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Tendon fixation in arthroscopic latissimus dorsi transfer for irreparable posterosuperior cuff tears: An in vitro biomechanical comparison of interference screw and suture anchors

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ABSTRACT

Background: The fixation of the tendon to the bone remains a challenging problem in the latissimus dorsi tendon transfer for irreparable cuff tears and can lead to unsatisfactory results. A new arthroscopic method of tendon to bone fixation using an interference screw has been developed and the purpose of this study was to compare its biomechanical properties to the ones of a standard fixation technique with anchors.
Methods: Six paired fresh frozen cadaveric human humeri were used. The freed latissimus dorsi tendon was randomly fixed to the humeral head with anchors or with interference screw after a tubularization procedure. Testing consisted to apply 200 cycles of tensile load on the latissimus dorsi tendon with maximal loads of 30 N and 60 N, followed by a load to failure test. The stiffness, displacements after cyclic loadings, ultimate load to failure, and site of failure were analysed.
Findings: The stiffness was statistically higher for the tendons fixed with interference screws than for the ones fixed with anchors for both 30 N and 60 N loadings. Likewise, the relative bone/tendon displacements after cyclic loadings were lower with interference screws compared to anchors. Load to failure revealed no statistical difference between the two techniques.
Interpretation: Compared to the standard anchor fixation, the interference screw fixation technique presents higher or similar biomechanical performance. These results should be completed by further biomechanical and clinical trials to confirm the interest of this new technique as an alternative in clinical use.

1. Introduction

Rotator cuff muscles are essential to shoulder function. Tears of rotator cuff tendons may happen for degenerative reasons or more rarely for trauma reasons. In case of failure of medical treatment after rotator cuff tears, surgical reinsertion of the tendon on humeral head may be proposed to restore shoulder function and decrease pain. In some cases, when reinsertion is not possible because of tendon retraction and muscle fatty degeneration, the tears become irreparable.

Latissimus dorsi transfer has been proposed for irreparable posterosuperior tears of the rotator cuff in symptomatic young and active patients (Gerber et al., 1988). The surgical principle is to transfer the humeral tendinous insertion of the latissimus dorsi muscle from the back of the diaphysis to the greater tuberosity of the humerus, trying to replace the function of the supraspinatus and/or the infraspinatus muscle.

Different techniques have been proposed to fix the latissimus dorsi tendon on to the greater tuberosity of the humerus. Gerber et al. (1988) and Warner and Parsons (2001) fixed it with transosseous sutures, while Habermeyer et al. (2006) and Millett et al. (2008) used classic anchors.

Since Gerber's original paper (Gerber et al., 1988), published clinical studies have usual good results but there remains up to 50% of fair and unsatisfactory results for latissimus dorsi transfer (Aoki et al., 1996; Birmingham and Neviaser, 2008; Codsi et al., 2007; Degreef et al., 2005; Gerber et al., 2006; Habermeyer et al., 2006; Irlenbusch et al., 2008; Miniaci and MacLeod, 1999; Moursy et al., 2009; Ozalay et al., 2005; Schoierer et al., 2001; Valenti et al., 2010). Unsatisfactory results may be due to poor tendon quality (Buijze et al., 2007), poor bone quality or poor fixation technique, and further investigations are needed to improve the results of this technique.

In addressing fixation quality, one of us (JK) developed a new fixation technique consisting of tubularization of the humeral insertion of the latissimus dorsi tendon and fixation of the tendon in the humeral head with an interference screw similar to anterior cruciate ligament (ACL) fixation (Kany et al., 2010). We currently perform this technique

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arthroscopically to prevent open approach through the deltoid which may be harmful specifically in multiple operated patients. We believe that this technique is easier to perform arthroscopically than the anchor technique, as there is no need to manipulate thin tendon and different anchors and sutures under arthroscopic control.

Before we advocate the arthroscopic assisted interference screw fixation technique of the latissimus dorsi transfer, we felt it was incumbent to prove that this fixation was as good if not superior to the gold standard of anchor fixation from a biomechanical point of view.

The purpose of this in vitro biomechanical study was to compare the stiffness, cyclic displacement and ultimate failure strength of two different methods of tendon to bone fixation: our interference screw fixation technique and the anchor fixation technique which is commonly reported in most published papers.

2. Methods

2.1. Specimen harvest and storage

Six paired fresh frozen cadaver humeri were harvested; the mean age was 62.7 (min 55–max 82); there were 4 women and 2 men. The humeri were dissected free of soft tissues except for the subscapularis tendon and the latissimus dorsi; the joint was visually inspected for an intact rotator cuff and no evidence of gleno-humeral arthrosis. Latissimus dorsi muscle was cut during harvesting at the level of the distal tip of the scapula with the humeral tendinous insertion preserved until day of testing. Humeri with attached latissimus dorsi were stored at −20 °C and allowed to thaw at 6 °C for 12 h prior to testing.

