# Morphological and Architectural variation of supraspinatus tendon_

**Jonathan Morris (Bsc, MSc STD** *Keele University, Staffordshire).*


## Abstract:

The aims of the article are to specifically look at the anatomical variations of one aspect of the supraspinatus muscle: the morphology and architecture of the insertion of the tendon around the greater tubercle. The article has explored four important techniques like embryological, cadaveric, ultrasound and MRI that can have been used for the detailed analysis of the supraspinatus tendon. The article has also critically evaluated the different studies, discussing whether certain techniques are superior for understanding the structure and function better than others. In anatomical research, all these methods are essential to help develop understanding of the differences in anatomical variation, with each method displaying strengths which contribute to anatomical knowledge of many structures, including the supraspinatus tendon.


## Introduction:

Since the start of civilisation, anatomical knowledge has always been sought using a range of different methods. A good early example is the ancient Egyptian practice of mummification, whereby at least an understanding of the location of various organs was essential to perform the task. In the ensuing ancient Greek and Roman times, physicians such as Hippocrates and Galen were pioneers in performing dissections on animals as well as live criminals in order to gain anatomical knowledge[3.] Following the fall of these empires, it was not until the Renaissance Period where the "rebirth" of seeking anatomical knowledge began to arise.

Today, there is considerable research that has either been, or is currently being, carried out on a wide range of anatomical structures and their functions. One such area of research relates to the supraspinatus, which makes up the rotator cuff of the shoulder. According to which textbooks are read, various interpretations are reached as to the anatomical structures of the supraspinatus tendon. An example of this is the innervation of the muscle. According to Standring et al[16] the supraspinatus muscle is innervated by the suprascapular nerve, via nerve root C5 and 6. However, according to Lindsay[9] the suprascapular nerve only originates from the C5 nerve root, and, according to Agur and Dalley[2] the suprascapular nerve originates from the C4, 5 and 6 nerve roots. This example alone shows the potential variation in human anatomy understanding, and it is clearly important to understand these variances, and why and where they occur.

The aims of the article are, therefore, to specifically look at the anatomical variations of one aspect of the supraspinatus muscle: the morphology and architecture of the insertion of the tendon around the greater tubercle. The article will explore four important techniques that can and have been used for the detailed analysis of the supraspinatus tendon. The article will also critically evaluate the different studies, discussing whether certain techniques are superior for understanding the structure and function better than others. It will be concluded, however, that a range of different research methods are essential to allow us to understand the anatomical structures of the tendon to the fullest extent.

## Embryology:

The predominant use for embryonic development is for improving clinical knowledge and the prevention of congenital diseases[15]. Embryonic studies show that muscles generally derive from the mesoderm, one of the three germ layers[10]. It is generally accepted that somites have various layers, including the ventral and dorsal aspect. The ventrolateral part near the mesodermal part of the budding forms the muscle which becomes the musculature within the limbs[10]. No research specifically on the supraspinatus tendon has been conducted by embryologists, however, simply because the muscle has yet to be developed.

Nevertheless, this research method has provided some valuable information. One paper by Abe et al[1] looks at the rotator cuff interval, which includes the anterior supraspinatus. The research used 20 fetus' shoulders from the average fetus age of 7-8 weeks (range of 7-15 weeks). Abe et al[1] used histological studies in order to research the anatomy of the rotator cuff interval. The research question formed by the study was clear, but generalised in terms of looking at the "rotator interval" as opposed to a specific structure. However, they used the same orientation with each histological sample that they obtained. The paper was not specific in its description of using "frontal or horizontal" planes of samples, thus making it harder to maintain the validity of the research. Furthermore, Abe et al [1] used hematoxylin and eosin for their staining solution, but did not state why.

Despite the weaknesses, Abe et al found some interesting evidence. The study stated that, initially at 9 weeks, the supraspinatus tendon, along with the infraspinatus and subscapularis, were seemingly altogether, being separated away from the joint cavity by the glenohumeral ligament. However, at 12 weeks the tendons have all managed to connect to the humeral head, following development of the shoulder complex. Abe et al[1] also suggest, by 12 weeks, that superficially and superiorly the supraspinatus tendon has formed closely with the infraspinatus tendon. The infraspinatus tendon, along with the coracohumeral ligament, seem to squeeze the insertion of the supraspinatus, but again the paper lacks detail as to where they found this specific insertion to be. The paper seems to demonstrate that the infraspinatus and supraspinatus tendons are as one, and form very closely. The research, therefore, may show that these tendons are not separate entities but are anatomically the same tendon.

