Simulation of Altered Excursion of the Pronator Quadratus

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Abstract

Keywords

- pronator quadratus
- distal radius fractures
- volar approach to ORIF of distal radius fracture
- complications of distal radius fracture
- forearm rotation

Background Loss of forearm rotation is frequently seen after healing of distal radius fractures.

Questions/Purposes Our purpose was to determine whether restricted excursion of the pronator quadratus muscle can affect forearm rotation.

Methods We evaluated the relationship between pronator quadratus excursion and forearm rotation in a cadaveric model. Eight adult fresh-frozen above-elbow specimens were attached to a mounting device that permitted free rotation of the forearm around its ulnar axis. Forearm rotation was measured with a protractor while alternating pronation and supination loads were applied. Measurements were repeated after restricting the excursion of pronator quadratus by 10, 20, and 30% of its initial length.

Results There was a mean 15° loss of supination for each 10% reduction in pronator excursion. There was no significant effect on pronation.

Conclusions We conclude that, independent of any bone deformity or nearby joint stiffness, posttraumatic scarring of this muscle may result in a loss of supination.

A loss of forearm rotation, particularly supination, is frequently seen as a consequence of distal radius fractures.¹ This may cause functional difficulties in daily activities such as supporting heavy loads, receiving coins or other small objects, and perineal hygiene.² Previous studies have identified distal radius fracture malalignment as a cause of restriction in forearm rotation and have implicated distal radioulnar joint (DRUJ) incongruity or capsular scarring.^{3,4} When bone alignment of the distal radius and ulna have been maintained or restored, Kleinman and Graham have implicated DRUJ capsular scarring alone as a cause of limited forearm rotation.⁵ Separately, a distal radius fracture with or without open reduction and plating may damage the pronator quadratus (PQ) muscle secondary to fracture displacement. Experientially, we have noted during open surgery for fracture management that the PQ muscle is often contused, lacerated, or entrapped in the fracture site. It seems probable that scarring

of the muscle would limit its function. Research examining this question related to any muscle is not abundant. However, in a rabbit model, Chung et al showed that muscle injury left to heal in shortened position would restrict function and that proactive maintenance of muscle length was necessary to preserve best function.⁶ The purpose of our study was to determine whether restricted excursion of the PQ muscle alone could affect forearm rotation.

Materials and Methods

Specimen Preparation

Eight adult, fresh-frozen, unmatched upper extremities were amputated at the mid-humerus. All of the specimens used appeared free from any prior trauma. The skin, subcutaneous tissue, and forearm flexor and extensor muscles were excised to the level of the wrist joint. The biceps tendon, elbow

Fig. 1 Diagram illustrating how the transosseous suture has been attached through the muscle insertion into the radius, passed over the superficial head of the PQ muscle, and attached through the muscle origin from the ulna. The suture has been secured to the ulna, and its variable end has been passed through a point at A (the most distal dorsal insertion of the muscle) and out through a hole B more dorsally on the radius. The distance A to B represents 10% of the suture length as measured from origin to insertion at point A.

capsule, wrist capsule, entire interosseous membrane, and PQ were left intact. To measure the PQ length and later simulate muscle contracture, a transosseous #5 braided polyester suture was attached to the distal ulna and stretched over the superficial surface of the PQ muscle belly to its origin on the radius (►Fig. 1). Two sutures were used to apply a load to the pronator teres and the biceps. The first was a #5 braided polyester suture that was attached to the radius with a screw and washer at the midpoint of the insertion of the pronator teres and then directed proximally and passed through an eyelet at the origin of the pronator teres on the medial epicondyle, so that tension on the suture produced a force in the normal line of pull of the pronator teres. A second #5 braided polyester suture was woven into the biceps tendon and passed through a screw eyelet placed in the anterior surface of the distal humeral shaft, which thus acted as a pulley for the free end of the suture. By using the sutures as described, we were able to use free weights to load the pronator teres and biceps directly. The wrist joint was stabilized to prevent flexion, extension, or lateral movements using a threaded-tip Kirschner wire (K-wire) inserted through the third metacarpal head into the distal radius.

Measurement Device

The specimen was then mounted vertically on the measurement device. This consisted of a metal block, which was connected at one end to a vertical metal rod supporting a transparent circular protractor (►Fig. 2). A Steinmann pin was inserted along the longitudinal axis of the ulna through the tip of the olecranon, to act as the axis of forearm rotation. This pin was secured to the mounting block such that the elbow was fixed in 90° of flexion. The longitudinal axis of the

Fig. 2 The testing frame, showing the sutures used for loading the biceps and pronator teres. The fixed end of the PQ suture is visible in the ulna, as is the measurement protractor. The distal biceps suture is seen to pass thru a 1:1 eyelet pulley, as does the pronator teres suture. In both instances the pulleys enable applied vertical loads to be redirected in a biomechanically correct direction.

ulna was aligned with the center of the circular protractor. A K-wire was inserted transversely into the radial styloid to act as a marker for angle measurements. For accuracy, a weighted suture was attached to the center of the protractor and extended over the edge to act as a plumb line, which enabled confirmation that the forearm remained vertical as it rotated. During each trial, measurements of forearm rotation about the axis of the ulna were made from the radial styloid marker K-wire to the protractor.

