Biomechanical Analysis of Four-Strand Extensor Tendon Repair Techniques

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Experience with flexor tendon repairs has suggested the superiority of the augmented Becker (MGH) technique for strength, toughness, and gap resistance. In an effort to apply these findings to the extensor tendons, 3 four-strand extensor tendon repair techniques were biomechanically tested in fresh human cadaver limbs: modified Bunnell, modified Krackow-Thomas, and MGH. Repairs were performed in Verdan’s zone VI. Repaired tendons were distracted at constant speed until rupture. Tendon load and tendon distraction were continuously monitored. Benchmark values for load were measured as fingers were pulled from full metacarpophalangeal (MP) joint flexion to full extension, to 1-mm gap formation at the tenorrhaphy, and to complete rupture of the repair. The MGH repair proved significantly more resistant to gap formation (stronger and tougher) than the Bunnell and Krackow-Thomas repairs (p < .02). No differences were seen between groups in repair performance at MP joint extension and at complete rupture. This study suggests that the MGH technique has superior gap resistance to the other four-strand methods tested for extensor tendon repair in Verdan’s zone VI. The MGH repair is recommended for extensor tendon repairs in zone VI when early postoperative motion regimens are considered. (J Hand Surg 1997;22A:838–842.)

 Advances in treatment of extensor tendon injuries in the past decade have come from modifications in postoperative therapy rather than modifications in surgical technique.1 Traditional postoperative treatment following repair of lacerated extensor tendons has included prolonged static splinting. Some of the patients treated in this manner have experienced difficulties leading to unsatisfactory results.2–5 More recent studies demonstrate improved results when dynamic postoperative splinting protocols, similar to those used following flexor tendon injuries, are employed.4–8 Despite these encouraging reports, the optimum or most appropriate regimen has not been clearly defined. Most protocols are empirical because little or no objective data exist upon which to base a rationally derived treatment protocol.

Studies on flexor tendon repair have demonstrated favorable biologic, mechanical, and clinical consequences of early range of motion (ROM) exercise programs. With such programs, tendon gap formation and rupture can occur when tensile loads across the tenorrhaphy exceed the strength of the repair. Resistance to gap formation and rupture have been clearly shown to be related to suture technique.9–11

Little information is available relative to these issues in extensor tendon repair and rehabilitation. This is partly due to difficulties inherent in dealing with the extensor tendons themselves: extensor tendons are hard to handle and suture because of their thin, flat morphology.2–5,12 Adhesions from the tendon to surrounding tissues often lead to extensor
lag and loss of finger flexion. This is especially prevalent in the complex injury of the dorsum of the hand. Attempts to extrapolate from knowledge gained from flexor tendons can be problematic: two-strand repairs in extensor tendons have been shown to be 50% as strong as the same repairs in flexor tendons. There has not been a report detailing the strength of four-strand repairs. In addition, there is no information available relative to the tensile loads borne by the extensor tendons during active or passive ROM.

The experience of the senior author (D. P. G.) with the superior strength and toughness of the augmented Becker (MGH) repair technique in the flexor tendon prompted interest in its application to the extensor mechanism. It is postulated that this type of four-strand tenorrhaphy may provide adequate strength to allow immediate postoperative active mobilization of extensor tendon repairs. This study was designed to (1) measure the resistance to gap formation of 3 four-strand suture techniques in a zone VI extensor digitorum communis (EDC) laceration model and (2) evaluate the tensile load required to achieve simulated active metacarpophalangeal (MP) joint flexion in the same dynamic cadaver model.

Materials and Methods

Hand Preparation

Eight fresh-frozen, unpreserved midarm-amputated cadaver specimens were used for study. The arms were cut transversely at the midforearm and then warmed to room temperature (38°C). The hands were examined for evidence of previous surgery or joint instability. Eight specimens were prepared, making 24 tendons available for study. The EDC tendons were exposed through a transverse skin incision at the midmetacarpal level. The junturae tendinum were divided. The musculotendinous junction of each tendon to be repaired and the flexor digitorum superficialis (FDS) tendons were exposed in the proximal forearm and tagged with 0-braided polyethylene sutures, using a Bunnell technique.

