Increased MR Signal Intensity in the Pronator Quadratus Muscle: Does It Always Indicate Anterior Interosseous Neuropathy?

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OBJECTIVE. The objective of this study was to assess the prevalence of increased signal intensity in the pronator quadratus in the general patient population. Using region-of-interest measurements, we measured the signal intensity of the pronator quadratus and of an adjacent flexor muscle. In addition, we performed independent subjective assessments of the pronator quadratus.

CONCLUSION. Increased signal intensity in the pronator quadratus is a frequent normal finding of unclear etiology and is not related to disease. Familiarity with this normal phenomenon is important to avoid overdiagnosis of denervation due to anterior interosseous nerve entrapment.

There are many causes of increased signal intensity on fluid-sensitive images of skeletal muscles, including acute exercise, trauma, infection, autoimmune disease, drugs, muscle necrosis, and denervation [1]. Muscle denervation, reflecting a subacute nerve injury, is usually depicted on MRI as diffuse increased signal on fluid-sensitive images in a single muscle or a group of muscles along the distribution of the affected nerve, with sparing of the adjacent fascial planes and subcutaneous fat [2]. The increased signal reflects a fluid shift into the extracellular space and develops secondary to a number of processes, such as peripheral entrapment, and to trauma and surgery [2]. Although these findings are well known, differentiation of denervation-related muscle signal alterations from other causes of muscle injury can be difficult.

Anterior interosseous nerve syndrome is a peripheral neuropathy of the anterior interosseous nerve in the proximal forearm [3]. The anterior interosseous nerve, a motor branch of the median nerve, supplies the pronator quadratus, flexor pollicis longus, and flexor digitorum profundus muscles of the middle and index fingers [4]. Thus, increased T2 signal on MRI in one or more of these muscles should raise the possibility of anterior interosseous nerve syndrome [5].

In our clinical practice, we have occasionally noted increased signal intensity on fluid-sensitive images of the pronator quadratus muscle, at both the wrist and forearm in patients without clinical evidence of anterior interosseous nerve syndrome. The purpose of this study was to quantify and subjectively assess the prevalence of increased signal intensity in the pronator quadratus in the general patient population because we have come to believe that it usually represents a normal finding rather than neuropathy.

Materials and Methods

Institutional review board approval and a waiver of informed consent were obtained for this retrospective HIPAA-compliant study.

A retrospective review of 100 consecutive 1.5-T MRI studies of the wrist in 98 patients (48 females and 50 males; two patients had bilateral studies) with a mean age of 36 years (range, 9–83 years) was conducted via a computer data search of all studies performed at our institution during a 3-month period. The patients were chosen irrespective of age, sex, and ethnicity. The studies were performed for a variety of reasons, the most common being wrist pain ($n = 28$). Other reasons were triangular fibrocartilaginous complex tear ($n = 16$), ligament tear ($n = 14$), fracture ($n = 11$), ganglion cyst ($n = 10$), scapholunate ligament tear ($n = 7$), mass ($n = 4$), and osteoid osteoma ($n = 2$). In addition, eight patients had one of the following indications: thumb pain, distal radioulnar joint injury, Kienböck disease, synovitis, scapholunate advanced collapse wrist, wrist edema, wrist injury, and rheumatoid arthritis. Clinical histories and MRI studies were evaluated for abnormal findings that would raise the possibility of an anterior interosseous nerve injury or other wrist disorder (e.g., infection, trauma, or tumor) that could explain the increased signal intensity in any of the

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volar wrist muscles. Eight wrists were excluded because of a history of recent trauma.

Ninety-five of the MR examinations of the wrist were performed using a 1.5-T scanner with a 5gp (Siemens Healthcare) surface coil. Five examinations were performed using a 3-T scanner. The field of view was 10–28 cm, and the matrix was 128–256 × 256–384. Oblique coronal T1 (TR/TE, 500/15), multiecho data imaging combination coronal (32/19; flip angle, 7°), fast multiplanar inversion-recovery coronal (4,000/48; flip angle, 150°; echo-train length, 8), axial proton density (3,000/35; echo-train length, 4), axial fat-suppressed proton density (TR/TE range, 4,000/31–79; echo-train length, 11), and oblique sagittal fat-suppressed proton density (2,500/31–79; echo-train length, 8) sequences were performed. Slice thickness was 1–6 mm.