Experimental Protocol

For each specimen, the center of the arc of rotation was set on the protractor as neutral (0°), with pronation measurement assigned negative values (0 to -90°) and supination measurements given positive values (0 to 90°). The maximum transverse length (LO) of the PQ was measured, with the forearm positioned in maximal supination, from position B as seen in ►Fig. 1 to the fixed suture end of the ulna. This length was used as an estimate of the resting muscle length of an intact PQ.

Starting with the forearm in neutral (0°), sequential pronator teres loads of 2, 4, and 6 lb (8.89, 17.8, and 26.7 N) were applied to the forearm through the suture at the pronator teres origin, as shown in ►Fig. 2. Three measurements were made of the resulting angle of forearm rotation, and the average degree of pronation was calculated. The loads chosen were similar to those previously used in our laboratory for similar testing and chosen on the basis of the measurements

Fig. 3 Compared with ►Fig. 1, the available PQ excursion has been reduced by 10% (distance A to B).

made by Brand et al.^{7,8} These loads correspond to those exerted during normal physiologic use of the arm.

Similarly, 2-, 4-, and 6-lb (8.89, 17.8, and 26.7 N) loads were applied to produce a supination force by attaching them through a hook to the biceps tendon suture. Each load was individually applied, and supination was measured three times. These measurements of forearm supination were recorded and averaged for each load.

The excursion of the PQ was then limited by 10% of its initial maximal length (L_0) by tightening the transosseous suture between the radial and ulnar attachments of the PQ and securing this suture at its new length (L_1) with a pair of hemostats. In ►Fig. 3 the original length of the PQ has been shortened. Suture point A (the point of original radius insertion) is now at the original dorsal radius suture exit. By design, the distance A to B is 10% of the full length of the PQ (origin on ulna to insertion on radius). Suture point A (the actual insertion point) has been moved to exit the dorsal radius. This location is where a hemostat was applied (our choice of a

hemostat to secure the suture in these locations was necessitated by experiment design, needing the suture to be available for measurement and adjustable). There was no suture slippage or suture failure. Measurements of forearm rotation were then repeated, using the same pronation and supination loads as in the previous set of measurements.

This protocol was then repeated after limiting the excursion of the PQ by 20% (L_2) and 30% (L_3) of its initial length.

Data Analysis

The effect of applied load and length of the PQ on mean forearm pronation and supination was analyzed by the use of a two-factor analysis of variance (ANOVA), with a p -value of less than 0.05 being considered significant. Pairwise comparisons were made using Tukey's test.

Results

Measurements of forearm rotation for the eight specimens, with the PQ intact, showed an average arc of motion of 124° (range 65–161°). The mean arc of pronation from neutral was 60° (SD = 11°). The mean arc of supination from neutral was 63° (SD = 13°). The mean resting length of PQ was 41 ± 4 mm. In ►Fig. 1 this is the distance from the fixed suture end to A (the most radial attachment of the PQ). ►Table 1 summarizes our results.

Pronation was not significantly affected by restricting the excursion of PQ. However, supination progressively decreased as the excursion of the PQ was progressively restricted (►Fig. 4). Reducing the initial excursion of the muscle by 10% (mean reduction of $3.75 \text{ mm} \pm 0.9 \text{ mm}$) resulted in a mean loss of 6° of supination ($p > 0.05$). At a 20% reduction of muscle excursion (mean reduction of $8.25 \text{ mm} \pm 0.9 \text{ mm}$ from the resting length), the mean supination loss was 32° ($p < 0.05$). After restricting the PQ by 30% of its initial length (mean reduction of $12.25 \pm 1.4 \text{ mm}$), a pronation contracture was established and a mean supination loss of 89° was measured ($p < 0.01$).

Table 1 Results from specimens tested in native and simulated contracture settings with all three loads applied

Specimen	Side	L_0	L_1	L_2	L_3
1	L	42	38	34	30
2	R	48	43	38	33
3	L	40	36	32	28
4	R	40	38	32	28
5	L	34	31	27	24
6	L	40	36	32	28
7	R	40	36	32	28
8	R	44	40	35	31
Mean		41 ± 4	37.25	32.75	28.75
Change from L_0		3.75	8.25 ± 0.9	12.5 ± 0.9	± 1.4

Abbreviations: L_0 , Resting length; L_1 , L_0 -10%; L_2 , L_0 -20%; L_3 , L_0 -30%.

