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Proximal humerus reconstruction in reverse total shoulder arthroplasty with proximal humeral bone loss using a lower trapezius tendon transfer with Achilles tendon-bone allograft: surgical technique and report of 2 cases

Franziska Eckers, MD, MA[a,b,*], Bettina Hochreiter, MD[a,c], Sarah Forsyth, M Physio, B BiomedSc[a,d], Eugene T. Ek, MBBS, PhD, FRACS[a,e]

[a]Melbourne Orthopaedic Group, Melbourne, Australia
[b]Department of Orthopedics and Traumatology, University Hospital Basel, Basel, Switzerland
[c]Department of Orthopedics, Balgrist University Hospital, Zurich, Switzerland
[d]Melbourne Shoulder Group, Melbourne, Australia
[e]Department of Surgery, Monash University, Melbourne, Australia

A R T I C L E I N F O

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Tendon transfer
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Proximal humeral bone loss (PHBL) in reverse total shoulder arthroplasty (RTSA) is associated with comparatively higher complication rates and inferior clinical outcomes, which is largely due to deficient soft tissue attachments, specifically the rotator cuff, affecting both function and prosthetic stability, as well as constituting a risk for infection.[5,7,36,38] Current RTSA designs offer a variety of options that assist surgeons in attaining prosthetic stability and adequate deltoid tensioning, even in such difficult situations Moreover, the use of allograft-prosthesic composites (APCs),[22,24] cortical strut grafts,[11,26] or megaprostheses[25,28] has been proposed to address PHBL, with satisfactory results regarding active forward elevation and abduction.[7,8] However, in deficiency of the posterior rotator cuff, in particular teres minor, restoration of active external rotation (ER) remains unpredictable.[12,6,31,20,40]

The most established techniques to address loss of ER in RTSA are the latissimus dorsi transfer[18] and, similarly, the l'Episcopo procedure.[4] Both require tendon integrity to allow for harvesting of a robust tendon, as well as sufficient bone stock to allow for tendon fixation. However, these factors are often compromised in the setting of PHBL, especially with revision surgery.

Here we present a new operative technique for restoration of active ER in patients with RTSA and PHBL, including a report of 2 cases. The technique comprises a modification of the lower trapezius transfer (LTT) which was previously described for treatment of irreparable posterosuperior rotator cuff tears.[15] Using an Achilles tendon allograft with its calcaneal insertion as an intercalary graft, this new procedure delivers a substitute for the posterior rotator cuff and the greater tuberosity.

Case reports

History case 1

A 55-year-old male presented 6 weeks after sustaining a posterior fracture dislocation of his left shoulder (Fig. 1, *a*) which had been managed by open reduction and internal fixation (ORIF). Assessment revealed persistence of the posterior dislocation and inadequate fracture reduction (Fig. 1, *b* and *c*). Closed and subsequently open reduction was attempted but failed. A fragmented

Institutional review board approval was not required for this case report.

*Corresponding author: Franziska Eckers, MD, MA, Department of Orthopedics and Traumatology, University Hospital Basel, Spitalstrasse 21, Basel 4031, Switzerland.

E-mail address: franziska.eckers@gmail.com (F. Eckers).