On the day of testing, one pair of specimen was randomised to either interference screw or anchor fixation.

2.2. Preparation of the latissimus dorsi muscle and tendon

Just after being defrosted, the latissimus dorsi was incised along the bone and prepared for fixation. Most of the muscle was removed from the underlying tendon. The muscle side of the tendon was wrapped into a gauze and fixed with N°6 Ethibond traction suture (Ethicon, Somerville, NJ) for fixation to the traction machine.

2.3. In vitro surgical technique

All the surgical procedures have been performed by the same surgeon (VKC) according to the implants and techniques designers' recommendations.

Interference screw fixation: the humeral tendinous insertion was tubularized with N° 3 Ethibond suture and calibrated with ACL calliper. A five millimetre diameter (usual diameter of the tubularized tendon) tunnel was drilled at the junction of middle and superior facets of the greater tuberosity of the humeral head close to the cartilage line (this point was defined as the reference insertion point). The tubularized tendon was passed into the tunnel with traction suture and fixed with a cone-shaped interference screw (GTS bioresorbable screw, 7 mm diameter, 30 mm length, Smith & Nephew, Andover, MA) (Fig. 1).

Anchor fixation technique: four Twinfix PK 6.5 mm (Smith & Nephew, Andover, MA) anchors were inserted into humeral head. The two superior anchors were 1 cm equidistant from the reference insertion point. The two inferior anchors were inserted laterally in the frontal plane 2 cm away from the superior ones. The humeral tendinous insertion was fixed with U type sutures and the proximal part of the tendon was oversewn to the subscapularis tendon with N° 0 Vicryl suture (Ethicon, Somerville, NJ).

2.4. Fixation of the specimen and loading

The distal half of the humerus was embedded in a custom made box with a low melting point alloy (MCP 70, Mining and Chemical Products Ltd., Wellingborough, England). This box allowed us to define and materialise the referential axis system relative to the humerus using a total of three V shaped pieces: two at the humeral epicondyles and the third at the humeral head. This referential system was used for the positioning of the humerus relative to the testing frame.

The embedded specimen was placed on an Instron testing machine (Instron, Norwood, MA) with the humeral shaft in a vertical position (Fig. 2). Tensile loads were applied on the muscle side of the tendon via cable and pulley. Using anthropometric data (DeLude et al., 1997; Le Corroller et al., 2009), we defined the direction of the retroversion axis at 36° off the plane passing through the medial and lateral epicondyles and the centre of the humeral head. The direction of load was in the plane of the superior facet of the greater tuberosity and in a plane perpendicular to the retroversion axis of the humeral head. It also passed through the reference insertion point and was in a cephalad direction, 6° from the horizontal plane.

Two kinds of tensile tests were performed. We first performed two successive cyclic non-destructive tests at 0.5 Hz: 200 cycles between 5 N and 30 N followed by 200 other cycles between 5 N and 60 N in two different loading procedures. At the beginning of each of these cyclic tests, a linear loading ramp was applied at 20 mm/min up to the maximal load (30 N or 60 N) for stiffness calculations. After the

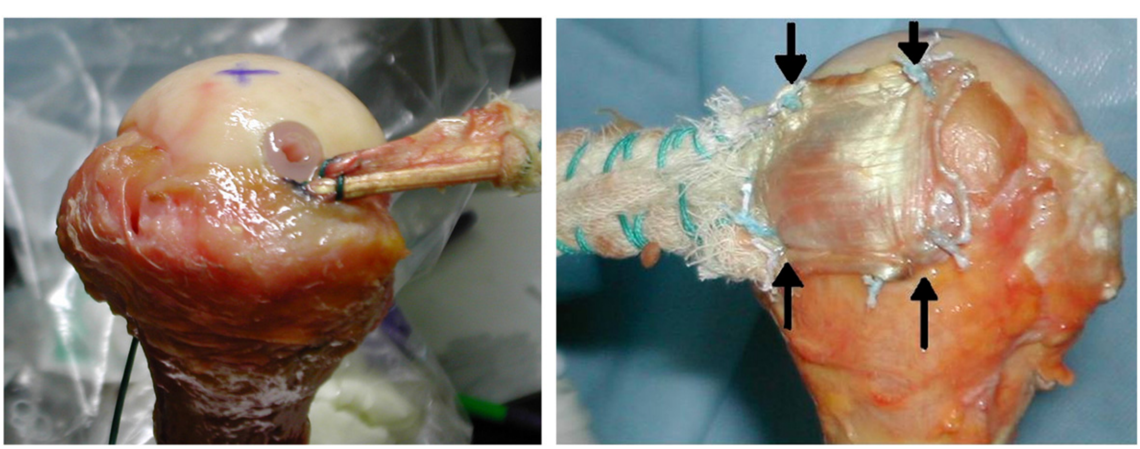

Fig. 1. Global view of the specimens after repair with the two techniques before testing: right (anchors fixation) and left (interference screw fixation).

