Shear wave elastography in the pronator quadratus muscle following distal radial fracture fixation: A feasibility study comparing the operated versus nonoperated sides

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Abstract

The aim of this study was to assess changes in shear wave velocity within the pronator quadratus muscle in patients following volar plate fixation for distal radial fractures compared to the contralateral nonoperated side. Shear wave velocity values were obtained in the short and long axis of the pronator quadratus muscle, which were analyzed separately. Patients were also stratified by age below or above 66 years. Statistical analysis was performed using paired sample Wilcoxon signed rank and t tests. Pearson and Spearman rank correlations were also used. Seventeen patients (nine women and eight men; age range 33–82, mean 62.4 years) were prospectively assessed following open reduction volar plate fixation of distal radial fracture. A statistically significant reduction in the velocities of the treated versus the nontreated side was observed in the long axis of the muscle (3.29 versus 3.59 m/second; t test $p = 0.035$). The data provide evidence for shear wave elastography as a quantitative measure to assess postoperative changes in muscle and a potential tool to monitor the efficacy of rehabilitation.

Keywords

Shear wave velocity, elastography, ultrasound, muscle, pronator quadratus

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Introduction

Distal radius fractures represent one of the most common injuries encountered in orthopedic practice making up 8–15% of all osseous injuries in adults, with a significant number requiring open reduction and volar plate fixation.¹ Despite being one of the most frequently performed orthopedic procedures there remains debate with respect to various interventions used in postoperative rehabilitation.² A painless stable wrist with good forearm function represents the primary goal of treatment.

The pronator quadratus contributes to forearm rotation and distal radioulnar joint stability. Pronation torque measurements have suggested a mean loss of pronator strength of up to 18.5% and the mean loss

of pronator durability of 12.9% indicating pronator insufficiency in the postoperative wrist compared to uninjured side.³ Ultrasonography of the pronator quadratus has been investigated in several studies evaluating normal and pathological states including occult distal forearm bone injuries and anterior interosseous nerve injury.^{4–7} Ultrasonographic measurements of pronator quadratus muscle cross sectional area and

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muscle thickness have also been shown to correlate with handgrip strength.⁸ Despite this, there has been no evaluation of pronator quadratus muscle shear wave sonoelastography to assess the altered mechanical properties following surgery.

Shear wave elastography (SWE) is a noninvasive technique allowing accurate objective assessment of the elastic properties within musculature.^{9–11} SWE utilizes acoustic radiation force impulse technology by which a focused acoustic beam generated by the US transducer compresses the underlying tissue inducing a local shear wave. The speed of wave propagation known as the shear wave velocity (SWV) is subsequently measured as it traverses the tissue, displayed as a parametric image or by selective region-of-interest (ROI) analysis in meters per second on the ultrasound image.

There have been numerous publications evaluating the passive and active SWE of musculature^{12–21} as well as several reports suggesting potential clinical utility of sonoelastography such as in the assessment of the quadriceps muscles in patients with patellofemoral pain syndrome²² and for presurgical evaluation of the supraspinatus muscle prior to rotator cuff repair.²³ Furthermore, physiological variations in SWV within muscle have been demonstrated related to increasing age,^{24,25} following exercise in the context of delayed onset muscle soreness²⁶ as well as in various

pathological states, including myositis,²⁷ neuromuscular disease,^{28,29} degenerative atrophy related to supraspinatus tendon disease,³⁰ and in the poststroke upper extremity.³¹

This study set out to evaluate whether there is a differential in mechanical SWVs elicited by SWE within the pronator quadratus muscle in patients following operative fixation of distal radial fractures where atrophic changes may be expected, using the contralateral nonoperated side as an internal control.

Methods

Study design and population

This study was approved by the Institutional Review Board. All data collection conformed to Health Insurance Portability and Accountability Act standards with consent obtained prospectively from all patients. Between 2014 and 2016, patients who had undergone open reduction internal fixation of distal radial fractures with malleable volar plate and interlocking screw fixation (Figure 1) were referred for postoperative ultrasound imaging including SWE assessment. The procedures were performed by three surgeons at our institution. In all surgical fixations, the pronator quadratus was elevated off of the distal radius while maintaining its periosteum with the muscle.

