The Stabilizing Effect of the Distal Interosseous Membrane on the Distal Radioulnar Joint in an Ulnar Shortening Procedure: A Biomechanical Study

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Investigation performed at the Mayo Clinic, Rochester, Minnesota

Background: The importance of the stabilizing effect of the distal interosseous membrane on the distal radioulnar joint, especially in patients with a distal oblique bundle, has been described. The purpose of this study was to evaluate the stability of the distal radioulnar joint after an ulnar shortening osteotomy and to quantify longitudinal resistance to ulnar shortening when the osteotomy was proximal or distal to the ulnar attachment of the distal interosseous membrane. These relationships were characterized for forearms with or without a distal oblique bundle.

Methods: Ten fresh-frozen cadavers were used. A transverse osteotomy and ulnar shortening was performed proximal (proximal shortening) and distal (distal shortening) to the ulnar attachment of the distal interosseous membrane. Distal radioulnar joint laxity was evaluated as the volar and dorsal displacements of the radius relative to the fixed ulna with 20 N of applied force. Testing was performed under controlled 1-mm increments of ulnar shortening up to 4 mm, with the forearm in neutral alignment, 60° of pronation, and 60° of supination. Resistance to ulnar shortening was quantified as the slope of the load-displacement curve obtained by displacing the distal ulnar segment proximally.

Results: In proximal shortening, significantly greater stability of the distal radioulnar joint was obtained with even 1 mm of shortening compared with the control, whereas distal shortening demonstrated significant improvement in stability of the distal radioulnar joint only after shortening of ≥4 mm in all rotational positions. Significantly greater stability of the distal radioulnar joint was achieved with proximal shortening than with distal shortening and in specimens with a distal oblique bundle than in those without a distal oblique bundle. The longitudinal resistance to ulnar shortening was significantly greater in proximal shortening than in distal shortening. The stiffness in proximal shortening was not affected by the presence of a distal oblique bundle in the distal interosseous membrane.

Conclusions: Ulnar shortening with the osteotomy carried out proximal to the attachment of the distal interosseous membrane had a more favorable effect on stability of the distal radioulnar joint compared with distal osteotomy, especially in the presence of a distal oblique bundle.

Clinical Relevance: When ulnar shortening osteotomy is performed, there is a stabilizing effect on the distal radioulnar joint because of increased tensioning of the distal interosseous membrane.

The ulnar shortening osteotomy is an effective treatment for ulnar impaction syndrome[1-3]. Multiple methods and techniques have been described[4-11]. Minimal attention has focused on the appropriate osteotomy site for an ulnar shortening procedure. As it is not uncommon for ulnar impaction to coexist with distal radioulnar joint abnormalities[1], the influence of the osteotomy site on distal radioulnar joint stability is important.

Structures contributing to distal radioulnar joint stability include the dorsal and palmar radioulnar ligaments, triangular fibrocartilage complex, extensor carpi ulnaris subsheath, ulnocarpal ligaments, distal interosseous membrane, and the

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osseous anatomy[12-14]. The triangular fibrocartilage complex is the major soft-tissue stabilizer of the distal radioulnar joint, of which the dorsal and palmar radioulnar ligaments are the primary components[15]. Nishiwaki et al. reported that ulnar shortening can stabilize the distal radioulnar joint by increasing the tension of the triangular fibrocartilage complex[16]. Several studies have indicated that the distal interosseous membrane acts as a secondary stabilizer of the distal radioulnar joint[17-20]. Noda et al. reported that twelve of thirty cadavers examined displayed an obvious thick fiber within the distal membranous portion of the distal interosseous membrane, which they designated as the distal oblique bundle[19]. This structure originated from approximately the distal one-sixth of the ulnar shaft and inserted into the inferior rim of the sigmoid notch of the radius. Moritomo et al. found that the distal oblique bundle was essentially an isometric stabilizer of the forearm and suggested that the distal oblique bundle, when present, may stabilize the distal radioulnar joint because of its close anatomic relationship with the distal radioulnar joint and the triangular fibrocartilage complex[18].

These recent studies have increased the understanding of the potential stabilizing effect of the distal interosseous membrane on the distal radioulnar joint in ulnar shortening, especially in patients with a distal oblique bundle. Moreover, intraoperatively, there may be difficulties in achieving the desired amount of ulnar shortening because of increased tension when approximating the ulnar bone ends following osteotomy. It seemed plausible that increased distal interosseous membrane tension accompanying ulnar shortening with an osteotomy carried out proximal to the attachment of the distal interosseous membrane may improve the stability of the distal radioulnar joint.

The purposes of this study were to evaluate distal radioulnar joint stability following ulnar shortening osteotomy and to quantify longitudinal resistance to ulnar shortening when the osteotomy was proximal or distal to the ulnar attachment of the distal interosseous membrane. These relationships were contrasted in forearms with and without a distal oblique bundle.

