ORIGINAL ARTICLE

Anatomic and CT scan assessment of Teres Minor: A new index of trophicity

C. Szymanski\textsuperscript{a,}\textsuperscript{*}, O. Boniface\textsuperscript{a}, X. Demondion\textsuperscript{b}, J.-Y. Deladerrière\textsuperscript{a}, T. Vervoort\textsuperscript{a}, A. Cotten\textsuperscript{c}, C. Maynou\textsuperscript{a}

\textsuperscript{a} Orthopedics Dept A, Roger Salengro Hospital, Lille Regional University Hospitals, Lille, France
\textsuperscript{b} Anatomy Laboratory, Lille Medicine Faculty, Lille, France
\textsuperscript{c} Musculoskeletal imaging Dept, Roger Salengro Hospital, Lille Regional University Hospitals, Lille, France

Accepted: 5 October 2012

KEYWORDS
Shoulder;
Rotator cuff;
Teres minor;
CT scan

Summary

Introduction: The present study reports the development of a CT assessment protocol for Teres Minor (TM) trophicity.

Hypothesis: Quantitative reproducible Teres Minor assessment on CT estimates the influence of muscle trophicity on the clinical and radiological results of palliative treatment of irreparable rotator cuff tear.

Materials and method: An anatomic study of 30 cadaveric shoulders confirmed a constant anatomic relation between Teres Minor and the inferior pole of the glenoid cavity. This landmark was used to develop a novel CT assessment of TM trophicity.

Results: The CT assessment showed excellent inter- and intra-observer reproducibility. The protocol defines a trophicity index, T2/G (T2 being TM thickness on axial CT slice, and G the maximum glenoid cavity thickness on axial slice), enabling reproducible TM analysis on preoperative arthro-CT.

Conclusion: The study validated the CT protocol, allowing application in pre- and postoperative assessment of irreparable rotator cuff tear.

Level of evidence: Level IV. Retrospective study.
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Introduction

The infraspinatus muscle provides external rotation and lowering of the humeral head \cite{1,2}; fatty infiltration plays a determining role in the functional and anatomic result of rotator cuff surgery \cite{3,4}. Tearing or major fatty infiltration of the infraspinatus impacts active shoulder-to-body external rotation; with the arm in abduction, on the other hand, external rotation may be conserved if Teres Minor (TM) trophicity is adequate \cite{5}. Walch et al. and Boileau et al. showed that TM trophicity impacts arthroscopic treatment of rotator cuff tears too great to be repaired by tenotomy of...
the long head of the brachial biceps [6,7]. The deleterious
effect of fatty infiltration of TM on reverse arthroplasty [8]
and latissimus dorsi flaps [9] has been demonstrated. Walch
et al. recommended a method of qualitative TM assessment
on four grades (normal, hypertrophic, atrophic or absent)
according to muscle thickness on transverse CT slices, tak-
ing normal thickness to be equal to approximately half the
anteroposterior diameter of the glenoid cavity [6,10].

The present study developed a method of precise and
reproducible CT analysis of TM trophicity.

Material and method

As a first step, an anatomic study determined the relations
between TM and the posterior part of the glenoid cavity,
in 30 cadaveric shoulders from 11 males and seven females
(mean age, 71 years).

Dissection was performed in the anatomy and organo-
genesis laboratory of the Medicine Faculty of Lille (France).
Specimens were preserved in formaldehyde. Scapulo-
humeral units were removed by median sagittal section
within the scapula and transverse section of the humerus.
Only the rotator cuff muscles were conserved. The glenoid
cavity was approached by raising the subscapularis muscle,
and the inferior pole was freed from the triceps insertion,
capsuloligamentous complex and labrum, then landmarked
by a needle tangential to the inferior pole (Fig. 1). The TM
was in all specimens easy to distinguish from the infraspin-
atus muscle. The inferior edge of the glenoid, marked by
the needle, projected over the TM muscle body in neutral rota-
tion in all specimens. Mean TM height was 26.4 mm (±3.4;
range, 15 to 30 mm); mean distance between the superior
and inferior limits of the TM and the inferior limit of the
glenoid was respectively 12.2 mm (±2.5; range, 7 to 17 mm)
and 14.1 mm (±2; range, 8 to 17 mm).