Tendon Repair

The EDC tendons to the index, long, and ring fingers were transversely lacerated in Verdan’s zone VI proximal to the junturae tendinum. The tendons were repaired by a single operator (R. F. H.) with 1 of 3 randomly assigned techniques: modified Bunnell, modified Krackow-Thomas, or MGH (Fig. 1). The Krackow-Thomas technique was modified by the addition of a continuous epitenon suture of 6-0 monofilament nylon. This suture was placed around the circumference of the tenorrhaphy. A running, locking suture of 4-0 braided polyethylene suture was started along the tendon edge, approximately 1 cm from the tendon junction, woven to a point 1 cm beyond the junction, and then woven back to the original starting point, where the suture was tied. A second suture of 4-0 braided polyethylene was similarly placed along the opposite tendon edge.

The modified Bunnell technique was constructed by placing 1 6-0 nylon epitenon suture and 2 4-0 braided polyethylene core sutures. The second core suture was placed immediately distal to the first, with care taken to avoid impaling the previously placed core suture with a needle.

The MGH repair was performed as described by Greenwald et al. for the flexor tendons. First, a 6-0 monofilament nylon epitenon suture was placed at the tendon junction. Next, beginning 1 cm from the tendon junction, 2 laterally placed criss-crossing

Figure 1. Repair techniques. MGH, augmented Becker repair.
sutures of 4-0 braided polyethylene were placed. After each cross was formed, the suture was pulled snugly to the point of tendon surface deformation.

Mechanical Testing

Each hand was mounted on the slide tray of the testing apparatus by drilling a 1.6-mm Kirschner wire (K-wire) transversely across the midshaft of the index, long, and ring finger metacarpals. A second wire was placed parallel to the first at the level of the carpus. The K-wires were attached to the frame with the palm facing down and the wrist in neutral position. A 200-g weight was suspended from the suture attached to the FDS tendons. This weight was chosen as the minimum required to fully flex the MD joints. The repaired extensor tendon to be tested was attached to a force transducer (Omega Engineering, Stamford, CT; accuracy ± 0.02% over 900-N range). The slide tray of the mechanical testing device was powered by a high-torque motor that provided a constant rate of tendon excursion of 4 cm/min. A linear variable differential transformer (LVDT) Lucas Schaevitz, Pennsauken, NJ; accuracy ± 0.1% over 20-cm range) was used to monitor tendon excursion. Output signals were amplified and noise was suppressed by a signal conditioner (Omega Engineering). Analog data were recorded continuously and sampled for digital conversion at 10 Hz (ADC488/16; IO Tech, Cleveland, OH). Digital data passed through a computer interface (Mac-SCSI 488; IO Tech) for collection and storage. Custom software was used to convert the data and format it for spreadsheet analysis.

Each repaired tendon was pulled until the sutures ruptured or pulled out of the tendon. An observer marked the data with an electronic touchpad at the point of 0° MP extension and at tenorrhaphy gap formation. Gap formation was noted visually with the aid of an electronically calibrated scale placed behind the repairs. Load required to achieve 0° MP joint extension and load required to achieve 1-mm tenorrhaphy gap formation were recorded. Repair strength was defined as load measured at 1-mm tenorrhaphy gap formation. Repair toughness (a measure of total energy required to cause gap) was calculated as the integral of the load displacement curve from displacement = 0 to displacement at tenorrhaphy gap formation. Displacement = 0 was determined to be the point during distraction where load was 5% over background.

Statistical Analysis

Factorial analysis of variance (StatView II for Macintosh, Abacus Concepts, Berkeley, CA) was performed. Intergroup comparisons of strength, toughness at gap formation, and load to 0° MP joint extension were performed by Fisher’s protected least squares design test. The level of significance was set at p < .05.

Results

None of the repairs failed before gap formation, and no gaps were observed prior to MP joint extension to 0°. The MGH technique was significantly more gap resistant (p < .01) and tougher (p < .02) than both the modified Krackow-Thomas and the modified Bunnell techniques (Fig. 2, 3). Comparison of the modified Bunnell and modified Krackow-Thomas showed no significant difference. There was no statistically significant difference between the groups in load required to reach 0° MP extension (Fig. 4).

All 3 techniques gapped under load prior to suture rupture. One tenorrhaphy repaired with a modified Bunnell failed by suture pullout. All other tenorrhaphies failed by core suture rupture. All 3 techniques produced a wide gap prior to suture rupture. An incidental observation made about the repairs was that the MGH was the only repair that maintained the flat morphology of the tendon cross-section. The other repairs caused considerable bunching of the tendons, leading to rounder cross-section morphology.