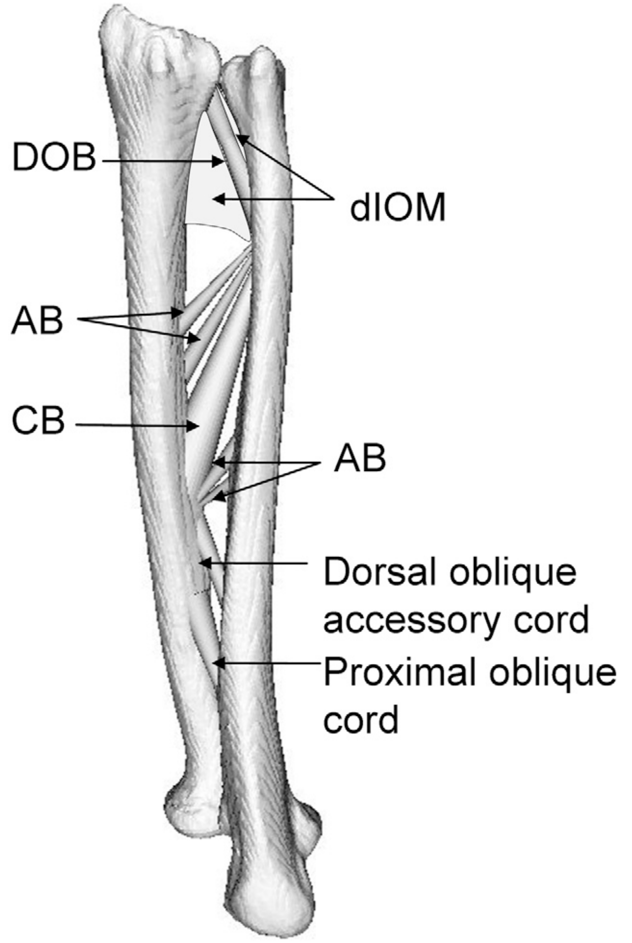

Fig. 1
Schematic structure of the interosseous membrane. There are distal, middle, and proximal portions. A distal oblique bundle (DOB) may be present within the distal interosseous membrane (dIOM). The middle portion includes the central band (CB) and the accessory band (AB). The proximal oblique cord and the dorsal oblique accessory cord are in the proximal membranous portion.

Materials and Methods

Ten fresh-frozen cadaveric upper extremities amputated at the midportion of the humerus were obtained by means of established procurement protocols through our institution. The ten extremities, including three right arms and seven left arms, were from five male and five female donors, with a mean age of seventy-nine years (range, fifty-nine to ninety-one years) at the time of death. All limbs were evaluated radiographically to rule out instability or articular pathology. Dissections after the investigation revealed no forearm with frank ligament or triangular fibrocartilage complex tears. Those noted to have mild wrist joint degeneration or chondromalacia on gross inspection were included. Posteroanterior radiographs of the wrist showed negative ulnar variance of 1 mm in one specimen and 2 mm in three specimens, with neutral variance in six specimens.

A skin incision was made along the radial side of the extensor carpi ulnaris to identify the ulnar attachment site of the distal interosseous membrane. The distal interosseous membrane was investigated in the same coronal plane as the central band and the accessory band[19] (Fig. 1). We identified the proximal attachment site of the distal interosseous membrane and measured its distance to the ulnar head. After all of the experimental steps were concluded, all structures except the interosseous membrane were removed to investigate whether a distal oblique bundle, descending from the ulna distally to the radius, was present[19]. The dorsal-volar thickness of the distal interosseous membrane was measured with use of a caliper (Precision Dial Caliper; General Tools and Instruments, New York, NY), and if the distal oblique bundle was present, its proximal-distal width was also measured.

Special attention was given to ensure that the proximal osteotomy site was at least 5 mm proximal to the proximal end of the attachment of the distal interosseous membrane. Two parallel proximal osteotomies were performed, with a 6-mm wafer of bone excised. The portion of the accessory band of the interosseous membrane attached to the excised bone was resected.

A modified seven-hole 3.5-mm AO dynamic compression plate was used for shortening (Fig. 2). The proximal three holes were combined into a single slot, which allowed controlled shortening of the ulna. After the osteotomy, the plate was tightened in its original position and the ulna was returned to its preosteotomy length, first by placing the excised bone back in its original position and then by removing it after plate tightening.

A previously described apparatus[20] was used to evaluate the contribution of the interosseous membrane to the constraint of the distal radioulnar

