Philip Kasten · Markus Loew · Markus Rickert

Repair of large supraspinatus rotator-cuff defects by infraspinatus and subscapularis tendon transfers in a cadaver model

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Abstract Transosseous repair of a supraspinatus tendon (SSP) defect (Patte size II) can be difficult if the tendon is retracted and the muscle atrophied. In this situation alternatives are margin convergence techniques, local tendon transfers or distant tendon transfers in massive tears. The object of this study was to compare two local tendon transfers in terms of the feasibility of the shift, the area covered by the shift and the force needed to accomplish the shift. Thirteen fresh-frozen cadaver shoulders were used. First a supraspinatus defect extending to the apex of the humeral head (Patte size II) was created. Transosseous repair was attempted with the infraspinatus (ISP) and with the subscapularis (SCP) in all cases; repair was successful in all ISP cases, while use of the SCP resulted in a successful repair in only 8 of the 13 (61.5%). A significantly ($P=0.012$) larger defect area was covered by the ISP transfer than by the SCP shift: $89.7\pm 8.5\%$ versus $31.2\pm 31.1\%$ of the original defect, respectively. The tensile force needed to accomplish the shift was significantly ($P=0.004$) lower when the ISP was used (15 ± 11 N) than with the SCP (37.1 ± 15 N). In this cadaver model the ISP shift proved more favourable than the SCP shift for covering a Patte size II SSP defect.

Résumé La réinsertion transosseuse du tendon du sus épineux (SSP) (Patte II) peut être difficile si le tendon est rétracté et le muscle atrophie. Dans ces conditions il faut utiliser une chirurgie de rapprochement des bords et des transferts tendineux dans les ruptures massives. Le but de cette étude est de comparer deux techniques de transferts tendineux, en termes de faisabilité, avec étude de la surface couverte par glissement et la force nécessaire pour accomplir celui-ci. 13 épaules de cadavres ont été utilisées,

une perte de substance a été créée dans le sus épineux à l'apex de la tête humérale (Patte II). Une réparation transosseuse a été réalisée avec le tendon du sous épineux du sous scapulaire. La réparation a été possible dans tous les cas avec utilisation du sous épineux mais, seulement dans 8 cas sur 13 lorsqu'on a utilisé le sous scapulaire (61,5%). Un defect beaucoup plus large, peut être couvert par un lambeau du sous épineux plutôt que par un lambeau du sous scapulaire ($89,7\pm 8,5\%$ versus $31,2\pm 31,1\%$) du defect. La force nécessaire pour accomplir cette translation est significativement plus basse avec le sous épineux qu'avec le sous scapulaire (15 ± 11 N versus $37,1\pm 15$ N). Un lambeau de rapprochement sous épineux semble plus favorable qu'un glissement sous scapulaire pour couvrir les pertes de substances Patte type II du sus épineux.

Introduction

Supraspinatus (SSP) tendon defects can often be repaired by transosseous sutures with excellent results [1, 9, 10, 17, 25, 26]. The rate of tendon-to-bone healing of full-thickness supraspinatus tears is good and averages 70–80% [2, 20]. However, primary repair of larger supraspinatus tendon tears can be compromised by the size of the tear, retraction of the musculotendinous unit, muscular atrophy and fatty infiltration; the repair may fail, and the supraspinatus may not regain its strength and remain non-functional [7, 11, 12].

As a consequence, alternative procedures have to be considered. Cuff debridement can provide pain relief and may restore some function in the elderly, but it cannot restore muscle strength [24]. Margin convergence techniques are able to reduce the defect and to restore the rotator cable [3–5], but closure of the defect is not possible with this technique in all cases.

Local tendon transposition and distant tendon transfers have been proposed for the management of large rotator-cuff tears [27]. However, there are no clear and established guidelines on what kind of tendon transfer should be performed in particular cases. Compared to distant tendon

P. Kasten · M. Loew · M. Rickert (✉)
Department of Orthopaedic Surgery,
University of Heidelberg,
Schlierbacher Landstrasse 200 A,
69118 Heidelberg, Germany
e-mail: markus.rickert@ok.uni-heidelberg.de
Tel.: +49-6221-966330
Fax: +49-6221-966311

transfers, such as the transfer of the latissimus dorsi tendon, local tendon transfers involve use of the subscapularis or the infraspinatus musculotendinous unit to cover a large superior defect of the rotator cuff [6, 18, 19]. Cofield published a paper on the use of the subscapularis (SCP) muscle for repair of chronic rotator cuff tears in 1982, and Neer reported on the use of the infraspinatus (ISP) for the same purpose in 1983 [18, 19].

Compared to distant tendon transfers, the use of local rotator-cuff tendons seems reasonable in terms of lower donor site morbidity and a limited surgical approach.

As a possible limitation, one has to consider that the SCP and the ISP tendons are responsible for the so-called transverse force couple [4], and detachment of one of these tendons may alter the biomechanics of the shoulder because an internal rotator (SCP) or an external rotator (ISP) is transferred in order to replace the SSP tendon.

However, since the muscles are transferred more laterally and cranially, from a biomechanical point of view, they should still be able to act as rotators and humeral head depressors and should stabilise the shoulder in the transverse force couple [13].

