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Tensile load on the flexor digitorum profundus tendon during palmar and lateral blocking exercises: Influence on blocking force and distal interphalangeal joint flexion angle

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A R T I C L E I N F O

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A B S T R A C T

Study Design: This is a basic science research.
Introduction: Isolating excursion of the flexor digitorum profundus (FDP) in zones I and II is common practice in the current management after flexor tendon repair. During this procedure, the proximal interphalangeal joint is sometimes fully extended with unmeasured external forces at the middle phalanx when the distal interphalangeal joint is actively flexed.
Purpose of the Study: The purpose of the study was to investigate the incremental effect of external force with palmar blocking versus lateral blocking and increased angles of flexion on internal tendon forces at the repair site for a safer application of force by the treating therapist.
Methods: Eight human cadaveric fingers were studied. To simulate palmar or lateral finger blocking, a compression force of blocking was applied from 5N (510 grams) to 25N (2,550 grams) on the skin surface of the palmar or the lateral aspect of each of these middle phalanges in 5N increments. The tensile load on the FDP tendon during distal interphalangeal joint flexion from 0° to 60° was measured in 10° increments.
Results: During palmar blocking, the tensile load was significantly increased with increases in palmar blocking force. However, no significant increase in the tensile load on the FDP tendon was observed at any lateral blocking.
Discussion: Lateral blocking exercise can be performed with less tensile force on the FDP tendon when performing blocking exercise after flexor tendon injury repair.
Conclusions: This study supports the concept that lateral blocking with incremental joint angles allows a safer application of force for the healing tendon.

Introduction

Controlling peritendinous adhesion after tendon repair with a controlled motion program remains one of the most unpredictable factors contributing to postoperative morbidity.[1] Active finger flexion without tendon adhesion to the surrounding tissue after flexor tendon repair remains an important issue in hand therapy.

Blocking exercise (BE) has been performed as a useful procedure after flexor tendon repair.[2] During this procedure, the proximal interphalangeal (PIP) joint is not necessarily extended completely to 0 degrees by therapists with an appropriate amount of volar support on the middle phalanx when the distal interphalangeal (DIP) joint is actively flexed (Fig. 1). However, we have no clear definition of the safe application of force with volar blocking as it relates to the work of flexion.

Distal joint motion is important to maintaining differential gliding of the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS).[3-6] Tendon gliding of the FDP occurs relative to the FDS tendon which assists in controlling collagen deposition as it occurs in early wound healing. We designated this type of BE as palmar blocking.

Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this article.

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Based on literature evaluating Muscle Testing of FDP strength (Fig. 2),[7] a lateral side gripping of the middle phalanx by therapists to hold PIP and MP joint in extension is used during active DIP joint flexion. We designated this type of BE as lateral blocking and have adopted this procedure for FDP tendon gliding after flexor tendon repair for a safer application of force.

Thus, two types of BEs are used in hand therapy and are believed to be effective treatments after flexor tendon repairs. However, the risk of repair rupture remains a concern when excessive force is loaded on to the tendon repair site.[2] Compression on the middle phalanx by blocking procedures may increase gliding resistance on the FDP tendon, which eventually increase the force applied to the tendon during DIP joint flexion.[4] There have been several reports concerning the tensile load on the flexor tendon during BE[8,9]; however, no reports on how these palmar and lateral blockings affect gliding of flexor tendons exist.

The purpose of this study was to investigate the FDP tensile load by applying incremental force to the palmar side of the middle phalanx (palmar blocking) and lateral side of the middle phalanx (lateral blocking) to simulate two types of blocking exercise. Our hypothesis is that the tensile load on the FDP tendon does not increase by lateral blocking, but increases by palmar blocking. The effect of blocking exercise on flexor tendon will then be discussed to reduce the risk of tendon rupture during postoperative mobilization exercises.

