Evaluation of the muscle volumes of the transverse rotator cuff force couple in nonpathologic shoulders

Iwein Piepers, MSc, Pieter Boudt, MSc, Alexander Van Tongel, MD*, Lieven De Wilde, MD, PhD

Department of Orthopaedic Surgery and Traumatology, Ghent University Hospital, Gent, Belgium

Background: The balance between the subscapularis muscle and the infraspinatus/teres minor muscles, often referred to as the rotator cuff transverse force couple (TFC), has been proposed to be a critical component for normal shoulder function. The relationship between the muscle volume and the power means that TFC can be evaluated with the measurement of the muscle volume of the subscapularis muscle and the infraspinatus/teres minor. The aim of this study is to evaluate an innovative computed tomography (CT)-based technique to measure the muscle volume and to evaluate if there is a significant difference between muscle volumes of both the subscapularis muscle and the infraspinatus/teres minor in nonpathologic shoulders.

Materials and methods: CT images of 27 shoulders (21 patients) with a full scapula and a proximal humeral head were evaluated. Two volume masks (subscapularis and infraspinatus/teres minor) were calculated on the basis of the assigned muscle contours on the transverse slices. The intraobserver and interobserver correlation coefficient was calculated.

Results: The intraobserver and interobserver correlation coefficient was excellent. The correlation between the anterior and posterior part of the TFC was strong. There was no significant difference between the volume masks.

Conclusions: Muscle volume of the TCF can be quantified using CT images. In nonpathologic shoulders, there is no significant difference between the muscle volume of the anterior (subscapularis) and posterior part (teres minor/infraspinatus) of the TFC.


Keywords: Transverse force couple; infraspinatus/teres minor; subscapularis; muscle volume; CT images

The balance between the subscapularis muscle and the infraspinatus/teres minor muscles, often referred to as the rotator cuff transverse force couple (TFC), has been proposed to be a critical component for normal shoulder function. In a shoulder with a balanced TFC, the resultant force of the anterior and posterior component is in line with...
the glenoid. An unbalanced TFC, for example, due to a supraspinatus and infraspinatus tear, can change the direction of the resultant force. Because the contact area of articulation between the humerus and the glenoid is small, alterations in the resultant force may consequently exaggerate changes in load transmission across the gleno-humeral joint.

The muscle force of the anterior and posterior part of the TFC can be measured with a muscle force test that isolates the rotator cuff muscles. Manual muscle tests are used to evaluate a muscle’s strength in a position in which it is believed to be most isolated from other muscle contributions. But because one cooperative function of the rotator cuff muscles is to maintain the humeral head within the glenoid cavity, true isolation (when all other surrounding muscles are inactive) is an unlikely state.

Another possibility to measure the muscle force is by measuring the volume of muscle, muscle anatomic cross-sectional area, or physiologic cross-sectional area, because a relationship exists among muscle volume \( (r = 0.649) \), the anatomic cross-sectional area \( (r = 0.733) \), and the physiologic cross-sectional area \( (r = 0.715) \). By measuring the muscle volume, in contrast to the clinical test, a muscle group can be isolated.

The aim of this study is to evaluate a novel computed tomography (CT)-based technique to measure the muscle volume of the anterior and posterior component in a non-pathologic shoulder and to evaluate if there is a difference between both muscle volumes.

### Materials and methods

The CT images used in this study were obtained by a Somatom Volume Zoom Siemens CT (Siemens, Erlangen, Germany).

The study evaluated 21 patients (27 shoulders) with a full scapula and a proximal head. There were 20 shoulders from female patients and 7 from male patients, with an overall mean age of 57 years (range, 46-73 years). The images were obtained in 9 patients (13 shoulders) during a CT thorax scan performed because of a lung problem. Ten patients (10 shoulders) had an arthro-CT of the contralateral side for shoulder pain, and 2 patients (4 shoulders) had a CT because of an acute clavicle fracture. Because the diseased shoulder or clavicle fracture cannot be positioned centrally in the CT gantry, both shoulders can be scanned simultaneously, therefore eliminating the need for supplementary irradiation.

