellies; to determine the branching pattern of the suprascapular nerve to the infraspinatus muscle; and to determine if the infraspinatus muscle was composed the neuromuscular compartments.

Methods

Twenty-four embalmed cadavers (12 male, 12 female, aged 45–91 years), randomly selected from teaching specimens, yielding 48 infraspinatus muscle–scapula complexes, were examined using standard dissection techniques. Institutional review board approval and body donor program approval were granted for this study. Cadavers were selected based upon the criteria of no visible surgery evident and having an intact shoulder girdle (undamaged postmortem). With the cadaver in the prone position the infraspinatus muscles were exposed by reflecting the skin, subcutaneous tissue, trapezius and deltoid muscles and the posterior scapular fascia from the posterior surface of the pectoral girdle region using scalpel, sharp probe, blunt probe and scissors (Zuckerman, 1981; Cooper et al., 1993). After being exposed, each infraspinatus muscle was inspected for evidence of fascial divisions or partitions. Each infraspinatus muscle was then removed from the cadaver and examined again to determine the specific partitions/divisions present in the muscle. The infraspinatus muscles were detached from their attachments on the medial border of the scapula and carefully reflected from the infraspinous fossa while maintaining the integrity of the suprascapular nerve branches. The teres minor muscle was reflected with the infraspinatus. Nerve branches were located and traced back to the main stem of the suprascapular nerve. The nerve branches were carefully cleaned using sharp dissection techniques and the aid of an illuminated 5× magnifying lens. After the nerve branches were traced back to the suprascapular nerve the muscles (infraspinatus and teres minor) were removed from the cadaver near their tendinous insertion on the greater tuberosity of the humerus.

Nerve branches from the suprascapular nerve were visually inspected and determined to be either first or second order nerve branches. A first order nerve branch was described as the first division into separate nerves from the main stem of the suprascapular nerve. A second order nerve branch was identified as the first division off of the first order nerve branch. These specific divisions were recorded and percentages of each were calculated for the infraspinatus muscle.

Results

The authors noted no sexual dimorphism or age-related changes in the current specimens. All 48 infraspinatus muscles were shown to be comprised visually of three separate muscle partitions. The partitions were described relative to

![Figure 1](photograph_of_infraspinatus muscle_from_posterior_aspect_showing_muscle_partitions_prior_to_nerve_dissection)
the whole muscle configuration as superior, middle, and inferior (Figure 1). Each partition resided within a separate fascial envelope, and all partitions were located deep to the posterior scapular fascia. The superior muscle partition arose from the inferior surface of the scapular spine and the deep surface of the infraspinatus fascia at the attachment of the fascia to the scapular spine. The fibers coursed transversely to attach distally to the posterior aspect of the greater tuberosity. The inferior partition arose from the inferior one-third of the medial border of the scapula, the infraspinous fossa, and the deep surface of the infraspinatus fascia. The fibers coursed superior-lateral in a manner parallel to the lateral border of the scapula. In 100% of specimens the inferior and superior partitions joined at variable distances proximal to their insertion on the posterior aspect of the greater tuberosity of the humerus. Forty muscles demonstrated a relationship of the inferior partition lying deep to the superior partition at the distal site of attachment (Figure 1). In the remaining eight muscles the distal attachments of the superior and inferior partitions did not overlap and were positioned adjacent to each other. The middle partition originated from the medial border of the scapula and from the posterior surface of the infraspinous fossa. The fibers of the middle partition coursed superior-lateral toward to the glenoid cavity deep to the superior and inferior partitions in all cases. Distally, the middle partition blended with the tendons of the superior and inferior partitions distal to the junction of the inferior and superior partitions and attached on the posterior aspect of the greater tuberosity of the humerus.

A first order branch of the suprascapular nerve was present in 91.6% of superior compartments, 100% of middle compartments, and 70.8% of inferior compartments. A first order nerve branch was demonstrated entering the superior, middle, and inferior compartments in 62.5% of muscles, entering the superior and middle compartments in 29.2% of muscles, and entering the middle and inferior compartments in 8.3% of muscles (Figure 2, Table 1).