Materials and methods

Eight middle fingers were taken from 8 human cadavers (1 female and 7 male) by amputation at the proximal end of the 3rd metacarpus of 3 right and 5 left hands. The mean age of specimens was 85 years (range, 82-93 years). Visual and radiological inspection of the specimens showed no evidence of previous injury, surgery, or deformity. The middle fingers were cut at the proximal end of the shaft of the metacarpal bones sparing the skin and tendons. Each digital extensor tendon was cut at the PIP joint level. The FDP and FDS tendons were separated and cut at the wrist joint level. The PIP and metacarpophalangeal (MP) joints of each finger were fixed at 0° of extension by passing an intramedullary 1.6 mm Kirchner wire through the metacarpal bone to the middle phalanx to eliminate PIP and MP joint motion. Fixation of the MP and PIP joint by a K-wire keeps both joints in full extension, then mobility of the DIP joint alone is allowed to measure tensile load testing of FDP tendons. These mechanical setting simulates lateral and palmar BE.

Each specimen was fixed on a specially designed fixation jig by 1.0 mm Kirchner wires. The proximal end of the FDP tendon was mounted on a materials testing machine (STA-1150; ORIENTEC Co, Ltd, Tokyo, Japan; capacity 500 N, accuracy ±0.2% FS) to assess FDP tendon loading. Three circular markers of 1 mm in diameter were placed on the lateral aspect of the center of each PIP and DIP joint as well as the distal phalanx to measure the angular motion of the DIP joint. Another marker was placed on the FDP tendon at the proximal end of the A1 pulley to measure FDP tendon gliding distance. The lateral view of each specimen was recorded using a digital video camera (resolution 1920 × 1080 pixels, HDRXR520V; Sony Corp, Tokyo, Japan) while the FDP tendon was pulled proximally at 20 mm/min allowing flexion of the DIP joint from 0° to 60° (Fig. 3). To simulate palmar or lateral blocking, a 7 mm wooden cylinder was applied to the palmar and then to the lateral sides of each middle phalanx. The compression force on palmar side or lateral side of the middle phalanx increased from 5 N to 25 N (in 5 N increments). It was loaded on the skin surface of the middle phalanx using one anteriorly or two laterally placed wooden cylinders (Figs. 4 and 5). The recorded video data were analyzed using Dartfish software version 4.0 (Dartfish Japan Co, Ltd, Tokyo, Japan)

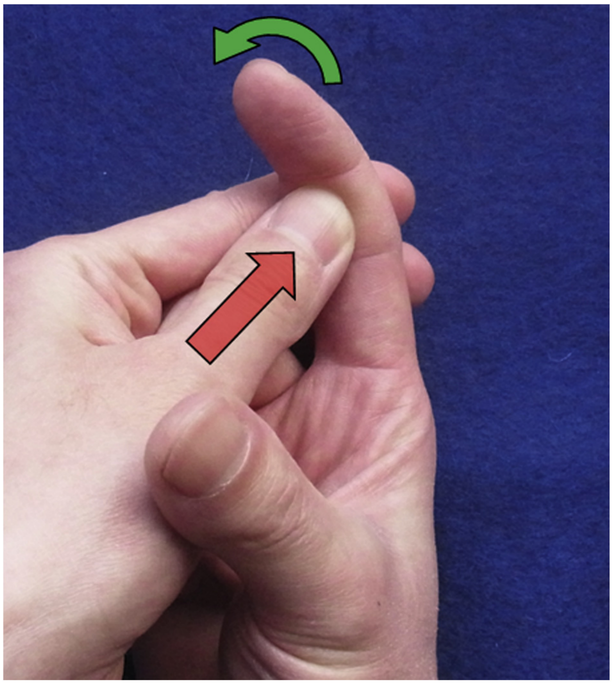

Fig. 1. Palmar blocking exercise. With the finger relaxed and in an extended position, the DIP joint is actively flexed. Compression force was applied by a thumb on the palmar skin surface of the middle phalanx. The motion of the FDS tendon is blocked while gliding of the FDP tendon is promoted. DIP = distal interphalangeal; FDS = flexor digitorum superficialis; FDP = flexor digitorum profundus.

