European Journal of Orthopaedic Surgery & Traumatology
https://doi.org/10.1007/s00590-020-02815-y

ORIGINAL ARTICLE

Stabilization of the radial head with the palmaris longus or the gracilis tendon: an anatomical feasibility study

Cyril Guetari[1] · Maud Creze[2] · Marc Soubeyrand[3]

Received: 29 April 2020 / Accepted: 15 October 2020

Abstract

Purpose The proximal radioulnar joint (PRUJ) and the radiocapitellar joint may be destabilized after trauma. Different techniques for stabilization of PRUJ have been proposed, but none of them can stabilize the radiocapitellar joint at the same time. We propose a ligamentoplasty to stabilize the radial head at these two joints by reconstructing the radial head annular ligament and the lateral collateral ulnar ligament (LCUL) with a single graft (palmaris longus or gracilis tendon of the knee).

Methods Fifteen cadaveric upper limbs were used to compare the stabilization obtained by performing our ligamentoplasty with the palmaris longus or the gracilis tendon. For each technique, the stabilization obtained was evaluated by measuring the displacement of the radial head in the anterior, lateral and posterior directions when a force of 1 N was applied in maximum supination, neutral rotation and maximum pronation. We also evaluated whether this technique could damage the ulnar nerve or the posterior interosseous nerve by dissecting them and whether it could limit the range of rotation of the forearm.

Results Our ligamentoplasty enables to restore PRUJ stability equivalent to the intact ligament condition. The palmaris longus was inconstant (13/15) and too short to allow concomitant reconstruction of the LCUL (except in one case). No nerve damage was found during the dissection, and the range of rotation of the forearm was not limited by the ligamentoplasty. We also report a clinical case with an excellent result and without complications.

Conclusion This ligamentoplasty we have described makes it possible to stabilize the radial head with respect to the radial notch of the ulna and with respect to the capitellum of the humerus. The gracilis tendon is more suitable than the palmaris longus because of its constant presence and length. A clinical series is now necessary to better evaluate this technique.

Keywords Proximal radioulnar joint · Elbow ligamentoplasty · Radial head · Elbow instability

Introduction

The radial head is an essential stabilizer of the elbow and forearm [1, 2]. It prevents valgus destabilization of the elbow in case of injury to the medial collateral ligament of the elbow. It also prevents proximal migration of the radius in case of longitudinal instability of the forearm (i.e., Essex-Lopresti injury). In order to ensure these functions, the radial head is articulated both with the capitulum of the humerus and with the radial notch of the ulna.

In case of injury to the lateral collateral ligament complex of the elbow [3], the joint between the radial head and the humeral capitulum (i.e., radiocapitellar) may be dislocated. In case of injury to the annular ligament of the radial head, the squared ligament of the elbow [4] and the interosseous membrane, the proximal radioulnar joint (PRUJ) may be dislocated [5, 6] as is the case with an Essex-Lopresti injury [7, 8], a crisscross injury [9], a Monteggia lesion [10–13] or

✉ Marc Soubeyrand
prmarcsoubeyrand@gmail.com

Cyril Guetari
cyrilguetari@gmail.com

Maud Creze
maud2602@hotmail.fr

[1] Public Assistance Hospital of Paris, Ecole de Chirurgie, 7 rue du Fer à Moulin, 75221 Paris, France

[2] Department of Radiology, Public Assistance Hospital of Paris, Universitary Hospital of Bicêtre, 78 rue du Général Leclerc, 94270 Le Kremlin-Bicêtre, France

[3] Department of Orthopaedic Surgery, Clinique Saint Jean L'Ermitage, 272 Av MArc Jacquet, 77000 Melun, France

Journal : Large 590	Article No : 2815	Pages : 9	MS Code : 2815	Dispatch : 21-10-2020

an improper repair of the annular ligament after a surgical approach of the radial head. In some patients, both the radiocapitellar joint and the PRUJ can be destabilized together.

In order to stabilize the PRUJ, several surgical strategies have been proposed (Table 1): reconstruction of the annular ligament with the triceps brachii tendon [14, 15], the forearm fascia or the palmaris longus [15–18]. Reconstruction of the quadrate ligament was also proposed by using the extensor carpi radialis longus tendon, but this technique involves drilling a tunnel in the radius with an increased theoretical risk of radius fracture [19]. However, these techniques only stabilize the PRUJ, but not the radiocapitellar joint.

In order to overcome these limits, we have developed a technique of ligamentoplasty to stabilize the radial head in front of the humerus, but also in front of the ulna: a complete and dynamic stabilization of the radial head by reconstructing at the same time the lateral collateral ulnar ligament (LCUL) of the elbow and the annular ligament of the radial head (Fig. 1). The palmaris longus tendon seemed an ideal candidate for this, but it is not constant in all individuals [20, 21]. In addition, the design of our ligamentoplasty requires sufficient graft length and we feared that the palmaris longus was not long enough. This is why we also wanted to evaluate the possibility of using the gracilis tendon of the knee as an alternative to the palmaris longus. Indeed this tendon is constant and of a greater length than the palmaris longus.

The main purpose of this study was to evaluate the anatomical feasibility of this ligamentoplasty technique by using alternatively the palmaris longus and gracilis tendons. The secondary objectives were to (1) evaluate the biomechanical effect of this ligamentoplasty on PRUJ stability and range of forearm rotation and (2) to evaluate the anatomical danger of the procedure for the neighboring neurovascular structures. AQ1

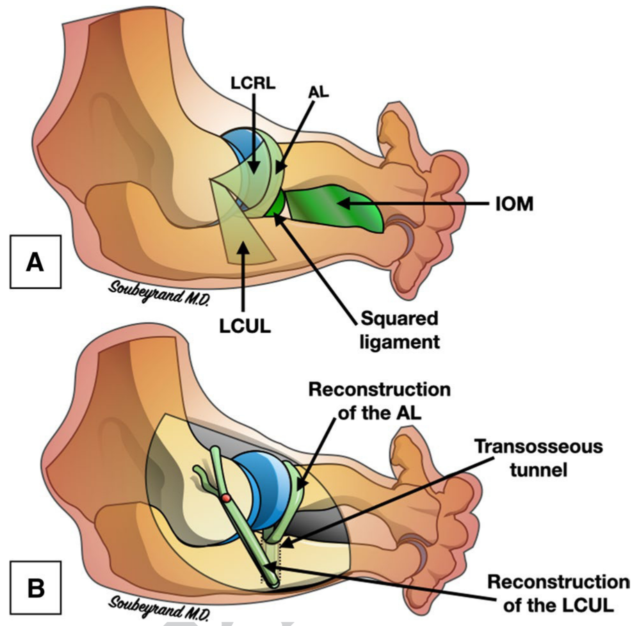

Fig. 1 The design of the ligamentoplasty allows simultaneous reconstruction of the radial head annular ligament (AL) as well as the lateral collateral ulnar ligament (LCUL). The AL is the primary stabilizer of the proximal radioulnar joint, while the interosseous membrane (IOM) and the squared ligament are secondary stabilizers

