Original Research

The Effect of Flexor Digitorum Profundus Dynamic Tenodesis on the Distal Interphalangeal Joint: A Cadaver Study

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Purpose: Flexor digitorum profundus (FDP) dynamic tenodesis on the distal interphalangeal (DIP) joint is reported as a treatment for FDP tendon injuries. Although good clinical outcomes have been reported, biomechanical study results are unknown. This study aimed to evaluate the flexion range of motion in DIP and proximal interphalangeal (PIP) joints that have undergone dynamic tenodesis using fresh-frozen cadavers.

Methods: We obtained 12 fingers from 3 fresh-frozen cadavers. Before and after the procedure, we assessed the relationships between the tension of the flexor tendons and the flexion angles of the DIP and PIP joints. We compared the maximum DIP and PIP joint angles using the Wilcoxon test. The distal portion of the FDP was split longitudinally and the ulnar slip was resected from the insertion of the tendon. The remaining radial half of the FDP tendon was passed beneath both slips of the flexor digitorum superficialis tendon, which was then sutured to the radial insertion of the FDP tendon using a mattress stitch.

Results: Maximum flexion angles of the DIP joint before and after the procedure were 48° ± 12° and 34° ± 8°, respectively; this difference was statistically significant. Maximum flexion angles of the PIP joint before and after the procedure were 74° ± 14° and 80° ± 9°, respectively; this difference was not statistically significant.

Conclusions: The flexion angle of the DIP joint was reduced after undergoing dynamic tenodesis. Biomechanically, dynamic tenodesis for the DIP joint using the remaining FDP tendon is a valuable procedure because it results in a flexion angle greater than 30°. Clinical relevance: The DIP joint can be flexed, and the PIP joint maintains good motion after the procedure. Therefore, FDP dynamic tenodesis on the DIP joint may be a choice in case of an isolated FDP tendon injury.

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It is common to encounter patients with finger flexor tendon injuries; the incidence of such injuries is reported to be 7.0/100,000 person-years. The injury occurs in a wide variety of situations and can include the flexor digitorum superficialis (FDS) tendon and/or flexor digitorum profundus (FDP) tendon. The injury can be located in any zone from I to V and may be acute or present late.

Isolated FDP tendon lacerations in zones III to V with an intact FDS are clinical challenges. In such cases, tenorrhaphy or tendon-to-bone technique is performed for an acute injury. Tendon graft reconstruction, distal interphalangeal (DIP) joint arthrodesis, or other methods are used for late-presenting injuries. However, tendon reconstruction can result in disturbance to gliding of the intact FDS tendon as a result of FDP and FDS tendon adhesion. Distal interphalangeal joint arthrodesis does not inhibit FDS tendon gliding, but it eliminates DIP joint mobility.
To resolve these problems, Kahn proposed dynamic tenodesis of the DIP joint. In this procedure, the affected FDP tendon is passed under the insertion of the FDS tendon and pulled to the distal side. In this method, the DIP joint can be flexed by traction of the intact FDS tendon. However, it remains to be clarified by how many degrees the DIP and proximal interphalangeal (PIP) joint can be flexed logically after the procedure and whether the procedure delivers promising results in clinical practice. In other words, we were unsure of the effectiveness of this dynamic tenodesis.

We hypothesized that dynamic tenodesis would be useful in restoring DIP flexion without PIP flexion loss in a theoretical setting. This study aimed to use fresh-frozen cadavers to evaluate flexion range of motion (ROM) in DIP and PIP joints that had undergone dynamic tenodesis.

**Materials and Methods**

**Specimens**

We obtained 12 fingers (6 each from the right and left hands) from 3 fresh-frozen cadavers (1 male and 2 females, mean age 80.3 years; range, 78–82 years). We excluded fingers with contractures and/or obvious deformity of the metacarpophalangeal, PIP, or DIP joint based on the findings of x-ray fluoroscopy. The cadavers were stored at −20°C and thawed at 25°C before the experiments. The specimens were continuously moistened with a sprayed saline solution to prevent drying.

Each specimen was amputated at the center of the humerus. An incision was made in the midline of the forearm palmar surface and the FDS and FDP tendons were identified and separated. Then, the musculotendinous junction was cut.