These patients were positioned in the CT gantry, according to a previously described method, in dorsal recumbency with a cushion on the belly and a strap around the body. The cushion keeps the arm adducted in the coronal plane and the forearm flexed in the sagittal plane of the body. This standardized position mimics a reproducible surgical position and minimizes positional errors.

None of the 21 patients recapitulated a history of chronic shoulder pain of the investigated shoulder. The pixel size of the images was a maximum of 0.977 mm and the slice increment was a maximum of 1.5 mm.

Concentrating the technique, the muscle contours were assigned on every transverse slide of the CT image by using the “Live-wire” option on the Mimics 14.12 (for Intel X86 Platform V14.0.0.90 1992-2012 [Santa Clara, CA, USA]; Materialise n.v., Leuven, Belgium) medical imaging software (Fig. 1).

Two volume masks were calculated from the assigned contours on the transverse slides. The first volume mask contained the subscapularis muscle (Fig. 2), and the second contained the infraspinatus and teres minor muscle (Fig. 2). By using the Mimics program, the volume of these masks and, therefore, these muscles could be calculated.

The correlation between the 2 volume masks were analysed. We next evaluated if a significant difference existed between the 2 volume masks in all shoulders and between the 2 volumes masks in shoulders scanned during a CT thorax scan or during a standardized CT shoulder scan.

The time required to contour both volume masks was monitored and measured in minutes.

All data were saved in Excel software (Microsoft Corp, Redmond, WA, USA), and the statistical analysis was performed with SPSS 21.0 software (IBM, Armonk, NY, USA).

The intraobserver correlation coefficient was calculated by 2 blinded separate measurements of a muscle contour on a transverse slide with a time interval of several days. The interobserver correlation coefficient was calculated by comparing the measurements of a muscle contour on a transverse slide between 2 different examiners.

### Results

The intraobserver correlation coefficient was 0.983 (range, 0.922-0.997; \( P < .001 \)), and the interobserver correlation coefficient was 0.973 (range, 0.958-0.983; \( P < .001 \)). The volumes for the anterior and posterior part of the TFC for both sexes were normally distributed (Shapiro-Wilk test: men, \( P = .818 \); women, \( P = .742 \)). The volumes of the anterior and posterior part can be seen in Figure 3 and Table 1. The correlation between the anterior and posterior part of the TFC was strong (Spearman’s \( r = .833 \); Fig. 3)
There was no significant difference between the anterior and posterior part of the TFC in the 27 shoulders (Mann-Whitney test: $P = .672$).

There was no significant difference between the 13 shoulders scanned during a CT thorax scan and the 14 shoulders that underwent a standardized CT shoulder scan (Mann-Whitney test: $P = .604$).

The mean time to obtain both volume masks in 1 shoulder was 125 minutes (range 90-160 minutes).

Discussion

Measurement of the rotator cuff muscle volume has been done before on cadavers$^{11}$ and on magnetic resonance imaging (MRI)$^{10,16,17}$. After dissection of the separate rotator cuff muscles in 5 cadavers, Keating et al$^{11}$ measured the muscle volume by monitoring the displaced water volume after immersion. Van Geelijn Vitringa et al$^{17}$ measured the muscle volume of the subscapularis and the infraspinatus in children with obstetric brachial plexus injury. However, they only measured the volume of a (standardized) 15-mm transverse segment of the muscle and not the volume of the entire muscle.$^{17}$ In another study, Juul-Kristensen et al$^{10}$ estimated volumes of rotator cuff muscles using MRI scans in 20 patients. The volume of each muscle was calculated from the average cross-sectional area of 3 MRI scans.$^{10}$

The study by Tingart et al$^{16}$ is the only one that measured the complete muscle volume on MRIs. Together with the cadaveric study of Keating et al,$^{11}$ these are, to our knowledge, the only studies that have measured the complete volume of the TFC as we did in our study.