Table 1 XXXX

References	Type of study	Strategy proposed for management of the radial head instability	Used graft	Comments
[16]	Clinical study	Ligamentoplasty	Triceps tendon slip	
[14]	Clinical study	Ligamentoplasty	Triceps tendon slip	Initial paper describing the original Bell Tawse technique
[15]	Clinical study	Ligamentoplasty + Ulna osteoromy	Triceps tendon slip	
[28]	Clinical study	Osteotomy + Annular ligament repair + Temporary pinning	N/A	Of a consecutive series of 39 Monteggia lesions, 8 were initially undiagnosed
[30]	Case report	Temporary pinning	N/A	Neglected Type I Monteggia Fracture Dislocation in Adult: surgery performed at 3 months post-trauma
[17]	Clinical study	Ulna bending osteotomy + Ligamentoplasty	Palmaris longus	22 patients with neglected Monteggia fracture: the graft was used to increase the length of the annular ligament torn in the trauma
[33]	Clinical study	Ulna osteotomy + Bell Tawse technique	Triceps tendon slip	21 patients with neglected Monteggia fracture
[32]	Clinical study	Ulna osteotomy with overcorrection of the angular deformity and bone elongation	N/A	9 patients with chronic post-traumatic dislocation of the radial head: Initial paper describing the original Hirayama technique
[37]	Clinical study	Ligamentoplasty	Palmaris longus	
[38]	Clinical study	Ligamentoplasty	Allograft	
[36]	Clinical study	Ligamentoplasty	Triceps tendon slip	

Journal : Large 590 | Article No : 2815 | Pages : 9 | MS Code : 2815 | Dispatch : 21-10-2020

Materials and methods

This is a cadaveric experimental study involving 15 upper limbs of patients who had donated their bodies to our institution. The upper limbs were disarticulated at the glenohumeral joint. Specimens with scars, instability, stiffness (in flexion–extension of the elbow or in pronation–supination) and deformity of the elbow or forearm were excluded.

Experimental protocol for evaluating radial head stabilization with ligamentoplasty

For each specimen, the elbow was approached through a posterolateral approach. As a reminder, on the lateral side of the elbow is the lateral collateral ligamentous complex of the elbow [3]. The latter is composed of the lateral collateral ulnar ligament (LCUL), the annular ligament (AL) and the radial collateral ligament (RCL) [3]. The LCUL and the RCL are inserted on the lateral epicondyle: The first one is also inserted on the ulna, while the other end of the second is inserted on the annular ligament. On the ulnar side of the elbow is the medial ulnar collateral ligament (MUCL), inserted on both the medial epicondyle and the ulna [22]. The RCL and the anterior capsule were severed in order to dislocate the elbow. The MUCL and posterior capsule were left intact as well as the AL. This allowed the PRUJ to be exposed and visualized through its superior aspect. The ulna was then stabilized by three pins attached to a frame made with external fixator pins (Hoffman 2, Stryker, Kalamazoo, USA). The radius was left free to rotate so as not to compromise pronation–supination (Fig. 2). A 3-mm-diameter pin was inserted in the center of the radial head using a drill motor (Fig. 3). A second reference pin was attached to the frame: In the anatomical position with the reduced PRUJ, the tips of both pins were exactly side by side.

At this experimental stage, none of the ligaments stabilizing the PRUJ were severed. A first stability assessment of the PRUJ was performed. To do this, the pin in the radial head was used as a joystick to successively apply a stress of 1 N (measured with a dynamometer) in the anterior, lateral and posterior directions. With such a stress, the 3-mm-diameter pin inserted in the radial head did not deform. The distance between the tips of both pins was measured using a digital caliper: It allowed to quantify the laxity in a given direction. Each measurement was taken twice by two independent observers. The arithmetic mean of the four measurements obtained in each of the three directions (anterior, lateral and posterior), *i.e.,* a total of 12 measurements, was finally recorded and considered as an overall quantification of the PRUJ laxity. These measurements were taken with the forearm in maximum pronation, neutral rotation and maximum supination.

Then the AL of the radial head, the squared ligament of the elbow and the interosseous membrane of the forearm were severed in order to destabilize the PRUJ. These ligaments are known to be stabilizers of PRUJ [4, 6, 23–25]. A new assessment of the PRUJ stability was performed according to the same protocol as described above (Fig. 4).

In a third step, we performed the ligamentoplasty that we designed (Fig. 5a). A 4-mm-diameter tunnel was made in the ulna. Its direction was antero-posterior, with an entry point just below the radial notch (Fig. 5b). The target exit point was the ulnar insertion zone of the LCUL. The palmaris longus (if present) and the homolateral gracilis tendon on

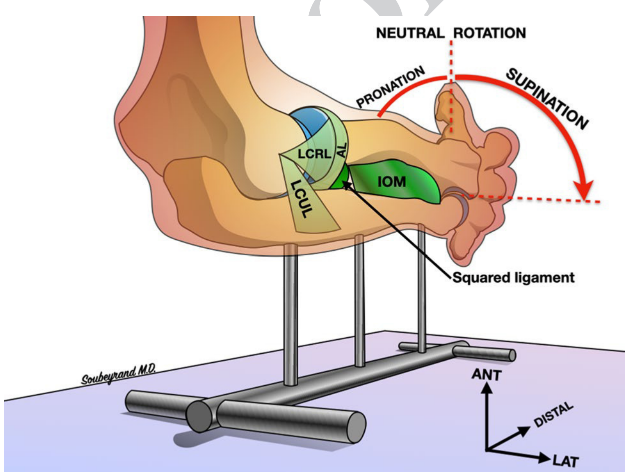

Fig. 2 Diagram of the experimental setup. The ulna is fixed in a frame composed of bars and pins of external fixator. The radius is left free so as not to impede the rotation of the forearm