**Discussion**

One purpose of this study was to determine if the infraspinatus muscle is comprised of neuromuscular partitions. The results demonstrate that, on a gross anatomical level, the infraspinatus muscles appeared to be arranged in three partitions however, each partition was not innervated by a first order nerve branch in all cases and the requirements for neuromuscular compartmentalization were not satisfied (Segal et al., 1991, 2002; English et al., 1993). In the current study, the infraspinatus muscles were shown to be comprised of superior, inferior and middle muscular partitions with each partition bounded by fascia. This arrangement satisfies one neuromuscular partitioning criterion dealing with specific morphological characteristics (English et al., 1993; Segal et al., 2002). The second criterion of neuromuscular partitioning, innervation to the partitioned region of muscle from a primary nerve branch, was demonstrated in 62.5% of infraspinatus muscles in the current study (Figure 2).

Multiple partitioned territories within a muscle allows for sub-volumes of muscle that can be activated differently during movement (English et al., 1993; Segal et al., 2002). More importantly these different volumes within a single

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<th>Table 1</th>
<th>Numbers and percentages of first order nerve branches present in muscular partitions in whole muscles. n = 48.</th>
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<td>n = 48</td>
<td>1st Order branches to superior, middle, inferior 1st Order branches to superior, middle 1st Order branches to middle, inferior 1st Order branches to superior, inferior</td>
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<tr>
<td>Number of occurrences</td>
<td>30</td>
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<td>Percentage occurrence (%)</td>
<td>62.5</td>
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muscle may be able to facilitate different responses from the muscle which can be linked to task-oriented, functional activities and the role of that particular muscle in those activities (Wolf et al., 1992; Segal et al., 2002).

The presence of superior, middle and inferior neuromuscular partitions in some of the infraspinatus muscles as described in the present study are consistent with the proposed functional sub-regions described by other investigators. Previous reports in the literature have alluded to different anatomical sub-regions of the infraspinatus muscle based on functional differences for various portions of the muscle. Langenderfer et al. demonstrated increased maximal moment capacity in inferior regions of the infraspinatus muscle when compared to superior regions of the muscle (Langenderfer et al., 2006). The moment capacity was also greater for the infraspinatus with the arm abducted at 10° compared to 60° abduction. Similarly, Halder et al. demonstrated that more central regions of the infraspinatus were mechanically stronger when compared to more superior regions of the muscle when tested in a position simulating 90° abduction (Halder et al., 2000). Further, the authors showed a greater strength of the middle regions of the infraspinatus when compared to the superior or inferior regions when tested in a simulated neutral arm position. The authors concluded that the infraspinatus is strong across its central regions and that this strength lends to the overall passive posterior stabilizing ability of the infraspinatus (Halder et al., 2000). The previous studies demonstrated different biomechanical characteristics of the different regions of the infraspinatus muscle that are associated with different arm positions.

Based on the results of the present study one could speculate that, in some cases, the function(s) of the infraspinatus muscle might be directly related to the neuromuscular partitions within the muscle. If the infraspinatus muscle is arranged and innervated in three neuromuscular compartments and if strength and function are specific to arm position then perhaps it is the neuromuscular partitions that are, in part, responsible for the variable functions of the infraspinatus muscle. The current study is limited in the fact that only embalmed specimens were used and no specific functional correlations are presented. Further, a stronger relationship between nerve course and innervation patterns may be gained by increased subject number.

The results of the current study offer clarification regarding the morphology and innervation of the infraspinatus muscle. One can speculate about the functional implications of the current work. Future investigations that are more focused on the direct functional implications of the neuromuscular partitioning in the infraspinatus muscle may illustrate the importance of the partitioned arrangement as it relates to injury management and rehabilitation.

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References