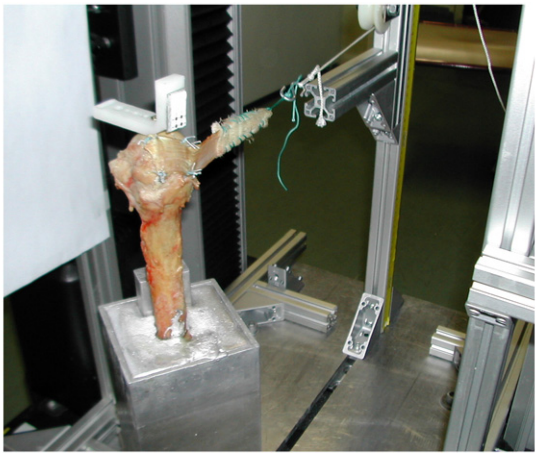

Fig. 2. Positioning of the specimen and direction of loading during the tests.

completion of these cyclic non-destructive tests, a load to failure test was performed at a 60 mm/min loading speed.

2.5. Measurements

During the different loadings, the applied load as well as the global displacement of the specimen was recorded allowing the drawing of global load-displacement curves.

We also optically measured the local displacement between the bone and the tendon near the insertion site. Landmarks were placed on the tendon close to the reference insertion point (at 3 to 5 mm) for the interference screw fixation technique and at 3 to 5 mm from the medial anchors, on the midline of the tendon for the anchor fixation technique (Fig. 3). Other landmarks were placed on a support fixed on the humeral head for calculation of relative displacements. The displacements were measured in the direction of loading using a video-camera and local load-displacement curves (Fig. 4) were obtained from which the stiffness of the fixation was calculated. The accuracy of these optical measurements was estimated at 0.1 mm (two pixels on images).

The mode of failure of the constructs was also analysed.

2.6. Data processing and statistical analysis

The following data were obtained from the local load-displacement curves:

- the stiffness of the fixation at the beginning of the 30 N cyclic loading, calculated between 10 and 30 N (slope of the linear regression curve);
- the stiffness of the fixation at the beginning of the 60 N cyclic loading, calculated between 10 and 60 N;
- the relative bone-tendon displacement at insertion area after 0, 50 100, 150 and 200 cycles, for 30 N and 60 N cyclic loadings;
- the load to failure (strength), defined as the maximal load value on the load-displacement curves during the load to failure test.

Wilcoxon signed-rank tests were used to compare these parameters between the two experimental groups (interference screw versus anchor fixation). A power analysis was also performed, given the small number of specimens (six pairs).

3. Results

The stiffness during the 30 N loading was significantly higher for interference screw fixation compared to anchor fixation (respectively 28.3 N/mm (SD 7.8 N/mm) and 17.8 N/mm (SD 3.3 N/mm), $P = 0.046$). Likewise, the stiffness for the 60 N loading was significantly higher for the screw fixation (79.3 N/mm (SD 20.3 N/mm) than for the anchor fixation (40.4 N/mm (SD 13.0 N/mm), with a P value of 0.002.

The relative bone-tendon displacement at insertion area after 0, 50, 100, 150 and 200 cycles, during both 30 N and 60 N loadings were lower for the screw fixation compared to those for the anchor fixation (Fig. 5). The differences were significant in all cases.

There was no significant difference in load to failure between the two techniques ($P = 0.589$), even if the mean value was higher with the screw fixation than with the anchor fixation: 252.4 N (SD 80.9 N) versus 227.4 N (SD 35.3 N).

All anchor fixed specimens failed by tendon tear at the tendon-anchors interfaces. None of the anchors pulled out. The mode of failure of the interference screw fixation technique varied: tendon pull out (three cases), tendon failure at the tendon-screw interface (one case), tendon cut through the bone (one case). No failure of the interference screw fixation was observed in one case where a failure of the fixation of tendon to the loading device occurred at 365 N.

4. Discussion

We compared in this in vitro cadaveric test, the biomechanical behaviour of a new arthroscopic method of tendon to bone fixation using an interference screw to the standard fixation with anchors in the latissimus dorsi tendon transfer for irreparable cuff tears. Both non destructive cyclic loads and monotonic load to failure were applied.