Figure 1. (a) PA radiograph of the right wrist following open reduction internal volar plate and screw fixation for distal radial fracture. (b) Lateral radiograph of the right wrist following open reduction internal volar plate and screw fixation for distal radial fracture. PA: Posteroanterior.

Ultrasound imaging protocol

All SWV examinations were performed using an Acuson S3000 ultrasound system (Siemens Healthcare; Mountain View, CA, USA) and a linear-array transducer with a 9 MHz by one operator (RA with more than 20 years of musculoskeletal ultrasound experience and three years of SWV imaging experience). Gray scale and SWV imaging (Figure 2) were performed in all patients, with at least three separate sample velocity measurements obtained for each color map generated in both the pronator quadratus muscle of the operated and nonoperated side. The sample regions placed within each ROI were then used to calculate mean SWV values with use of incorporated customized Virtual Touch Imaging and Quantification (Siemens Medical Systems) software. Subjects were scanned in the resting position with their wrist supported in supination, so as not to induce muscle contraction. Image data were obtained in the approximate mid portion of each pronator quadratus muscle group avoiding the myotendinous junction (Figure 2). Measurements were obtained in both the long and short axis of the muscle.

Statistical analysis

The long- and short-axis values were analyzed separately. The treated and untreated sides were compared using paired sample Wilcoxon signed rank and t tests. Spearman rank correlations were used to characterize the association of the SWV measurements with age. The median age was 66 (mean $\pm$ SD: 62.4 ± 11.9 ; range: 33–82 years). Patients were divided into two groups based on age <66 years ($n=8$) and ≥ 66 ($n=9$) for analysis.

Clinical follow-up

An assessment of fracture healing was made as well as any postoperative complications documented.

Results

Between 2014 and 2016, 17 patients (nine women and eight men) who had undergone open reduction internal fixation of distal radial fractures with malleable volar plate and interlocking screw fixation were prospectively evaluated. The side involved was the left ($n=7$) and

Figure 2. (a) Gray-scale ultrasound images of the pronator quadratus muscle (white arrows) acquired in the sagittal plane, i.e. the short axis of the muscle. (b) Gray-scale ultrasound images of the pronator quadratus muscle (white arrows) acquired in the transverse plane, i.e. the long axis of the muscle with SWV measurements displayed. (c) Sonoelastogram acquired in the sagittal plane, i.e. the short axis of the muscle with SWV measurements displayed. (d) Sonoelastogram acquired in the transverse plane, i.e. the long axis of the muscle with SWV measurements displayed. SWV: shear wave velocity.

right ($n = 10$). The duration between surgery and ultrasound studies ranged from 4 to 29 months; mean 10.8 months.

A statistically significant reduction in the velocities of the treated group versus the nontreated side was observed in the long axis of the muscle (3.29 versus 3.59 m/second; t test $p = 0.035$). No significant difference between the two sides was observed in short axis (Tables 1 and 2).

Table 3 shows the Spearman correlation and p value for the association of age with the long- and short-axis velocities on the treated and untreated sides. No one correlation was significant ($p > 0.2$) and all would be characterized as weak ($|r| < 0.2$) or moderate ($0.2 < |r| < 0.3$).

One patient required operative revision for potential subchondral screw penetration of the joint. All other fractures were documented as healing or healed based on follow-up clinical examination and plain radiographic appearances.

Discussion

There is increasing interest in the practical clinical utility of SWE in the context of various rehabilitation protocols. High SWV has been associated with high spasticity and poor function in the poststroke upper limb and has been suggested as a reliable quantitative measure for disease progression and treatment follow-up.³¹ Reports have also suggested potential clinical

Table 1. The mean, standard deviation (SD), median, and interquartile range (IQR) of each measure on the treated and untreated sides. Results are presented for all patients and stratified by subject age.