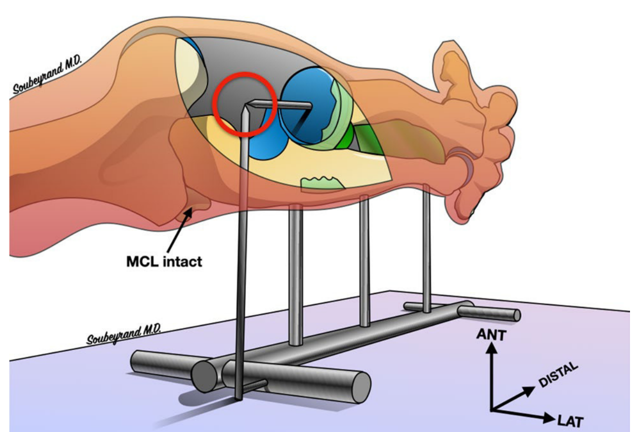

Fig. 3 The lateral collateral ulnar ligament (LCUL) was severed as well as the anterior capsule in order to dislocate the elbow. The medial ulnar collateral ligament (MCL) was left intact. Two pins were inserted, in the radial head and attached to the experimental frame, respectively. In an anatomical position, the tips of the two pins are side by side

Journal : Large 590	Article No : 2815	Pages : 9	MS Code : 2815	Dispatch : 21-10-2020

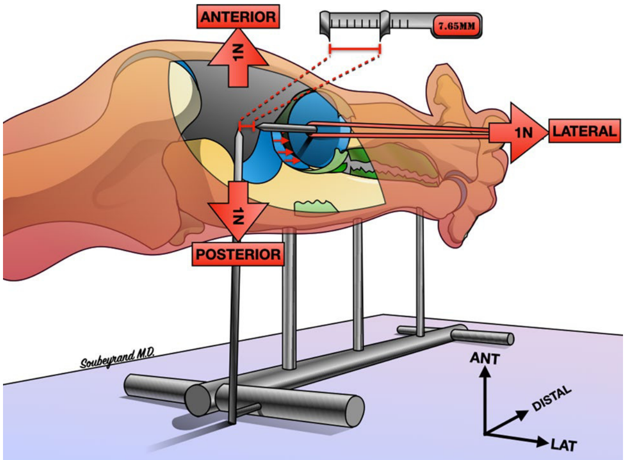

Fig. 4 The laxity of the proximal radioulnar joint (PRUJ) is tested by exerting a traction of 1 N (N) in the anterior, lateral and posterior directions, respectively. Each displacement is measured using a digital caliper. In the injured configuration, the interosseous membrane, square ligament and annular ligament were severed to simulate PRUJ instability

the knee were harvested from the same body. Each tendon was used successively to perform the ligamentoplasty as follows: The tendon was folded in a loop around the neck of the radius, and then, the two free ends were passed through the ulnar tunnel. The graft was placed under tension and this tension was maintained by clamping the two strands flush with the exit point of the ulnar tunnel. A new stability assessment was then performed as described above with the palmaris longus tendon or the gracilis tendon. For each ligamentoplasty performed with either tendon, the elbow was reduced by placing the humerus back in its anatomical position in front of the ulna and radius (Fig. 5c). An attempt was then made to return the free strands of the graft to the lateral epicondyle in order to reconstruct the LCUL. The graft was considered long enough if it extended at least 1.5 cm beyond the apex of the lateral epicondyle. Indeed, we believe that this length of tendon is the minimum required to achieve a fixation on the humerus with sufficient strength to allow early rehabilitation of the elbow in the postoperative period.