These anatomic data confirmed that TM was in all cases
in neutral rotation with respect to the inferior pole of the
glenoid cavity, thus allowing the CT trophicity assessment
protocol to use the latter as landmark on axial slices in neu-
tral rotation: the muscle behind the lowest axial glenoid
slice was systematically the TM.

The second step of analysis tested the inter- and
intra-observer reproductibility of the CT assessment
retrospectively on 40 scans from 40 patients operated on
between 2000 and 2005 by arthroscopic tenotomy of the long
head of the brachial biceps tendon for massive irreparable
rotator cuff tear. Four observers with varying surgical expe-
rience (1 senior professor, 1 assistant senior registrar and 2
interns) performed CT analysis on a set protocol. CT slices
were all in neutral rotation. A transverse slice (T2) just
under the glenoid cavity was preselected as reference, and
the slices immediately above and below were designated T1
and T3 respectively. On each image, the observer traced
the tangent to the bone crest of the infraspinatus fossa parallel
to the TM axis. Maximum TM thickness was then measured on
slices T1, T2 and T3, tracing the perpendicular to the tangen-
t of the bone crest of the infraspinatus fossa (Fig. 2). The
observer then selected the transverse slice showing the greatest
anteroposterior endocortical glenoid diameter (G) (Fig. 3). Inter-
and intra-observer reproducibility of slice choice, TM thickness and glenoid diameter was
assessed from two successive readings by each observer at a
1-month interval. Fatty infiltration of TM was also assessed
on the Goutallier and Bernageau classification [11] at both

Figure 1 Posterior view of left Teres Minor. Needle positioned
at inferior pole of glenoid cavity.

Figure 2 Teres Minor thickness on axial slice T2 in neutral
rotation at inferior pole of glenoid cavity.

Figure 3 Parameter G: endocortical glenoid cavity diameter.
time-points. Inter- and intra-observer correlations were analyzed by Pearson’s linear correlation coefficient and Fermanian’s coefficient. Interobserver concordance was calculated on Fleiss’s method. Fatty infiltration grade reproductibility was assessed on the non-parametric Wilcoxon test.

Each radiology file contained pre- and postoperative (1 year) AP and lateral shoulder views. Subacromial space and Hamada-Fukuda [12] osteoarthritis grades were noted to test for any correlation between them and the T2/G TM trophicity index.

The series of 40 arthro-CT scans included 25 females and 15 males, with a mean age of 68.3 years; the dominant side was involved in 27 cases. Preoperative arthro-CT with 2–3 mm consecutive slices was available in all cases, allowing measurement of T2, G and T2/G.

**Results**

**Reproductibility**

CT measurement reproducibility was very satisfactory. There were no significant interobserver differences in reference-slice choice (“NT2” in Table 1), TM thickness on slices T1, T2 and T3 (Table 1), or glenoid cavity size (“G” in Table 1).

The Fermanian intra-observer reproducibility coefficient was very satisfactory: systematically greater than 0.91. There was no observer effect, and good interobserver concordance on the Fleiss method, with kappa systematically greater than 0.8. Fatty infiltration assessment gave less satisfactory results, with two significant intra-observer discrepancies, although interobserver concordance was satisfactory.

There were no significant differences with regard to the three TM thickness measurements (on T1, T2 and T3) by the four observers.

<table>
<thead>
<tr>
<th>Observer</th>
<th>NT2</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.99987</td>
<td>0.97178</td>
<td>0.97747</td>
<td>0.97197</td>
<td>0.80853</td>
</tr>
<tr>
<td>2</td>
<td>0.99971</td>
<td>0.97641</td>
<td>0.97111</td>
<td>0.97265</td>
<td>0.98152</td>
</tr>
<tr>
<td>3</td>
<td>0.99985</td>
<td>0.98001</td>
<td>0.97789</td>
<td>0.98328</td>
<td>0.91386</td>
</tr>
<tr>
<td>4</td>
<td>0.99998</td>
<td>0.97188</td>
<td>0.97497</td>
<td>0.96529</td>
<td>0.98155</td>
</tr>
</tbody>
</table>

Reliability: F. Fermanian’s coefficient, NT2: slice T2 selected as reference; G: glenoid cavity diameter.