Ages	Measure	Treated				Untreated			
		Mean	SD	Median	IQR	Mean	SD	Median	IQR
<66 ($n = 8$)	Long-axis PQ	3.25	0.32	3.22	0.54	3.53	0.46	3.41	0.81
≥66 ($n = 9$)	Long-axis PQ	3.32	0.29	3.30	0.43	3.66	0.48	3.47	0.75
All ($n = 17$)	Long-axis PQ	3.29	0.30	3.28	0.46	3.59	0.46	3.47	0.74
<66 ($n = 8$)	Short-axis PQ	3.05	0.70	2.91	1.11	3.46	1.27	2.97	1.93
≥66 ($n = 9$)	Short-axis PQ	3.16	0.91	3.13	1.02	3.61	0.89	3.43	0.87
All ($n = 17$)	Short-axis PQ	3.11	0.80	2.97	1.00	3.54	1.05	3.31	1.22

PQ: Pronator Quadratus.

Table 2. The mean, standard deviation (SD), median, and interquartile range (IQR) of the within-subject difference between the treated and untreated sides in terms of each measure and the p values from a paired sample Wilcoxon and t tests to compare the treated and untreated sides. Results are presented for all patients and stratified by subject age.

Ages	Measure	Mean	SD	Median	IQR	P values	
						t test	Wilcoxon
<66 ($n = 8$)	Long-axis PQ	−0.28	0.37	−0.14	0.63	0.074	0.080
≥66 ($n = 9$)	Long-axis PQ	−0.33	0.69	−0.49	1.10	0.188	0.343
All ($n = 17$)	Long-axis PQ	−0.31	0.55	−0.16	0.68	0.035	0.052
<66 ($n = 8$)	Short-axis PQ	−0.41	1.53	0.05	1.67	0.477	0.834
≥66 ($n = 9$)	Short-axis PQ	−0.45	0.71	−0.42	1.09	0.094	0.097
All ($n = 17$)	Short-axis PQ	−0.43	1.13	−0.38	1.22	0.137	0.142

PQ: Pronator Quadratus.

Table 3. Spearman correlation and p value for the association of age with the long- and short-axis velocities on the treated and untreated sides.

Side	Measure	Correlation	P value
Treated	Long axis	0.13	0.621
Treated	Short axis	−0.13	0.616
Untreated	Long axis	0.19	0.459
Untreated	Short axis	0.28	0.283

utility of sonoelastography in the assessment of the quadriceps muscles in patients with patellofemoral pain syndrome²² and presurgical evaluation of the supraspinatus muscle prior to rotator cuff repair.²³ SWE has shown promise in monitoring muscle training³² and could allow an additional quantitative measure of pronator quadratus mechanical properties during postoperative rehabilitation.

The pronator quadratus contributes to forearm rotation and distal radioulnar joint stability which can be compromised as a result of distal radius fracture and operative fixation. At the time of surgery the pronator quadratus is identified and usually released from its insertion on the radial side of distal radius in all subtypes of volar approach.

Ultrasonography of the pronator quadratus has been investigated in several studies evaluating normal and pathological states.^{4–7} Ultrasonographic measurements of pronator quadratus muscle cross sectional area and muscle thickness have been shown to correlate with handgrip strength.⁸ It would therefore be expected that the normalization of SWV values compared to the uninjured contralateral “internal control” wrist may allow an additional metric to evaluate and monitor the efficacy of physical therapy.

Following distal radial injury and resultant disuse there is frequently atrophy and fatty infiltration of the forearm and wrist musculature including the pronator quadratus. In the rotator cuff it has been demonstrated that SWV tends to decrease with increasing fatty infiltration of the supraspinatus muscle in patients with tendonopathy.³⁰ Our results demonstrate a similar significant SWV decrease in the long axis of the treated side compared to the untreated side. This is also congruent with the findings of Carpenter et al.²⁹ who demonstrated significantly lower mean SWV values in patients with GNE-related myopathy (a chronic myopathic autosomal recessive disease caused by biallelic mutations in the GNE gene encoding for a protein with key enzymatic activities in sialic acid biosynthetic pathway which leads to progressive muscle weakness

and wasting) than in control subjects. Although it is important to note however that in GNE myopathy, fat deposition is the primary structural abnormality and that disuse atrophy is likely morphologically different due to the amount of fibrous deposition in addition to fat. Interestingly, statistical difference was demonstrated only in the long axis of the muscle which may represent the optimal orientation for SWE muscle evaluation, likely related to the orientation of muscle fibers, as suggested by prior work in the biceps brachii and medial gastrocnemius.³³ No significant correlation was identified between SWV and increasing age in contrast to work by Eby et al.^{24,25} who found that velocities increased with advancing age.