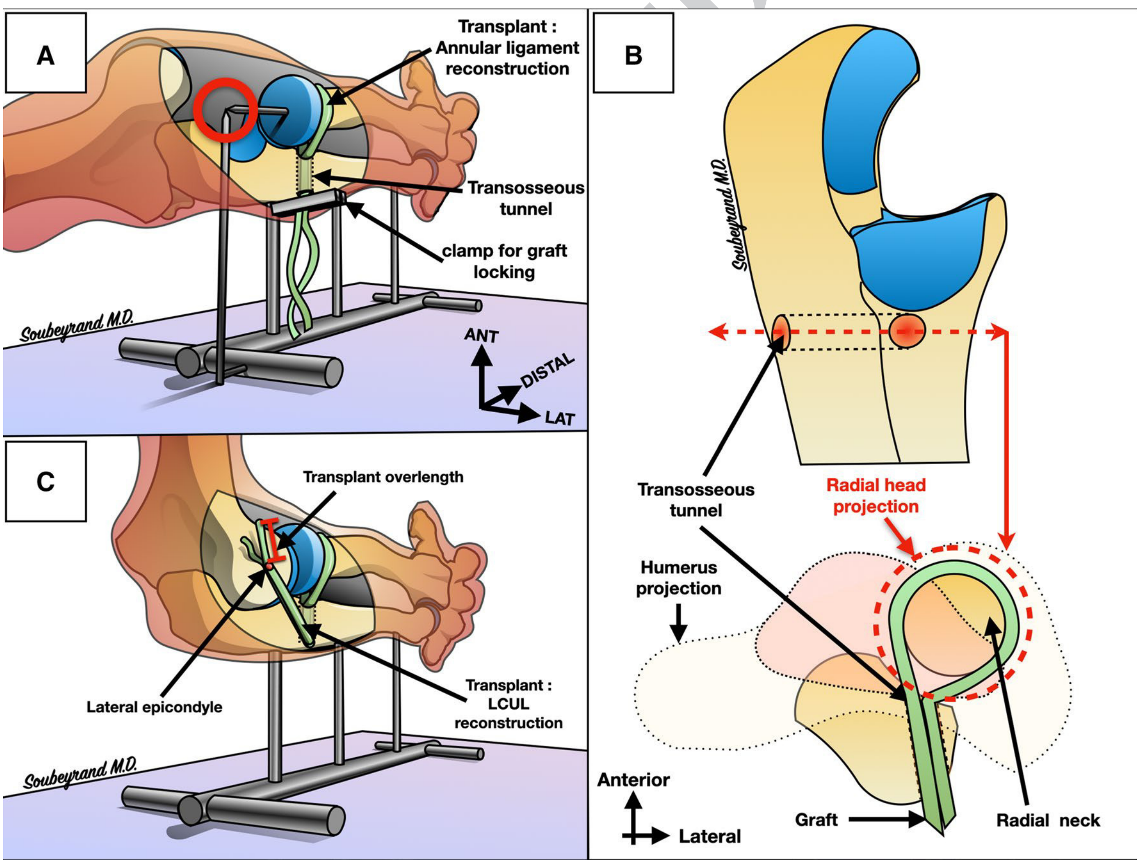

Fig. 5 Experimental protocol. **a** The stability of the proximal radioulnar joint is also tested after reconstruction of the annular ligament with the palmaris longus and with the gracilis tendon. **b** The entry point of the transosseous tunnel is located just below the radial incision of the ulna. Its direction is from front to back as shown in the anatomical section. **c** In the final stage the elbow is reduced and the graft is redirected to the lateral epicondyle. A minimum overlength of 1.5 cm from the top of the lateral epicondyle was considered necessary to ensure proper fixation

Journal : Large 590	Article No : 2815	Pages : 9	MS Code : 2815	Dispatch : 21-10-2020

In total, there were four successive configurations for each forearm: (1) intact, (2) destabilized, (3) ligamentoplasty with the palmaris longus (LPL) and (4) ligamentoplasty with the gracilis (LGT).

Experimental protocol to assess the anatomical risk of this technique

At the end of each ligamentoplasty, we performed a dissection of the ulnar nerve as well as the posterior interosseous nerve. Indeed these two structures are the most at risk of being damaged during the realization of this technique. Their status (intact/injured) was recorded.

Moreover, the risk of any ligamentoplasty is to generate joint stiffness: In the case of our study, the theoretical risk was that the ligamentoplasty would limit the range of rotation of the forearm. We therefore measured mobility in maximum pronation and maximum supination for the three configurations. Each measurement was repeated twice by two independent observers using a goniometer, and the arithmetic mean of these four measurements was then recorded.

Statistical analysis

Data were analyzed using Prism software (GraphPad softwares) for Mac OS. One-way ANOVA with multiple comparisons and post hoc analyses using the Bonferroni comparison test were the primary tests, whereas paired *t*-test were used to compare the range of motions between each experimental configuration, using a $p < 0.05$ significance level. Throughout the text and figures, the mean value ± SEM notations are used in describing the results.

Results

The mean age of the specimens was 83 years (69–91). Eight were females, and seven were males. Out of 15 specimens, only 12 had a palmaris longus and they all had gracilis tendon.

As indicated by the ANOVA, the combined sections of the annular ligament, the square ligament and the interosseous membrane resulted in significant laxity in all three positions of forearm rotation (maximum supination, neutral rotation and maximum pronation) and in all three directions: anterior (intact VS destabilized: $p < 0.001$), lateral (intact VS destabilized: $p < 0.001$) and posterior (intact VS destabilized: $p < 0.001$). The occurrence of this laxity was observed in all specimens.

Ligamentoplasty, whether performed using the palmaris longus (Fig. 6) or the gracilis tendon (Fig. 7), restored stability equivalent to the intact configuration, in the three positions of rotation of the forearm (maximum supination, neutral rotation and maximum pronation) and in the three directions: anterior (intact VS LPL: nonsignificant (ns)), lateral (intact VS LPL: ns) and posterior (intact VS LPL: ns).

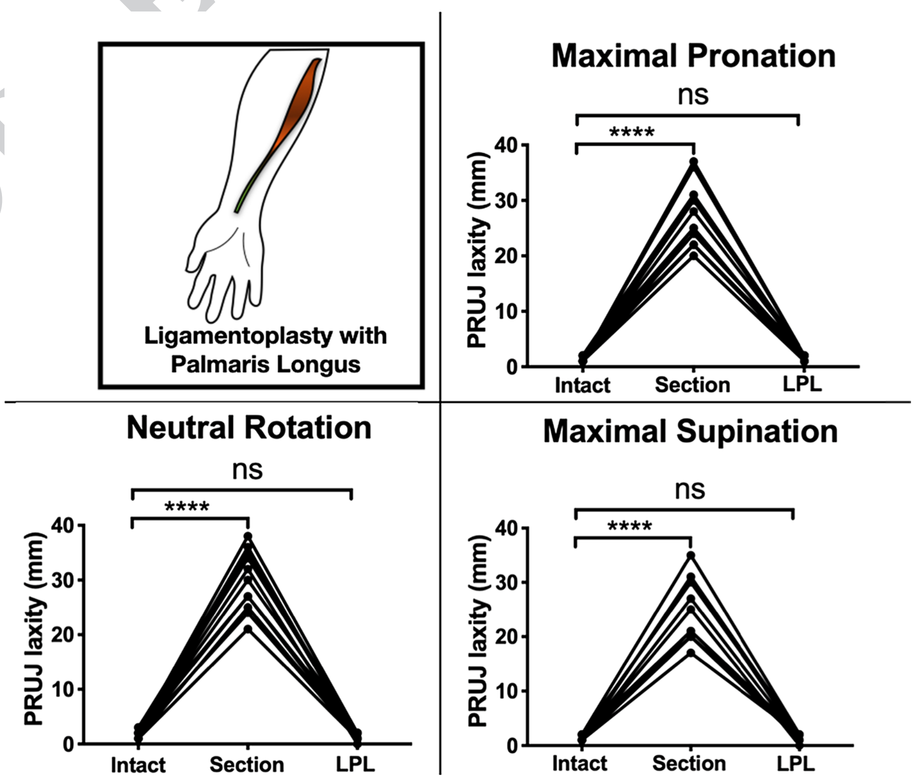

Fig. 6 Results of testing the proximal radioulnar joint (PRUJ) in the three positions of forearm rotation (maximum pronation, neutral rotation, maximum supination) and in the three configurations (intact, destabilized (section of the interosseous membrane, square ligament and annular ligament), ligamentoplasty with the gracilis tendon (LGT)). *ns* not significant. **** = statistically significant