**CT measurement results**

Mean TM thickness (T2) was 19.1 mm (range, 8.9–29 mm). Mean glenoid cavity diameter (G) was 24.6 mm (range, 20–29.8 mm). Mean T2/G ratio was 0.78 (range, 0.35–1.28). T2 and G showed no correlation, as TM trophicity varied between specimens. The trophicity index (T2/G) correlated with pre- and postoperative subacromial space (P < 0.0001). Sample size required grouping stages 1–2 and 3–4 into two cohorts to analyze correlation between TM trophicity index and Hamada-Fukuda grade: two groups were defined according to whether or not there was a deterioration of at least two grades between pre- and postoperative values; a significant correlation was thereby demonstrated between trophicity index (T2/G) and both preoperative Hamada-Fukuda grade (P < 0.0001) and pre- to postoperative grade evolution. To determine a T2/G threshold for unfavorable prognosis, multivariate principal component analysis was performed on the series of 40 scans (Fig. 4). A T2/G threshold of 0.75 showed optimal sensitivity and specificity in distinguishing two groups according to subacromial space and change in Hamada-Fukuda grade, giving 23 patients with T2/G < 0.75 and 17 with T2/G > 0.75. Tables 2 and 3 present the main data for the two groups. The T2/G ratio appeared reliable and reproducible, with a ratio greater than 0.75 seeming to correspond to slowed humeral head ascension (by conservation of the subacromial space) and

### Table 1. Interobserver reproducibility: Pearson linear correlation coefficient between measurements made at 1 month’s interval for each observer (significant on Student t test at P < 0.0001).

<table>
<thead>
<tr>
<th></th>
<th>NT2</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observer 1</td>
<td>0.99987</td>
<td>0.97178</td>
<td>0.97747</td>
<td>0.97197</td>
<td>0.80853</td>
</tr>
<tr>
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<td>0.99971</td>
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<td>0.97111</td>
<td>0.97265</td>
<td>0.98152</td>
</tr>
<tr>
<td>Observer 3</td>
<td>0.99985</td>
<td>0.98001</td>
<td>0.97789</td>
<td>0.98328</td>
<td>0.91386</td>
</tr>
<tr>
<td>Observer 4</td>
<td>0.99998</td>
<td>0.97188</td>
<td>0.97497</td>
<td>0.96529</td>
<td>0.98155</td>
</tr>
</tbody>
</table>

Reliability: F. Fermanian’s coefficient, NT2: slice T2 selected as reference; G: glenoid cavity diameter.

### Table 2. Preoperative data according to normal or atrophic teres minor status.

<table>
<thead>
<tr>
<th>TM trophicity</th>
<th>Age</th>
<th>Sex (%)</th>
<th>FU (months)</th>
<th>T2/G</th>
<th>E SAS</th>
<th>Hamada</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.75 (23 cases)</td>
<td>70 ± 9</td>
<td>♂: 41</td>
<td>71 ± 31</td>
<td>0.51 ± 0.1</td>
<td>5.6 ± 1.6</td>
<td>1.5 ± 0.7</td>
</tr>
<tr>
<td>&gt; 0.75 (17 cases)</td>
<td>67 ± 7</td>
<td>♂: 35</td>
<td>65 ± 32</td>
<td>0.98 ± 0.1</td>
<td>7.6 ± 0.9</td>
<td>1 ± 0.2</td>
</tr>
</tbody>
</table>

SAS: subacromial space (mm).

* Significant difference between groups (P < 0.05).

### Table 3. Postoperative data according to normal or atrophic teres minor status.

<table>
<thead>
<tr>
<th>TM trophicity</th>
<th>SAS</th>
<th>Hamada</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.75 (atrophy)</td>
<td>3.1 ± 1.3</td>
<td>2.7 ± 0.8</td>
</tr>
<tr>
<td>&gt; 0.75 (normal aspect)</td>
<td>7.2 ± 1.1</td>
<td>1.1 ± 0.3</td>
</tr>
</tbody>
</table>

SAS: subacromial space (mm).

* Significant difference between groups (P < 0.05).
delayed osteoarthritic evolution. These preliminary results will require closer clinical (Constant score [13]) and radiological analysis in a subsequent study.