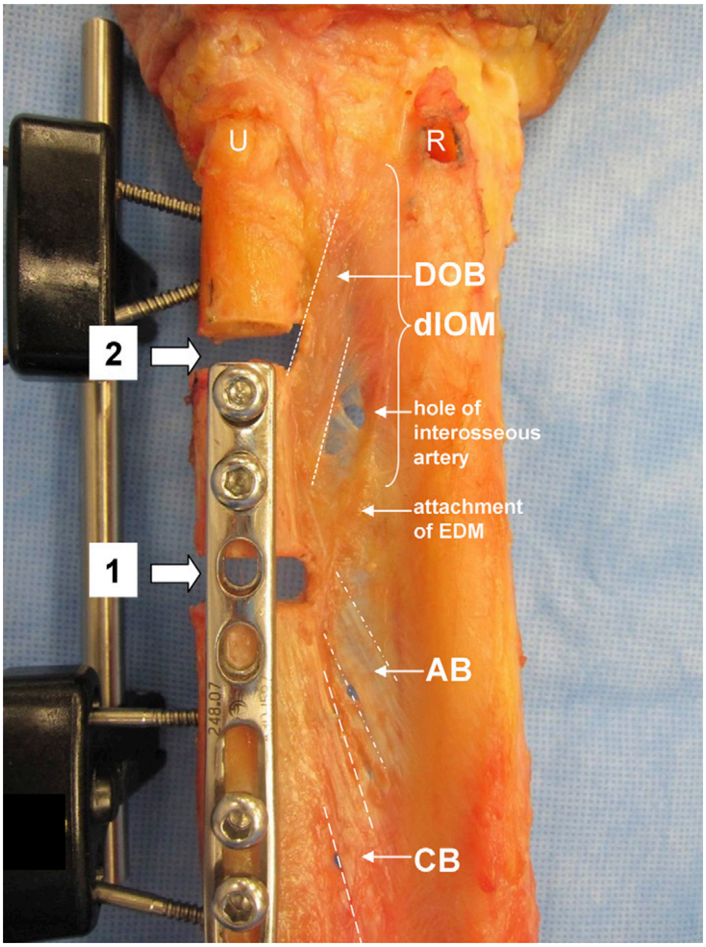

Fig. 2

Proximal shortening was performed with use of a custom-made plate, and distal shortening was done with use of the external fixator. A transverse osteotomy and ulnar shortening was performed proximally (proximal shortening; wide arrow, 1) and distally (distal shortening; wide arrow, 2) to the ulnar attachment of the distal interosseous membrane (dIOM). DOB = distal oblique bundle, R = radius, U = ulna, AB = accessory band, CB = central band, and EDM = extensor digiti minimi.

joint in each of three forearm rotational positions (Fig. 3-A). The humerus was clamped to the device, and the proximal part of the ulna was fixed securely to the testing frame, with use of a 3.5-mm bone plate, with the elbow flexed 90°. Tests were performed with the forearm in neutral alignment, 60° of pronation, and 60° of supination. Forearm rotation was measured with a clinical goniometer. The radiocarpal joint was fixed in the neutral position with use of a wrist external fixator (OrthoFrame/Mayo Wrist Fixator; OrthoLogic, Phoenix, Arizona) with the pins placed in the radial shaft and the second metacarpal.

After the desired forearm rotation was secured, testing was performed with volar and dorsal translation of the radius relative to the ulna in the transverse plane of the radius. The sum of the volar-to-dorsal displacement of the radius relative to the ulna was measured with use of a force-displacement probe placed on the distal end of the radius. The probe was attached through a hole drilled in the radius just proximal to the Lister tubercle, with use of a threaded rod placed perpendicular to the coronal plane of the radius and ulna with the forearm in neutral position. The probe incorporated a linear potentiometer (model TR50; Novotechnik, Ostfildern, Germany), with a linearity of ±0.15%, and a force transducer (model MLP-25; Transducer Techniques, Temecula, California), with a sensitivity of 0.02 N. For the evaluation of distal radioulnar joint laxity, displacement of the radius relative to the ulna was measured for volar and dorsal tensile forces of 20 N applied to the radius, with use of the method of Kihara et al.[17]. Distal radioulnar joint laxity was calculated by averaging four cycles of movement in each forearm position before shortening and after controlled shortenings at 1-mm intervals up to 4 mm, with use of the slotted plate. The 1-mm increments were measured with use of a caliper (Precision Dial Caliper; General Tools and Instruments).

Measurement of the longitudinal resistance to ulnar shortening was performed by securing the humerus, the proximal part of the ulna, and the radius to the apparatus. The radius was fixed to the frame through the connecting bar of the wrist external fixator. The resected distal end of the ulna was connected, through two threaded pins, to the vertical uniaxial load frame (MTS 810; MTS Systems, Eden Prairie, Minnesota), which provided the controlled shortenings and allowed monitoring of the compressive force required to achieve that shortening (Fig. 3-B). The plate was removed after connection of the distal end of the ulna to the MTS load frame, to prevent any rotation and dislocation of the ulna. One-dimensional load-displacement data were obtained continuously. The maximum compressive force required to shorten the ulna, without obvious disruption of the soft tissues, and the velocity of the ulnar shortening were based on previous studies[14,16]. This testing was also performed with the forearm in neutral rotation, 60° of pronation, and 60° of supination. Three cycles of load-displacement measurements were performed for each forearm position and were recorded dynamically on a personal computer.

After the laxity of the distal radioulnar joint and the longitudinal resistance to proximal shortening were tested, the plate on the ulna was tightened in the original position before the shortening, and a wrist external fixator (OrthoFrame/Mayo Wrist Fixator; OrthoLogic) was then attached for distal