Journal : Large 590 | Article No : 2815 | Pages : 9 | MS Code : 2815 | Dispatch : 21-10-2020

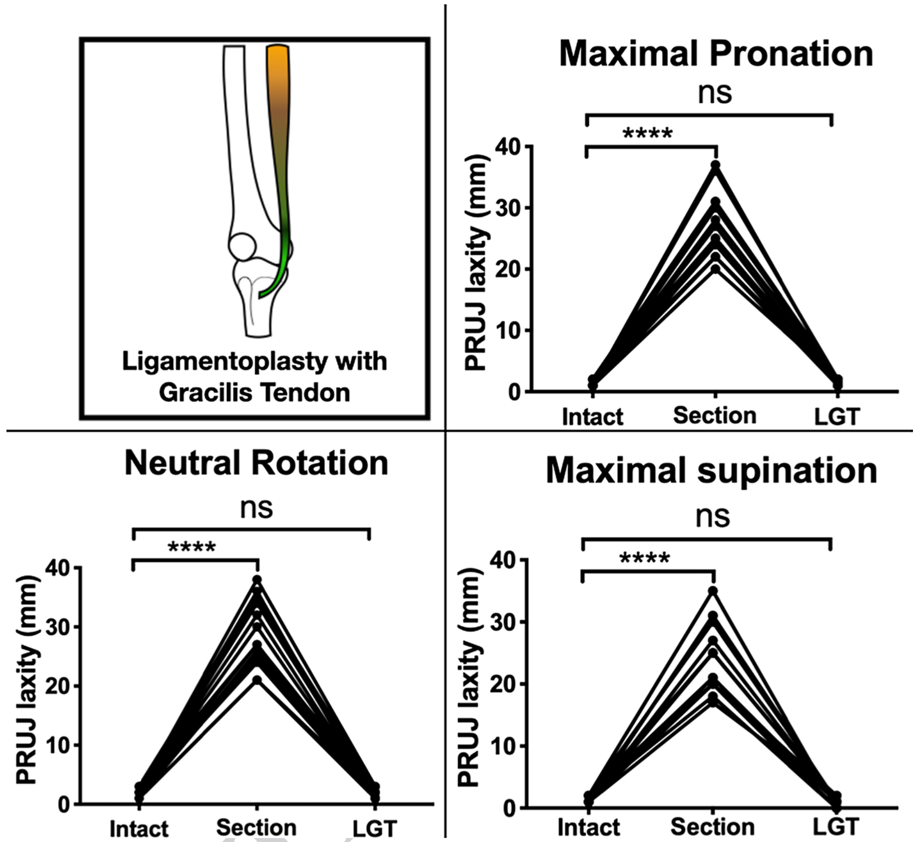

Fig. 7 Results of testing the proximal radioulnar joint (PRUJ) in the three positions of forearm rotation (maximum pronation, neutral rotation, maximum supination) and in the three configurations (intact, destabilized (section of the interosseous membrane, square ligament and annular ligament), ligamentoplasty with the palmaris longus (LPL)). *ns* not significant. ****= statistically significant

In the intact configuration, the average maximum supination was 87° (±0.62), while the average maximum pronation was 87.4° (±0.49). In the LGT configuration, the mean maximum supination was 87.5° (±0.35), while the mean maximum pronation was 87° (±0.53). In the LPL configuration, the mean maximum supination was 87.5° (±0.43), while the mean maximum pronation was 87.7° (±0.25). The paired *t*-test showed no significant difference between the intact configuration and the LGT and LPL groups, respectively.

The dissections performed after ligamentoplasty revealed neither ulnar nerve damage nor damage to the posterior inteerosseous nerve.

Finally, in all cases where the ligamentoplasty was performed with the gracilis tendon, there was sufficient length to achieve fixation of the graft on the lateral epicondyle (associated reconstruction of the LCUL). This was only possible in 1 out of 15 cases when we used the palmaris longus.

Discussion

During this experimental work, we showed that the ligamentoplasty we designed to simultaneously reconstruct the annular ligament and the LCUL made it possible to restore normal stability of the radial head. This was done without compromising the range of rotation of the forearm, whether using the palmaris longus or the gracilis tendon. We confirmed the fact that the palmaris longus was not constant, thus limiting its use. The ligamentoplasty technique appeared to be anatomically safe for the ulnar nerve and the posterior interosseous nerve. Finally, concomitant reconstruction of the LCUL was possible in all cases with the gracilis tendon and in only one case with the palmaris longus.

The annular ligament is the primary stabilizer of the PRUJ [26, 27], while the square ligament and interosseous membrane are secondary stabilizers [5, 7]. In case of injury to the annular ligament of the radial head and the interosseous membrane, the proximal radioulnar joint (PRUJ) may be dislocated [5, 6] as is the case with an Essex-Lopresti injury [7, 8], a crisscross injury [9], a Monteggia lesion [6–9] or an improper repair of the annular ligament after a surgical approach of the radial head. In case of acute Monteggia lesion, the PRUJ automatically relocates as the ulnar fracture is reduced. Apart from this rather favorable situation, PRUJ instability can sometimes persist. This instability can be of variable intensity, ranging from episodes of dynamic subluxation to complete and permanent dislocation of the radial head. Although rare, this condition is really challenging, especially when the lesion is in chronic phase. In case of chronic PRUJ instability, some authors proposed stabilizations by temporary radiocapitellar pinning, but with mixed

Journal : Large 590	Article No : 2815	Pages : 9	MS Code : 2815	Dispatch : 21-10-2020

results [28–31]. For chronic neglected Monteggia lesions, it has been proposed to perform bending/lengthening osteotomies of the ulna and/or shortening/rotation osteotomies of the radius with specific complications of the osteotomies [16, 17, 32–34]. Other authors have proposed reconstruction of the annular ligament by using various grafts such as a bundle of the triceps brachii tendon as described by Bell Tawse [14, 15, 35, 36], a portion of the antebrachial fascia [14], the palmaris longus [37] or an allograft [38]. Reconstruction of the quadrate ligament was also proposed by using the extensor carpi radialis longus tendon [19]. However, this technique involves drilling a tunnel in the radius with an increased theoretical risk of radius fracture and it mechanically limits the rotation of the radius. In most of these techniques, the grafts are fastened to the ulna's surface which limits the intrinsic resistance of the construct to maintain the radial head in proper position. Therefore, these techniques require a postoperative immobilization. In the pediatric population, which is the most concerned in the literature with neglected Monteggia's lesions, the potential for recovery of joint amplitudes is better than in the adult population. In adults, postoperative immobilization of the elbow quickly leads to stiffness of prono-supination and flexion–extension. Another limitation of these techniques is that they do not stabilize the radiocapitellar joint. The ligamentoplasty we have developed makes it possible to reconstruct the annular ligament and the LCUL ligament with a single graft. Therefore, it results in the stabilization of the radial head with respect to the ulna (PRUJ), but also with respect to the capitellum of the humerus (radiocapitellar joint). This may be useful in unusual clinical situations such as the one reported below where instability of the PRUJ is associated with lateral instability of the elbow.