Discussion

External rotation of the humerus depends on the infraspinatus and TM muscles and the posterior head of the deltoid. While several authors have demonstrated muscle force to be directly proportional to physiological cross-sectional area [14,15], other parameters such as muscular bundle pennation angle and lengthening during movement are equally important. Langenderfer et al. [16] reported that infraspinatus and TM force were identical at 10° abduction, whereas the latter was twice that of the former at 60° abduction. Kuhlman et al. [17], measuring isometric force in external rotation at varying degrees of abduction, before and after interscalene block, found TM to account for 25% of external rotation at 0–30° abduction and for 50% at 30–60°. Thus, when the infraspinatus is functional, the TM can be considered merely accessory to external rotation, whatever the degree of abduction. In contrast, when the infraspinatus is non-functional, TM recruitment is greater when the upper limb is in abduction, especially as the deltoid muscle then ceases to contribute to external rotation [18]. In the present anatomical study, the TM muscle body could be identified and separated from the infraspinatus in all cases, being always distinguished by a posterior and inferior fascia. The anatomic relation between the TM and the inferior pole of the glenoid cavity was constant, enabling the latter to serve as a reliable anatomic landmark for CT trophicity analysis in neutral rotation. CT slice level was of variable precision, as horizontal slices did not necessarily pass through the inferior pole; even so, the superior and inferior limits of the TM muscle body lay on average at more than 10 mm from the inferior pole, so that imprecision of level (2–3 mm) was not enough for horizontal slices to pass above or below the muscle. Thus, a muscle facing the posterior side of the inferior pole of the glenoid cavity can safely be taken to be the TM. Muscle thickness measurements on three adjacent slices (T1, T2 and T3) were not significantly different, although thickness was not assessed according to subacromial distance. The cadaver study found a mean TM body height of 26.4 mm, so that a few millimeters’ humeral ascension would not affect the relation of TM to the glenoid cavity. Tracing the tangent to the infraspinatus bone crest was sometimes complicated by the presence of contrast medium, and the TM axis could not always be easily located. The posterior limit of TM was sometimes confused with the anterior limit of the deltoid. Despite these possible sources of error, however, inter- and intra-observer reproducibility was very satisfactory, allowing this CT analysis to be used to assess muscle trophicity impact. Clinical analysis using trophicity criteria could be of interest, and will be the subject of a subsequent study.

Mean endocortical glenoid cavity diameter in the present series was 24.6 mm, close to the findings of Bicknel et al. (22.9 mm) [19]. It was significantly greater in males, and correlated with teres minor thickness, while the T2/G ratio was independent of sex, age and dominance. The arthro-CT study of 40 arthroscopic brachial biceps tenotomy patients with irreparable rotator cuff tear found a significant correlation between TM trophicity and postoperative radiological results: deterioration in subacromial space height and Hamada-Fukuda grade was observed below a trophicity index threshold of 0.75. These findings confirm those of Walch et al. [6] and Boileau et al. [7] of a significant relation between TM atrophy and palliative arthroscopy results in non-repaired rotator cuff tear. The present findings also confirmed the lowering action of TM on the humeral head reported in experimental studies [20]. When the TM trophicity index was less than 0.75, change in Hamada-Fukuda grade at follow-up was greater. In absence of a functioning infraspinatus muscle, conserved TM trophicity may thus be considered as slowing disalignment of the humeral head.

The present CT assessment method should enable potential recovery of lateral rotation after reverse arthroplasty to be foreseen. This aspect was previously raised by Simovitch et al. [8], who reported a negative impact of fatty infiltration of TM on active external rotation in 42 patients undergoing reverse arthroplasty, with a minimum 2 years’ follow-up; the study was mainly based on sagittal MRI slices, on which there was good intra-observer agreement on the degree of fatty infiltration. Thus, the present T2/G ratio seems more reliable and reproducible than subjective assessment of amyotrophy or fatty degeneration.

Conclusion

On the basis of a preliminary anatomical study, a CT method of TM trophicity measurement showed excellent intra-and Interobserver reproducibility. Application in a series of patients undergoing palliative brachial biceps tenotomy for irreparable rotator cuff tear confirmed the undeniable prognostic interest of TM trophicity with respect to 1-year radiology results. Further study should seek to determine, in a series of patients, whether a 0.75 threshold on this trophicity index is predictive of better postoperative clinical results after arthroscopic rotator cuff repair or reverse shoulder arthroplasty.
Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References