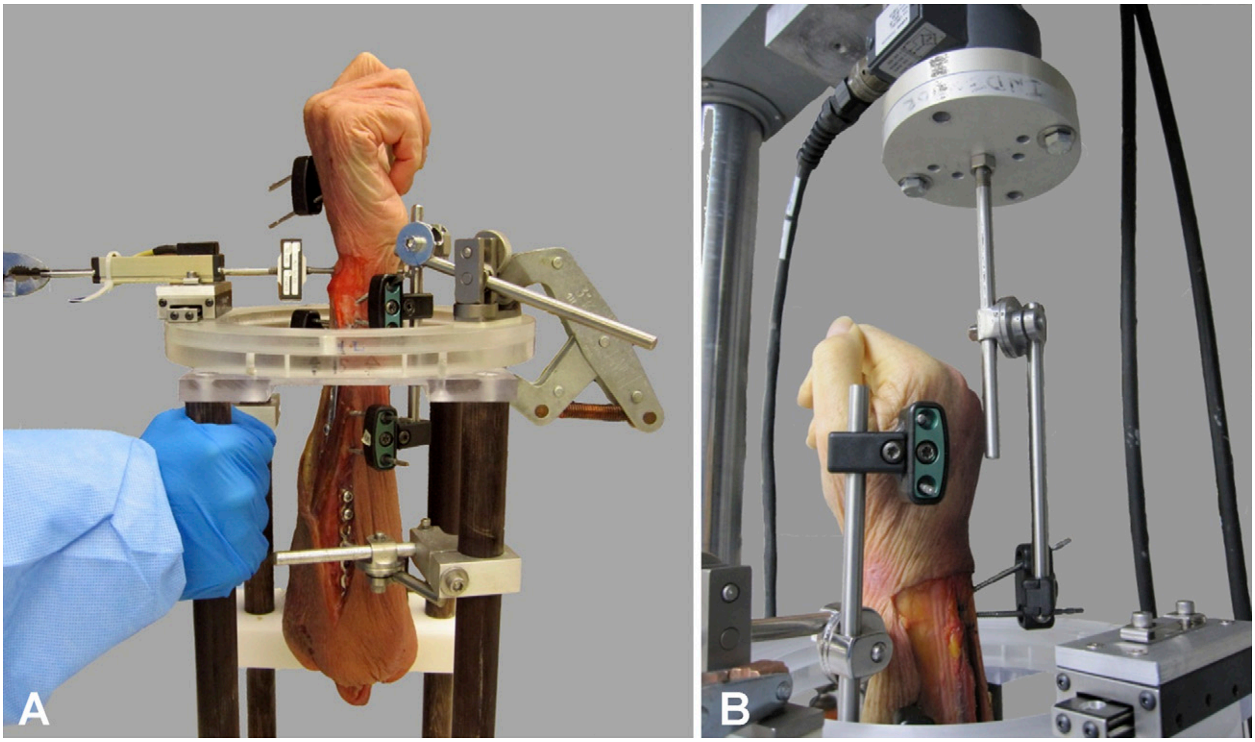

Fig. 3

Fig. 3-A The testing device for examining distal radioulnar joint laxity. The humerus and ulna were affixed firmly to the device to allow 60° of forearm rotation. The radius was manually translated in the volar and dorsal directions with the force-displacement probe attached to the distal end of the radius. **Fig. 3-B** The testing device for examining the resistance to ulnar shortening. The distal ulnar segment was displaced proximally with use of the vertical uniaxial load frame.

shortening between the distal end of the ulna and the ulnar shaft. The plate used for the proximal shortening was too bulky distally and interrupted the motion of the distal radioulnar joint. The distal osteotomy site was distal to the ulnar origin of the distal oblique bundle, which, on the basis of prior studies, is approximately 15% (range, 13% to 21%) of the ulnar shaft[19]. The distal osteotomy was performed identically to the proximal osteotomy. Distal radioulnar joint laxity was examined before and after controlled increments of 1 mm of shortening up to 4 mm with use of the external fixator. Finally, longitudinal resistance to distal shortening was measured by connecting the resected distal end of the ulna to the uniaxial load frame.

Distal radioulnar joint laxity was evaluated with respect to the amount of shortening, the shortening site, and forearm rotational positions. The data were statistically analyzed with use of three-factor repeated-measures analysis of variance (ANOVA). Then, distal radioulnar joint laxity after shortening was compared with the control (0 mm of shortening) for each shortening site and each forearm position with use of single-factor repeated-measures ANOVA and the Fisher least significant difference test.

The specimens were then divided into two groups: those with and those without a distal oblique bundle. Distal radioulnar joint laxity was analyzed in terms of the amount of proximal shortening, the presence of a distal oblique bundle, and forearm rotation with use of three-factor repeated-measures ANOVA. Distal radioulnar joint laxity after proximal shortening was then compared with the control (0 mm), both in the group with a distal oblique bundle and the group without a distal oblique bundle in each forearm rotational position, with use of single-factor repeated-measures ANOVA and the Fisher least significant difference test.

Linear regression analysis was used to investigate the changes of distal radioulnar joint stability in neutral rotation following proximal shortening as a function of the thickness of the distal interosseous membrane. For the four specimens with a distal oblique bundle, linear regression analysis was performed to assess the relationship between the laxity of the distal radioulnar joint after proximal shortening in the neutral forearm position and the thickness of the distal oblique bundle. No specimen had positive ulnar variance. There was negative ulnar variance in four specimens and neutral variance in six specimens. Distal radioulnar joint laxity was analyzed, with use of two-factor repeated-measures ANOVA, as a function of the amount of proximal shortening in neutral position and of the presence of negative ulnar variance.

To quantify longitudinal resistance to ulnar shortening, the steepest slope of the load-displacement curve was calculated within the consistent linear region from 3 mm of shortening to 4 mm of shortening. Resistance to shortening was evaluated, with use of two-factor repeated-measures ANOVA, in terms of the shortening site and forearm rotational position.

Shortening resistance was also evaluated, with use of two-factor repeated-measures ANOVA, in terms of the presence or absence of a distal oblique bundle and forearm rotational position.

To investigate the change in longitudinal stiffness following proximal shortening along with the thickness of the distal interosseous membrane, linear regression analysis was performed to assess the relationship between the longitudinal stiffness after proximal shortening in the neutral forearm position and the thickness of the distal interosseous membrane. For the four specimens with a distal oblique bundle, linear regression analysis was also performed to assess the relationship between the longitudinal shortening resistance following proximal shortening in neutral forearm position and the thickness of the distal oblique bundle. The longitudinal stiffness was analyzed, with use of the Student t test, after proximal shortening according to the presence of negative ulnar variance.

Statistical analyses were performed with use of SPSS 11.0 for Windows (SPSS, Chicago, Illinois). The level of significance was defined as $p < 0.05$.

Sources of Funding

Funding for this study was provided by institutional research support. There was no external funding utilized for this investigation.