Fig. 4 Increasing loss of supination with increasing loss of PQ excursion (simulated contracture), shown for three loads, with standard deviations (in this scenario the error bars represent the ranges of observed measures, with the wider bar for each state representing the average).

Notably, significant reduction in motion was observed at all testing lengths regardless of applied load. That is, greater force could not overcome the experimental muscle contracture.

Discussion

Previous studies of outcome and complications of distal radius fracture did not examine loss of forearm rotation in detail.^{9–12} A small number of investigators have dealt with the pathomechanics of loss of forearm rotation. In a cadaver study, Kihara et al evaluated the effects of dorsally angulated distal radius fractures on the DRUJ and found limited pronation and supination, as a result of lack of congruency of the DRUJ and tightness of the interosseous membrane.⁴ Bronstein et al studied the effect of distal radius fracture malalignment patterns on forearm rotation in a cadaver model.³ Their results suggested that acute loss of forearm rotation could be expected with ulnar translation of 5 mm or radial shortening of 10 mm, because of DRUJ incongruity from fracture malalignment. Rotational loss was not seen acutely with dorsal tilt or radial translation patterns, and the authors felt that, in these situations, any limitations of rotation could be the result of capsular scarring.

Like these authors, we have anecdotally observed persistent supination loss in some patients with good bony reductions (open and closed) despite therapy and adequate time for recovery postinjury. Kapandji identified that supination is the most important forearm movement, as its loss cannot be compensated by the shoulder, while a lack of pronation can be compensated by shoulder abduction.² Morrey et al described the range of elbow and forearm motion required to complete a series of everyday tasks.¹³ They reported that most activities of personal care and hygiene require supination to perform successfully.

The PQ is intimately related to the distal radius and to the DRUJ. An anatomic study by Koebke et al documented the two-headed nature of this muscle, the superficial head being the motor for pronation, and the deep head serving to maintain transverse forces at the DRUJ.¹⁴ Both heads are

seen to insert into the capsule of the DRUJ. Stuart confirmed these findings in anatomic studies and in vivo studies.¹⁵ Because the superficial head of the PQ directly overlies the distal radius where it is fractured and often displaced, it is probable that the PQ muscle is concomitantly injured in these fractures, and anecdotally we have seen such injuries. Radiological evidence of injury to the PQ is implicit in the “pronator quadratus sign,” or displacement of the relatively radiolucent plane overlying the muscle on lateral wrist X-ray by hematoma or edema within the muscle. Sasaki and Sugioka evaluated the usefulness of this sign and found displacement of the radiolucent shadow in 85% of 34 acute, undisplaced extra-articular distal radius fractures.¹⁶ Repeat X-ray examination at 6 weeks after injury showed the sign in only 32% of the 34 cases. The meaning of these temporal observations is not conclusive. One should, however, consider the PQ exposed to swelling in association with the original fracture trauma.

A recent clinical study examined the potential hazards of failing to repair the PQ after open volar approach.¹⁷ This study did not find a clear outcome difference between patients in whom repair was attempted and patients in whom it was not. However, this is not the question examined by this biomechanical study, in which PQ excursion is limited. Also, we note that the above study could not test the integrity of muscle repair in follow-up. Consequently, we still attempt to restore PQ muscle position after any volar distal forearm dissection—although this is a separate issue from impact of a PQ contracture.

As noted in the introduction, Kleinman and Graham have described capsular stiffness and scarring as causal agents related to loss of normal forearm rotation postinjury.¹ Another soft tissue structure to be considered as related to DRUJ stability and forearm motion is the distal interosseous membrane (DIOM). As discussed by Moritomo, this structure plays an important role in maintaining stability of the DRUJ.¹⁸ However, neither the DRUJ capsule nor the DIOM would necessarily be directly injured by relative volar displacement of the proximal metaphyseal segment/fragment of a distal radius fracture. Moreover, maintaining the integrity of these structures if they do not need to be released seems preferable. In the case of the capsule we would prefer to leave the nutrition to the joint intact, and release of the capsule could damage the TFCC and result in new joint instability. The DIOM should be isometric to joint rotation, so its release in the absence of bone deformity would be unlikely to have an effect other than potentially causing DRUJ instability.

