

Examination of the Pronator Quadratus Muscle during Hardware Removal Procedures after Volar Plating for Distal Radius Fractures

Jae-Hwi Nho, MD, Hyun Sik Gong, MD*, Cheol Ho Song, MD*,
Seung Myung Wi, MD*, Young Ho Lee, MD*, Goo Hyun Baek, MD*

Department of Orthopedic Surgery, Soonchunhyang University College of Medicine, Cheonan,
**Department of Orthopedic Surgery, Seoul National University College of Medicine, Seoul, Korea*

Background: It is not clear whether the pronator quadratus (PQ) muscle actually heals and provides a meaningful pronation force after volar plating for distal radius fractures (DRFs). We aimed to determine whether the length of the PQ muscle, which is dissected and then repaired during volar plating for a DRF, affects the forearm rotation strength and clinical outcomes.

Methods: We examined 41 patients who requested hardware removal after volar plating. We measured the isokinetic forearm rotation strength and clinical outcomes including grip strength, wrist range of motion, and disabilities of the arm, shoulder and hand (DASH) scores at 6 months after fracture fixation. During the hardware removal surgery, which was performed at an average of 9 months (range, 8.3 to 11.5 months) after fracture fixation, we measured the PQ muscle length.

Results: The average PQ muscle length was 68% of the normal muscle length, and no significant relationship was found between the PQ muscle length and the outcomes including isokinetic forearm rotation strength, grip strength, wrist range of motion, and DASH scores.

Conclusions: This study demonstrates that the length of the healed PQ muscle does not affect isokinetic forearm rotation strength and clinical outcomes after volar plating for DRFs. The results of this study support our current practice of loose repair of the PQ that is performed by most of the surgeons to prevent tendon irritation over the plate, and suggest that tight repair of the PQ is not necessary for achieving improved forearm function.

Keywords: *Distal radius fracture, Volar plating, Pronator quadratus, Isokinetic strength*

The volar locking plate systems for open reduction and internal fixation of a distal radius fracture (DRF) have become a popular treatment option.^{1,2)} During the fracture repair through a volar approach, the pronator quadratus (PQ) muscle is stripped off the radius in order to apply the volar plate.³⁾ However, it is generally difficult to repair the PQ muscle at the end of the operation, because the muscle

fascia is not strong enough to hold sutures,⁴⁻⁶⁾ and the muscle can also be injured due to the fracture.^{7,8)} However, a recent study evaluated the integrity of the PQ muscle repair radiographically by using radiopaque hemoclips, and it reported that PQ repairs are generally durable.⁹⁾

The PQ muscle plays an important role in forearm pronation.^{10,11)} Regarding the role of the PQ muscle, McConkey et al.¹⁰⁾ showed that anesthetizing the PQ muscle resulted in a 21% decrease in pronation torque in healthy volunteers, and Armangil et al.¹²⁾ reported that the mean loss of pronation strength was 18.5% in patients operated by a volar approach compared to uninjured forearm. On the contrary, Swigart et al.⁹⁾ found that there was no significant difference between the extent of PQ injury ob-

Received August 25, 2013; Accepted September 29, 2013

Correspondence to: Hyun Sik Gong, MD

Department of Orthopedic Surgery, Seoul National University Bundang Hospital, Seoul National University College of Medicine, 82 Gumi-ro 173beon-gil, Bundang-gu, Seongnam 463-707, Korea

Tel: +82-31-787-7198, Fax: +82-31-787-4056

E-mail: hsgong@snu.ac.kr

served during the fracture fixation and clinical outcomes that included wrist motion and grip strength. In addition, studies reported outcomes that were not significantly different between injured and uninjured forearms or between PQ repair in patients with a DRF treated with volar plating.^{4,13,14} However, none of the studies have assessed the correlation between the actual anatomical healing status of PQ after volar plating and clinical outcomes.

In this study, we evaluated the degree of healing of the PQ muscle during the process of hardware removal in patients who had undergone volar plating for DRFs. The purpose of this study was to determine whether the length of the healed PQ muscle, which is dissected during volar plating for a DRF, has any impact on the clinical outcomes such as isokinetic forearm rotation strength, grip strength, wrist range of motion (ROM) and disabilities of the arm, shoulder and hand (DASH) scores.