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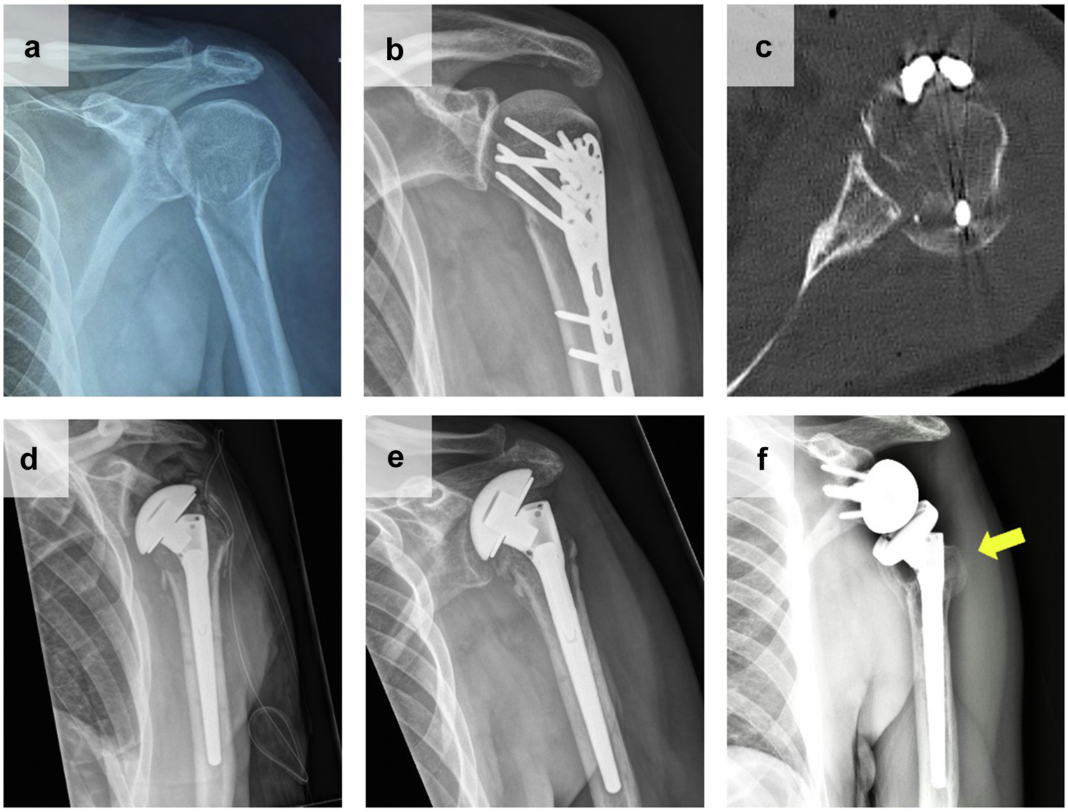

Figure 1 (**a**-**f**) Case 1, imaging studies. (**a**) Initial radiograph demonstrating a posterior fracture dislocation of the left shoulder. (**b**) and (**c**) Persistence or recurrence of a posterior glenohumeral dislocation and malreduction of the fragments after ORIF. (**d**) Postoperative radiograph after revision to hemiarthroplasty with reconstruction of the tuberosities. (**e**) Six-month radiograph after hemiarthroplasty demonstrating fragmentation, dislocation and partial resorption of the greater tuberosity and superior migration of the humeral head. (**f**) One-year radiograph after conversion to RTSA and LTT+. The yellow arrow indicates the calcaneal bone block which appears united with the proximal body of the prosthesis and the humeral shaft. *ORIF*, open reduction and internal fixation; *LTT*, lower trapezius transfer; *RTSA*, reverse total shoulder arthroplasty.

greater tuberosity and an osteopenic humeral head with malpositioning of the nonunited fragments were observed. A revision ORIF was deemed futile and hemiarthroplasty with a convertible revision stem and a pyrocarbon head (Tornier HRS and Flex, Stryker, Kalamazoo, MI, USA) was performed, along with reconstruction of the tuberosities (Fig. 1, *d*). However, during the postoperative course, the patient failed to functionally improve. He exhibited pseudoparalysis,[1,16] limited active ER and an ER lag, with resultant poor spatial control of his upper limb. Imaging studies showed fragmentation and resorption of the greater tuberosity, with bone deficiency of approximately 37 mm and superior humeral head migration indicating rotator cuff failure (Fig. 1, *e*). Conversion to RTSA combined with a lower trapezius transfer with bone block (LTT+) was decided and performed as described below.