We have demonstrated in vitro a consistent and significant loss of forearm supination when the excursion of this muscle is restricted. In the clinical setting, a traumatic process producing scarring of the PQ might have the same effect on muscle excursion and consequently, forearm rotation. Possibly, contracture occurrence would be less likely if the fracture were immobilized in full supination. Previous authors have supported the practice of immobilizing distal radius fractures in supination to minimize deforming forces.^{9,19} Our study lends evidentiary support to this practice.^{5,18,20,21} A major drawback of this study is that the PQ was considered in isolation, whereas prior authors have demonstrated that a

loss of forearm rotation was due to a contracture of the DRUJ capsule, and that this was amenable to an open capsulotomy. We also acknowledge that a suture does not have the same tensile strength or mechanical properties as the PQ muscle, introducing a source of error. In addition, we are assuming that decreased excursion is equivalent to shortening of the PQ muscle, which may not occur clinically.

Ethical Review

No IRB review was required, as this was a cadaver study.

Portions of this work were previously presented in poster format at the ASSH Annual Meeting (2000).

This study was performed in the Biomechanics Laboratory at the University of Minnesota under the direction of Jack Lewis, PhD.

Conflict of Interest

None

References

- Putnam MD, Rosenwasser MP, Koval K, Hanel DP. Distal Radius Study Group. Purpose, Method, Results, and Implications for Reporting Outcomes. In: Slutsky DJ, Osterman AL, eds. *Fractures and Injuries of the Distal Radius and Carpus: The Cutting Edge*. Philadelphia: Elsevier; 2008:33–46
- Kapandji A. Biomechanics of pronation and supination of the forearm. *Hand Clin* 2001;17(1):111–122, vii
- Bronstein AJ, Trumble TE, Tencer AF. The effects of distal radius fracture malalignment on forearm rotation: a cadaveric study. *J Hand Surg Am* 1997;22(2):258–262
- Kihara H, Palmer AK, Werner FW, Short WH, Fortino MD. The effect of dorsally angulated distal radius fractures on distal radioulnar joint congruency and forearm rotation. *J Hand Surg Am* 1996; 21(1):40–47
- Kleinman WB, Graham TJ. The distal radioulnar joint capsule: clinical anatomy and role in posttraumatic limitation of forearm rotation. *J Hand Surg Am* 1998;23(4):588–599
- Chung MS, Baek GH, Oh JH, Lee YH, Bin SW, Gong HS. The effect of muscle length and excursion on muscle contracture after tendon injury: a study in rabbit soleus muscles. *Injury* 2007;38(10): 1139–1145
- Van Heest AE, Murthy NS, Sathy MR, Wentorf FA. The supination effect of tendon transfer of the flexor carpi ulnaris to the extensor carpi radialis brevis or longus: a cadaveric study. *J Hand Surg Am* 1999;24(5):1091–1096
- Brand PW, Beach RB, Thompson DE. Relative tension and potential excursion of muscles in the forearm and hand. *J Hand Surg Am* 1981;6(3):209–219
- Cooney WP III, Dobyns JH, Linscheid RL. Complications of Colles' fractures. *J Bone Joint Surg Am* 1980;62(4):613–619
- Gliatis JD, Plessas SJ, Davis TRC. Outcome of distal radial fractures in young adults. *J Hand Surg [Br]* 2000;25(6):535–543
- Glowacki KA, Weiss APC, Akelman E. Distal radius fractures: concepts and complications. *Orthopedics* 1996;19(7):601–608
- Solgaard S. Function after distal radius fracture. *Acta Orthop Scand* 1988;59(1):39–42
- Morrey BF, Askew LJ, Chao EY. A biomechanical study of normal functional elbow motion. *J Bone Joint Surg Am* 1981;63(6): 872–877
- Koebke J, Werner J, Piening H. Der Musculus pronator quadratus—eine morphologische und funktionelle Analyse. *Anat Anz* 1984; 157(4):311–318
- Stuart PR. Pronator quadratus revisited. *J Hand Surg [Br]* 1996; 21(6):714–722
- Sasaki Y, Sugioka Y. The pronator quadratus sign: its classification and diagnostic usefulness for injury and inflammation of the wrist. *J Hand Surg [Br]* 1989;14(1):80–83
- Hershman SH, Immerman I, Bechtel C, Lekic N, Paksima N, Egol KA. The effects of pronator quadratus repair on outcomes after volar plating of distal radius fractures. *J Orthop Trauma* 2013;27(3): 130–133
- Moritomo H. The distal interosseous membrane: current concepts in wrist anatomy and biomechanics. *J Hand Surg Am* 2012;37(7): 1501–1507
- Sarmiento A, Zagorski JB, Sinclair WF. Functional bracing of Colles' fractures: a prospective study of immobilization in supination vs. pronation. *Clin Orthop Relat Res* 1980;(146):175–183
- Kleinman WB. Distal radius instability and stiffness: common complications of distal radius fractures. *Hand Clin* 2010;26(2): 245–264
- Kleinman WB. DRUJ contracture release. *Tech Hand Up Extrem Surg* 1999;3(1):13–22