METHODS

Subjects

The Institutional Review Board of Seoul National University Bundang Hospital (B-1103/123-106) approved the design and protocol of this study.

From March 2009 to February 2012, we prospectively recruited 41 consecutive patients who requested a hardware removal procedure after volar plating for DRFs for reasons such as vague discomfort due to the hardware or a personal desire to remove the metal implant from their body. We excluded the patients who underwent operations because of hardware-related complications, such as flexor or extensor tendon injuries. We also excluded the patients who had an associated carpal bone injury, a neurovascular injury, multiple fractures, complex regional pain syndrome, or a condition that may affect the muscle function, such as stroke. We did not operate on ulnar styloid fractures in these study patients. There were 33 women and 8 men, with an overall mean age of 55 years (standard deviation [SD], 12 years; range, 21 to 71 years). The right wrist was injured in 16 patients and the left wrist was injured in 25 patients.

All of the patients were operated on by one of the authors and the PQ muscles were routinely stripped off at the radial insertion. Fractures were fixed using a volar locking plate system (Acumed, Hillsboro, OR, USA). The PQ muscle was repaired to the insertion as close as possible using absorbable sutures with the forearm in supination at the end of the operation. Postoperatively, wrists were immobilized using a short-arm volar plaster splint. At one week postoperatively, a removable wrist brace was

placed on wrists. Physiotherapy was started at 2 weeks postoperatively, and braces were used for 6 weeks as needed.

Clinical Evaluations

At 6 months after the fracture repair operation, all of the patients underwent isokinetic evaluation of forearm rotation strength, and clinical examinations including assessment of grip strength and wrist ROM, and patient-reported outcome questionnaires that use the DASH scores.

Isokinetic muscle strength was measured at a constant movement rate throughout the ROM.¹⁵⁻¹⁷ It has been reported that measurement of isokinetic strength of forearm rotation is a valid and reliable method for evaluating the muscle function.^{16,17} We performed tests using a Biodex System 3 PRO (Biodex Co., Shirley, NY, USA) at the speed of 90°/sec. We first assessed the non-involved sides and then we assessed the injured sides. Patients performed 10 repetitive isokinetic exercises, and we measured the peak torque (Nm, the highest torque measured) and total work (J, the greatest amount of work performed). We measured the grip strength using the Jamar dynamometer (Asimow Engineering, Los Angeles, CA, USA) with the elbow flexed at 90° and the forearm in neutral rotation. We recorded the results in kilograms.¹⁸ A single physician measured the wrist ROM using a standard goniometer. We also requested the patients to complete the DASH questionnaire,¹⁹ which evaluates general disabilities related to the upper extremity. The DASH scores range from 0 to 100, where lower scores indicate less upper extremity disability.

The radiographs of all initial fractures were reviewed and fractures were classified according to the AO classification as type A (extra-articular fractures), B (partial articular fractures), or C (complex articular fractures) and their subtypes.²⁰ Of the 41 patients with a DRF, fracture in one patient was classified as type A1, fracture in 8 patients was classified as type A2, fracture in none of the patients was classified as type A3, fracture in 2 patients was classified as type B1, fracture in none of the patients was classified as type B2, fracture in 1 patient was classified as type B3, fracture in 6 patients was classified as type C1, fracture in 13 patients was classified as type C2, and fracture in 10 patients was classified as type C3.