Our study has several limitations

As with any study conducted on cadavers, the question arises as to what the in vivo translation will yield. For example, there is a theoretical risk of graft resorption or radioulnar synostosis that cannot be ruled out until the technique has been used in living patients. Of course, we have not yet been able to carry out a clinical series, but it just so happens that we have had to use this technique on a 44-year-old patient who fell from his height onto his left hand. He had a very unusual association of injury with a distal radioulnar disjunction, a forearm interosseous membrane tear (diagnosed by ultrasound), a radial shaft fracture, a proximal radioulnar disjunction and a posterolateral elbow dislocation (Fig. 8). We reinserted the triangular fibrocartilage complex, performed an interosseous membrane ligamentoplasty with a semitendinosus tendon graft reinforced with two tight ropes to stabilize the forearm, reduced and fixed the radius fracture. We also used the ligamentoplasty we describe in this article to stabilize the PRUJ and the elbow. The gracilis tendon was used, reinforced with a non-absorbable suture along its entire length. Fixations of the graft to the ulna and lateral epicondyle of the humerus were performed with G2 anchors (Mitek°). Early rehabilitation was started, passive without limit and active supported until the sixth week. From the sixth week, the patient was allowed to resume a normal life. At 1 year postoperatively, the result is excellent with a complete absence of pain, normal preservation of the radius/ulna relationship and a stable elbow. The mobility in flexion–extension is − 5°/120°, and in pronation–supination, it is 85°/85°. On the radiographs, the radial head appears properly reduced in front of the ulna and the humerus. There is also a notch on the neck of the radius corresponding to the imprint of the graft, but which is of no consequence. This notch indirectly proves that the graft has not resorbed. An MRI would be the imaging procedure of choice for direct visualization of the graft, but the excellent clinical condition of the patient did not justify such an imaging procedure. The patient had no pain at the knee harvesting site. Although limited, this first clinical experience is very encouraging.

Another limitation of the study is that we did not test the mechanical strength of the ligamentoplasty. This is essential to enable early rehabilitation to be envisaged, which guarantees the recovery of correct joint mobility. In particular, the choice of graft fixation on the humerus plays an important role. In the clinical case reported above, we used two anchors, but it would also have been possible to create a transosseous tunnel in the lateral epicondyle. A subsequent biomechanical study would be necessary to clarify these technical points.

Finally, a limitation of this technique is the use of autologous grafts. This study shows that the palmaris longus is sufficient for isolated reconstruction of the annular ligament, but that if the surgical project is to also reconstruct the LCUL at the same time, the use of the gracilis tendon is to be preferred. We chose to study the palmaris longus and the gracilis tendon because they are commonly used in ligament surgery. However, the palmaris longus is inconsistent, which is a well-known fact that we have confirmed in our study [39]. On the other hand, the gracilis tendon is constant, but requires the harvesting on another limb with the risk of complications specific to the harvesting (pain, scarring problems and failure of harvesting by surgeons of the upper limb who are not accustomed to it). An interesting approach would be to use artificial ligaments composed of polyethylene terephthalate, for example. A specific clinical study would be necessary to evaluate the interest of this.

In conclusion, this ligamentoplasty technique allows the stabilization of the radial head. A first clinical case is encouraging, but a clinical study is now necessary to clarify the potential and limits of this ligamentoplasty.

Journal : Large 590	Article No : 2815	Pages : 9	MS Code : 2815	Dispatch : 21-10-2020