By use of region-of-interest measurements, the signal intensity values of the pronator quadratus and of an adjacent flexor muscle were measured on axial fat-saturated proton density images at the distal radial level by a radiologist with 4 years of general radiology experience. The flexor digitorum superficialis was used approximately 80% of the time for comparison because it was the most prominent adjacent muscle. Alternatively, the flexor carpi ulnaris muscle belly was used when the flexor digitorum superficialis was less prominent. A region of interest, composed of 5–8 pixels, was drawn in the bellies of the selected muscles in approximately the same location in each study, while avoiding inclusion of nearby fat, bone, vessels, and fascia.

In addition, two radiologists, one with 22 years of musculoskeletal radiology experience and one with 7 years of musculoskeletal radiology experience, reviewed the studies independently. Each radiologist noted, subjectively, whether there was abnormal increased signal within the pronator quadratus.

The measurements were analyzed using an exact Wilcoxon's matched-pairs signed rank test, Pearson's correlation coefficients, Mann-Whitney test, Levene test, Spearman's rank correlation, and least squares regression.

Results

Objective Assessment

The signal intensity measurements of the pronator quadratus was greater than that of an adjacent flexor muscle in 79 of the 100 MRI examinations (79%) reviewed (Fig. 1A). In these cases, increased signal intensity was seen throughout the pronator quadratus muscle (Figs. 1B and 2). On average, the signal intensity value of pronator quadratus was 16.6% higher than that of the flexor muscle for the same patient. In our analysis, the mean ± SD signal intensity for the pronator quadratus was 309.2 ± 199.1 HU and that for an adjacent flexor muscle was 273.2 ± 190.6 HU. This difference in signal intensity values between the pronator quadratus and flexor muscle was further supported by an exact Wilcoxon's matched-pairs signed rank test as a way to assess the significance of the difference between the two numbers. This test showed that the mean signal intensity value of pronator quadratus was statistically significantly higher than that of an adjacent flexor muscle ($p < 0.0001$) when the measurements were provided for the same patient. There was also a highly significant ($p < 0.0001$) positive correlation of 0.968 between the measured values of the pronator quadratus and flexor muscles. A regression line can be used to predict the region of interest of the pronator quadratus from the region of interest of the flexor muscle by the following equation: predicted pronator quadratus = (33.02 + 1.011) × observed flexor muscle (Fig. 3).

There was no significant difference between males and females in terms of the signal intensity values of either the pronator quadratus muscle ($p = 0.506$) or the adjacent flexor muscle ($p = 0.931$). Although males were observed to have a higher mean signal intensity value for either the pronator quadratus or the flexor muscle than did females, these differences were not found to be significant. There was a trend for the signal intensity of the flexor muscle to exhibit greater variation among