History case 2

A 57-year-old female with a complex medical and psychiatric history was referred 2 years after sustaining a right proximal humeral fracture (Fig. 2, *a*), initially treated by an ORIF (Fig. 2, *b*), and subsequently complicated by avascular necrosis. She had undergone implant removal and arthrolysis (Fig. 2, *c* and *d*), followed by conversion to a RTSA (Trabecular Metal humerus, Comprehensive glenoid; Zimmer Biomet, Warsaw, IN, USA). The most pertinent clinical finding was marked weakness of ER with a significant ER lag and positive Hornblower's sign. Fig. 2, *e* represents the corresponding radiograph with deficiency of the greater tuberosity and the adjacent humeral cortex measuring approximately 45 mm. Reconstruction with an LTT+ was indicated. Of note, intraoperatively the latissimus dorsi tendon insertion was not present, most likely disrupted from the previous surgery.

Surgical technique

The operation is performed in the beach chair position (~60°), such that the upper part of the operating table is flush with the patient's spine. The anatomic landmarks and skin incisions are marked. The upper limb is disinfected and draped, and the forearm is secured in an arm holder. Anteriorly, access for a deltopectoral approach, and, posteriorly, access for detachment and release of the LT tendon are needed (Fig. 3).

The LTT + can be applied in both the primary and revision arthroplasty setting. The RTSA technique is dictated by the individual clinical scenario and is subject to surgeon preference. With regard to the humeral implant, it is our preference to use a fracture or revision stem with diaphyseal press-fit or cement fixation, a slim metaphyseal geometry that can later be "wrapped" by the bone-graft, and surface coating (i.e., Hydroxyapatite or Titanium plasma spray coating) that enables osseointegration.[39]

Lower trapezius (LT) tendon harvest

As previously described,[14] a 10-cm to 15-cm long oblique incision across the scapular spine towards the medial boarder of the scapula is performed (Fig. 3). The LT, which originates from T2 to T10 and converges to an approximately 5-cm long tendon inserting on the dorsal scapular spine tubercle,[29] is identified

