Relative Motion Flexion Splinting for Flexor Tendon Lacerations: Proof of Concept

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Abstract

Background: The principle of relative motion has allowed patients to regain a higher degree of hand function, while protecting extensor tendon repairs. The purpose of this study was to determine whether the principle of relative motion could be a viable method to protect a flexor tendon repair. **Methods:** Four fresh-frozen cadaver arms were each mounted on a testing apparatus (wrist in 30° of extension, metacarpophalangeal [MCP] joints blocked to 70°–80°). A minimum of 11 N was used to cyclically load the flexor digitorum profundus and extensor digitorum communis tendons to maximum allowable flexion and extension for 25 cycles. Measurements of elongation of the tendons were obtained through the use of differential variable reluctance transducers. Testing was performed in both intact and repaired (single 6-0 nylon suture) middle finger tendons (zone 3) with and without a relative motion flexion splint (RMFS), which placed the affected finger in 15° to 25° of relative flexion at the MCP joint. **Results:** In all 4 hands, elongation was restricted to less than 1.3 mm in repaired tendon in the RMFS compared with elongation >2 mm in the nonsplinted condition. Average elongation was 0.86 mm (SD = 0.45). Visual examination of the tendons demonstrated no gapping with the use of the RMFS in any of the hands. All repairs had suture breakage and repair rupture without the RMFS. **Conclusions:** This study demonstrates that the RMFS decreases elongation and eliminates tendon-repair gapping after flexion/extension cycling in a cadaver model. It provides proof of concept that the RMFS may be a viable protective mechanism for flexor tendon repairs in zone 3.

Keywords: flexor tendon, relative motion, flexor tendon repair, flexor tendon rehabilitation, splint

Introduction

While the shift from passive flexion to early controlled active finger flexion protocols after flexor tendon repair has resulted in a better range of motion and a decreased rate of tendon adhesions, the early active motion protocols still involve relatively long periods of immobilization with interspersed sessions of motion. The protocol described by Dr Bo Tang in 2007¹¹ typically involves 4 daily sessions (morning, noon, evening, and before sleep), although episodes of 5 to 6 per day can be utilized. However, this scheme not only involves hours of time between activity sessions, it also utilizes a splint that hinders activities of daily living and function and requires patients to dedicate specific time toward their rehabilitation.

The concept of relative motion splinting to protect extensor tendon repairs was first described by Howell et al in 2005.⁴ The principles of relative motion as it pertains to tendons with a common muscle belly have been outlined by Merritt.⁶ Since their publication, the postoperative management of extensor tendon repairs has been transformed from protocols involving long postoperative immobilization to near-immediate motion. The relative motion extension splint also allows patients to use their hands with less impediment, as the “yoke” portion of the splint does not greatly impede function in activities of daily living and

light activity.⁶ In addition, patients do not need to spend specific time during their day to dedicate to rehabilitation. Movement occurs as a spontaneous and necessary part of their day-to-day life.

The “proof of concept” that assisted the adoption of this extensor tendon rehabilitation protocol was published in a study by Sharma et al wherein a cadaver model was used to demonstrate the protective nature of the relative motion concept in extensor tendon repairs.¹⁰

The purpose of this study was to determine whether the principle of relative motion could be an effective and feasible method to protect a flexor tendon repair.

Materials and Methods

Four fresh-frozen cadaver arms were used in this study. The flexor digitorum profundus (FDP) tendons of the middle

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Figure 1. Schematic configuration of mounting apparatus.

fingers were dissected in the palm (zone 3), while the muscle belly of the FDP and extensor digitorum communis (EDC) was dissected proximally in the forearm, proximal to the musculotendinous junction. The pulley system of the fingers was not disrupted.

Each arm was mounted on a testing apparatus with the wrist in 30° of extension. A forearm-based dorsal splint was then applied which blocked the metacarpophalangeal (MCP) joints at 50° (Figure 1). A relative motion flexion splint was then fabricated to place the middle finger in 15° to 25° of relative flexion.

A minimum of 11 N was used to cyclically load the FDP and EDC tendons to produce alternating maximum allowable flexion and extension for 25 cycles.⁷ Load was considered adequate if full flexion (finger pads touching the palm) and full extension of the proximal interphalangeal (PIP) joints were achieved. Measurements of elongation (the distance between 2 fixed points on the tendon) of the tendons were obtained with and without the relative motion splint through the use of differential variable reluctance transducers (DVRTs; Lord MicroStrain, Williston, Vermont). Measured in the intact tendon, elongation reflects the inherent laxity of the tendon during flexion. In the tenotomized (cut) condition, elongation is a measurement of gap formation.

Following intact tendon testing in both the nonsplinted and splinted conditions, a tenotomy was made in the FDP tendon in zone 3 and immediately repaired with a single, simple interrupted 6-0 nylon suture. Measurement of elongation was repeated with and without the relative motion splint. The tendon was visualized to determine whether visible gapping was present after cycling in both the splinted and nonsplinted conditions.

Data Analysis

Elongation distance was defined as the distance from the shortest state of the tendon to the maximum elongated state

of the tendon during a flexion/extension cycle. Data acquisition was performed using the “Smart Motherboard” system from the manufacturer of the DVRTs (Lord MicroStrain). The maximum measureable elongation of the DVRTs was 3.3 mm. If at any point during the cycling the magnitude of elongation exceeded 3.3 mm as measured by the transducers, this was considered a repair failure.^{3,9}

The maximum elongation distances were compared descriptively between the splinted and nonsplinted states both with the tendon intact and “repaired.” The percent reduction in elongation due to application of the splint was calculated. In cases where the elongation was greater than 3.3 mm, the percentage was calculated using 3.3 mm as the denominator with the understanding that the reduction in elongation would be considered higher than the calculated percentage.