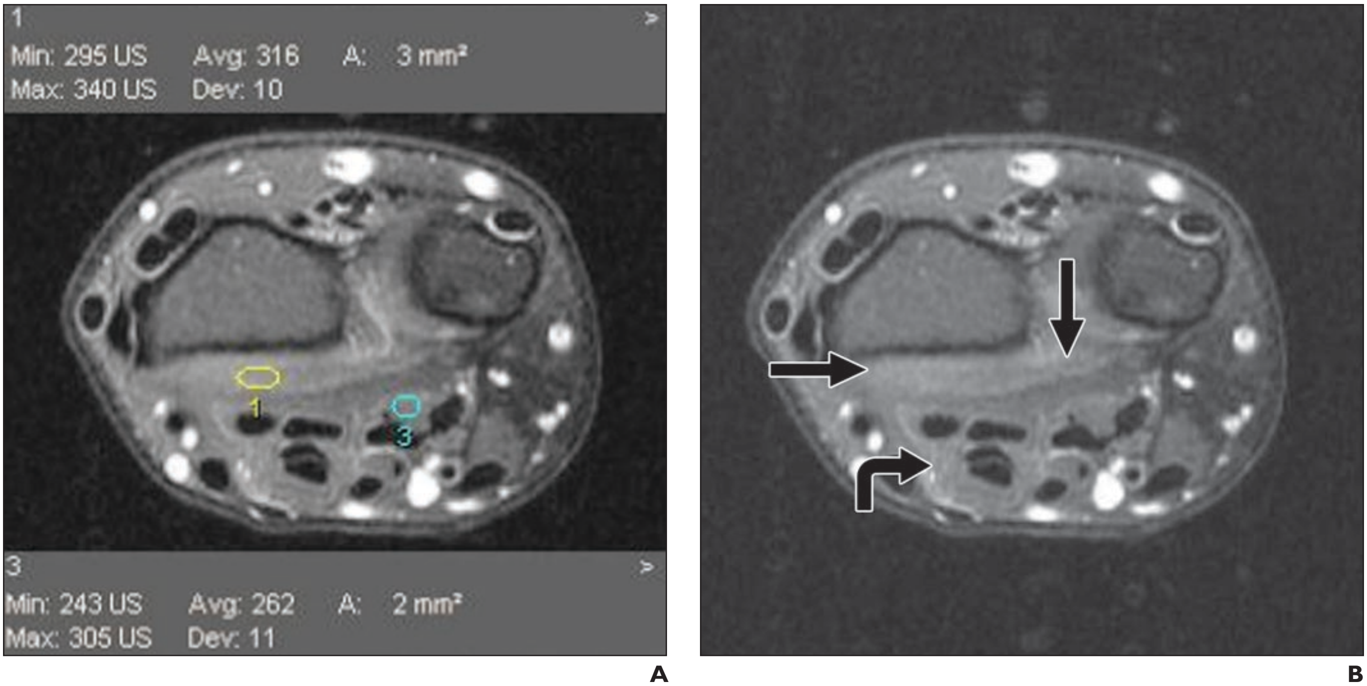

Fig. 1—Distal forearm of asymptomatic 61-year-old man.
A, Axial fat-suppressed proton density image shows diffuse homogeneous increased signal intensity in pronator quadratus muscle (*region of interest (ROI) 1 or 3*) compared with adjacent flexor muscle (*ROI 1 or 3*). Minimum (Min), maximum (Max), average (Avg), and SD (Dev) signal intensity values are provided. A = area of *ROI*.
B, Axial fat-suppressed proton density image shows diffuse homogeneous increased signal intensity in pronator quadratus muscle (*straight arrows*) compared with adjacent flexor muscles (*curved arrow*).

males than females, but the sex difference in the variation of flexor muscle signal intensity values did not achieve statistical significance ($p = 0.153$). There was also no significant sex difference in terms of the variation in the signal intensity values of the pronator quadratus muscle ($p = 0.417$) (Table 1).

A regression analysis to predict signal intensity values of the pronator quadratus and flexor muscles as a function of age and sex showed no significant interaction with either age ($p = 0.207$) or sex ($p = 0.166$). In other words, neither the signal intensity values of the pronator quadratus or flexor muscle nor the association between the two is dependent on sex or age. With regard to the association with age, Pearson's correlation coefficient for the flexor muscle was 0.11 ($p = 0.263$) and Pearson's correlation coefficient for the pronator quadratus muscle was 0.076 ($p = 0.453$).

Subjective Assessment

The two radiologists noted abnormal, increased signal in the pronator quadratus in 53% and 54% of the patients, respectively. This abnormal signal was homogeneous and tended to involve the radial aspect of the pronator quadratus more than the ulnar aspect. Although these findings were most obvious on the fat-saturated proton density images, they were also seen on the non-fat-saturated images but were not seen on the T1-weighted images.

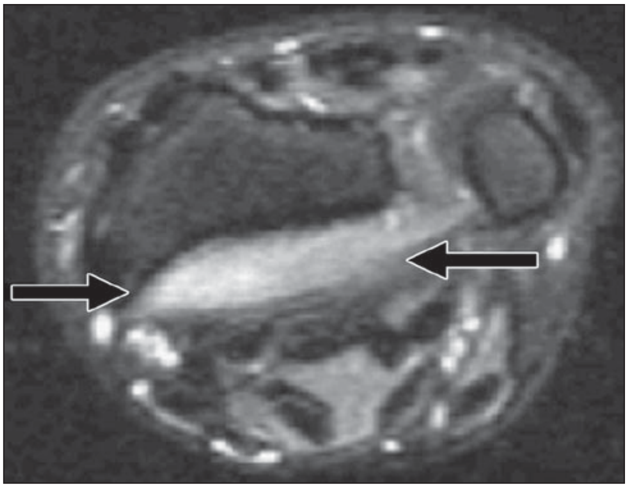

Fig. 2—Wrist of 41-year-old asymptomatic woman. Axial fat-suppressed proton density image shows diffuse homogeneous increased signal intensity in pronator quadratus muscle (*arrows*).

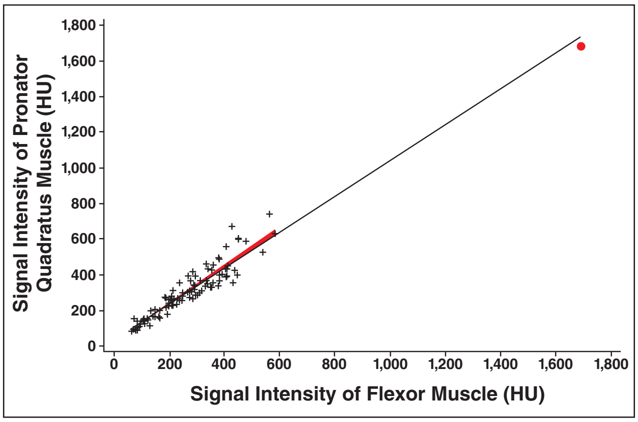

Fig. 3—Scatterplot of signal intensity values of pronator quadratus muscle versus flexor muscle shows regression lines to predict pronator quadratus from value of flexor muscle observed for same patient using all available data (*black line*). Data were reduced from 100 to 99 bivariate pairs through deletion of data (*red dot*) for one wrist. In that wrist, signal intensity values of flexor and pronator quadratus muscles were more than twofold higher than those observed in all other wrists (*red line*).