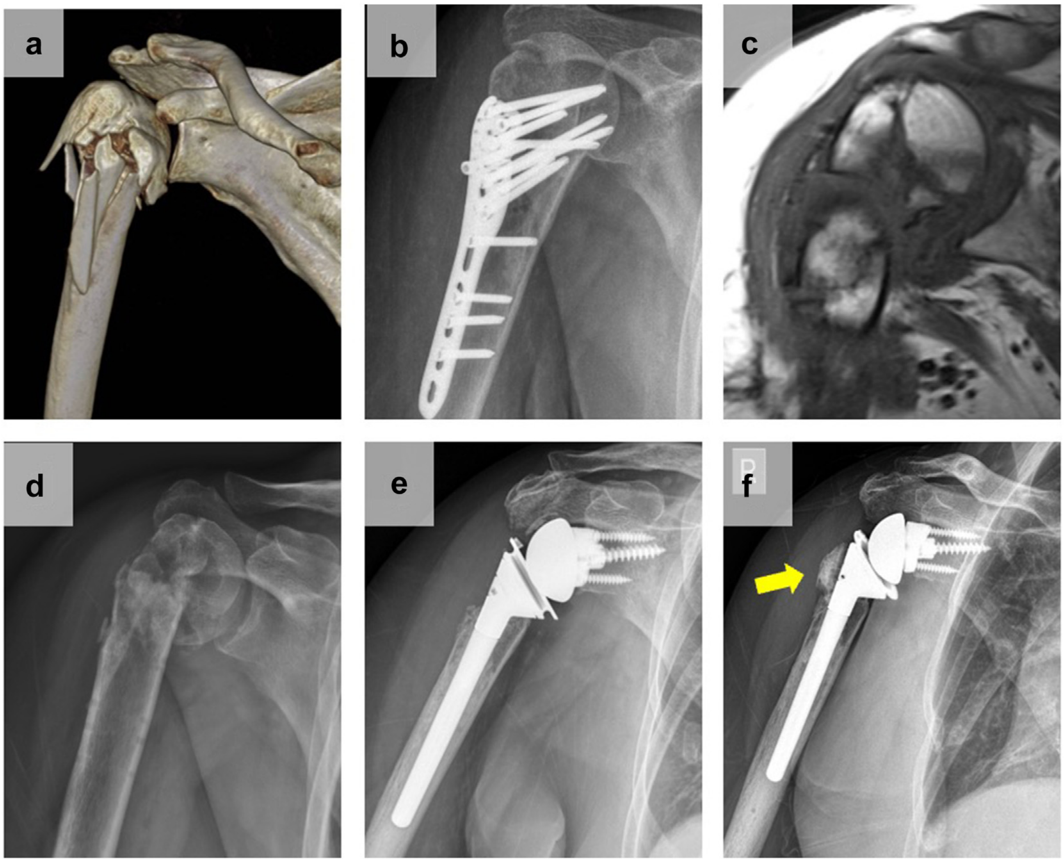

Figure 2 (**a**-**f**) Case 2, imaging studies. (**a**) Initial radiograph demonstrating a right comminuted proximal humeral fracture. (**b**) Status post ORIF with LCP. (**c**) and (**d**) Avascular necrosis, affecting the tuberosities and the metaphysis of the proximal humerus. (**e**) Radiograph after implantation of a RTSA; in the absence of a greater tuberosity and posterior rotator cuff, the patient presented an ER lag and a positive Hornblower's sign. (**f**) One-year radiograph after supplement LTT+. The *yellow* indicates the calcaneal bone block which appears united with the proximal body of the prosthesis and the humeral shaft. *ER*, external rotation; *LTT*, lower trapezius transfer; *ORIF*, open reduction and internal fixation; *RTSA*, reverse total shoulder arthroplasty.

(Fig. 4, *a*). It is detached, elevated off the underlying infraspinatus muscle, separated from the middle trapezius, and mobilized medially, taking care not to injure the neurovascular pedicle including the spinal accessory nerve and the main muscular branch of the superficial transverse cervical artery.[29] The tendon is tagged (Fig. 4, *b*).

Preparation of the bone-tendon allograft

Preparation of the graft is illustrated in Fig. 5, *a-e*. A nonirradiated Achilles tendon-bone allograft with a minimum total length of 240 mm is used. The calcaneal bone block is shaped to match the proximal humeral implant. Two No. 5 FiberWire sutures (Arthrex, Naples, FL, USA) are passed transosseously and along the adjacent tendon edges with locking stitches, with 1 suture limb exiting the distal part of the bone graft and one exiting the tendon at the bone-tendon junction.

Graft fixation and LTT+ transfer

Graft fixation is performed with the humeral component not reduced (Fig. 6, *a*). The osseous part of the graft is positioned, aiming for ample surface contact between the graft and the native humeral shaft and with the implant's metaphysis. The 2 suture limbs are passed circumferentially around the stem, and each are tied to their pair. Two additional double-stranded loop sutures (NICELOOP™; Tornier, Inc., Bloomington, MN, USA) are fed through the tendon at the bone-tendon-junction and are cerclaged around the stem under maximum tension using sequential cow-hitches (Fig. 6, *b*).[27]

From the anterior extending toward the posterior incision, the space deep to the deltoid, along the infraspinatus muscle, is developed for passage of the graft. Its tendinous portion is tunneled through and retrieved posteriorly, avoiding any graft impingement around the base of the scapular spine. Its aponeurotic part is split into 3 tails, with approximately 20:60:20 width ratio. The shoulder is reduced and placed in 45° abduction and 45° ER before the superior and inferior tails are weaved through the LT muscle in a Pulvertaft fashion, using No.2 FiberWire (Arthrex, Naples, FL, USA) in a vertical mattress fashion.[19] The intermediate tail is stitched to the margins of the LT with No. 1 Polydioxanone suture (Fig. 6, *c*), providing a smooth surface for the transfer to glide.

At the end of the procedure, the shoulder is taken through a gentle range of motion (ROM) to assess fixation and excursion of the LTT+. After closure and dressing of both wounds, a brace is applied holding the shoulder in approximately 30° abduction and 20° ER.

Postoperative protocol

To protect the tendon transfer during healing, the arm is placed in an abduction/ER brace for 6 weeks. Loading of the operated limb as well as any internal rotation and horizontal adduction or activation of the LTT+ is avoided during that time.