Under our testing conditions, the stiffness provided by the interference screw was statistically higher than the one provided by

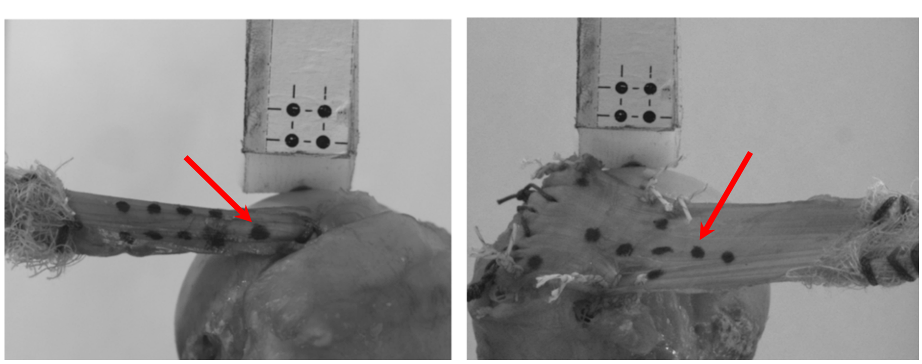

Fig. 3. Landmarks for optical measurement of the relative bone–tendon displacement near insertion area for the two techniques: right (anchors fixation) and left (interference screw fixation). The arrows indicate the landmark used for comparisons between the two techniques.

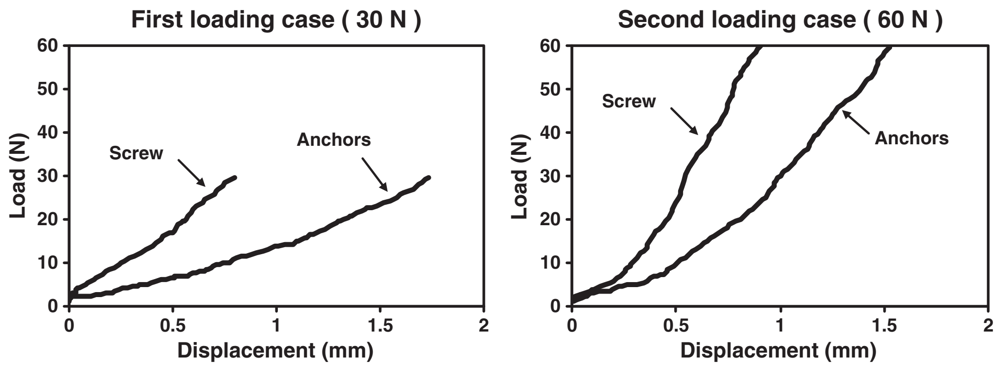

Fig. 4. Typical load vs relative bone–tendon displacement curves obtained during the initial loading ramp of the two different successive cyclic loading cases (30 N and then 60 N loading) for the two sides of one subject (an anchor fixation was used for one side and an interference screw was used for the other one).

the anchor fixation. Moreover, the relative bone/tendon displacements after cyclic loadings were statistically lower with interference screws compared to anchors. Load to failure revealed no statistical difference between the two techniques, even if it tends to be higher for the interference screw technique.

From these results, it can be concluded that the interference screw fixation technique has higher or at least comparable biomechanical performance than anchor fixation for fixation of tendon on greater tuberosity in latissimus dorsi transfer.

Many clinical series about latissimus dorsi transfer for irreparable cuff tears have been published with good results (Aoki et al., 1996; Birmingham and Neviaser, 2008; Degreef et al., 2005; Gerber et al., 2006; Habermeyer et al., 2006; Irlenbusch et al., 2008; Miniaci and MacLeod, 1999; Moursy et al., 2009; Nové-Josserand et al., 2009; Warner and Parsons, 2001; Valenti et al., 2010; Weening and Willems, 2010; Zafra et al., 2009). However unsatisfactory (fair or poor) results may rise as high as 50%, when latissimus dorsi is used as a secondary or salvage procedure, when subscapularis is non intact or with teres minor fatty infiltration (Costouros et al., 2007; Degreef et al., 2005; Gerber et al., 2006; Miniaci and MacLeod, 1999; Moursy et al., 2009; Nové-Josserand et al., 2009; Valenti et al., 2010; Warner and Parsons, 2001; Werner et al., 2006). It has not been proven that adding the teres major tendon to the latissimus dorsi tendon gives better results although a few authors advocate this technique (Boileau et al., 2007; Herzberg et al., 1999; Schoierer et al., 2001).

The arthroscopic fixation technique of the latissimus dorsi transferred tendon on the greater tuberosity has been described by Gervasi et al. (2007) and Millett et al. (2008). We are not aware of any clinical publication series of patients operated with an arthroscopic technique. Both authors rely on anchors for fixation of the tendon on the greater tuberosity. Millett et al. (2008) advocate allograft or Achilles tendon autograft in case of the latissimus dorsi being too short, and Gervasi et al. (2007) advocate avoiding full coverage of the greater tuberosity as “the tendon may be split by sutures”. Indeed, the latissimus dorsi tendon has been described anatomically as very thin: 1 mm in the anatomical study published by Buijze et al. (2007). Those two mechanisms, short tendon, and splitting of the tendon by the sutures may explain, in part, the failure rate in open surgery series and are also, in part, our explanation of our personal failures in our experience of this surgery before adopting our current arthroscopic technique (Kany et al., 2010).

