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Autologous bridging of rotator cuff tears with a hamstring tendon patch. A cadaver feasibility study and biomechanical testing☆,☆☆,☆☆☆

Jörn Kircher[a,e,*], Felix Schmidt[b], Thelonius Hawellek[c], Jan Hubert[c], Achim Hedtmann[a], Klaus Püschel[d], Michael Hahn[b], Andreas Niemeier[c]

[a] ATOS Klinik Fleetinsel Hamburg, Department of Shoulder and Elbow Surgery, Admiralitätstrasse 3-4, 20459 Hamburg, Germany
[b] Institute of Biomechanics, University Hospital Hamburg-Eppendorf, Lottestrasse 59, 22529 Hamburg, Germany
[c] Department of Orthopaedics, University Hospital Hamburg-Eppendorf, Eppendorfer Landstrasse 60, 20249 Hamburg, Germany
[d] Department of Legal Medicine, University Hospital Hamburg-Eppendorf, Butenfeld 34, 22529 Hamburg, Germany
[e] Department of Orthopaedics, University Hospital, Medical Faculty, Heinrich-Heine-University Düsseldorf, Moorenstr. 5, 40255 Düsseldorf, Germany

1. Introduction

Rotator cuff tendon tears (RCT) are a prevalent condition that affects the elderly population, which results in a high socioeconomic burden. Small and mid-sized tendon tears can be treated surgically by rotator cuff repair (RCR) with a high success rate in regard to improvement of symptoms and shoulder function. Improved surgical technique over time lead to re-tear rates for small and medium size tears that are rarely above 10–20% (Chona et al., 2017). Surgical repair of large and massive RCTs is challenging and results are less predictable: re-tear rates after large and massive RCT reconstructions range from 3.3% up to 94% in clinical studies (Bigliani et al., 1992; Bishop et al., 2006; Chung et al., 2013; Galatz et al., 2004; Gerber et al., 2000; Hanusch et al., 2009; Henry et al., 2015; Kim et al., 2012; Papadopoulos et al., 2011; Yamaguchi et al., 2011; Zumstein et al., 2008). (Table 1) Chronic tendon tears and failed RCR often display a central tendon defect that cannot successfully be covered by the remaining cuff tendon tissue. Partial repair with or without a so-called interval slide, tendon transfers such as the latissimus dorsi transfer and the use of allogenic patches for bridging (Bond et al., 2008; Gupta et al., 2013; Mori et al., 2013; Wong et al., 2010) or augmentation (Barber et al., 2012; Ciampi et al., 2014; Encalada-Diaz et al., 2011; Giannotti et al., 2014; Proctor, 2014) are treatment options in such situations. None of these has proven to be a universally applicable and reliable procedure.

Since all extracellular matrices are likely to induce some form of resorption process and inflammatory response (Iannotti et al., 2006; Walton et al., 2007) autologous tissue is unlikely to do so. Additionally the ideal patch material would be capable of transmitting physiological loads and would thereby allow early rehabilitation, would reduce the risk of graft failure and would serve as an inductive template during graft remodelling (Ricchetti et al., 2012).

The purpose of this study was to test, whether autologous hamstring tendons (Semitendinosus ST, Gracilis GR) can be used to produce a (1) large enough and (2) strong enough patch for bridging of iRCT's.

2. Materials and methods

Hamstring tendons were harvested from fresh human cadavers through a vertical approach at the proximal tibia using a tendon stripper in a similar technique as established for cruciate ligament reconstruction. Fascia and muscle tissue was carefully removed from harvested tendons and the tendons were labelled and stored at −72 °C until further processing. The study was approved by the ethical committee of the Medical Association in Hamburg ("Ärztekammer Hamburg"); all legal and ethical issues were taken into consideration. (Püschel, 2016)

For this test series a randomly chosen number of $n = 10$ hamstring tendon grafts were used from a pool out of $n = 50$ tendons. The mean age of the patients was 61 (44–84) (3 females), mean height 179.3 cm (160–195), mean weight 96.6 kg (72–149) and a mean BMI 30.4 (20–50).