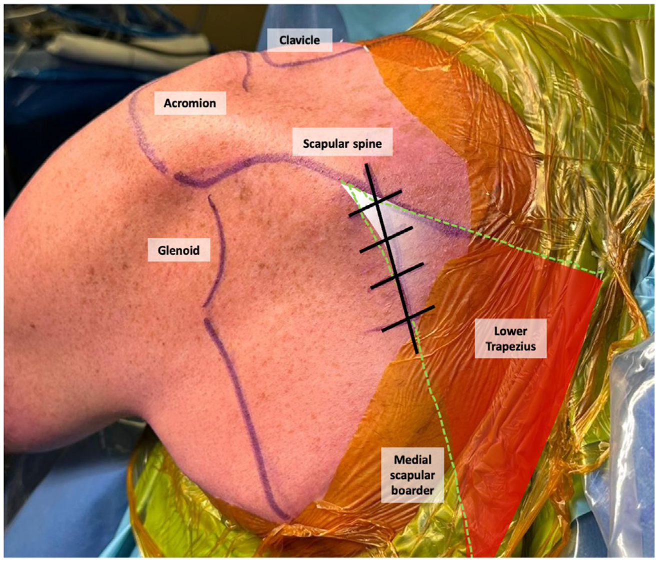

Figure 3 Set up and anatomical landmarks. The patient is in beach-chair position. The lower trapezius (red) originates from T2 to T10 and inserts on the dorsal scapular spine tubercle in the medial one-third of the scapular spine. The *black line* indicates the planned skin incision.

Passive abduction and flexion to 90° in a fixed 20° ER position are allowed. After 6 weeks, physiotherapy focusing on postural control, scapulothoracic stability and movement patterns, recruitment and strengthening of the deltoid muscle, and ROM is commenced. From the 3-month mark, recruitment and control of the LTT+ are performed, initially in isolation concentrically, then combined with ER of the shoulder joint, progressing to active ER and positional control of the upper limb through the ROM. Return to full activities including return-to-sport is technically allowed at 6 months postoperatively but depends on the patient's functional improvements and physical demands.

Follow-up case 1

At latest follow-up 1 year postoperatively, the patient had an active forward elevation of 150°, ER of 50° in adduction, abduction of 90°, and functional internal rotation to first lumbar vertebrae (Fig. 7, *a-d*). His subjective shoulder value had increased from 10% to 65%. He was very satisfied with his progress. X-rays showed fusion of the calcaneal bone block to the humeral shaft, and no signs of graft resorption or secondary displacement (Fig. 1, *f*).

Follow-up case 2

At latest follow-up approximately 2 years postoperatively, the patient presented an unchanged active forward elevation and abduction of 90° but improved ER in adduction and abduction to 0° (previously abdomen), and functional internal rotation to the third lumbar vertebra (previously thigh). Her subjective shoulder value had improved from 40% to 60% and she was satisfied with the result. Radiographically, the calcaneal bone block was still present, without evidence of resorption (Fig. 2, *f*).

Discussion

Here we describe a novel application and technical variation of the lower trapezius transfer that is suitable in the setting of RTSA and PHBL. At present, there is no gold standard for treatment for this difficult, but not uncommon situation. Our technique allows for management of a combined problem with a single solution, restoring active ER function on one hand, and reconstructing bony deficiency of the lateral proximal humeral metaphysis on the other hand.

The 2 established tendon transfer options for restoration of ER in RTSA are the latissimus dorsi transfer (LDT)[18] and the l'Episcopo procedure.[4] In native, rotator cuff deficient shoulders, the LTT, described by Elhassan et al,[15] has recently emerged as a promising additional option. To date, there are no published clinical data on the use of the LTT in the setting of RTSA. However, a 2020 cadaveric study by Chan et al[9] reported effectiveness of both the LTT and the LDT in restoring ER in RTSA, with the LTT's moment arm being most favorable in adduction, and the LDT's in abduction. Interestingly, especially when considering application in the context of RTSA, the LTT exerts a comparatively lower adduction force,[33] which may offload the deltoid during shoulder elevation