Moursy et al. (2009) advocate harvesting the tendon with a small piece of humeral bone and improved significantly their results with 10% failure rate compared to 27% failure rate with their previous technique where the tendon was classically harvested without bone. They assume the rupture of the transferred tendon – fixed without bone chip – to be responsible for a substantial number of the reported unsatisfactory results in the literature. Confirming our own clinical experience, they often found the tendon to be thin and insubstantial. To our knowledge, it is the only reported technical modification which seems to decrease the failure rate. However, this was not a randomised comparative study and there could be a bias with the learning curve of the initial technique explaining part of the better results of the second technique.

To address these questions, we developed a new fixation technique consisting of tubularization of the humeral insertion of the latissimus dorsi tendon and fixation of the tendon in the humeral head with an interference screw similar to anterior cruciate ligament (ACL) fixation (Kany et al., 2010). We currently perform this technique arthroscopically. Using a tubularized tendon and an interference screw fixation may prevent bad fixation with too short or too thin tendons and splitting of the tendon by the anchor sutures. Moreover, a tubularized tendon is – in

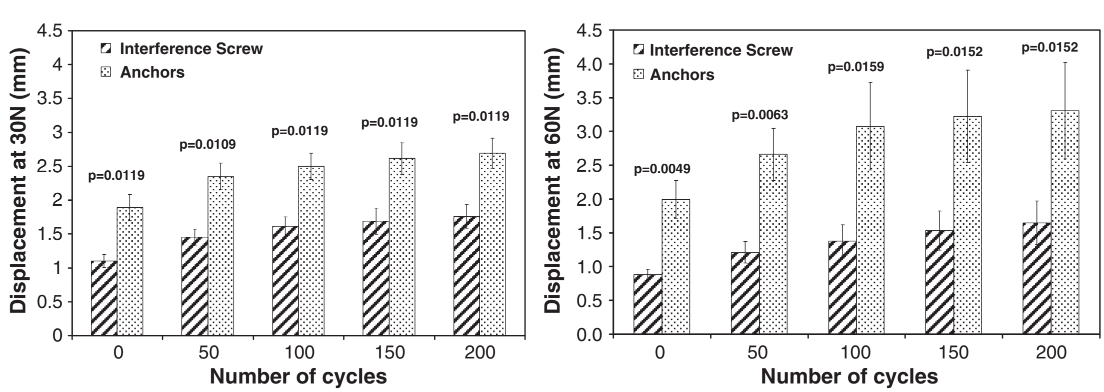

Fig. 5. Relative bone–tendon displacement near insertion area after 0, 50, 100, 150 and 200 cycles, for the two different successive cyclic loading cases: 30 N and then 60 N cyclic loads (mean values and standard deviations). The p values of the Wilcoxon signed-rank tests comparing the two techniques are also presented.

our hands – easier to manipulate and transfer under arthroscopic control with no risks of tendon damage and no complex manipulation of different anchor sutures.

The present in vitro study aimed to assess the biomechanical properties of this fixation technique compared to the usual anchor fixation. Our results support this new technique as being an alternative to anchor fixation, regarding the quality of the fixation.

We only found two in vitro biomechanical studies on latissimus dorsi transfer (Aoki et al., 1997; Werner et al., 2006). Werner et al. (2006) however, focused on the biomechanical role of the subscapularis tendon and did not analyse the fixation technique of the latissimus dorsi tendon. Aoki et al. (1997) analysed the effect of a Teflon felt augmentation on the strength and the stiffness of a four horizontal mattress sutures fixation used to attach the end of the latissimus dorsi on the greater tuberosity. They found that the tensile strength was significantly improved after augmentation. Nevertheless, the interference screw and anchor fixations were not involved.

We found many studies comparing the mechanical behaviour of interference screw and anchor fixations, but they addressed the tenodesis of the long head of the biceps or the distal biceps brachii tendon repair (Golish et al., 2008; Krushinski et al., 2006; Kusma et al., 2008; Mazzocca et al., 2005; Ozalay et al., 2005; Richards and Burkhart, 2005).

We used the data from these studies and from the one of Aoki et al. (1997) to find suitable loading parameters (loads, number of cycles, frequencies of cyclic testing, loading to failure speed), as there are no other similar studies in literature.

When comparing the interference screw and anchor fixations repairs, even if the tested screws and anchors varied, these studies generally concluded to a superiority of the interference screw technique in terms of strength (load to failure), stiffness or displacements. Nevertheless, the differences were not always statistically significant. The same trend was observed in the present study. Reduced displacement at bone tendon interface and increased stiffness or strength are assumed to promote the healing process, but this process is also affected by other mechanical parameters such as contact surface or pressure (Grimberg et al., 2010) and by biological factors (Nourissat et al., 2010).