Observation of the Pronator Quadratus Muscle

Hardware removal was performed at an average of 9 months (range, 8.3 to 11.5 months) after initial volar locking plating by one surgeon under regional or general anesthesia. Briefly, an incision was made overlying the

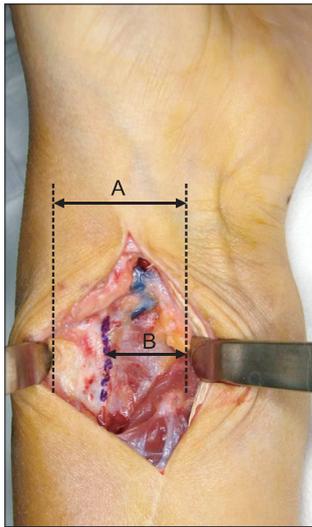


Fig. 1. Intraoperative photograph of the pronator quadratus (PQ) muscle covering the volar plate. The length of the healed PQ muscle was measured using a ruler at 2 cm proximal to the distal radioulnar joint between the lateral border of the ulna and the lateral margin of the muscular part along the direction of its fibers (B). For the reference length of the PQ muscle, we measured the length between the lateral border of the ulna and the lateral border of the radius (A). The relative length of the PQ muscle was calculated as B/A (%).

flexor carpi radialis (FCR) tendon along the old operative scar. The FCR tendon was retracted ulnarly after its tendon sheath was opened, and then the PQ muscle was examined. The distal radioulnar joint (DRUJ), which was identified by palpating its proximal capsule with a probe, was used as the distal landmark of the PQ muscle. The radial border of the ulna, which was identified by inserting a retractor on the ulna, was used as the ulnar landmark of the PQ muscle. The length of the healed PQ muscle was measured using a ruler at 2 cm proximal to the DRUJ between the lateral border of the ulna and the lateral margin of the muscular part along the direction of its fibers (B in Fig. 1). For the reference length of the PQ muscle, we measured the length between the lateral border of the ulna and the lateral border of the radius (A in Fig. 1). The relative length of the healed PQ muscle was calculated as B/A (%) (Fig. 1). Measurements were performed by a single operating surgeon throughout the study, who was blinded to the isokinetic and clinical outcomes.

Data Analysis

Isokinetic forearm rotation strengths were expressed as a percentage of those of the contralateral sides. Similarly, grip strength and wrist ROM were expressed as a percentage of those of the contralateral sides. Adjustment for hand

dominance was considered for assessing grip strength, as grip strength of the dominant hand was reported to be 10% greater than that of the non-dominant hand.¹⁸⁾ For assessing isokinetic forearm rotation strength, data with and without adjustment for hand dominance were calculated, as studies showed that the rotational strength is not different between the dominant and non-dominant forearms when measured by isokinetic tests.^{15,21)}

We categorized the patients based on the median value of the relative PQ muscle length into either group A (lower half) or group B (upper half). The 2 groups were compared in terms of demographic data, isokinetic forearm rotation strength, and clinical outcomes including grip strength, wrist ROM, and DASH scores. We compared categorical data using the chi-square test and continuous data using the *t*-test. We performed correlation analyses to determine the relationship between the relative PQ muscle length and the variables.

For the retrospective power analysis, we used the peak pronation strength as the primary outcome and attempted to determine a difference of 25% between the two groups, with a SD of 24% in overall patients for an effect size of 1. Thus, the power analysis indicated that a sample size of 17 would provide 80% statistical power to detect an effect of this size between the two groups ($\alpha = 0.05$, $\beta = 0.2$) with the use of the *t*-test. Therefore, the comparison between the group A ($n = 23$) and group B ($n = 18$) met the statistical power requirements of this study.

RESULTS

The average relative length of the PQ muscle was 68% of the normal reference length. Twenty-three patients were included in group A (lower half; less than 68%) and 18 patients were included in group B (upper half; equal to or more than 68%). There were no statistically significant differences in isokinetic forearm pronation strength and clinical outcomes including grip strength, wrist ROM, and DASH scores between the two groups (Table 1). There were no statistically significant differences in age ($p = 0.905$) and fracture type ($p = 0.579$) between group A and group B. However, there was a significant difference in the proportion of involvement of the dominant hand ($p = 0.028$), with group A including a greater number of dominant hands than group B (Table 1).