**Tension of flexor tendon and flexion angle of DIP and PIP joints after surgery**

Before surgery, we assessed the relationships between the tension of the FDP tendon and flexion angle of the DIP joint and between the tension of the FDS tendon and flexion angle of the PIP joint. The forearm was fixed in supination to a dedicated jig using a 0.12-inch Kirschner wire. The wrist and metacarpophalangeal joint were fixed using a 0.079-inch Kirschner wire in a neutral flexion-extension position and at 90° flexion, respectively. The FDP tendon was pulled proximally at a rate of 1 mm/s using a precision universal tester (Autograph 20kN X plus, Shimadzu, Kyoto, Japan), with the traction force recorded at 100 Hz. At preloading, the tendon was initially pulled at a traction force increasing from 0 to 5 N; then, the tendon was pulled until the fingertip reached the surface of the palm (Fig. 1).

We evaluated the angles of the DIP and PIP joints using an electromagnetic 3-dimensional tracking system (FASTRAK, Polhemus, Colchester, VT). The source emitted an electromagnetic field detected by the sensors, allowing the location and angular orientation of each sensor relative to the source to be known with a root mean square accuracy of 0.76 mm for the x, y, or z positions and 0.15° for the receiver orientation within 300 mm. The sensors were attached with double-stick tape and nonelastic tape (ZONAS, Johnson & Johnson, New Brunswick, NJ) on the skin and nail in the middle of the proximal and midphalanx (Fig. 2). The rotation angles of each bone (distal, middle, and proximal phalanx) were measured and recorded at a rate of 40 Hz. The DIP and PIP joint angles were calculated using the 2 respective equations:

\[
\text{DIP joint angle} = \text{rotation angle of proximal phalanx} - \text{rotation angle of middle phalanx} \quad \text{(Eq.1)}
\]

\[
\text{PIP joint angle} = \text{rotation angle of middle phalanx} - \text{rotation angle of distal phalanx} \quad \text{(Eq.2)}
\]

**Surgical procedure**

We assessed dynamic tenodesis as per Kahn’s procedure. A Bruner incision was created distal to the A1 pulley. The tendon sheath was exposed and the FDP was cut between the A1 and A2 pulleys. This is because we wanted to keep the A2 pulley intact to evaluate the dynamic tenodesis under the best conditions. Pulleys A3, C2, A4, C3, and A5 were resected to provide space for tenodesis manipulation, whereas the A2 pulley was left in place. The distal portion of the FDP was split longitudinally and the ulnar slip was resected from the insertion of the tendon (Fig. 3A). The short vincula of FDS tendon was dissected to pass the remaining radial half of the FDP tendon beneath both slips of the FDS tendon.
The remaining radial half of the FDP tendon was then sutured to the radial insertion of the FDP tendon. Cincinnati, OH, whereas the tension was held in place (Fig. 3C).

The remaining radial half of the FDP tendon was then sutured beneath both slips of the FDS tendon. The FDP tendon was pulled until the clamp of the precision universal tester. After preloading, the FDS tendon was pulled at a tension such that the base of the distal phalanx at the FDP insertion and joined to a proximal motor in the palm or distal forearm. A single-stage graft is usually performed when the FDP tendon is not repaired early and the tissue around the tendon is not severely damaged, and for cases in which the FDP tendon is disrupted but the FDS tendon remains intact. For instance, this would be done in a young individual with supple joints, and when there is need for reasonably active DIP joint function (on the ulnar side of hand when making a fist).3 A 2-stage tendon graft involves placing the graft from the palm to fingertip after inserting a temporary silicone spacer to develop a smooth gliding bed around the implant. The 2-stage graft is used when the flexor tendon sheath is not present, usually because of the chronicity of a flexor tendon injury.

With tendon reconstruction, there is a high risk for adhesion and graft rupture, which can impair the flexion of the PIP joint. There have been reports of ruptures of the graft after reconstruction that required tenolysis.4,5 In addition, patients who undergo the 2-stage procedure require prolonged, burdensome treatment and long-term rehabilitation after the procedure.6,7 Previous studies have recommended that light resistance and strengthening exercises with resisted motion can be started at 8 weeks after the operation5,7 and that only patients with strong motivation and who demonstrated full passive motion and the absence of bone or severe skin injuries should be considered as candidates.8 Dynamic tenodesis may be a good option for patients who are unsatisfied with the rehabilitation, such as elderly patients or those who wish to return to their routine at the earliest.

In the context of an isolated FDP injury, many surgeons consider indications for arthrodesis of the DIP joint to be an unstable or unreconstructable DIP joint, unreconstructable pulleys, or failed tendon reconstruction.9 Distal interphalangeal joint arthrodesis can stabilize the DIP joint and save the function of the PIP joint. Activities such as pinching become easier after DIP joint arthrodesis; however, a disadvantage of arthrodesis is the loss of ROM.