We found differences between the two techniques regarding the mode of failure. All anchor fixed specimens failed by tendon tear at the tendon-anchors interfaces and none of the anchors pulled out. The mode of failure of the interference screw fixation technique was more variable and included tendon pull out, tendon failure at the tendon-screw interface, tendon cut through the bone. The weakest element in the anchor constructs was the tendon itself and not the anchors fixation into the bone or the sutures. This is in agreement with the above discussions about the latissimus dorsi tendon anatomy. The mode of failure of the interference screw can be affected by several parameters as the bone quality, the diameter of the hole drilled in the bone (5 mm in our case for all specimens), the diameter of the tubularized tendon, the diameter of the screw (7 mm cone-shaped for all specimens). Due to the small number of specimens, the relative influence of these different parameters could not be analysed.

The positions of the landmarks used for the optical measurement of the relative displacement between the bone and the tendon near the insertion site could affect the data. For the interference screw fixation technique, we choose to analyse the displacements of a landmark placed on the tendon close to the reference insertion point (at 3 to 5 mm from the screw). For the anchor fixation, the analysed landmark was at 3 to 5 mm from the medial anchors, on the midline of the tendon. These two landmarks can be considered as equivalent if we define the insertion area as the box delimited by the four anchors in anchor fixation technique.

The great differences in stiffness between the 30 N and 60 N loadings can be explained by two facts. First, the load-displacement curves were non-linear (Fig. 4) and the stiffness was generally higher for higher loads. Secondly, the 30 N and 60 N stiffness corresponded to two different successive loadings (30 N and then 60 N). The behaviour of the bone-tendon construct could have been modified by the first 30 N loading. In particular, the existing micro-gaps or mismatch in the bone-tendon fixation could have been suppressed after the first loading. Hence, it is not relevant to compare the stiffness for 30 N and 60 N loading cases for a given technique, but it is relevant to compare the stiffness of the two techniques for a given loading case.

For the insertion of the interference screw, we used a point at the junction of middle and inferior facet of the greater tuberosity that we currently use in the patients. This point is not too close to the edge of the greater tuberosity in order to have enough bone for tunnel drilling and interference screw placement. The posterosuperior placement allows to pass a traction guide through the tunnel and anterior cortex of the humerus (Kany et al., 2010).

Anatomical study by Schoierer et al. (2001) is in favour of placement of the tendon on the middle and inferior facet of the greater tuberosity at the infraspinatus insertion site in order to get better active external rotation. This technical point is also advocated by Boileau et al. (2007) when transferring both latissimus dorsi and teres major to the lateral aspect of the humerus with or without reversed prosthesis.

Habermeyer et al. (2006) conducted a clinical study with an open single incision study allowing fixation of the latissimus dorsi tendon on the infraspinatus insertion site. They had overall 77% of good results but they did not compare their site of fixation with the superior facet fixation site.

Magermans et al. (2004a, 2004b) conducted a biomechanical finite element study where it seemed that transfer to the supraspinatus insertion site was the best option to restore external rotation and anterior elevation moment arm.

All other authors use Gerber's initial technique with fixation of the latissimus dorsi tendon to the superior facet of the greater tuberosity with anchors or transosseous sutures, attachment to the subscapularis and sometimes to the remaining supra and infraspinatus stump when possible. We then tried to reproduce coverage of the greater tuberosity for the anchor technique, as advocated by Gerber et al. (1988).

The present study has some limitations. It only can address the immediate post operative biomechanical properties of the tested fixation techniques. The long term behaviour of the fixations, affected by many other factors, cannot be predicted by this study alone. In particular, there was no biological comparison of bone tendon healing with these two methods. Moreover even if the applied loads were realistic in terms of direction and magnitude (peak of 60 N for non destructive cyclic tests), they were not able to reproduce the actual complex in vivo situation.

The number of tested cadaveric specimens was limited to six pairs (right and left sides of the same subjects). For each subject, one side was randomly tested with one of the fixation techniques. This paired aspect of the comparisons increased the power of the statistical tests, allowing us to detect statistical differences between the two techniques for all but two mechanical parameters. The only parameter for which the difference was not statistically significant was the failure load ($p = 0.589$), with a post hoc power of 0.089 indicating a high risk type II error i.e. failing to detect a significant difference even though it exists.

5. Conclusion

Compared to the standard anchor fixation technique, the arthroscopic interference screw fixation technique presents higher or similar biomechanical performance – in terms of stiffness, cyclic displacements, load to failure – under the testing conditions and within the limits of these in vitro experiments.

The interference screw technique easier to perform arthroscopically in our experience and the tubularization of the latissimus dorsi tendon may address any kind of tendon even the thinnest ones, which may not be the case for anchor fixation technique.