Another paper, by Fealy et al[4] has a similar approach to Abe et al[1] except the study focused more on the joint capsule and labrum rather than the rotator cuff muscles. This paper discusses the minimal ossification of the scapula, which in turn impacts on the origin of the supraspinatus, and therefore the tensions on the supraspinatus tendon. This could therefore mean that if not formed correctly, the supraspinatus may not have the appropriate torsion onto the humerus, which could affect shoulder stability, all from a very early age. Fealy et al[4] make a significant point of stating that they were not aware of how the fetus subjects perished, and so are inferring that the shoulder joints they were experimenting on were healthy, without pathology. However, Fealy et al[4] paper has similar weaknesses to those present in Abe et al[1] findings, which suggests reasons as to why further research are needed to develop our understanding of the fetal shoulder joint.

## Cadaver studies:

Upon reviewing the literature, there is a high proportion of research that shows cadaveric studies as the anatomist's choice for analysing the anatomy of the supraspinatus tendon. While using cadavers means that anatomists can look directly into the supraspinatus tendon, there are weaknesses to this method, including the state of the specimens used, as tissue starts to deteriorate quickly once obtained. There is also the question of the age of the specimens, which could show signs of pathology, and may not be representative of the adult population. Cadaveric studies tended to use histological studies, of a similar sort used in embryonic research. Further, there is also cadaveric research used to analyse animal supraspinatus tendons. This may give general overviews of the anatomy, but there is a high risk of generalising conclusions to the human population.

From analysing the evidence available, it was difficult to find information from studies in the literature regarding the anatomy of the supraspinatus tendon via cadaveric methods. A lot of studies seemed to focus on pathology or how the pathology came about. Other studies have examined supraspinatus, but either of only the muscle belly, or both the muscle and tendonous unit. One paper, for example, by Roh et al[14] examines the muscle belly and tendon, so have taken the evidence only for the tendon aspect. In addition, once more appropriate studies were identified; a common problem was the age of the specimens. For example, one study undertaken by Roh et al[14] had the mean age from 25 embalmed cadavers of 82 years. Another study by Halder et al[5] had a mean age of 77 years from 13 cadavers. This alone could create problems in the validity of the results obtained. However, as donations of cadaver specimens are not easily obtained, it is difficult to discard results of these studies based on this factor alone. In fact, there is value in these papers that can show very interesting findings which can help with anatomical knowledge.

The study by Roh et al[14] tried to examine the gross morphological aspect of the supraspinatus muscle and tendon. From their findings, the study found that, in comparison to the anterior and posterior supraspinatus tendon, although their average mean cross sectional area was proportionally 0.9:1 (anterior = 26.4 ±11.3 mm² and posterior = 31 .1 ± 10.1 mm²), the anterior tendon had to manage tensile strength of up to 288% more than the posterior tendon. The assumption is that "Tensile strength is proportional to the physiologic cross sectional area (PCSA)" of the muscle[14]. The paper overall was difficult to understand initially, but the results obtained can be of value. The results mean that if a patient tears only part or even fully the posterior aspect of the supraspinatus tendon, the patient may still functionally be able to use the shoulder, as a lot more stress is applied to the anterior portion of the tendon.

Another study undertaken by Kolts[8] showed some interesting results. The paper describes a similar pattern to using 37 cadaveric shoulders to examine the gross anatomy of the supraspinatus. Although the paper describes the age range of patients (49-82 years), there is no mention of the mean, which can affect the reliability of the results. The paper does not mention the ratio of male to female cadavers used. However despite these provisos, in 10 of the specimens used, the supraspinatus was seen to be inserting onto the lesser tubercle of the humerus, and even in some instances merging with the subscapularis tendon. The value of the information could be significant, as the results could further indicate variation of anatomy for the tendon for surgical techniques, as well as how the tendon may function differently. Using surgical techniques to operate on the supraspinatus may, therefore, need to consider the position and function of other rotator cuff tendons. The paper raises further questions as to whether the differentiation of tendons in the rotator cuff occur fully, or could potentially all work as one tendon. According to Kolts[8] a significant amount of the population could demonstrate this variation. It is clear, however, that more research into this specific anatomical variation would be needed to substantiate Kolts' results.