Results

All specimens had a distal interosseous membrane distal to the central band and accessory band, spanning between the radius and the ulna under the region of the pronator quadratus muscle. The proximal ulnar attachment of the distal interosseous membrane averaged 59 mm (range, 53 to 63 mm) from the distal end of the ulna, a site that was approximately at the distal 23% of the total ulnar length. The mean thickness of the membranous part of the distal interosseous membrane was 0.6 mm (range, 0.3 to 1.3 mm). The proximal margin of the proximal osteotomy site averaged 66 mm (range, 61 to 69 mm), and the distal osteotomy site averaged 31 mm (range, 27 to 35 mm) from the distal end of the ulna. On the basis of prior studies identifying the ulnar origin of the distal oblique bundle at the distal 15% of the ulna[19], this was calculated to be 39 mm (range, 13 to 21 mm) from the ulnar head.

An obvious thick fiber descending from the proximal part of the ulna to the distal end of the radius within the distal interosseous membrane—recognized as the distal oblique bundle—was found in four of the ten forearms. The distal oblique bundle originated from about 54 mm (range, 50 to 57 mm) from the ulnar head (which was approximately 21% of the total ulnar length distally) and ran distally toward the distal radioulnar joint. The mean width of the distal oblique bundle was 5.1 mm (range, 4 to 7 mm), and its mean thickness was 1.2 mm (range, 1.0 to 1.3 mm).

Distal radioulnar joint laxity was significantly affected by the amount of ulnar shortening ($p < 0.01$), by the shortening site ($p < 0.01$), and by the forearm rotational position ($p < 0.01$).

In all three forearm positions, with proximal shortening of the ulna, the distal radioulnar joint laxity decreased as the amount of shortening increased (Fig. 4). Proximal shortening stabilized the distal radioulnar joint more than distal shortening did for all amounts of shortening (Figs. 4 and 5).

With the forearm in the neutral position, proximal shortening significantly reduced distal radioulnar joint laxity, even for only 1 mm of shortening ($p < 0.05$), with further laxity reduction occurring ($p < 0.01$) for each additional increment of shortening. By contrast, even 4 mm of distal shortening failed to significantly reduce laxity compared with the control. With the forearm in the 60° pronated position, there was a significant difference in distal radioulnar joint laxity with only 1 mm of proximal shortening compared with controls ($p < 0.05$) and for each subsequent shortening (2, 3, and 4 mm; $p < 0.05$, 0.01, and 0.01, respectively). With distal shortening, a significant difference was found only after 4 mm of shortening ($p < 0.01$) (Fig. 5). In the 60° supinated position, there was a significant difference in distal radioulnar joint stability with only 1 mm of proximal shortening compared with the controls ($p < 0.01$), and for each subsequent shortening ($p < 0.01$). With distal shortening, there was a significant difference only after 4 mm of shortening ($p < 0.05$).

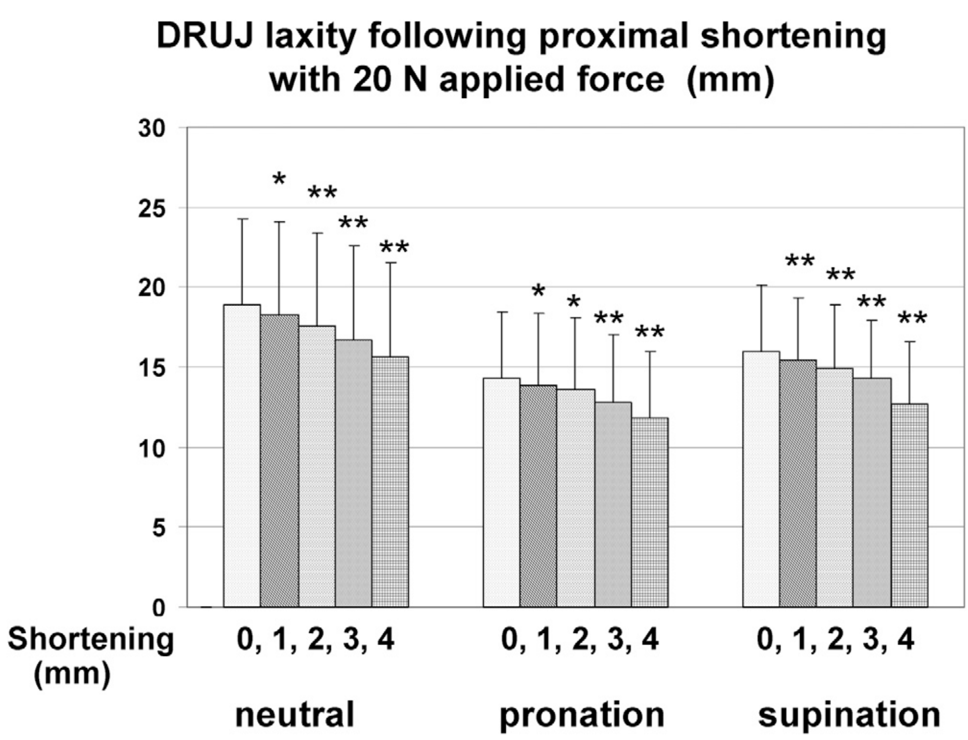

Fig. 4

Distal radioulnar joint (DRUJ) laxity following proximal shortening of the ulna in neutral forearm alignment, 60° of pronation, and 60° of supination. The abscissa represents the amount of ulnar shortening, and the ordinate represents the mean total volar and dorsal displacement of the radius relative to the ulna under 20 N of volar and dorsal load. The error bars indicate the standard deviation. *The difference was significant compared with the control ($p < 0.05$). **The difference was significant compared with the control ($p < 0.01$).