To our knowledge there are no clinical or experimental studies that compare the use of the ISP and the SCP in a local tendon transfer. Therefore, the purpose of this cadaveric study was to compare the use of ISP and SCP tendon transfers to repair a standardised supraspinatus defect (Patte size II [21]) by analysing the feasibility of each tendon transfer, the area of the defect that can be covered by the tendons (primary outcome measure), the force required for the transfer, and the intramuscular lengthening of the transfer.

Materials and methods

The study was approved by the institutional ethical committee of the authors' university. Thirteen fresh-frozen shoulder specimens (four right and nine left), each including the scapula and the proximal third of the humerus, were obtained. The rotator cuff was grossly intact in each of the 13 specimens. These shoulders were taken from 8 male and 5 female cadavers, and the age at the time of death ranged between 53 and 82 years (mean 67.5, standard deviation ± 12.4). The soft tissues, including skin and subcutaneous fat, the deltoid muscle, the subacromial bursa, and the acromion, were removed to allow free access to the entire rotator cuff.

The scapula of each thawed specimen was fixed in a clamp, with the medial margin of the scapula perpendicular to the floor and the scapular spine approximately parallel to the floor. The humeral head was transosseously fixed against the glenoid with a 3-mm K-wire avoiding distal subluxation after opening of the glenohumeral joint. A supraspinatus tendon defect was created by resecting the tendon up to the apex of the humeral head in the frontal plane and along its insertion at the greater tuberosity from the lateral part of the bicipital groove to the superior part of the ISP insertion in the sagittal plane (Patte size II defect,

Fig. 1). The biceps tendon was left in place. The area of the defect was measured by drawing the margins on transparent graph paper.

The sequence of transfer of the infraspinatus and then of the subscapularis tendon, or vice versa, was randomised. The transfer of the ISP and then the SCP transfer are described in the following account.

The infraspinatus tendon was dissected away from the capsule up to the glenoid. The overall length of the infraspinatus tendon and muscle was measured, and the muscle was divided into two halves along its length. In each half a Hall effect transducer (Microstrain DVRT, Burlington, Vermont, USA) covering a length of 30 mm and with a measuring capacity of 9 mm was inserted parallel to the muscle fibers in the middle part of the vertical extension of the infraspinatus. A juxtaglenoid release was performed around the ISP muscle. Three stitches (Ethibond, J&J, Norderstedt) were inserted into the infraspinatus tendon using the Mason-Allen technique, and the flap was moved to the greater tuberosity to cover the rotator-cuff defect. The force necessary to pull the tendon into place was measured five times by the same observer (Fig. 2a) using digital scales (CH 15 K 20, Kern, Germany), and at the same time the change in the length of the muscle was monitored by the Hall effect transducers and recorded on a personal computer (Dell, USA). The infraspinatus tendon was then fixed at the greater tuberosity into a trough using three transosseous holes. The area that remained uncovered was outlined on transparent graph paper and measured. The area covered by the transfer was calculated by subtracting the area uncovered from the total area of the Patte size II defect (Fig. 2b). Closure of the rotator-cuff defect was then accomplished by means of side-to-end sutures attaching the ISP to the SSP stump and side-to-side sutures attaching the ISP to the rotator interval (Fig. 2c). The biceps tendon was left intact and in place.

Fig. 1 Antero-lateral view of a specimen with an SSP defect (Patte size II) extending to the apex of the humeral head. (*In* Rotator interval, *BT* biceps tendon, *SCP* subscapularis, *SSP* supraspinatus, *ISP* infraspinatus, *Cor* coracoid)

The donor site was closed medially by approximation of the teres minor muscle. Then the K-wire was removed, the humeral head was subjected to gravity, and the spontaneous position of the proximal humerus was measured using a goniometer.

In the second part, the infraspinatus was reinserted transosseously at the original site and the glenohumeral joint was fixed again with a K-wire. Then the subscapularis tendon was dissected away from the capsule and mobilised by blunt dissection up to a point 3 cm medial to the glenoid. The SCP muscle was released more extensively than the ISP because otherwise transposition would have been impossible. Hall effect transducers were inserted parallel to the muscle fibers in each longitudinal half of the subscapularis muscle in the middle third. The procedure detailed above was then applied to shift the tendon to cover the SSP defect, and the force needed to pull the muscle and the movement within the muscle was recorded. The subscapularis tendon was inserted at the greater tuberosity using the same holes as for the ISP fixation, and the area left uncovered was measured.

Statistics Mean and standard deviation were calculated for continuous variables. The Wilcoxon test was applied to determine whether the differences in outcome parameters

were significant. A two-tailed *P* value equal to or less than 0.05 was considered to indicate significance. All other tests were exploratory and were calculated without alpha adjustment. Data analysis was performed with SPSS for Windows 12.0 (SPSS, USA).