Utilizing the graft as described above, our technique presents the possibility to achieve fixation of a tendon transfer in pathoanatomic situations that would potentially not allow for easy attachment of such a transfer. With its proximal, off-set, posterolateral position on the proximal humerus, a close to anatomic insertion site for the new external rotator is mimicked, which has been shown to be advantageous.[17,33] As in native shoulders, allograft interposition between the LT and the proximal humerus is required, which may be a concern regarding tissue healing and elongation over time.[33,35]

The manifestations and the relevance of PHBL in RTSA[2,12,13,32] have previously been discussed by several authors, mostly in the context of fracture sequelae and revision arthroplasty. In summary, the literature states, that clinical outcome is highly dependent on the integrity of the greater tuberosity and that loss of humeral bone stock attributes to complications, particularly loss of ER function and instability.[5,2,10,20,32] According to Boileau et al,[5] 61% of fracture RTSA patients with loss of the greater tuberosity have an ER lag. In 2014, Greiner et al[20] published that the extent of the metaphyseal bone defect of the lateral cortex is significantly correlated with poor postoperative outcome. A cut off value of three centimeters was proposed. In such situations, the LTT+ could be a viable option. Conceptually it is similar to APC techniques combined with rotator cuff reconstructions.[37,3] Notably, Sanchez-Sotelo et al[37] and Boileau et al[3] have reported on APC with added rotator cuff reconstruction and l'Episcopo transfer, respectively, and have observed significant improvements of ROM, including ER, and reliable graft-host healing. While APC is typically performed in massive PHBL, we consider the LTT+ suitable for moderate PHBL with a defect size between three and five centimeters, affecting the epiphysis and metaphysis of the proximal humerus, corresponding to type B bone loss according to Boileau et al.[3]

Not only PHBL, but also poor soft tissue support compromises humeral implant and glenohumeral stability in RTSA. Gutiérrez et al[21] suggested that the most effective approach to increase stability is through the joint compressive force generated by active and passive structures of soft tissue together. The LTT+ could contribute to stability via three different mechanisms: first, by increased active compressive force across the glenohumeral joint,[23,30] second, by improved "deltoid wrapping" stemming from the calcaneal bone block increasing the muscle's lateral offset,[34] and thirdly, passively by addition of the joint-spanning structure. Biomechanical testing as well as clinical and radiological follow-up observation of carefully selected patients are warranted and pending.

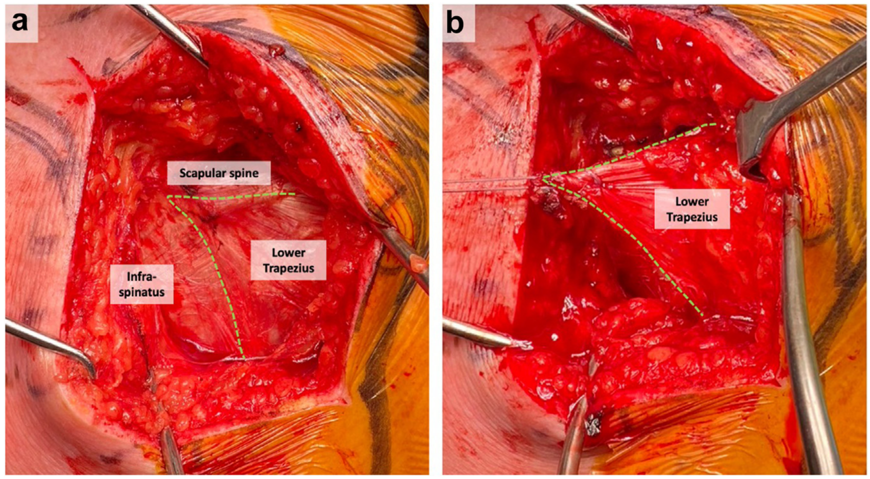

Figure 4 (**a**) and (**b**) Harvesting of the LT tendon. (**a**) The LT's inferior boarder and attachment (*green dotted line*) on the scapular spine are identified. (**b**) The LT tendon is detached and tagged. The muscle is released off the underlying infraspinatus and medially to the neurovascular pedicle. *LT*, lower trapezius.