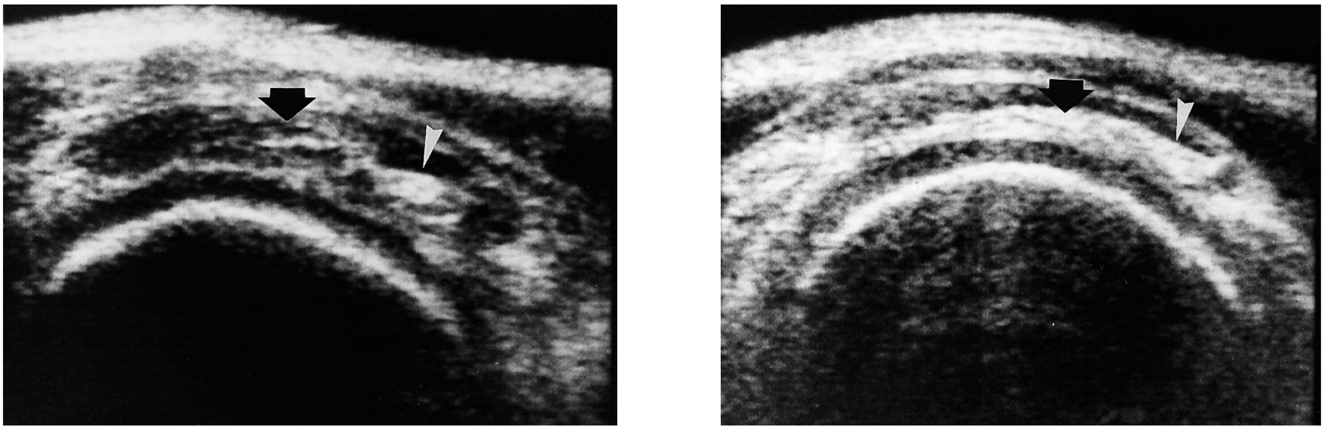
## Ultrasound (US):

Using US as a method for gaining anatomical knowledge has strengths and weaknesses. A positive aspect is that using US means that pictures can be taken to aid research and thus help with reproducibility. US can also be used on in-vivo subjects, so that the normal average age of subjects could be more reflective of the population. Further, US can help analyse dynamic movement of the supraspinatus tendon, amongst other soft tissue structures, so that function can be researched, in a way unavailable with cadaveric specimens, thus being more accurate, valid and reliable. US can also be used to look at vascularity, measuring blood vessels and blood flow. In anatomical research, analysing blood flow is important because we know that if an anatomical structure is well vascularised, then there is more chance of healing the soft tissue following any lesion. However, there are disadvantages in that sometimes US cannot measure everything. One example involving the supraspinatus tendon is under the acromion on the scapula, which causes "shadowing". The US will unfortunately be unable to pick up underneath the acromion as it relies on echoes in which bone reflects back strongly and, therefore, the equipment is unable to "see". Using US is highly specialised, which means a qualified professional must use the equipment.

Upon searching for papers on the specific technique of using US to analyse the supraspinatus tendon with no pathological changes, there seemed to be surprisingly few papers available. However, one paper that uses US as a means of analysing the supraspinatus tendon is by Turrin & Cappello[17]. The research project used US to study the right shoulder only of 12 healthy subjects. There are some weaknesses to the research that initially decrease the value of the paper. One such weakness is the fact of having an ambiguous research question, which states the researchers "undertook the following study to look for more detailed anatomic features at sonography and to address features that could cause a misdiagnosis"[17]. Although the title of the study suggests that the supraspinatus tendon is predominantly what the researchers wanted to look at, the research question is not clear about this. In addition, the paper makes some assumptions which are not clear. One is the position of the subjects while the US was performed. The paper describes the subjects' position as supine, with the arm under scrutiny being let to drop towards the floor, the forearm in pronation and elbow in extension. This position is denoted as the best to get a clear view of the supraspinatus tendon; however, this is not shown to be proven by preliminary studies, nor referenced by previous research. A 10 year old subject was used to analyse the supraspinatus, but there is no clear reason why. The paper states that the young subject was used as there is "less acromial shadowing" which could affect the view via the US, but again no reference or preliminary work was done to validate this. The paper also uses only the right shoulder, which could show discrepancies between dominant and non-dominant arms.