Figure 2. Mean load to gap formation (strength) ± standard error of the mean. MGH, augmented Becker repair.
Discussion

We found superior strength and toughness characteristics of the MGH technique compared to the Bunnell and Krackow-Thomas repairs. The fact that the MGH repair resisted gap formation to a significantly higher degree is consistent with earlier reports on work in flexor tendons describing the mechanical advantage of the “finger-trap” design of the MGH tenorrhaphy.9,10

Loads required to extend the MP joints to 0° were roughly half of those seen at gap formation for the Krackow-Thomas and Bunnell repairs and one third of the load at gap seen with the MGH repair. Variations in load to MP joint extension are likely due to differences between anatomic specimens (joint size, morphology).15 The limitation of this cadaver model does not allow us to make a strong statement about the significance of this difference. Clinical testing is required to determine normal extensor tendon loads during physiologic motion and during protected rehabilitation protocols. Notwithstanding, it can clearly be stated that the MGH repair resists gap formation better than the other four-strand techniques tested.

Newport and Williams2 reported that the two-strand modified Bunnell repair provided the greatest strength in their human cadaver model. They suggested that loss of extension was still likely to result from weakness of extensor suture techniques and their propensity for gapping with flexion. The maximum strength of the modified Bunnell repair in their study was 1,425 g, roughly equivalent to 14 N, or approximately equal to the force required to achieve full MP joint extension in our model. Based on this data, we would expect fewer failures, owing to the additional strength afforded by four-strand repairs. The improved strength of four-strand repairs over that of two-strand repairs is consistent with Savage’s findings in the flexor tendons.11 The significantly higher gap resistance of the MGH technique suggests its superiority for use in extensor tendons as well as in flexors.

Kerr and Burczak8 reported their results for 46 two-strand tendon repairs in Verdan’s zones VI, VII, and VIII managed with immediate postoperative dynamic passive extension. They allowed full MP joint flexion from the inception of therapy and reported no tendon ruptures or extensor lags. They did not specify the wrist position used in their technique, but their illustrations indicate the wrist was in neutral or slightly extended. While their report indicates that two-strand techniques performed well at the tensile loads experienced by the tendon at maximum finger flexion, not everyone has experienced similar success.2-4,12 Given its superior strength, the MGH extensor tenorrhaphy should tolerate the loads required for immediate active full finger flexion and should result in fewer problems related to gap formation.

Ultimate strength of a repair is proportional to the size and number of suture strands crossing the repair whereas resistance to gap formation derives from
suture purchase, or grasp. We defined repair failure as gap formation at the tenorrhaphy. This represents a more clinically appropriate endpoint because the extensor mechanism functions as an interconnected linkage system in which the relative lengths of its various components are critical to proper function.2,16 The fact that there were no differences between the repair groups in ultimate rupture strength (as contrasted with strength to gap formation) reinforces the concept that it is the design of the repair and not the amount of suture material that is responsible for resistance to gap formation. If failure had resulted from suture pullout, then we would have likely seen more variability in the data, owing to differences in suture purchase between different techniques. Load at ultimate rupture in this study is merely a reflection of the strength of 4 strands of suture. Load to gap formation is more correctly defined (owing to clinical ramifications of gapping) as the strength of the repair. None of the 3 techniques tested prevented gap formation prior to suture rupture. The MGH, however, performed significantly better. We believe the superior purchase of the MGH technique in the tendon results from its ability to grasp the epitenon and to convert longitudinal loads into compression. The collagen of the tendon core is longitudinally oriented. By contrast, the collagen of the epitenon forms an interlacing lattice.17 Thus, the area of the tendon best suited to convert longitudinal shear force from the suture into compression force without slippage is the epitenon layer. The MGH technique has multiple sites of purchase in the epitenon. Furthermore, when loaded, the crisscrossing lattice of suture appears to create a fingertrap-like effect around the tendon. Preloading during construction is critical to the success of the tenorrhaphy: each crossing of the suture strands must be loaded to the point of tendon deformation. We believe the preloading of the sutures significantly contributes to the superior performance of the MGH technique in extensor tendon repairs.

The MGH technique is recommended for extensor tendon repair in Verdan zone VI when early active postoperative mobilization programs are being considered.

References