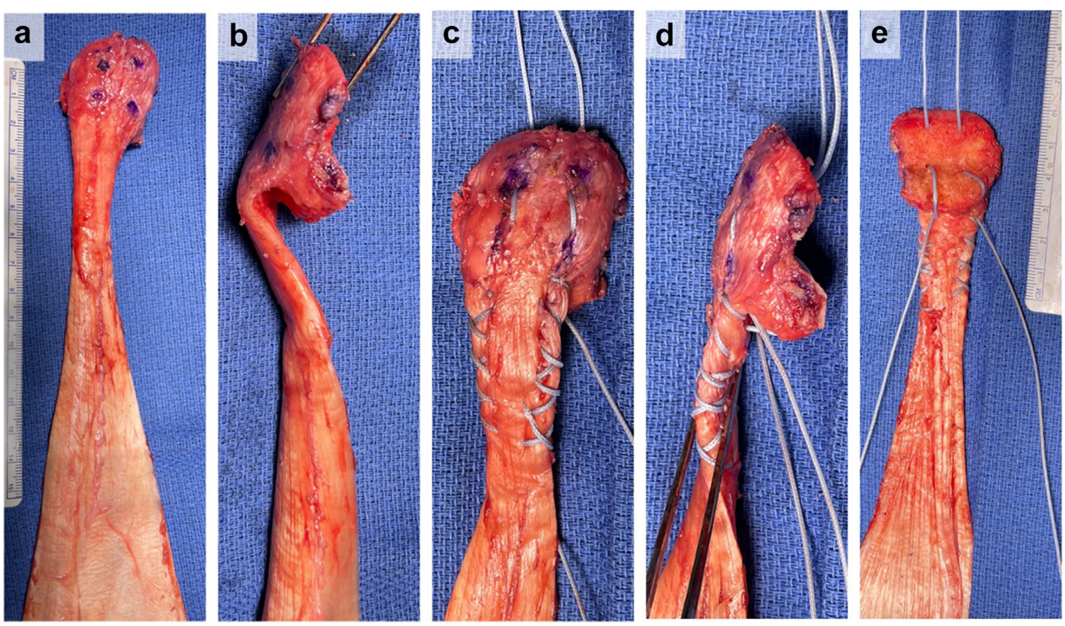

Figure 5 (**a-e**) Preparation of the Achilles tendon-bone allograft. (**a**) and (**b**) show the dimensions of the graft, with the bone block already shaped to match the proximal part of the stem. Sites for transosseous perforation have been marked. (**c-e**) illustrate the stitch configuration of the FiberWire sutures that will later be used for fixation of the bone block to the prosthesis.