The tendons were defrosted and kept wet with saline solution during the entire process of patch preparation. Each hamstring tendon was separately processed and divided longitudinally into two equal tendon stripes. Each tendon stripe was armed with a running interlocking stitch (Krackow) of 2 cm at both ends with #2 FibreWire (Arthrex, Naples, FL). A quadrangular frame of about 4 cm side lengths was created on a custom made workbench and the first tendon stripe was passed around two opposite suture sides in a vertical fashion (Fig. 1A). Both ends were tied to the frame on opposite corners for

☆ The study was approval by the local ethics committee of the University of Hamburg.
☆☆ All authors have read and approved the final submitted manuscript. They warrant that the article is the authors' original work, hasn't received prior publication and isn't under consideration for publication elsewhere.
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* Corresponding author at: ATOS Klinik Fleetinsel Hamburg, Department of Shoulder and Elbow Surgery, Admiralitätstr. 3-4, 20459 Hamburg, Germany.
E-mail address: j-kircher@web.de (J. Kircher).

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Table 1
Retear rate after rotator cuff repair for large and massive RCT. *: 38% for open reconstruction and 76% for arthroscopic RCR.

	Re-tear-rate %
Bigliani et al. 1992 (Bigliani et al., 1992)	3
Gerber et al. 2000 (Gerber et al., 2000)	41
Galatz et al. 2004 (Galatz et al., 2004)	94
Bishop et al. 2006 (Bishop et al., 2006)	38/76*
Zumstein et al. 2008 (Zumstein et al., 2008)	57
Hanusch et al. 2009 (Hanusch et al., 2009)	17
Yamaguchi et al. 2011 (Yamaguchi et al., 2011)	9
Papadopoulos et al. 2011 (Papadopoulos et al., 2011)	52
Kim et al. 2012 (Kim et al., 2012)	42
Chung et al. 2013 (Chung et al., 2013)	39

initial stabilization. The second tendon stripe was horizontally passed in an up and down fashion through the existing vertical tendon strands in a weaving technique, finally resulting in tendon patch. Both suture ends of the second tendon stripe were also tied to the frame on opposite corners for initial stabilization. Using #2 FibreWire (Arthrex, Naples, FL), all four sides of the patch were sutured to pieces of a polypropylene belt (about 4x6cm) with a running Krackow-stitch to create a stable construct to be mounted into the testing frame (Fig. 1A). The polypropylene belt was found to be the ideal material in a pretesting series with a negligible elongation under the given testing variables. After completion of the assembly each patch was labelled in a blinded manner and stored again at −72 °C until final testing.

For the testing a number of $n = 10$ patches were randomly selected ($n = 2$ GR and $n = 8$ ST). Each of the four sides was mounted into a quadrangular metal tube, manually pretensioned and secured at the side with metal bars under direct compression of M6 metal screws. (Fig. 1B) The testing was performed under continuous expansion (10 mm/min) after pretensioning with 10 N in a material testing machine (Zwick/Roell, Ulm, Germany) until failure. To mimic resulting forces from the humeral head in vivo the load was transmitted via a 44 mm Cobalt-Chromium ball at the centre of the patch (Fig. 1C). The maximum force and resulting tension were measured.

3. Results

The mean maximum force until failure was 1481.3 N (850.6–1901.9) and the mean tension was 1.54 N/mm^2 (0.9–2.0). (Figs. 2 and 3).

ST and GR patches were comparable in maximum force and tension. The main mode of failure was the pull-out of the polypropylene belt from the testing apparatus.