Tingart et al$^{16}$ measured the volume in 10 cadaveric shoulders without rotator cuff tear (mean age, 76 years). The patients in our study had no history of shoulder pain on the investigated side (mean age, 59 years). The contours of the supraspinatus, subscapularis, infraspinatus, and teres minor muscles were traced by hand on each sagittal scan. The muscle volume of each rotator cuff muscle was calculated, using 3-dimensional image analysis software, by considering the contoured area of each muscle and the thickness of each MRI slice. We used the transverse slides of the CT scan, as originally described by Goutallier et al,$^{7}$ for the evaluation of the fatty degeneration of rotator cuff muscles, and obtained good intraobserver and interobserver variability.$^{12}$
Teres minor and infraspinatus were measured as a whole instead of as 2 separate muscles, similar to previous published reports. This was done for several reasons. First, it is impossible to discern the difference between teres minor and infraspinatus on every slice. Next, the teres minor and infraspinatus were hence seen as one functional unit of the TFC. They are both the most powerful external rotators and have almost the same functions. Because of this similar function, this technique remains suitable to use in different shoulder pathologies concerning axial rotation, such as in longstanding cuff tears (anterosuperior vs posteroinferior), where the quantification of the muscular volume can probably help to decide if a muscle transfer may be necessary. For example, additional studies of cuff tear arthropathy have revealed hypertrophy of the teres minor in long-standing posteroinferior rotator cuff tears. In these patients no latissimus dorsi transfer may be necessary.

Another reason to concentrate on the TFC is the biomechanical observation that all of the different subregions of the subscapularis (superior, middle and inferior), at the anterior side of the scapula, as well as the infraspinatus (superior and inferior) and the teres minor, at the posterior side of the scapula, behave as, respectively, internal rotators or external rotators, independent of the degree of abduction/flexion. This is in contrast with the supraspinatus muscles, which are external rotators during abduction and internal rotators during flexion.

This study demonstrated that there is no significant difference between the muscle volume of the anterior component (subscapularis) compared with the posterior component (teres minor and infraspinatus). This means that the muscle volumes are in balance, and as a consequence, due to the correlation ($r = 0.649$) between muscle strength-size and muscle volume, also the muscle force of nonpathologic shoulders. To our knowledge this is the first time the theory that a balance exists in the TFC has been demonstrated. These results were also indirectly described by Keating et al. When counting the muscle volume of the infraspinatus and the teres minor together, these numbers are almost equal to the muscle volume of the subscapularis.

This study also showed that there is no significant difference between both muscle volumes independent of the position of the shoulder in adduction and in full elevation. This confirms the theory of Swammerdam that the shape of the muscle might change in different positions but not the volume.

We hope to demonstrate with ongoing studies that this technique will be able to demonstrate subtle change in the TFC in the pathologic shoulder so that it can be used to make a treatment plan such as, for example, strengthening of a specific muscle group in instability. It also can be helpful to evaluate the muscle force preoperatively and postoperatively.

This technique has several weaknesses. Although the CT method presented in this study is highly accurate, it proved to be time-consuming for regular clinical use. Therefore, ongoing work is focused on the development of a simple and time-efficient technique with comparable accuracy and reliability, designed specifically for clinical practice. The complete scapula and proximal humerus need to be scanned to obtain a correct measurement of the complete muscle volume. This means the scan area is larger and the irradiation is higher than normal.

Another weakness is that the mean age of the patients is 57 years. Differentiating the infraspinatus from the deltoid on an axial cut can sometimes be very difficult in younger patients, and this may influence the reproducibility of our results.

### Conclusions

Muscle volume of the TCF can be quantified using CT images. In nonpathologic shoulders, there is no significant difference between the muscle volume of the anterior (subscapularis) and posterior part (teres minor/ infraspinatus) of the TFC.

### References

3. Brookham RL, McLean L, Dickerson CR. Construct validity of muscle force tests of the rotator cuff muscles: an electromyographic