Correlation analyses indicated there were no significant correlations between the relative PQ muscle length and patient age ($p = 0.904$), isokinetic peak pronation strength ($p = 0.178$) or total pronation work ($p = 0.534$), isokinetic peak supination strength ($p = 0.211$) or total

Table 1. Demographic Data and Clinical Outcomes

Variable	Overall	Group A (n = 23)	Group B (n = 18)	p-value
Age (yr)	55 ± 12	55 ± 13	55 ± 10	0.905
Fracture type				0.579
A	9	6	3	
B	3	2	1	
C	29	15	14	
Affected hand (dominant:non-dominant)	16:25	12:11	4:14	0.028
Relative muscle length of the pronator quadratus (%)	68 ± 32	42 ± 18	91 ± 11	< 0.001
Isokinetic strength (%)*				
Peak pronation strength	79 ± 24 (79 ± 24)	85 ± 23 (81 ± 23)	72 ± 25 (77 ± 24)	0.163 (0.587)
Total pronation work	72 ± 47 (73 ± 45)	81 ± 60 (77 ± 56)	64 ± 27 (69 ± 28)	0.315 (0.648)
Peak supination strength	81 ± 50 (92 ± 48)	77 ± 57 (96 ± 55)	86 ± 38 (85 ± 38)	0.320 (0.221)
Total supination work	91 ± 83 (89 ± 84)	97 ± 89 (95 ± 89)	85 ± 79 (80 ± 79)	0.703 (0.789)
Grip strength (%)	69 ± 16	70 ± 17	67 ± 15	0.744
Wrist range of motion (%)				
Flexion	54 ± 13	54 ± 13	53 ± 14	0.752
Extension	64 ± 13	67 ± 11	61 ± 15	0.237
Pronation	78 ± 12	80 ± 9	74 ± 16	0.211
Supination	75 ± 13	77 ± 13	73 ± 13	0.364
DASH score	13 ± 13	13 ± 14	13 ± 11	0.912

Values are presented as mean ± SD.

DASH: disabilities of the arm, shoulder and hand.

*For isokinetic strength, values after adjusting for hand dominance are presented in the parentheses.

supination work ($p = 0.815$), grip strength ($p = 0.744$), and wrist pronation ($p = 0.269$) or supination ROM ($p = 0.939$).

All of the measured values in the injured sides were significantly lower than those in the normal sides at 6 months postoperatively (all $p < 0.001$). The average DASH score was 13 points (Table 1). All of the 41 patients achieved fracture union, and there were no cases of infection, neuropathy, or complex regional pain syndrome.

DISCUSSION

During volar plating for DRF repair, the PQ muscle, which is thought to be an important contributor to forearm pronation, is usually dissected. However, none of the studies have assessed the relationship between actual postoperative length of the healed PQ muscle and clinical outcomes. In this study, we assessed the healing status of the PQ

muscle during hardware removal procedures in patients who had undergone volar plating for DRFs. The results of this study showed that the length of the healed PQ muscle does not affect the clinical outcomes of volar plating for DRFs such as isokinetic forearm strength, grip strength, wrist ROM, and DASH scores.

The results of this study support the previous findings that dissection of the PQ muscle has minimal clinical impact on forearm rotation function.^{4,13,14} In a previous study that used isokinetic testing, Huh et al.⁴ found that after loose repair of the PQ muscle after volar plating, both pronation and supination strengths were lower in the operated sides than in the normal sides at 6 months postoperatively; but at 1 year postoperatively, pronation strength was not significantly different and the decrease in pronation strength did not affect clinical outcomes. Furthermore, Hershman et al.¹³ and Tosti and Ilyas¹⁴ reported

that no significant differences were found in clinical outcomes between patients who underwent PQ repair and those who did not undergo PQ repair.

The PQ muscle is composed of superficial and deep heads. The superficial head takes origin from the dorsoulnar border of the ulna and inserts into the broad flat volar surface of the radius, and the deep head has a similar origin, but from a slightly more volar part of the ulna, and inserts into the whole ulnar border of the distal radial shaft extending dorsally to the interosseous membrane.¹¹⁾ Thus, the superficial head is thought to contribute to pronation of the forearm, and the deep head to stabilization of the DRUJ.^{11,22)} During volar plating for DRF repair, the superficial head is dissected off the radius. Therefore, we consider that dissection of only the superficial head of PQ during volar plating and its subsequent healing with a shortened length may not affect its postural function during pronation, and that the undisturbed deep head of PQ does continue to function as a stabilizer of the DRUJ. We consider that anesthetizing the PQ muscle resulted in a relatively large 21% decrease in pronation torque in healthy volunteers in the study by McConkey et al.¹⁰⁾ could be attributable to the fact that both the superficial and deep heads of the PQ muscle were paralyzed by lidocaine injection.