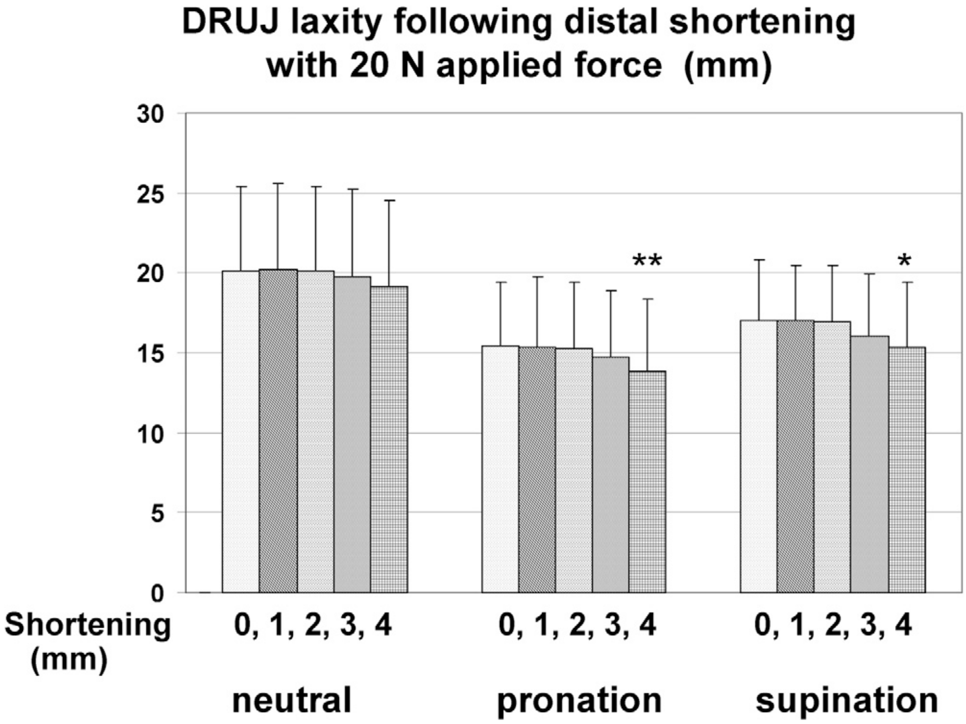

Fig. 5
Distal radioulnar joint (DRUJ) laxity following distal shortening of the ulna in neutral forearm alignment, 60° of pronation, and 60° of supination. The abscissa represents the amount of ulnar shortening, and the ordinate represents the mean total volar and dorsal displacement of the radius relative to the ulna under 20 N of volar and dorsal load. The error bars indicate the standard deviation. *The difference was significant compared with the control ($p < 0.05$). **The difference was significant compared with the control ($p < 0.01$).

Distal radioulnar joint laxity was significantly affected by the amount of proximal shortening ($p < 0.01$), by the presence of a distal oblique bundle ($p < 0.05$), and by forearm rotational positions ($p < 0.05$).

In all three forearm positions, the distal radioulnar joint in the group with a distal oblique bundle had less laxity than the group without a distal oblique bundle, for all shortenings from 1 to 4 mm (Figs. 6 and 7). In the neutral position, the distal oblique bundle group had a significantly different distal radioulnar joint laxity with a 1-mm proximal shortening compared with the controls ($p < 0.05$), and with each subsequent shortening (2, 3, and 4 mm; $p < 0.05$, 0.05, and 0.01, respectively). In

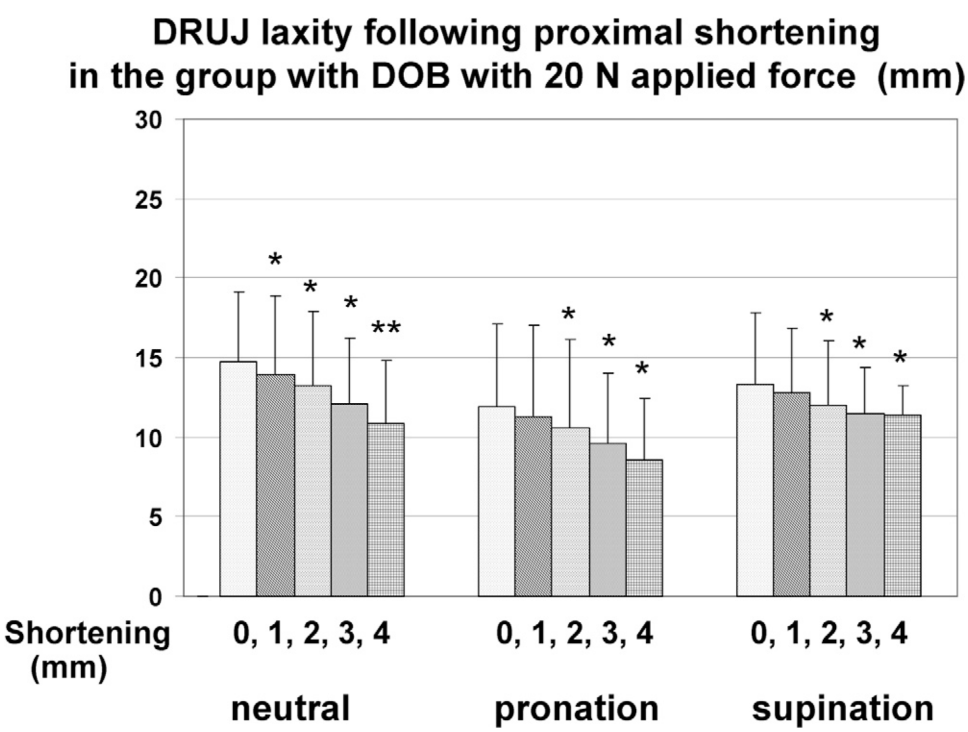

Fig. 6
Distal radioulnar joint (DRUJ) laxity following proximal shortening in the group with a distal oblique bundle (DOB) in neutral forearm alignment, 60° of pronation, and 60° of supination. The abscissa represents the amount of ulnar shortening, and the ordinate represents the mean total volar and dorsal displacement of the radius relative to the ulna under 20 N of volar and dorsal load. The error bars indicate the standard deviation. *The difference was significant compared with the control ($p < 0.05$). **The difference was significant compared with the control ($p < 0.01$).