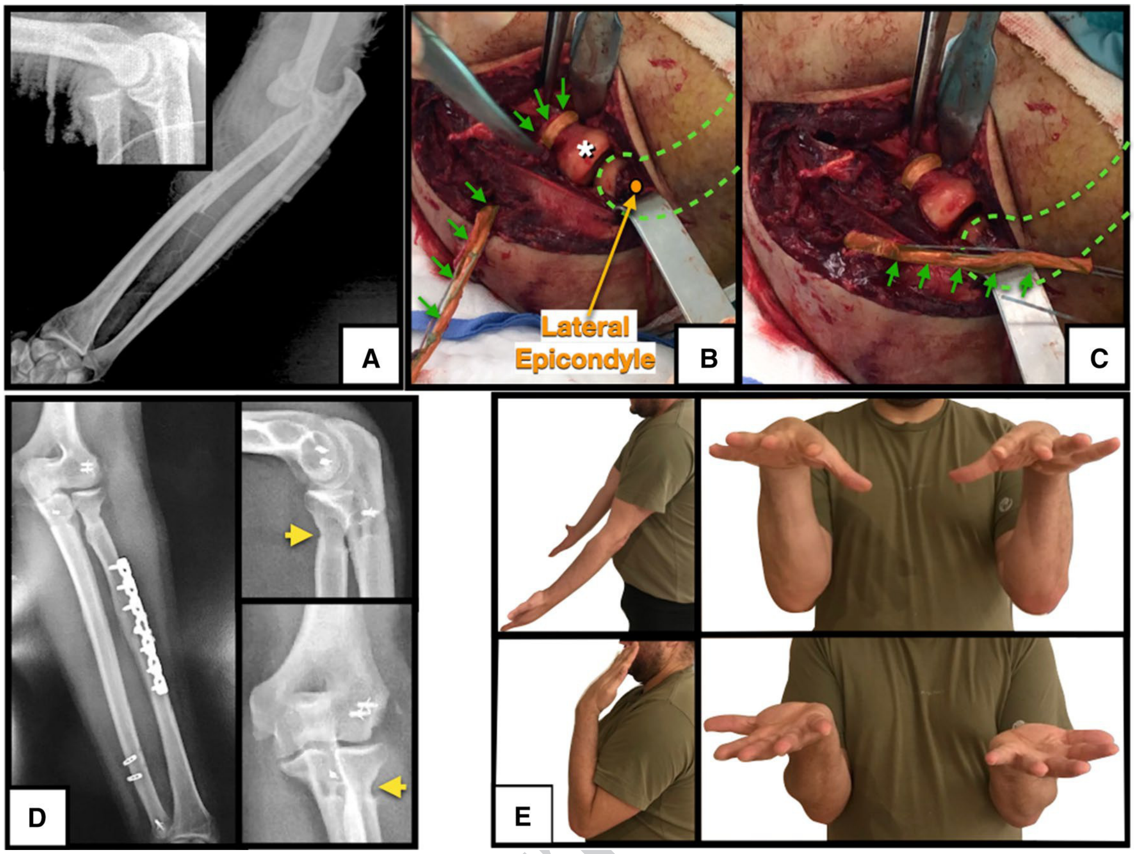

Fig. 8 Illustrations of the clinical case. **a** Preoperative radiographs showing dislocation of the humero-ulnar and proximal radioulnar joints. **b** Intraoperative view after reconstruction of the annular ligament and transosseous passage of the gracilis tendon (green arrows). Discontinuous green line: humerus. **c** The gracilis tendon is then rerouted to the lateral epicondyle. **d** Postoperative radiographs at 1 year. A notch appears on the neck of the radius (yellow arrow) corresponding to the imprint of the graft. **e** mobility of the elbow and forearm at 1 year postoperatively

Author contributions All authors made contributions to the conception and design of the study, acquisition of data, analysis and interpretation of data and drafting the article or revising it, and gave final approval of the submitted version.

Funding This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Availability of data and material Experimental data are available.

Compliance with ethical standards

Conflict of interest None of the authors have a conflict of interest to declare.

Ethical approval This study was conducted at the Paris School of Surgery. The ethical rules of our institution were respected.

Consent to participate In this article, we report the clinical case of a patient who has given his written consent for the use of his anonymized data for the purposes of this publication.

References

1. Green JB, Zelouf DS (2009) Forearm instability. J Hand Surg Am 34(5):953–961. https://doi.org/10.1016/j.jhsa.2009.03.018
2. McGlinn EP, Sebastin SJ, Chung KC (2013) A historical perspective on the essex-lopresti injury. J Hand Surg Am 38(8):1599–1606. https://doi.org/10.1016/j.jhsa.2013.04.031
3. Camp CL, Fu M, Jahandar H, Desai VS, Sinatro AM, Altchek DW, Dines JS (2019) The lateral collateral ligament complex of the elbow: quantitative anatomic analysis of the lateral ulnar collateral, radial collateral, and annular ligaments. J Shoulder Elb Surg 28(4):665–670. https://doi.org/10.1016/j.jse.2018.09.019
4. Otayek S, Tayeb AE, Assabah B, Viard B, Dayan R, Lazure T, Soubeyrand M (2016) Squared ligament of the elbow: anatomy and contribution to forearm stability. Surg Radiol Anat 38(2):237–244. https://doi.org/10.1007/s00276-015-1539-z
5. Otayek S, Tayeb AA, Assabah B, Viard B, Dayan R, Lazure T, Soubeyrand M (2015) Squared ligament of the elbow: anatomy and contribution to forearm stability. Surg Radiol Anat. https://doi.org/10.1007/s00276-015-1539-z