Some authors have recommended preserving the PQ muscle,^{5,6,23)} or completely repairing the PQ muscle at the end of operation.^{6,10,13,24)} However, it is generally difficult to repair the PQ muscle at the radial margin of the radius since the muscle fascia is not strong enough to hold sutures.⁴⁻⁶⁾ Although Swigart et al.⁹⁾ reported that repair of the PQ muscle is durable on the basis of their radiographic examination of the radiopaque hemoclips, it is not certain whether absence of movement of the radiopaque hemoclips actually guarantees that the length of the muscle fibers is maintained. Furthermore, the length of the PQ muscle fibers is short compared with other forearm muscles, and the mean length of the superficial head is 36.6 mm (SD, 0.5 mm) and that of the deep head is 23.0 mm (SD, 0.3 mm).¹¹⁾ Thus, an overly tight repair may potentially cause an ischemic contracture of the PQ muscle or limited forearm supination due to the short excursion of the PQ muscle.^{8,25)}

In the current study, we did not find any difference in isokinetic forearm rotation strength and wrist ROM between the two groups. However, there was a significant

difference in the proportion of involvement of dominant hands ($p = 0.028$), with group A (lower half) including a greater number of dominant hands than group B (upper half). We suspect that the PQ muscles in the dominant sides healed with a more shortened length than those in the non-dominant sides because patients with involvement of the dominant hand may have started to use the wrist earlier, resulting in gap formation at the PQ repair site.

Some limitations of the present study need to be considered. First, only those patients who requested hardware removal were included in this study; thus, there may be a selection bias and the study may not represent the general status of PQ after injury. However, all of the patients were consecutively recruited, and our patients had DASH scores close to the normal value, and outcomes were comparable to those of previous studies.^{1,4)} Second, we measured only the length of the PQ muscle in the direction of its fibers. Measurement of the cross-sectional area or width along the radial or ulnar margin may reflect a different status of the PQ muscle. Third, pronator teres and other forearm flexor muscles could have an influence on forearm pronation, but the current isokinetic testing could not exclude the effect of these muscles. Lastly, we analyzed the clinical outcomes at 6 months after fracture fixation and prior to hardware removal procedures, since we thought that interpretation of the outcomes measured after hardware removal is difficult due to the effect of hardware removal surgery. However, the PQ muscle status at 6 months after fracture fixation may not represent the long-term follow-up status of the PQ muscle since muscle recovery may take time despite the fact that muscle length may not change over time.

In summary, this study demonstrates that the length of the healed PQ muscle does not affect the outcomes of volar plating for DRFs in terms of isokinetic forearm rotation strength, grip strength, wrist ROM, and DASH scores. The results of this study support our current practice of loose repair of the PQ muscle that is performed by most of the surgeons to prevent tendon irritation over the plate, and suggest that tight repair of the PQ muscle is not necessary for achieving improved forearm function.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