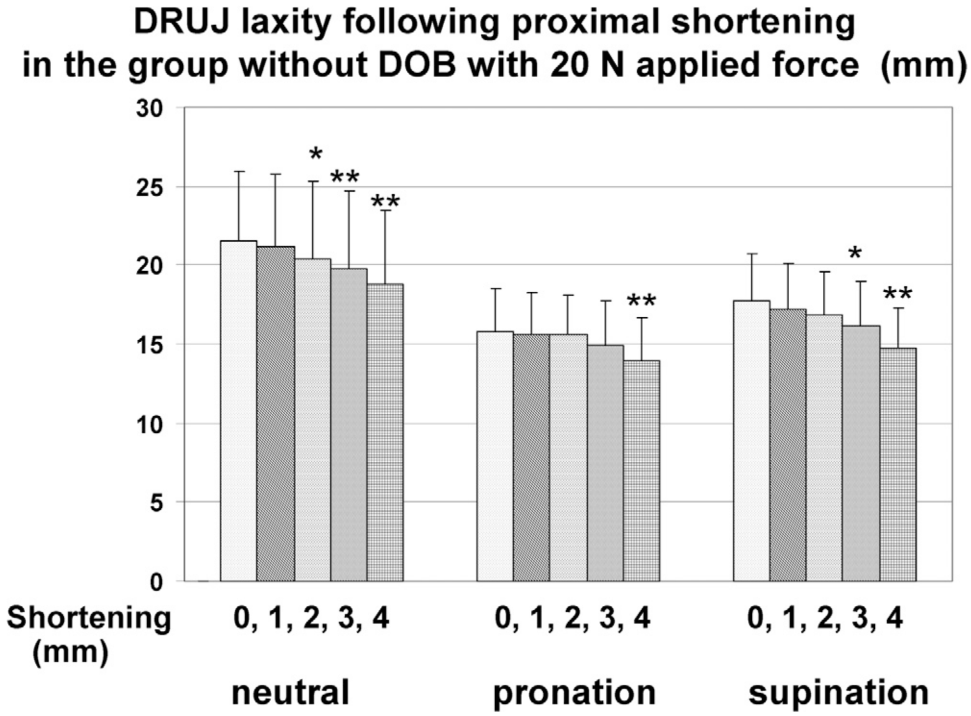

Fig. 7

Distal radioulnar joint (DRUJ) laxity following proximal shortening in the group without a distal oblique bundle (DOB) in neutral forearm alignment, 60° of pronation, and 60° of supination. The abscissa represents the amount of ulnar shortening, and the ordinate represents the mean total volar and dorsal displacement of the radius relative to the ulna under 20 N of volar and dorsal load. The error bars indicate the standard deviation. *The difference was significant compared with the control ($p < 0.05$). **The difference was significant compared with the control ($p < 0.01$).

the group without a distal oblique bundle, there was a significant difference with 2 mm of proximal shortening ($p < 0.05$) and with each subsequent shortening (3 and 4 mm; $p < 0.01$). In 60° of pronation, the distal oblique bundle group had a significantly different distal radioulnar joint laxity with 2 mm of proximal shortening compared with the control ($p < 0.05$) and with each subsequent shortening (3 and 4 mm; $p < 0.05$). In the group without a distal oblique bundle, there was a significant difference only after 4 mm of proximal shortening ($p < 0.01$). In 60° of supination, the distal oblique bundle group had significantly different distal radioulnar joint laxity with 2 mm of proximal shortening compared with the control ($p < 0.05$) and with each subsequent shortening (3 and 4 mm; $p < 0.05$). The group without a distal oblique bundle had a significant difference with 3 mm ($p < 0.05$) and 4 mm ($p < 0.01$) of proximal shortening.

A significant positive linear correlation was detected between distal radioulnar joint laxity following proximal shortening in the neutral forearm position and the thickness of the distal interosseous membrane ($R^2 = 0.544$, $p < 0.01$), and between distal radioulnar joint laxity following proximal shortening in the neutral position and the thickness of the distal oblique bundle ($R^2 = 0.652$, $p < 0.01$). Distal radioulnar joint laxity was significantly affected by the amount of proximal shortening in neutral position ($p < 0.01$) but not by the presence of negative ulnar variance.

When proximal and distal shortening were compared, in the neutral forearm position, the average stiffness (and standard deviation) was 9 ± 4 N/mm after proximal shortening and 5 ± 3 N/mm after distal shortening. Corresponding values were 9 ± 3 N/mm compared with 5 ± 3 N/mm for 60° of pronation and 9 ± 3 N/mm compared with 5 ± 3 N/mm for 60° of supination. The longitudinal resistance to ulnar shortening was significantly affected by the shortening site ($p < 0.01$) but not by the forearm rotational position.