Despite the weaknesses seen within the Turrin & Cappello's paper[17], there are some positive aspects in terms of reliability. The research was methodological in its approach to always using the same shoulder for examination, and the position used was clear, with a diagram to illustrate this. The paper also describes the use of anatomical landmarks to show where they would study and take pictures, which, although specific to the individual measured, maintains reproducibility. The study used 12 subjects, and had a mean age of 35 years (range 18-47) which shows a good range of subjects used diminishing the danger of degenerative changes occurring at the supraspinatus tendon. In addition, the research data was analysed by two experienced sonographers, although these were the researchers themselves which could raise the potential for bias in their results.

Overall, the valuable information shown from the paper seem to demonstrate that there are actually two parts of the tendon, which show two completely different sections, the anterior and posterior supraspinatus tendon. Turrin & Cappello[17] describe the anterior part of the tendon as cylindrical, whereas the posterior tendon is described as flat. As seen in the Roh et al[14] study, the anterior tendon was far stronger than the posterior tendon, which would suggest the cylindrical shape is used for stronger function, which could be applied to other tendons in the body. The US lateral view of the supraspinatus tendon, seen in Figure 1, shows the anterior tendon (white arrow) and the posterior tendon (black arrow). Figure 1a to 1b illustrates the view going outwards on a lateral plane with the anterior tendon staying uniform, whereas the posterior tendon thickens. The uniform pattern of the anterior tendon, therefore, may show the reason why Roh et al[14] found this tendon to be significantly stronger than the variable thickness of the posterior tendon. These results are useful and therefore the paper has value for the research findings. However, due to the weaknesses of the paper, more research would be needed in order to help corroborate its conclusions.



Another paper by Kim et al[7] tries to investigate the whole supraspinatus muscle. This includes the superficial, middle and inferior part of the anterior and posterior portions of the supraspinatus muscle belly. The paper had a more specific and focused research question than Turrin and Cappello[17], and Kim et al[7] interestingly use the Roh et al[14] cadaveric study discussed earlier as part of their introduction to the research question. Kim et al's [7] research studies used a much more specific protocol relating to the position of the subject, along with more in-depth inclusion and exclusion criteria. The protocol used, however, was developed from a previous study, conducted by the same researchers, which could introduce bias and thus affect results. The study was also more specific in wanting to analyse the fibre bundle length, pennation angle of the muscle to the tendon, and muscle thickness, as well as measuring these in different arm positions. However, reading the resultant paper gives the impression that too many aspects were being measured, meaning the study itself is at times difficult follow. Kim et al[7] may have benefitted from only looking at one specific aspect of the supraspinatus. Furthermore, although Kim et al[7] also describe the positions of the patients, more information would be helpful in order to improve the repeatability of their methodology, and thus improve the reliability of the results.

By using the cadaveric method of gaining anatomical knowledge, the researchers were able to use the results to develop their US study. These developments therefore allow us to understand the anatomy of the supraspinatus tendon. An example of this is shown in the study by Kim et al[7], where they used a cadaveric study to analyse the supraspinatus musculotendinous unit. The researchers found that, as well as an anterior and posterior supraspinatus tendon, there were two more separate sections, the extra- and intra-muscular portion. Furthermore, Kim et al[7] found that in 16 of the 17 subjects, one anterior intra-muscular tendon was seen. However in one subject, two intra-muscular tendons were seen. These findings could have happened congenitally, following the formation of the muscles from the embryo formation. Further, the anterior deep and middle layers of the supraspinatus connect to the intra-muscular tendon, and therefore it may be deduced from these results that the superficial layer connects to the extra-muscular layer. These results show the further complexities that help explain the reason why the supraspinatus tendon can potentially be prone to injury. Therefore, when the rotator cuff is surgically repaired, the supraspinatus tendon may need more in-depth surgery to connect the specific attachments for normal anatomy and thus better recovery.

## Magnetic Resonance Imaging (MRI):

Using MRI as a means of analysing supraspinatus tendon morphology has many strengths. The fact of being able to see the soft tissue in such detail allows for better quantitative measurement of musculotendinous morphology[18]. As with US, MRI can be used to take still pictures so that a “slice by slice” account of the anatomy can be analysed, in various 3-dimensional planes. MRI can be even more specific than ultrasound in analysing anatomy and vasculature, but is more difficult to use for functional movement. Usually the subject has to be motionless; otherwise the radiological picture obtained will be inaccurate. The cost of using MRI for research may also be a limiting factor, especially in relation to more cost-effective US research methods.