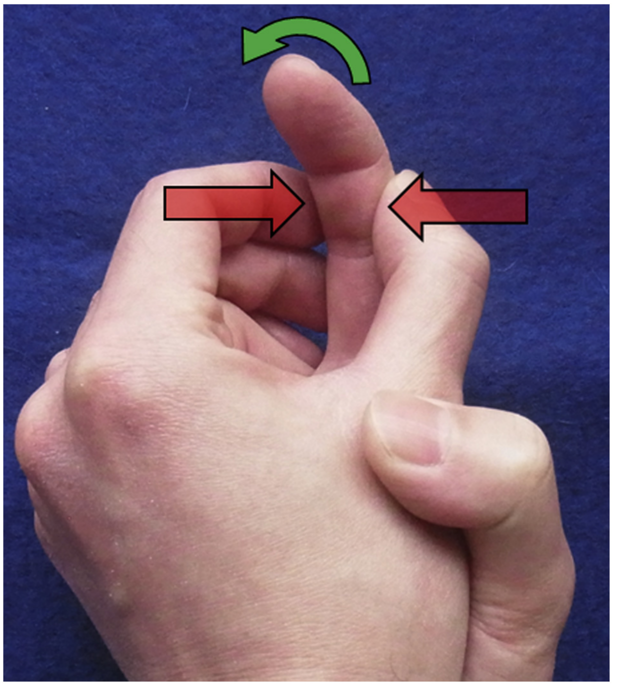

Fig. 2. Lateral blocking exercise. With the finger relaxed and in an extended position, the DIP joint is actively flexed. Compression force was applied by a thumb and a finger on the lateral skin surface of the middle phalanx following the procedure for evaluating Muscle Testing of FDP strength.[7] The motion of the FDS tendon is blocked while gliding of the FDP tendon is promoted. DIP = distal interphalangeal; FDS = flexor digitorum superficialis; FDP = flexor digitorum profundus.

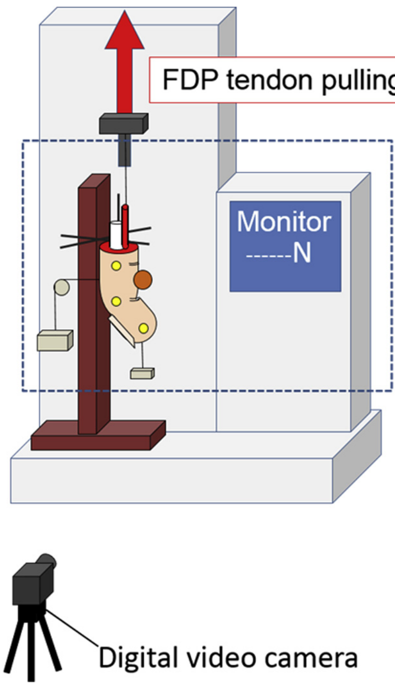

Fig. 3. Mechanical testing apparatus. The device for the measurement of tensile loading on the FDP tendon to simulate the BE procedure. The FDP tendon was pulled by the testing machine, and compression force was applied from 5 N to 25 N at 5 N increments. The motion of the DIP joint was also recorded by digital video camera. BE = blocking exercise; DIP = distal interphalangeal; FDP = flexor digitorum profundus.

and the tensile load on each FDP tendon during DIP joint motion from 0° to 60° in 10° increments was measured.

This study was approved by the institutional review board of the university.

Statistical analysis

Results were expressed as means ± standard deviations (SDs). Repeated measure two-way analysis of variance with Tukey's post hoc test was used for the comparison of the tensile loads on the FDP

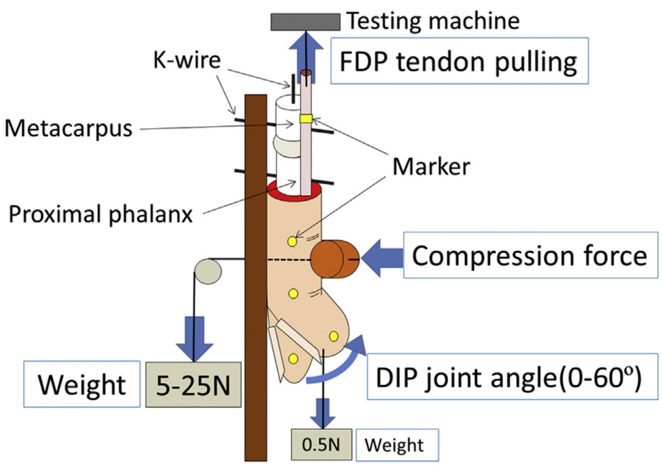

Fig. 4. Palmar blocking. The cadaveric middle finger was cut at the shaft of the metacarpal bone, and the FDP tendon was pulled by the testing machine. Compression force was applied to the palmar side of middle phalanx from 5 N to 25 N by a wooden cylinder. A 0.5 N weight was applied to the tip of the finger to simulate the tensile force on the extensor tendon. FDP = flexor digitorum profundus.