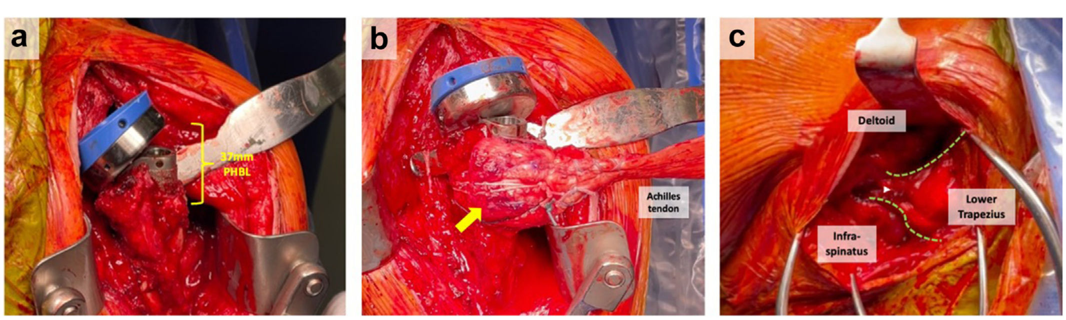

Figure 6 (**a-c**) Graft fixation and LTT + transfer. (**a**) Intraoperative photograph demonstrating the extent of the PHBL and the deficient tuberosities (approximately 37 mm) and the implanted reverse humeral component (Aequalis Flex Revive; Tornier, Inc., Bloomington, MN, USA). (**b**) The calcaneal bone block (*yellow arrow*) is fixed with 2 transosseous and transprosthetic single-stranded suture cerclages, and 2 additional double-stranded transtendinous and perihumeral cerclages. (**c**) Posterior incision illustrating the Achilles tendon–LT tendon interface: The Pulvertaft weave is covered by the intermediate limb of the Achilles aponeurosis. The green dotted lines indicate the superior and inferior border of the LTT+, the white arrow its trajectory. *LTT*, lower trapezius transfer; *PHBL*, proximal humeral bone loss; *LT*, lower trapezius.

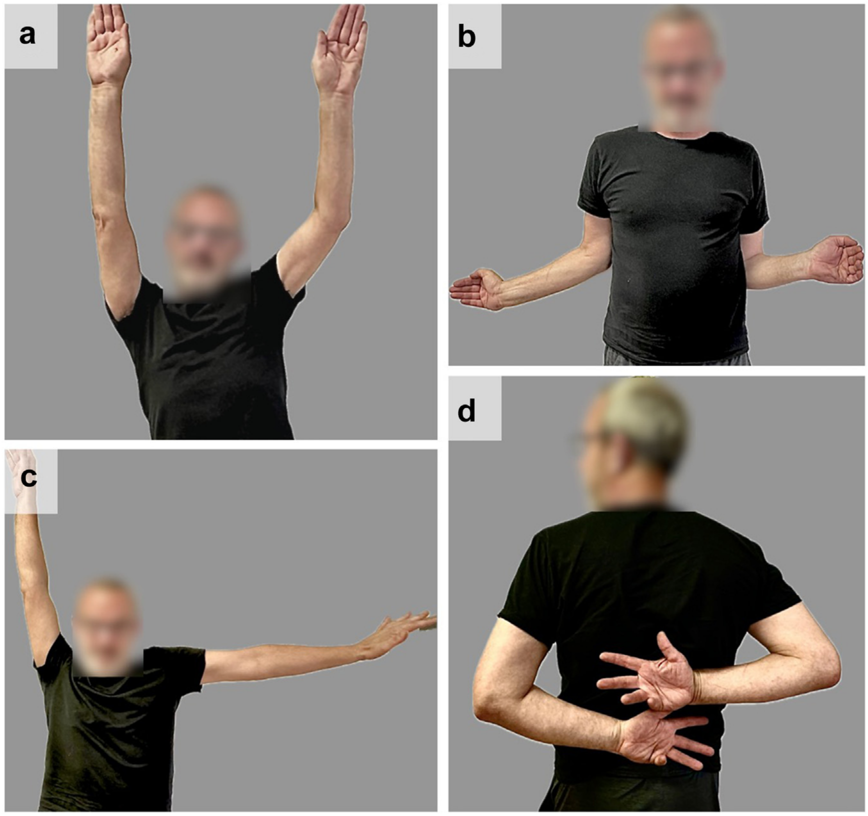

Figure 7 (**a**-**d**) Case 1, ROM one year postoperatively. (**a**) Forward elevation: 150°. (**b**) ER in adduction: 50°. (**c**) Abduction in coronal plane: 90°. (**d**) Functional internal rotation: 1st lumbar vertebrae. *ER*, external rotation; *ROM*, range of motion.

Conclusion

Bone loss of the humeral metaphysis in RTSA is associated with an increased complication rate and significant functional limitations, specifically with prosthetic instability and with loss of active ER. The herein presented novel technique comprising a lower trapezius transfer utilizing an Achilles tendon and calcaneal bone allograft (LTT+) provides a combined solution for reconstruction of the bony deficiency and restoration of active ER function.

Disclaimers:

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Patient consent: The two patients reported on herein were informed that data concerning their cases would be submitted for publication, and they provided consent.

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