4. Discussion

Here we describe that autologous woven tendon (ST or GR) patches from ten post-mortem donors withstand elongation forces and tension in the order of magnitude as they occur in vivo. Only one clinical study by Mori et al. has previously described the bridging of massive RCT with autologous tissue (Mori et al., 2013). The authors used fascia lata as a graft in $n = 24$ patients (group A) in a retrospective comparative study to fill the gap between the intact inferior parts of the posterosuperior rotator cuff and the intact subscapularis in the front by arthroscopic patch grafting and compared the radiological and clinical results with $n = 24$ patients who underwent arthroscopic partial repair (group B). Both groups in their study were comparable in all demographic and preoperative baseline characteristics (such as tear size). Radiological and clinical results were favourable in the autologous patch group. Two shoulders (8.3%) had re-tears of the infraspinatus tendon (ISP) and three (12.5%) had graft tears resulting in an overall re-tear rate of 20.8% in group A, which is in contrast to 10 (41.7%) of re-tears of the repaired ISP and SSP in group B. Also functional scores

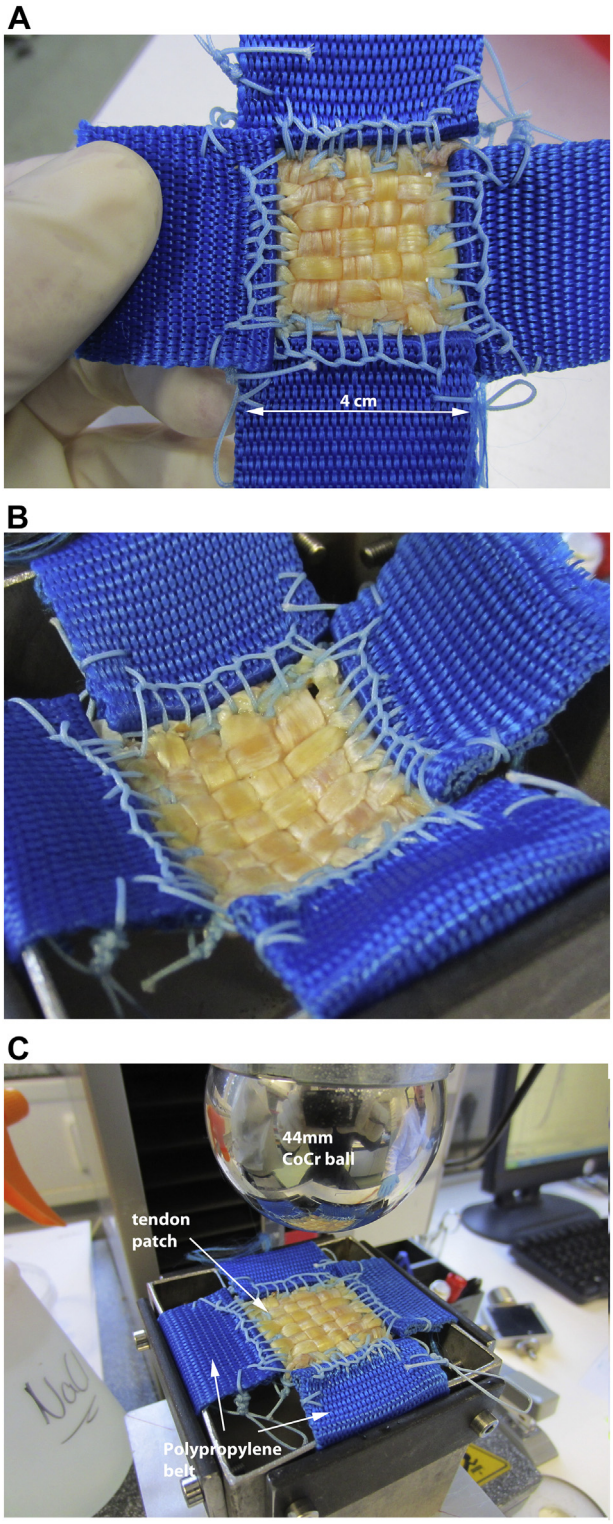

Fig. 1. Semitendinosus-Patch (patch No. 10 in Fig. 3) before testing (A) and after application of load to failure (B) (force 1380.0 N; tension 1.4 N/mm^2). The patch is sutured to a polypropylene belt on all four sides for fixation in the testing apparatus. The patch is vertically loaded with a 44 mm Cobalt-Chromium ball (C).

(Constant score, ASES score), pain and range of motion and muscle strength were significantly better in group A. Furthermore the authors observed a significantly better result for all clinical parameters (except forward flexion) for patients without ISP re-tear.

Successful bridging of the cuff defect was reported by two other