Despite its obvious potential benefits, the literature reveals few MRI studies that actually measure the morphology of the supraspinatus tendon. One paper by Nakajima et al[12] looks into the anatomy of the supraspinatus tendon on cadavers, and forms part of the research question, however the results and discussion focus on what type of MRI technique is best to gain more accurate data for measuring morphology, so therefore the techniques used help to gain anatomical knowledge. Another study by Jones[6] focuses on the “critical zone” of the supraspinatus tendon, which is located approximately one centimetre away from the humeral head attachment. Jones[6] only reference to the morphology of the supraspinatus tendon is that the musculotendinous junction appears at the highest point of the humeral head in all the healthy volunteers analysed. These findings are very difficult to interpret as no other specifics are described, such as how far in the sagital plane the tendon lies, or even in the frontal plane, despite having MRI as a 3-dimensional tool. This, therefore, shows that both the Nakajima et al[12] and Jones[6] studies are of limited value to gaining anatomical knowledge as to the tendon morphology of supraspinatus.

A study by Neumann et al[13] also wanted to look at variations of different MRI signal intensities, finding which signal was best for imaging the supraspinatus tendon. The study was explicit in describing the method, including the MRI scanner and planes of view used, the number of subjects (32: 23 men and 9 women), which shoulders were used (55 shoulders used: 31 right and 24 left), and age range (mean 26 years old, range 22-45 years). However, the major weakness of the study came from the results, which focused on shoulders that were asymptomatic, but showed signs of degeneration. The researchers clearly wanted to look at normal anatomy, but the study started to review abnormal shoulder structures. Furthermore, the resultant paper then discusses the various MRI signal intensities, and barely covers the architecture or morphology of the supraspinatus tendon. The one aspect of architecture the study describes, briefly, is where the musculotendinous junction starts. Neumann et al[13] describe the musculotendinous junction in relation to the "humeral head", in which 30 shoulders of subjects started at "12 o'clock over the humeral head". The study found 18 of subjects' shoulders were 15 degrees lateral to the humeral head, 4 shoulders were 30 degrees lateral, and 3 shoulders were 15 degrees medial to the humeral head. As with the Jones[6] study, these descriptions are vague, and do not specifically allow for knowing the 3-dimensional co-ordinates that MRI can allow, thus decreasing value.

Nevertheless, the value of recognising these anatomical variations is significant in relation to whether this can link in functionally with the strength of the muscle. One such instance is that the tendon could be weaker if the tendon forms more laterally, which future MRI studies could investigate. In summary, these studies show that although MRI can allow for better anatomical knowledge of the supraspinatus tendon, all the available literature seems to focus on the method of MRI itself, or with pathology as opposed to anatomical variations, architecture and morphology. However, it is clear that MRI research may significantly help anatomists to increase their understanding of the supraspinatus tendon, by seeing the different variations and therefore the functions of the tendon.

## Conclusion:

Overall, there are at least four significant research methods that can be used to look at the architecture and morphology of the supraspinatus tendon. Embryological research has enabled anatomists to propose that the supraspinatus and infraspinatus tendon may actually be the same tendon, rather than two separate entities. Cadaveric studies have helped to show that, although there is an anterior and posterior supraspinatus tendon that roughly has the same cross-sectional area, the anterior portion deals with 288% more torsion than the posterior portion. Kolts[6] even found the variation of the subscapularis tendon attaching with the supraspinatus tendon on the lesser tubercle of the humerus, showing further anatomical variations. US studies have allowed further analysis of the tendon, showing not only that there is an anterior and posterior, but also an extra-muscular and intra-muscular part to the supraspinatus tendon. Further, the anterior is shown as a cylindrical structure whereas the posterior aspect is the more flat-shaped tendon, which could account for the different functions the tendons have to carry out for the strength and stability of the glenohumeral joint. Finally, there are MRI studies that show variations of normal anatomical features, and, although limited, these studies are of significant potential value in finding more 3-dimensional information about the supraspinatus tendon. In anatomical research, all these methods are essential to help develop understanding of the differences in anatomical variation, with each method displaying strengths which contribute to anatomical knowledge of many structures, including the supraspinatus tendon.

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