These combined surgical and biomechanical advantages make this technique an interesting alternative to anchor fixation in latissimus dorsi transfer.

Our results should be completed by further biomechanical and clinical trials to confirm the interest of this new technique in clinical use. A multicenter clinical study is currently conducted to evaluate long term clinical results of this interference screw fixation.

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References

Aoki, M., Okamura, K., Fukushima, S., Takahashi, T., Ogino, T., 1996. Transfer of the latissimus dorsi for irreparable rotator cuff tears. J. Bone Joint Surg. Br. 78, 761–766.
Aoki, M., Fukushima, S., Okamura, K., 1997. Mechanical strength of latissimus dorsi tendon transfer with Teflon felt augmentation. J. Shoulder Elbow Surg. 6, 137–143.
Birmingham, P.M., Neviaser, R.J., 2008. Outcome of latissimus dorsi transfer as a salvage procedure for failed rotator repair with loss of elevation. J. Shoulder Elbow Surg. 17, 871–874.
Boileau, P., Chuinard, C., Roussanne, Y., Neyton, L., Trojani, C., 2007. Modified latissimus dorsi and teres major transfer through a single delto-pectoral approach for external rotation deficit of the shoulder: as an isolated procedure or with a reverse arthroplasty. J. Shoulder Elbow Surg. 16, 671–682.
Buijze, G.A., Keereweer, S., Jennings, G., Vorster, W., Debeer, J., 2007. Musculotendinous transfer as a treatment option for irreparable posterosuperior rotator cuff tears: teres major or latissimus dorsi? Clin. Anat. 20, 919–923.
Codsi, M.J., Hennigan, S., Herzog, R., Kella, S., Kelley, M., Leggin, B., et al., 2007. Latissimus dorsi tendon transfer for irreparable posterosuperior rotator cuff tears. Surgical technique. J. Bone Joint Surg. Am. 89 (Suppl. 2), 1–9.
Costouros, J.G., Espinosa, N., Schmid, M.R., Gerber, C., 2007. Teres minor integrity predicts outcome of latissimus dorsi tendon transfer for irreparable cuff tears. J. Shoulder Elbow Surg. 16, 727–734.
Degreef, I., Debeer, P., Van Herck, B., Van Den Eeden, E., Peers, K., De Smet, L., 2005. Treatment of irreparable rotator cuff tears by latissimus dorsi muscle transfer. Acta Orthop. Belg. 71, 667–671.
DeLude, J.A., Bicknell, R.T., MacKenzie, G.A., Ferreira, L.M., Dunning, C.E., King, G.J.W., et al., 1997. An anthropometric study of the bilateral anatomy of the humerus. J. Shoulder Elbow Surg. 16, 477–483.
Gerber, C., Vinh, T.S., Hertel, R., Hess, C.W., 1988. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. A preliminary report. Clin. Orthop. 232, 51–56.
Gerber, C., Maquieira, G., Espinosa, N., 2006. Latissimus dorsi transfer for the treatment of irreparable rotator cuff tears. J. Bone Joint Surg. Am. 88, 113–120.
Gervasi, E., Causero, A., Parodi, P.C., Raimondo, D., Tancredi, G., 2007. Arthroscopic latissimus dorsi transfer. Technical note. Arthroscopy 23, 1243.
Golish, S.R., Caldwell III, P.E., Miller, M.D., Singanamala, N., Ranawat, A.S., Treme, G., et al., 2008. Interference screw versus suture anchor fixation for subpectoral tenodesis of the proximal biceps tendon: a cadaveric study. Arthroscopy 24, 1103–1108.
Grimberg, J., Diop, A., Kalra, K., Charousset, C., Duranthon, L.-D., Maurel, N., 2010. In vitro biomechanical comparison of three different types of single and double row arthroscopic rotator cuff repairs: analysis of continuous bone–tendon contact pressure and surface during different simulated joint positions. J. Shoulder Elbow Surg. 19, 236–243.
Habermeyer, P., Magosch, P., Rudolph, T., Lichtenberg, S., Liem, D., 2006. Transfer of the tendon of latissimus dorsi for the treatment of massive tears of the rotator cuff: a new single-incision technique. J. Bone Joint Surg. Br. 88, 208–212.
Herzberg, G., Urien, J.P., Dimnet, J., 1999. Potential excursion and relative tension of muscles in the shoulder girdle: relevance to tendon transfer. J. Shoulder Elbow Surg. 8, 430.
Irlenbusch, U., Bracht, M., Gansen, H.K., Lorenz, U., Thiel, J., 2008. Latissimus dorsi transfer for irreparable rotator cuff tears: a longitudinal study. J. Shoulder Elbow Surg. 17, 527–534.