**Statistical analysis**

Values for the flexor tendon tension and flexion angles of the DIP and PIP joints were extracted from the data at every 20th measurement point per second. We compared the maximum DIP and PIP joint angles before and after surgery using the Wilcoxon t test and considered differences significant at \( P < .05 \).

**Results**

Maximum angles of the joints were compared at a traction force of 20 N because this level of force in the FDS tendon was sufficient for the fingertip to reach the palm of the hand. The mean and SD of maximum flexion angles of the DIP joint before and after the procedure were 48° ± 12° and 34° ± 8°, respectively, with a statistically significant difference (\( P = .002 \) (Fig. 4). The mean and SD of maximum flexion angles of the PIP joint before and after surgery were 74° ± 14° and 80° ± 9°, respectively, which was not statistically significantly different (\( P = .100 \) (Fig. 5).

**Discussion**

This study assessed changes in the maximum flexion angles of the DIP and PIP joints after we performed dynamic tenodesis. The maximum flexion angle of the DIP joint significantly changed after the procedure; however, that of the PIP joint did not significantly change. Flexor tendon reconstruction includes single-stage tendon grafting and 2-stage reconstruction. In single-stage free tendon grafting, after the flexor division, the injured tendons are excised and replaced with a suitable tendon graft. This is secured to the base of the distal phalanx at the FDP insertion and joined to a proximal motor in the palm or distal forearm. A single-stage graft is usually performed when the FDP tendon is not repaired early and the tissue around the tendon is not severely damaged, and for cases in which the FDP tendon is disrupted but the FDS tendon remains intact. For instance, this would be done in a young individual with supple joints, and when there is need for reasonably active DIP joint function (on the ulnar side of hand when making a fist).3 A 2-stage tendon graft involves placing the graft from the palm to fingertip after inserting a temporary silicone spacer to develop a smooth gliding bed around the implant. The 2-stage graft is used when the flexor tendon sheath is not present, usually because of the chronicity of a flexor tendon injury.
In their study on dynamic tenodesis, Pritsch and Sammer\(^2\) reported that the DIP joint was flexed by active motion of the PIP joint with the palmaris longus tendon. Their cadaveric study achieved good results similar to those in our study, although their method differed dramatically from that proposed by Kahn.\(^2\) Kahn's method did not require an intact tendon and is straightforward because it involves an incision only on the palmar side. However, it cannot be used in patients with a short distal stump of the FDP tendon or in those with FDP avulsion.

The mean maximum angle for active DIP joint flexion after single- and 2-stage reconstruction was reported to be 33° to 49° and 39° to 66°, respectively.\(^4,10\)\(^13\) Kahn\(^2\) reported a flexion angle of the DIP joint from 34° to 48°. Our cadaveric study obtained results similar to those of clinical tendon reconstruction and demonstrated that the flexion force of the PIP joint was maintained.

In the current study, the FDP was cut between the A2 and A1 pulleys. In contrast, in clinical practice, we believe that the FDS finger with a tear in the FDP tendon around the PIP joint is common, and in this case, tendon extension using a half-sliced tendon was recommended, as described by Kahn.\(^2\) However, we did not adopt tendon extension in this study because it would not allow us to evaluate the effects of dynamic tenodesis itself properly. The results of dynamic tenodesis in patients with a short distal stump, such as those requiring tendon extension, may be inferior to the current findings.

Our study had certain limitations. First, the flexion angle of the DIP joint was reduced after undergoing dynamic tenodesis. However, dynamic tenodesis allowed DIP joints to have a ROM greater than 30°. For most activities of daily living, the required flexion angle of the DIP joint is reported to be less than 30°.\(^4,14\) Therefore, we recognized that biomechanically, dynamic tenodesis of the DIP joint using the remaining FDP tendon is a valuable procedure because it results in a flexion angle greater than 30°. Moreover, in the current study, the active flexion angles of the PIP and DIP joints under normal conditions were not good. By flexing only the finger to be measured without flexing the other fingers, the subject joint could not be fully flexed by the traction force of the tendon. It might have been better to flex the other fingers as well. The age of the specimen might be older than that of a clinical patient presenting with an FDS finger. However, it was difficult to insert a wire into the bone to secure the sensor while preserving the tendon. In addition, the presence of metal near the sensor alters the magnetic field and affects the data. Therefore, this study adopted a means of fixing the sensor to the skin. Finally, this was a cadaveric study. The action of the intrinsic muscles, especially the lumbricals, is different from that of the living organism; this is an unavoidable limitation. Furthermore, we could not evaluate scarring, increased tendon bulk within the tendon sheath, altered gliding, and increased resistance (all observed clinically) in a cadaveric specimen. We thus believe that clinical results with this technique may be worse than those reported in the current study.

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