Discussion

Increased muscle signal on fluid-sensitive images is a nonspecific finding, with causes ranging from physiologic phenomena to muscle necrosis. The pattern of signal alteration, however, can provide guidelines for narrowing the differential diagnosis. The increased signal is typically focal in muscle contusion and is localized to the musculotendinous junction after a muscle strain [6]. Hematoma may also be seen with either entity. Heterogeneous muscle signal and involvement of the subcutaneous fat and fascial planes are common in compartment syndrome and in infectious and inflammatory processes, such as pyomyositis, myositis, and myonecrosis [7–9]. Unlike most of the other causes of increased muscle signal, denervation-related abnormal muscle signal is commonly homogeneous and diffuse and spares the surrounding soft tissues. It also usually follows a specific nerve distribution. There may not be significant MRI abnormalities in the acute phase of muscle denervation [2]. Most injuries manifest in the subacute phase, with increased T2 signal believed to reflect a shift in water from the intracellular to extracellular compartment.

One of the MRI features of anterior interosseous nerve injury is denervation-related increased signal intensity on fluid-sensitive images of the pronator quadratus, flexor pollicis longus, or radial aspect of the flexor digitorum profundus muscles [10]. Our review of 100 consecutive MRI examinations of the wrist indicates, however, that the increased signal intensity is a frequent and, likely, asymptomatic muscle attribute of the pronator quadratus. The high prevalence of our findings relative to the scarcity of anterior interosseous nerve syndrome further supports our results. The signal intensity in the pronator quadratus was 16.6% higher than that of an adjacent flexor muscle in the same patient. The increased signal was un-

TABLE 1: Signal Intensity of Flexor Muscle and Pronator Quadratus Muscle Among 98 Patients

Patient Sex	Signal Intensity (HU)	
	Flexor Muscle	Pronator Quadratus Muscle
Female ($n = 48$)[a]	258.6 ± 118.8	307.3 ± 142.9
Male ($n = 50$)[b]	287.3 ± 240.8	311.0 ± 242.7
p		
Mann-Whitney test	0.931	0.506
Levene test	0.153	0.417

Note—Data are mean ± SD. For p values, Mann-Whitney test was used to asses sex differences in terms of the signal intensity levels of the flexor muscle and pronator quadratus muscle, and Levene test was used to assess sex differences with respect to the variation in signal intensity values of flexor muscle and pronator quadratus muscle.

[a] Forty-nine wrists.

[b] Fifty-one wrists.

related to the patient sex and age, was statistically significant ($p < 0.0001$), and was seen in 79% of the wrists.

The subjective evaluations of the pronator quadratus were similar for the two radiologists. One radiologist thought that there was abnormal increased signal in the pronator quadratus compared with the adjacent flexor muscles in 53% of the wrists, whereas the other radiologist noted abnormal increased signal in 54% of the wrists. This abnormal signal was homogeneous and tended to involve the radial aspect of the pronator quadratus more than the ulnar aspect. The reason for the preference of the radial aspect is not clear.

Familiarity with the prevalence of relative increased pronator quadratus signal intensity is important to avoid the overdiagnosis of anterior interosseous nerve syndrome on MRI studies of either the forearm or wrist. Direct signs of denervation other than increased signal in the pronator quadratus, such as increased signal, abnormal shape, and course of the anterior interosseous nerve, should also be sought. In addition, because anterior interosseous nerve syndrome may also affect the flexor pollicis longus and flexor digitorum profundus, evaluation of these muscles for increased T2 signal or denervation atrophy is recommended before anterior interosseous nerve syndrome is diagnosed. Most important, the MRI findings should be correlated with clinical features compatible with anterior interosseous nerve syndrome, such as weakness of the pronator quadratus, flexor pollicis longus, and flexor digitorum with no associated sensory deficit [3]. Correlation with electrodiagnostic study results may also be performed to confirm imaging findings.