Kany, J., Kumar, H.A., Chang, V.K., Grimberg, J., Garret, J., Valenti, P., 2010. Mini invasive axillary approach and arthroscopic humeral head interference screw fixation for latissimus dorsi transfer in massive and irreparable posterosuperior rotator cuff tears. Techn. Shoulder Elbow Surg. 11, 8–14.
Krushinski, E.M., Brown, J.A., Murthi, A.M., 2006. Distal biceps tendon rupture: biomechanical analysis of repair strength of the Bio-Tenodesis screw versus suture anchors. J. Shoulder Elbow Surg. 16, 218–223.
Kusma, M., Dienst, M., Eckert, J., Steimer, O., Kohn, D., 2008. Tenodesis of the long head of biceps brachii: cyclic testing of five method fixation in a porcine model. J. Shoulder Elbow Surg. 17, 967–973.
Le Corroller, T., Aswad, R., Pauly, V., Champsaur, P., 2009. Orientation of the rotator cuff insertion facets on the humerus: comparison between individuals with intact and torn rotator cuffs. Ann. Anat. 191, 218–224.
Magermans, D.J., Chadwick, E.K.J., Veeger, H.E.J., Rozing, P.M., Van der Helm, F.C.T., 2004a. Effectiveness of tendon transfers for massive rotator cuff tears: a simulation study. Clin. Biomech. 19, 116–122.
Magermans, D.J., Chadwick, E.K.J., Veeger, H.E.J., Rozing, P.M., Van der Helm, F.C.T., 2004b. Biomechanical analysis of tendon transfers for massive rotator cuff tears. Clin. Biomech. 19, 350–357.
Mazzocca, A.D., Bicos, J., Santangelo, S., Romeo, A.A., Arciero, R.E., 2005. The biomechanical evaluation of four fixation techniques for proximal biceps tenodesis. Arthroscopy 21, 1296–1306.
Millett, P.J., Yen, Y.M., Huang, M.J., 2008. Arthroscopically assisted latissimus dorsi transfer for irreparable rotator cuff tears. Techn. Shoulder Elbow Surg. 9, 76–79.
Miniaci, A., MacLeod, M., 1999. Transfer of the latissimus dorsi muscle after failed repair of a massive tear of the rotator cuff. A two to five-year review. J. Bone Joint Surg. Am. 81, 1120–1127.
Moursy, M., Forstner, R., Koller, H., Resch, H., Tauber, M., 2009. Latissimus dorsi tendon transfer for irreparable rotator cuff tears: a modified technique to improve tendon transfer integrity. J. Bone Joint Surg. Am. 91, 1924–1931.
Nourissat, G., Diop, A., Maurel, N., Salvat, C., Dumont, S., Pigenet, A., et al., 2010. Mesenchymal stem cell therapy regenerates the native bone–tendon junction after surgical repair in a degenerative rat model. PloS One 5, e12248.
Nové-Josserand, L., Costa, P., Liotard, J.P., Safar, J.F., Walch, G., Zilber, S., 2009. Results of latissimus dorsi tendon transfer for irreparable cuff tears. Orthop. Traumatol. Surg. Res. 95, 108–113.
Ozalay, M., Akpinar, S., Karaeminogullari, O., Balcik, C., Tasci, A., Tandogan, R.N., et al., 2005. Mechanical strength of four different biceps tenodesis techniques. Arthroscopy 21, 992–998.
Richards, D.P., Burkhart, S.S., 2005. A biomechanical analysis of two biceps tenodesis fixation techniques. Arthroscopy 21, 861–866.
Schoierer, O., Herzberg, G., Berthonnaud, E., 2001. Anatomical basis of latissimus dorsi and teres major transfers in rotator cuff tears surgery with particular reference to the neurovascular pedicles. Surg. Radiol. Anat. 23, 75–80.
Valenti, P., Kalouche, I., Diaz, L.C., Kaouar, A., Kilinc, A., 2010. Results of latissimus dorsi tendon transfer in primary or salvage reconstruction of irreparable rotator cuff tears. Orthop. Traumatol. Surg. Res. 96, 133–138.
Warner, J.J.P., Parsons, I.M., 2001. Latissimus dorsi tendon transfer: a comparative analysis of primary and salvage reconstruction of massive, irreparable rotator cuff tears. J. Shoulder Elbow Surg. 10, 514–521.
Weening, A.A., Willems, W.J., 2010. Latissimus dorsi transfer for treatment of irreparable rotator cuff tears. Int. Orthop. 34, 1239–1244.
Werner, C.M.L., Zingg, P.O., Lie, D., Jacob, H.A.C., Gerber, C., 2006. The biomechanical role of the subscapularis in latissimus dorsi transfer for the treatment of irreparable rotator cuff tears. J. Shoulder Elbow Surg. 5, 736–742.
Zafra, M., Carpintero, P., Carrasco, C., 2009. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. Int. Orthop. 33, 457–462.