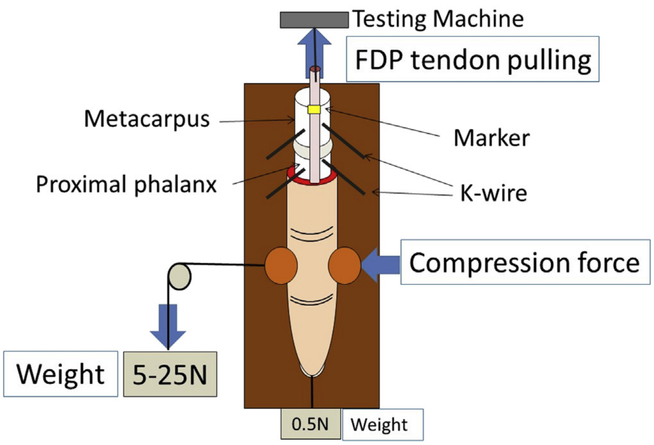

Fig. 5. Lateral blocking. The cadaveric middle finger was cut at the shaft of the metacarpal bone, and the FDP tendon was pulled by the testing machine. Compression force was applied to the lateral side of middle phalanx from 5 N to 25 N by two wooden cylinders. A 0.5 N weight was applied to the tip of the finger to simulate the tensile force on the extensor tendon. FDP = flexor digitorum profundus.

tendon in accordance with the DIP joint angle at each compression force during finger blocking. Statistical tests were performed using SPSS 17.0 software (SPSS Inc, Chicago, IL). All significance levels were set as $\alpha = 0.05$.

Results

The tensile load on the FDP tendon was increased with increases the DIP joint flexion angle in fingers without blocking, as well as in fingers with both lateral and palmar blocking (Figs. 6 and 7). During palmar blocking, the tensile load on the FDP tendon significantly increased with increases in the palmar blocking force at DIP joint flexion 30 to 60° ($p < .05$) (Fig. 6). However, no significant increase in the tensile load on the FDP tendon was observed at any lateral blocking force (Fig. 7).

The mean tendon gliding distance was 1.25 ± 0.4 mm in 10° incremental steps of the DIP joint flexion even when either palmar or lateral blocking was applied.

Discussion

The present study was undertaken to clarify the relationship between two types of BE, performed from the palmar or lateral sides, by measuring the tensile load on the FDP tendons and flexion angle of the DIP joints. Schuind et al[8] reported that the mean tensile load on the index finger FDP during blocking exercise was 19 N (1-29 N). Sapienza et al[9] also reported the tensile load on the FDP tendon in the blocking exercise. However, these reports did not measure the flexion angle of the DIP joint or the compression force on the fingers. Our results demonstrated that although palmar blocking force influences the tensile load on the FDP tendon during blocking exercise, lateral blocking forces do not affect the tensile load on the FDP tendon.

Previous in vitro studies reported that the Bunnell suture (2-strand) has a tensile strength of 3930 g immediately after suturing, 2500 g of Tsuge (2-strand), and 4300 g of double-looped suture (4-strand).[10] However, in vivo studies reported that about one to 2 weeks after tendon suturing, tensile strength decreases with Bunnell suture up to 630 g, Tsuge 1200 g, and double-looped suture 2150 g. Recent in vivo studies of postoperative passive or controlled active digital motion with 6 or 8 strand sutures demonstrated that tensile load of the repaired tendon remains initial level and