- Chung KC, Watt AJ, Kotsis SV, Margaliot Z, Haase SC, Kim HM. Treatment of unstable distal radial fractures with the volar locking plating system. *J Bone Joint Surg Am*. 2006;88(12):2687-94.
- Lozano-Calderon SA, Doornberg JN, Ring D. Retrospective comparison of percutaneous fixation and volar internal fixation of distal radius fractures. *Hand (N Y)*. 2008;3(2):102-10.
- Protopsaltis TS, Ruch DS. Volar approach to distal radius fractures. *J Hand Surg Am*. 2008;33(6):958-65.
- Huh JK, Lim JY, Song CH, Baek GH, Lee YH, Gong HS. Isokinetic evaluation of pronation after volar plating of a distal radius fracture. *Injury*. 2012;43(2):200-4.
- Dos Remedios C, Nebout J, Benlarbi H, Caremier E, Sam-Wing JF, Beya R. Pronator quadratus preservation for distal radius fractures with locking palmar plate osteosynthesis: surgical technique. *Chir Main*. 2009;28(4):224-9.
- Heidari N, Clement H, Kosuge D, Grechenig W, Tesch NP, Weinberg AM. Is sparing the pronator quadratus muscle possible in volar plating of the distal radius? *J Hand Surg Eur Vol*. 2012;37(5):402-6.
- Fallahi F, Jafari H, Jefferson G, Jennings P, Read R. Explorative study of the sensitivity and specificity of the pronator quadratus fat pad sign as a predictor of subtle wrist fractures. *Skeletal Radiol*. 2013;42(2):249-53.
- Chloros GD, Papadonikolakis A, Ginn S, Wiesler ER. Pronator quadratus space and compartment syndrome after low-energy fracture of the distal radius: a case report. *J Surg Orthop Adv*. 2008;17(2):102-6.
- Swigart CR, Badon MA, Bruegel VL, Dodds SD. Assessment of pronator quadratus repair integrity following volar plate fixation for distal radius fractures: a prospective clinical cohort study. *J Hand Surg Am*. 2012;37(9):1868-73.
- McConkey MO, Schwab TD, Travlos A, Oxland TR, Goetz T. Quantification of pronator quadratus contribution to isometric pronation torque of the forearm. *J Hand Surg Am*. 2009;34(9):1612-7.
- Stuart PR. Pronator quadratus revisited. *J Hand Surg Br*. 1996;21(6):714-22.
- Armangil M, Bezirgan U, Basarir K, Bilen G, Demirtas M, Bilgin SS. The pronator quadratus muscle after plating of distal radius fractures: is the muscle still working? *Eur J Orthop Surg Traumatol*. 2014;24(3):335-9.
- 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):130-3.
- Tosti R, Ilyas AM. Prospective evaluation of pronator quadratus repair following volar plate fixation of distal radius fractures. *J Hand Surg Am*. 2013;38(9):1678-84.
- Gallagher MA, Cuomo F, Polonsky L, Berliner K, Zuckerman JD. Effects of age, testing speed, and arm dominance on isokinetic strength of the elbow. *J Shoulder Elbow Surg*. 1997;6(4):340-6.
- Drouin JM, Valovich-mcLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol*. 2004;91(1):22-9.
- Oh JH, Yoon JB, Kim JY, Oh CH. Isokinetic muscle performance test can predict the status of rotator cuff muscle. *Clin Orthop Relat Res*. 2010;468(6):1506-13.
- Gunther CM, Burger A, Rickert M, Crispin A, Schulz CU. Grip strength in healthy caucasian adults: reference values. *J Hand Surg Am*. 2008;33(4):558-65.
- Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand). The Upper Extremity Collaborative Group (UECG). *Am J Ind Med*. 1996;29(6):602-8.
- Graff S, Jupiter J. Fracture of the distal radius: classification of treatment and indications for external fixation. *Injury*. 1994;25 Suppl 4:S-D14-25.
- Matsuoka J, Berger RA, Berglund LJ, An KN. An analysis of symmetry of torque strength of the forearm under resisted forearm rotation in normal subjects. *J Hand Surg Am*. 2006;31(5):801-5.
- Gordon KD, Dunning CE, Johnson JA, King GJ. Influence of the pronator quadratus and supinator muscle load on DRUJ stability. *J Hand Surg Am*. 2003;28(6):943-50.
- Sen MK, Strauss N, Harvey EJ. Minimally invasive plate osteosynthesis of distal radius fractures using a pronator sparing approach. *Tech Hand Up Extrem Surg*. 2008;12(1):2-6.
- Cross AW, Schmidt CC. Flexor tendon injuries following locked volar plating of distal radius fractures. *J Hand Surg Am*. 2008;33(2):164-7.
- Berglund LM, Messer TM. Complications of volar plate fixation for managing distal radius fractures. *J Am Acad Orthop Surg*. 2009;17(6):369-77.