The cause for the increased signal intensity in the pronator quadratus is unclear. A similar phenomenon of increased muscle signal is occasionally noted in the supinator and in the gastrocnemius muscles. One explanation could be the magic angle effect resulting from either horizontal or spiraling orientation of fibers in those muscles. Furthermore, several groups of researchers have attempted to correlate T1 and T2 relaxation times with muscle properties, such as fiber type, fiber distribution, and fiber activity [11–15]. A review of these studies reveals that the relationship of these muscle properties to the relaxation times is not fully understood. Thus, although it is possible that the increase in signal intensity in the pronator quadratus muscle is related to the magic angle effect, its fiber type composition, prevalence of fat within the muscle, or a sign of recent activity, a clear answer is not available at this time. The increased signal intensity is likely multifactorial in origin and will be explained as physiologic and functional imaging continues to advance in use and scope.

There are a few limitations to our study. The retrospective nature of the study hindered our ability to obtain a complete clinical history and pertinent follow-up information and may have introduced a sample bias. Another limitation is that clinical cases, not asymptomatic patients, were used for the study. On the basis of the clinical histories provided, however, none of the patients had any symptoms consistent with anterior interosseous nerve syndrome. The small sample pool of patients and the lack of surgical correlation are other limitations.

In summary, we found that diffuse homogeneous increased signal intensity in the pronator quadratus on fluid-sensitive images compared with that in the adjacent flexor muscles is a frequent and is likely a normal finding of no clinical significance. We hypothesize that the cause of increased signal may be multifactorial and may possibly be related to muscle fiber type and activity. Careful correlation of increased signal intensity in pronator quadratus with clinical findings and other MRI pathologic findings should be performed before assuming muscle disease such as anterior interosseous nerve–related denervation.

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References

1. May DA, Disler DJ, Jones EA, Balkissoon AA, Manaster BJ. Abnormal signal intensity in skeletal muscle at MR imaging: patterns, pearls, and pitfalls. *RadioGraphics* 2000; 20:S295–S315
2. Fleckenstein JL, Watumull D, Conner KE, et al. Denervated human skeletal muscle: MR imaging evaluation. *Radiology* 1993; 187:213–218
3. Chin DHCL, Meals RA. Anterior interosseous nerve syndrome. *J Am Soc Surg Hand* 2001; 1:249–257
4. Standring S. *Gray's anatomy: the anatomical basis of clinical practice*. New York, NY: Elsevier, 2005:772
5. Grainger AJ, Campbell RS, Stothard J. Anterior interosseous nerve syndrome: appearance at MR imaging in three cases. *Radiology* 1998; 208:381–389
6. Resnick D, Goergan TG. Physical injury: concepts and terminology. In: Resnick D, ed. *Diagnosis of bone and joint disorders*, 4th ed. Philadelphia, PA: Saunders, 2002:2759
7. Resnick D, Goergan TG. Physical injury: concepts and terminology. In: Resnick D, ed. *Diagnosis of bone and joint disorders*, 4th ed. Philadelphia, PA: Saunders, 2002:2761–2762
8. Resnick D. Dermatomyositis, polymyositis, and other inflammatory myopathies. In: Resnick D, ed. *Diagnosis of bone and joint disorders*, 4th ed. Philadelphia, PA: Saunders, 2002:1230–1235
9. Nunez-Hoyo M, Gardner CL, Motta AO, Ashmead JW. Skeletal muscle infarction in diabetes: MR findings. *J Comput Assist Tomogr* 1993; 17:986–988
10. Bencardino JT, Rosenberg ZR. Entrapment neuropathies of the upper extremity. In: Stoller D, ed. *Magnetic resonance imaging in orthopaedics and sports medicine*, 3rd ed. New York, NY: Lippincott, Williams & Wilkins, 2006:1960
11. Fisher MJ, Meyer RA, Adams GR, et al. Direct relationship between proton T2 and exercise intensity in skeletal muscle MR images. *Invest Radiol* 1990; 25:480–485
12. Fleckenstein JL. Muscle water shifts, volume changes, and proton T2 relaxation times after exercise. (letter) *J Appl Physiol* 1993; 74:2047–2048
13. Houmard JA, Smith R, Jendrasiak GL. Relationship between MRI relaxation time and muscle fiber composition. *J Appl Physiol* 1995; 78:807–809
14. Kuno S, Katsuta S, Inouye T, et al. Relationship between MR relaxation time and muscle fiber composition. *Radiology* 1988; 169:567–568
15. Parkkola R, Alanen A, Kalimo H, et al. MR relaxation times and fiber type predominance of the psoas and multifidus muscle: an autopsy study. *Acta Radiol* 1993; 34:16–19