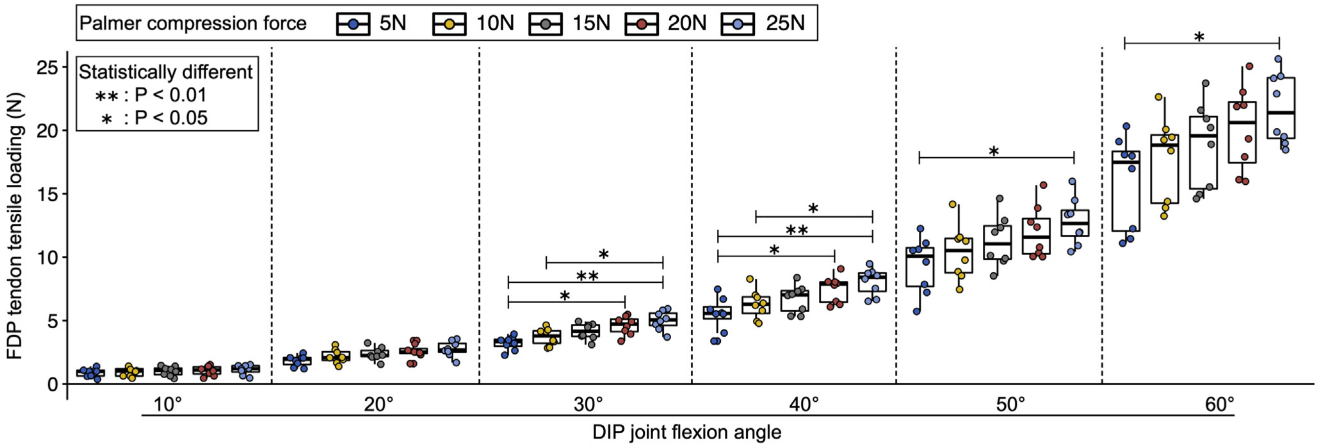

Fig. 6. Comparison of the tensile load on the FDP tendon at each palmar compression force and DIP joint flexion angle. It was significantly increased with increases in the palmar blocking force ($p < .05$, $p < .01$). DIP = distal interphalangeal; FDP = flexor digitorum profundus.

increase at 3 to 6 weeks or later.[11,12] In addition, a tensile load of 10 N applied to repaired flexor tendon is known to cause 1 mm gap at the tendon repair site by 4-strand suture which eventually caused tendon rupture or adhesions.[13] Based on tensile load values of the FDP tendons in this study, lateral blocking did not show 10 N by any compression force from 10° to 50° DIP flexion, whereas palmar blocking showed significant increase of tensile load over 10 N at 50° or greater DIP flexion.

Clinically, it is difficult for therapists to closely control the amount of blocking force applied during BE after flexor tendon repairs. Lateral blocking exercise during which the tensile load on the FDP tendon increases with the flexion angle of the DIP joint irrespective of the amount of blocking force, this suggests that therapists can estimate tensile load of the FDP tendon by observation of the DIP flexion angle.

Palmar or lateral blocking is but one element that increases internal tendon force at the anastomosis. Internal tendon forces or the work of flexion are also increased by the resistance of the suture material, pulleys, edema, inflammation associated with wound healing, the antagonistic muscle tendon unit, joint angle, external load as applied at the finger, and speed of exercise.[14]

The annular pulley is an important structure in finger flexion as it prevents bowstringing of the flexor tendons. However, even slight damage to the pulley itself can affect the amount of gliding resistance of the flexor tendon.[15,16] After partial or complete A4 pulley release, work of flexion was significantly less than that achieved by leaving the A4 pulley intact.[17] In addition, in the case of flexor tendon injuries in zone I, flexor tendon repairs are performed at the A4 pulley level. Instead of palmar blocking, lateral blocking may be indicated in such cases to avoid direct pressure on these repair sites.

Our results showed that the mean tendon gliding distance was 1.25 ± 0.4 mm in 10° steps of DIP joint flexion. McGrouther et al[3] reported that the FDP tendon gliding distance was 1.0 ± 0.4 mm in 10° steps of DIP joint flexion. Horibe et al[18] also reported that the FDP tendon gliding distance was 1.1 mm in 10° steps of DIP joint flexion. Gelberman et al[19] also reported that at least 35° of passive DIP joint motion is needed to affect 3 to 4 mm differential glide of the FDP on the FDS. Duran et al[20] reported that adhesions of the flexor tendon can be prevented by tendon gliding of 3-5 mm. Based on the results of our blocking study, effective gliding of FDP tendons may be obtained when BE are performed at DIP joint flexion angles of 0° to 30° to 50°.