Results

Using the ISP tendon transfer closure of the SSP defect was possible in all cases and after SCP transfer in 8 (61.5%) of the 13 cases. After removal of the K-wire used for glenohumeral fixation, in 5 (62.5%) of 8 cases in the SCP group the spontaneous position of the arm was found to be in 10–45° abduction [mean value (MV) 28°, standard deviation (SD) $\pm 17.5^\circ$]. After ISP shift, there was a similar spontaneous abduction of 10° in 1 of the 13 cases.

The initial size of the SSP defect averaged $389.8 \pm 82.1 \text{ mm}^2$. After transposition of the ISP tendon the remaining defect was $41.2 \pm 29.2 \text{ mm}^2$ and after transfer of the SCP tendon it was $288.7 \pm 143.3 \text{ mm}^2$. In the test of the primary outcome measure, i.e., the area covered by the shift, a significant ($P=0.012$) difference was found between the ISP ($89.7 \pm 8.5\%$) and the SCP shift ($31.6 \pm 31.2\%$) (Fig. 3). The force necessary to perform the shift was

Fig. 2 (a) After mobilisation of the ISP, the force needed to transpose the muscle to the greater tuberosity was measured. (b) After transosseous fixation of the shifted ISP, the uncovered area was measured (gray area) and (c) the rotator cuff was closed

significantly ($P=0.004$) lower in the ISP group (15.9 ± 1.08 N) than in the SCP group (37.2 ± 1.51 N) (Fig. 4). The average ISP muscle length, at 14.55 ± 1.21 cm, was significantly longer ($P=0.012$) than the SCP muscle, at 12.68 ± 1.10 cm. There was a significant difference ($P=0.002$) in total muscle lengthening, as measured by the Hall effect transducer in 3 cm, between the ISP (MV 1.3 ± 0.97 mm) and the SCP (MV 2.28 ± 1.88 mm). There was no significant difference between medial and lateral lengthening within either muscle or between ISP and SCP in lengthening in either the lateral or the medial section.

Discussion

The supraspinatus tendon is the one most frequently affected in degenerative rotator-cuff disease. Repair of large chronic supraspinatus tears with retraction and fatty degeneration may not be associated with a successful outcome in all cases [7, 12]. If the goal is recovery of function and pain relief, the defect should be closed with tendinous tissue [27]. For cases in which the defect is limited to one tendon of the rotator cuff, local transposition from the rest of the cuff has been proposed. [6, 8, 18, 19, 22] Similar muscle amplitude [14], strength [14], and availability coupled with low donor site morbidity seem to favour the use of local transpositions.

To evaluate the extent of the rotator-cuff defect, MRI or an ultrasound examination should be available preoperatively. If the SSP defect is limited to Patte size II and seems to be irreparable as a result of muscle atrophy and a marked degree of retraction, a transosseous tendon repair will probably fail. In this situation one should consider alternative techniques like side-to-side sutures to minimise the defect and to restore the transverse force couple as described by Burkhart [3, 4] or, as in this study, local tendon transfers. If the ISP is intact, a more lateral approach to the rotator cuff can be selected in preference to an antero-lateral one for performance of an ISP shift.

From a biomechanical point of view one has to keep in mind that by using this type of non-anatomical repair, the force vector of the transferred tendons is changed, and shoulder kinematics could be affected. Our assumption was that the transferred muscle-tendon units for both infraspinatus and subcapularis transfers will be able to act as rotators as before. There are data that the infraspinatus and

Fig. 4 Tensile force needed to complete shift (N)

subscapularis have similar effects on depression of the humeral head [13]. Since the transferred muscles are inserted at the same supero-lateral area, we assumed that in both cases their depressor function would increase while the rotating force is preserved. In fact, our group was able to show that the range of motion for flexion, abduction and rotation did not differ after ISP and SCP transfers [15].

Additionally, the surgeon must bear in mind that the use of local tendon transfers might lead to stiffness of the shoulder if the repair is done too tightly, or larger defects could develop if the tendons do not heal. The latter may lead to two-tendon defects including the supraspinatus and the infraspinatus, leading to significant instability in the glenohumeral joint as described by Loehr et al. [16].

To our knowledge, this cadaver study is the first to compare use of the ISP and the SCP to cover a Patte size II SSP defect in a standardised fashion. In this model the ISP shift had some advantages compared with the SCP shift. The most important issues were that a larger defect area could be covered and that lower forces were necessary to pull the tendon into the defect. This is an important consideration because muscles can only be stretched to a certain extent without compromising both proprioception and function [7, 12], facts to be borne in mind when muscle/tendon transfers are performed. Furthermore, too much tension within a muscle/tendon unit can compromise vascularity and healing and lead to necrosis and re-rupture [23, 27].

However, the study neither provides data indicating the superiority of local tendon transfers over distant tendon transfers or margin convergence techniques nor is it able to simulate the tendon degeneration and retraction that usually occur in the clinical situation. Great caution must therefore be exercised in any attempt to extend these data obtained in a cadaver study to an in vivo situation.

In summary, our data show that if an isolated SSP defect extends to the apex of the humeral head and cannot be closed by a transosseous repair, an infraspinatus tendon transfer is able to cover larger defect areas and is easier to transpose into the defect than a subscapularis tendon transfer.

Fig. 3 Defect area covered by the muscle transfer (%)

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