With the forearm in the neutral position, the average resistance to proximal shortening was 11 ± 4 N/mm for the group with a distal oblique bundle compared with 7 ± 3 N/mm for the group without a distal oblique bundle. Corresponding values were 11 ± 2 N/mm compared with 8 ± 3 for 60° of pronation and 9 ± 4 N/mm compared with 8 ± 3 N/mm for 60° of supination. The longitudinal resistance to ulnar shortening was not significantly affected either by the presence of a distal oblique bundle following the proximal shortening or by forearm rotational position.

A significant linear positive correlation was found between the longitudinal resistance to ulnar shortening after proximal shortening in the neutral forearm position and the thickness of the distal interosseous membrane ($R^2 = 0.441$, $p < 0.05$). There was no correlation between the longitudinal resistance to ulnar shortening after proximal shortening in the neutral position and the thickness of the distal oblique bundle. No association was detected between the longitudinal resistance to ulnar shortening after proximal shortening in the neutral position and the presence of negative ulnar variance.

Discussion

Previous reports have suggested that ulnar shortening improves distal radioulnar joint stability by increasing the tension of the ulnocarpal ligaments[1,21]. While the radioulnar ligaments are important stabilizers of the distal radioulnar joint in wrists with positive ulnar variance, they may become loosened over time by ulnar shortening. In this study, a significantly greater longitudinal effect was found with proximal ulnar shortening than with distal shortening. In light of this, and given the close anatomic relationship of the distal interosseous membrane with the distal radioulnar joint, ulnar shortening appears to involve a distal radioulnar joint-stabilizing mechanism because of increased tension of the distal interosseous membrane, which has not been previously described.

The recommended osteotomy site in an ulnar shortening procedure has been approximately 50 to 60 mm proximal to the ulnar styloid[4,8], which corresponds to the distal 25% portion of the ulna[16]. However, no biomechanical justification was given for the location. Such an osteotomy site may result in disruption of the distal interosseous membrane, thus compromising distal radioulnar joint stability. Nishiwaki et al. examined the stabilizing effect of ulnar shortening, and found that ≥3 mm of shortening was required to obtain a significant difference in distal radioulnar joint laxity[16]. However, 10 mm of bone was removed at the distal 25% portion of the ulna for that shortening, so it is reasonable to infer that the distal interosseous membrane may have been at least partially sectioned. In the present study, in which we took great care to preserve the ulnar attachment site of the distal interosseous membrane, distal radioulnar joint laxity was significantly reduced, even with 1 mm of shortening, compared with controls. We submit that, when ulnar shortening is performed to improve distal radioulnar joint stability, it is important to preserve the distal interosseous membrane, which requires that the osteotomy be at least 60 mm from the ulnar styloid process. In this study, the presence of a distal oblique bundle had a significant impact on distal radioulnar joint stability. These findings are supported by recent anatomic and in vivo biomechanical studies, wherein the distal oblique bundle changed minimally in length during forearm rotation and was therefore an isometric stabilizer of the forearm[18].

Potential nonunion of the osteotomy is an important consideration when ulnar shortening is performed to improve stability of the distal radioulnar joint. Little attention has been paid to the effect of the distal interosseous membrane on the force required to close the osteotomy. The present data showed significant differences in the longitudinal closure difficulty for proximal compared with distal osteotomy sites, depending on the distal interosseous membrane thickness. These results suggest that a proximal osteotomy and a thicker distal interosseous membrane could be risk factors for nonunion. For patients without instability of the distal radioulnar joint, it therefore may be advantageous to perform a distal osteotomy[22,23], or to release the distal interosseous membrane, for better healing of the ulna.

This study has several limitations. First, some specimens had negative ulnar variance, whereas most ulnar shortening procedures are for patients with positive ulnar variance[1]. However, in the present study, distal radioulnar joint laxity was not notably affected by negative ulnar variance. Second, motion of the fixed ulna may have occurred during testing. There was a gap in distal radioulnar joint laxity before the shortening sequence between the proximal and distal shortening (Figs. 4 and 5). The repetitive procedure to examine distal radioulnar joint stability may have caused a viscoelastic soft-tissue response or a small rotation at the osteotomy site, leading to mild alignment changes in the distal radioulnar joint. The external fixator may have confounded the force-displacement measurements by masking the effects of several ligaments between the carpus and the radius and ulna. However, the triangular fibrocartilage and radioulnar ligaments provided much of the distal radioulnar joint stability. The results of this study did not represent just the effect of the distal interosseous membrane band, although the sample size is too small to isolate individual structural influences. In the comparison of distal radioulnar joint stability following ulnar shortening and longitudinal resistance to ulnar shortening between proximal or distal osteotomy, and between conditions of the distal interosseous membrane with or without a distal oblique bundle, some significant differences emerged. However, it is not immediately evident whether those differentials would be of clinical consequence.

This study provides useful and practical information. Distal radioulnar joint laxity was decreased by the increased tensioning of the distal interosseous membrane accompanying ulnar shortening. An osteotomy proximal to the ulnar attachment of the distal interosseous membrane should improve distal radioulnar joint stability. Typically, approximately 40% of distal interosseous membranes have a distal oblique bundle. If so, an enhanced distal radioulnar joint-stabilizing effect can be expected; if not, additional or alternative procedures may be considered when instability of the distal radioulnar joint remains a concern. For patients with impaction syndrome and a stable distal radioulnar joint, an osteotomy performed distal to the ulnar attachment of the distal interosseous membrane, or sectioning of the distal interosseous membrane when it is thick, may allow better healing of the osteotomy site. ■

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