When to introduce blocking exercise after the repair of a flexor tendon is still controversial. After surgery, Tang et al[21] commenced blocking exercises at 4 weeks, and Clancy et al[22] at 6 weeks. Usually, gliding exercises of flexor tendons after repair is determined by the tendon gliding resistance and the strength of the repair. It is

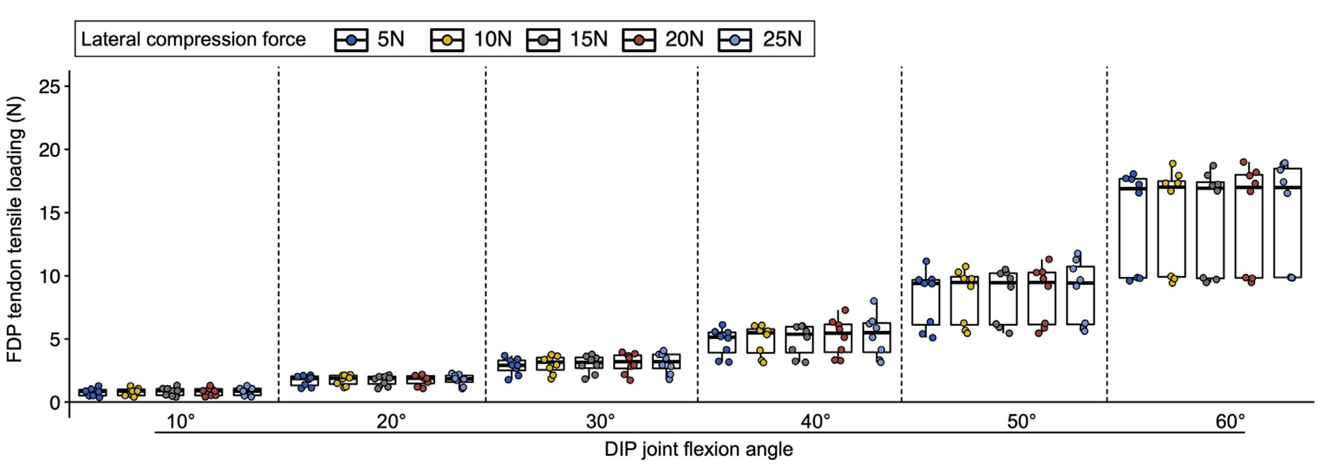

Fig. 7. Comparison of the tensile load on the FDP tendon at each lateral compression force and DIP joint flexion angle. No significant difference in the tensile load on the FDP tendon was observed at any lateral blocking force between fingers. DIP = distal interphalangeal; FDP = flexor digitorum profundus.

commonly accepted that repaired flexor tendons are at their most vulnerable for rupture within the first 3 to 4 weeks after repair and that they increase in strength after this time, gaining their most strength by day 112.[23] It is known that increases in the work of flexion and tendon gliding resistance are also modified by the management of postoperative edema in the surrounding tissues.[24-26] Based on the results of this study, it may be possible to adjust the amount of loading on the FDP tendon by observing the DIP flexion angle and blocking force, which may allow therapists to introduce blocking exercise more precisely and carefully in the early postoperative period.

Limitations

There are a number of limitations to this study. First, finger specimens were obtained from aged cadavers. BE in a clinical setting is not only applied to elderly patients but also to younger patients. Second, only the tensile load on the FDP tendon was measured, with FDS tendon tension not measured. Long et al[27,28] reported that the FDS tendon only works during strong finger flexion. However, simultaneous rupture of the FDP and FDS tendons is not rare in clinical cases. Further studies are required to clarify optimum blocking exercises for the PIP joint. Third, the present study did not measure tensile load on repaired tendons. It is known that increases in the work of flexion and tendon gliding resistance are observed after flexor tendon repair in cadavers.[29,30]

Further large-scale studies are required by clinicians to assess rupture rates and total range of motion of the PIP and DIP joints at the end of therapy intervention when using the traditional anterior blocking exercises versus the proposed lateral blocking exercises.

Conclusions

Although palmar blocking force influenced the tensile load of the FDP tendon during the blocking exercise, lateral blocking force did not increase the tensile load of the FDP tendon. This study supports the concept that lateral blocking with incremental joint angles allows a safer application of force for the healing tendon. Angles of flexion can be more safely increased per increased tensile strength of the repair between week 4 and 6.

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