The overall long-axis mean velocity was 3.66 m/second in the normal untreated side and 3.29 m/second in the treated side, average age 62.4 years. Roskopf et al.³⁰ reported the mean normal supraspinatus SWV as 3.0 m/second $\pm$ 0.5 and that in patients with tendinopathy to be 2.5 m/second $\pm$ 0.5, where the average age was 51.9 years. Agten et al.²⁶ assessed delayed-onset muscle soreness in the brachialis muscle demonstrating temporal changes in SWV that increased after exercise in men (before exercise, 3.00 $\pm$ 0.30 m/second; peak (15 minutes after exercise), 4.04 $\pm$ 0.90 m/second) and women (before, 2.82 $\pm$ 0.40 m/second; peak (one day after exercise), 3.23 $\pm$ 0.40 m/second).²⁶ These values are considerably higher than velocities in neck musculature measured in healthy volunteers by Kuo et al.³⁴ who demonstrated a mean velocity of 2.1 m/second $\pm$ 0.5 for the trapezius, 1.2 m/second $\pm$ 0.3 for the levator scapulae, 1.1 m/second $\pm$ 0.2 for the scalenus anterior muscle, and 0.9 m/second $\pm$ 0.1 for the sternocleidomastoid muscle.³⁴ Variation in the orientation of acquired data and the systems used may in part account for these differences, as well as the intrinsic structural composition of the different musculature.

Several limitations of this study should be considered. Although it is postulated that the measured SWV reflects the tissue stiffness of muscle tissue, the precise biomechanical and histopathologic alterations within the pronator quadratus muscle following operative fixation are not fully known. One patient underwent operative revision for potential subchondral screw penetration of the joint. All other fractures went on to heal radiologically and clinically with no postoperative complications identified, therefore it is uncertain how or if these changes in SWV are reflected clinically. There was only one ultrasound operator therefore no way to check the reproducibility of the SWV measurements. There was a lack of standardization given the varying time duration postsurgery at which the scans were performed, the effect of which on SWV is uncertain. There is no gold standard for correlation; however, the presence of an asymptomatic contralateral

wrist would hopefully serve to compensate for this. We did not adjust for handedness, although it is not clear whether this would affect the results in any significant way. SWV values vary depending on positioning of the ROI interrogated such as how close they are taken from the central tendon and also vary related to depth, therefore maintaining consistency is difficult. Avoiding the central tendon is necessary and given the limited resolution of elastograms, the SWV values may have been elevated somewhat. Every attempt was made to avoid placing the central tendon in the sample volumes and use of split screen was helpful in this regard. Orientation of the probe clearly plays a role due to the anisotropic nature of muscle and current ultrasound systems are not ideally suited for sampling in anisotropic media. Furthermore, the sample size is small and further larger scale work is required to confirm these findings. Despite this, the pattern of SWV alteration in an immobilized injured wrist is congruent with findings reported elsewhere related to muscle degeneration.

In summary, there is a significant decrease in long-axis velocity within the pronator quadratus muscle of the treated wrists compared to the uninjured normal contralateral side. Our results are compatible with findings recently published elsewhere in the literature and demonstrate evidence for SWE as a useful quantitative measure to assess postoperative changes in muscle. This may potentially provide an adjunct in assessing the efficacy of various rehabilitation protocols in the restoration of normal muscle properties in such cases.

Declaration of Conflicting Interests

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Guarantor

Dr Ronald S Adler.

Contributors

RA and CB devised the study. CB undertook the study and wrote the manuscript. JB advised on the statistical aspects of the study. All authors reviewed, edited and approved the manuscript.

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