6. Hayami N, Omokawa S, Iida A, Kraisarin J, Moritomo H, Mahakkanukrauh P, Shimizu T, Kawamura K, Tanaka Y (2017) Biomechanical study of isolated radial head dislocation. BMC Musculoskelet Disord 18(1):470. https://doi.org/10.1186/s12891-017-1829-1
7. Soubeyrand M, Lafont C, De Georges R, Dumontier C (2007) Traumatic pathology of antibrachial interosseous membrane of forearm. Chir Main 26(6):255–277. https://doi.org/10.1016/j.main.2007.09.004
8. Loeffler BJ, Green JB, Zelouf DS (2014) Forearm instability. J Hand Surg Am 39(1):156–167. https://doi.org/10.1016/j.jhsa.2013.07.010
9. Leung YF, Ip SP, Ip WY, Kam WL, Wai YL (2005) The crisscross injury mechanism in forearm injuries. Arch Orthop Trauma Surg 125(5):298–303. https://doi.org/10.1007/s00402-005-0805-7
10. Bryan RS (1971) Monteggia fracture of the forearm. J Trauma 11(12):992–998
11. Cheung EV, Yao J (2009) Monteggia fracture-dislocation associated with proximal and distal radioulnar joint instability. a case report. J Bone Jt Surg Am 91(4):950–954. https://doi.org/10.2106/JBJS.H.00269
12. Deshpande S, O'Doherty D (2001) Type I monteggia fracture dislocation associated with ipsilateral distal radial epiphyseal injury. J Orthop Trauma 15(5):373–375
13. Rehim SA, Maynard MA, Sebastin SJ, Chung KC (2014) Monteggia fracture dislocations: a historical review. J Hand Surg Am 39(7):1384–1394. https://doi.org/10.1016/j.jhsa.2014.02.024
14. Bell Tawse AJ (1965) The treatment of malunited anterior monteggia fractures in children. J Bone Jt Surg Br 47(4):718–723
15. Cappellino A, Wolfe SW, Marsh JS (1998) Use of a modified Bell Tawse procedure for chronic acquired dislocation of the radial head. J Pediatr Orthop 18(3):410–414
16. Oner FC, Diepstraten AF (1993) Treatment of chronic post-traumatic dislocation of the radial head in children. J Bone Jt Surg Br 75(4):577–581
17. Nakamura K, Hirachi K, Uchiyama S, Takahara M, Minami A, Imaeda T, Kato H (2009) Long-term clinical and radiographic outcomes after open reduction for missed monteggia fracture-dislocations in children. J Bone Jt Surg Am 91(6):1394–1404. https://doi.org/10.2106/JBJS.H.00644
18. Wang MN, Chang WN (2006) Chronic posttraumatic anterior dislocation of the radial head in children: thirteen cases treated by open reduction, ulnar osteotomy, and annular ligament reconstruction through a Boyd incision. J Orthop Trauma 20(1):1–5
19. Ghinea CA, Gavriliu S, Georgescu I, Vlad C, Japie E, Parvan A, Ghita R (2013) Burnei's technique in the treatment of radial head displacement; innovative surgery. study on two cases. J Med Life 6(1):26–33
20. Raouf HA, Kader GA, Jaradat A, Dharap A, Fadel R, Salem AH (2013) Frequency of palmaris longus absence and its association with other anatomical variations in the Egyptian population. Clin Anat 26(5):572–577. https://doi.org/10.1002/ca.22186
21. Yong MW, Yusof N, Rampal L, Arumugam M (2017) Prevalence of absence of palmaris longus and its association with gender, hand dominance and absence of FDS tendon to little finger among Malay population. J Hand Surg Asian Pac 22(4):484–489. https://doi.org/10.1142/S021881041750054X
22. Cinque ME, Schickendantz M, Frangiamore S (2020) Review of anatomy of the medial ulnar collateral ligament complex of the elbow. Curr Rev Musculoskelet Med 13(1):96–102. https://doi.org/10.1007/s12178-020-09609-z
23. Soubeyrand M, Ciais G, Wassermann V, Kalouche I, Biau D, Dumontier C, Gagey O (2011) The intra-operative radius joystick test to diagnose complete disruption of the interosseous membrane. J Bone Jt Surg Br 93(10):1389–1394. https://doi.org/10.1302/0301-620X.93B10.26590
24. Soubeyrand M, Wassermann V, Hirsch C, Oberlin C, Gagey O, Dumontier C (2011) The middle radioulnar joint and triarticular forearm complex. J Hand Surg Eur 36(6):447–454. https://doi.org/10.1177/1753193410396976
25. Adams JE (2017) Forearm instability: anatomy, biomechanics, and treatment options. J Hand Surg Am 42(1):47–52. https://doi.org/10.1016/j.jhsa.2016.10.017
26. Galik K, Baratz ME, Butler AL, Dougherty J, Cohen MS, Miller MC (2007) The effect of the annular ligament on kinematics of the radial head. J Hand Surg [Am] 32(8):1218–1224. https://doi.org/10.1016/j.jhsa.2007.06.008
27. Biewener A, Bischoff F, Rischke T, Tille E, Nimtschke U, Kasten P, Schaser KD, Nowotny J (2019) Instability of the proximal radioulnar joint in monteggia fractures-an experimental study. J Orthop Surg Res 14(1):392. https://doi.org/10.1186/s13018-019-1367-7
28. David-West KS, Wilson NI, Sherlock DA, Bennet GC (2005) Missed monteggia injuries. Injury 36(10):1206–1209. https://doi.org/10.1016/j.injury.2004.12.033
29. Tosun B, Selek O, Buluc L, Memisoglu K (2008) Chronic post-traumatic radial head dislocation associated with dissociation of distal radio-ulnar joint: a case report. Arch Orthop Trauma Surg 128(7):669–671. https://doi.org/10.1007/s00402-007-0456-y
30. Agarwal A, Pawar I (2017) Neglected type I monteggia fracture dislocation in adult. J Clin Diagn Res 11(8):RD01–RD02. https://doi.org/10.7860/JCDR/2017/28250.10468
31. Chen HY, Wu KW, Dong ZR, Huang SC, Kuo KN, Wang TM (2018) The treatment of chronic radial head dislocation in monteggia fracture without annular ligament reconstruction. Int Orthop 42(9):2165–2172. https://doi.org/10.1007/s00264-018-3943-6
32. Hirayama T, Takemitsu Y, Yagihara K, Mikita A (1987) Operation for chronic dislocation of the radial head in children. reduction by osteotomy of the ulna. J Bone Jt Surg Br 69(4):639–642
33. Datta T, Chatterjee N, Pal AK, Das SK (2014) Evaluation of outcome of corrective ulnar osteotomy with bone grafting and annular ligament reconstruction in neglected monteggia fracture dislocation in children. J Clin Diagn Res 8(6):LC01-04. https://doi.org/10.7860/JCDR/2014/9891.4409
34. Liao S, Pan J, Lin H, Xu Y, Lu R, Wu J, Zhao M, Chen H, Cai M, Ding X, Zhao J (2019) A new approach for surgical treatment of chronic monteggia fracture in children. Injury 50(6):1237–1241. https://doi.org/10.1016/j.injury.2019.04.017
35. Boyd HB, Boals JC (1969) The monteggia lesion. a review of 159 cases. Clin Orthop Relat Res 66:94–100
36. Bhaskar A (2009) Missed monteggia fracture in children: is annular ligament reconstruction always required? Indian J Orthop 43(4):389–395. https://doi.org/10.4103/0019-5413.55978
37. Lloyd-Roberts GC, Bucknill TM (1977) Anterior dislocation of the radial head in children: aetiology, natural history and management. J Bone Jt Surg Br 59-B(4):402–407
38. Pari C, Puzzo A, Paderni S, Belluati A (2018) Annular ligament repair using allograft for the treatment of chronic radial head dislocation: a case report. Acta Biomed 90(1):154–157
39. Yammine K, Eric M (2020) Morphometric analysis and surgical adequacy of palmaris longus as a tendon graft. a systematic review of cadaveric studies. Surg Radiol Anat 42(3):259–267. https://doi.org/10.1007/s00276-019-02381-x

Journal : **Large 590**	Article No : **2815**	Pages : **9**	MS Code : **2815**	Dispatch : **21-10-2020**

Journal: **590**
Article: **2815**

Author Query Form

Please ensure you fill out your response to the queries raised below and return this form along with your corrections

Dear Author

During the process of typesetting your article, the following queries have arisen. Please check your typeset proof carefully against the queries listed below and mark the necessary changes either directly on the proof/online grid or in the 'Author's response' area provided below

Query	Details Required	Author's Response
AQ1	Table: A table caption must have a descriptive title; however, none was provided for Table 1. Please supply a title for the said table.	