Results

The individual trial results for both splinted and nonsplinted states with intact and “repaired” tendons are shown in Table 1. The percent reduction in mean and maximum elongation due to splint application is presented in Table 2, and comparison of maximum elongation in all conditions is shown in Figure 2. Elongation of greater than 2 mm was not observed in any splinted condition. All nonsplinted conditions in which the tendon was “repaired” resulted in observable gapping. A representative video of both the nonsplinted and splinted conditions in the “repaired” scenario is shown in Online Videos 1 and 2.

Discussion

The use of relative motion to protect tendon repairs while enabling immediate active motion has been well documented for extensor tendon lacerations. While the primary goal of protecting the tendon repair has been shown, the greater benefit of relative motion after extensor tendon repair has been the increase in postoperative hand function that it enables. Patients have been able to perform activities of daily living as well as return to some forms of work with the use of their injured hand which results in less downtime, less loss of productivity, and less frustration with the comparatively lengthy time of immobility associated with traditional tendon rehabilitation protocols.

The biomechanics of relative motion are based on the concept of movement of multiple tendons based on a single motor. For the extensor tendons, this is the EDC muscle. The term “disengagement” was coined by Garland and Miles² in their study examining neural control of the FDP muscle based from work in the 1970s by Gandevia and McCloskey.¹ They observed that the distal interphalangeal (DIP) joint of the middle finger cannot exert torque if the PIP joint of the middle finger was flexed and the adjacent fingers were extended fully. Partial “disengagement” of the FDP was possible if the extension to the adjacent fingers was not full.

Table 1. Average Elongation.

Arm	Splinted	Tenotomy	Mean elongation ± SD, mm	Greatest elongation, mm
1	No	No	0.19 ± 0.02	0.22
1	Yes	No	0.07 ± 0.04	0.1
1	No	Yes	1.10 ± 0.46	1.95
1	Yes	Yes	0.11 ± 0.01	0.13
2	No	No	>3.3	>3.3
2	Yes	No	0.45 ± 0.06	0.6
2	No	Yes	>3.3	>3.3
2	Yes	Yes	0.28 ± 0.02	0.32
3	No	No	0.70 ± 0.26	0.98
3	Yes	No	0.80 ± 0.20	0.99
3	No	Yes	>3.3	>3.3
3	Yes	Yes	1.65 ± 0.28	1.95
4	No	No	1.24 ± 0.05	1.30
4	Yes	No	0.65 ± 0.85	0.80
4	No	Yes	1.20 ± 0.79	1.30
4	Yes	Yes	0.81 ± 0.27	1.02

Table 2. Percent Reduction of Mean and Maximum Elongation Due to Splint Application Compared With Nonsplinted State.

Arm	Tenotomy	% Reduction in mean elongation	% Reduction in maximum elongation
1	No	63	55
1	Yes	90	93
2	No	>87	>82
2	Yes	>92	>90
3	No	-10	-1
3	Yes	>50	>41
4	No	48	38
4	Yes	34	22

Given these principles of the FDP tendons and the largely single motor, this study shows that the concept of relative motion also applies to the protection of FDP tendons after a single suture “repair.” The high elongation in the intact, non-splinted state of arm 2 indicates a substantially inherently lax tendon. It is not known whether this would have been the case in vivo or whether this degree of laxity occurred after death of the donor. However, the relative motion splint was shown to reduce the elongation attributable to the high degree of inherent laxity as well. The reduction in maximum elongation ranged from 22% to 93% compared with the non-splinted state, and in none of the arms was an elongation distance of greater than 2 mm observed.

This study examined only middle finger zone 3 tendon repairs due to the technical difficulties in reliably measuring elongation in zone 2 or zone 1 which is caused by the limited space present in full flexion of the fingers and the size of the DVRTs. Future studies may require the use of non-invasive techniques of measuring tendon elongation to fully

investigate the use of relative motion in zone 2 or 1.⁸ However, there is evidence to demonstrate that flexor tendons glide longer distances in zones 4 and 3 than in zone 2, which should result in even smaller elongation values in zone 2 than the ones reported in this study of tendons in zone 3.^{5,8}

We theorize that a relative motion protocol for flexor tendon repair will have the following additional benefits:

1. It will allow early active motion of the affected digit(s) while protecting the repair site without the necessity of a regimented protocol. Allowing limited hand use with a relative motion splint could replace the protocol-like nature of current rehabilitation strategies and facilitate program adherence and, ultimately, outcomes.
2. Given that current flexor tendon rehabilitation protocols involve some form of immobilization of all of the fingers, the use of relative motion may enable patients to at least perform basic activities of daily living and possibly allow light hand use at work such as for typing, if for no other reason than allowing noninjured fingers near-full function while protecting the tendon repair.
3. Allowance of the use of the noninjured digits might mitigate the observed phenomenon of stiffness in the unaffected digits that is associated with nearly whole-hand immobilization currently in use in most flexor tendon protocols.

Our data suggest that the concept of relative motion should be investigationaly pursued as a viable method of protecting flexor tendon repairs allowing for immediate active range of motion.

Figure 2. Maximum elongation observed in splinted, nonsplinted, tenotomy (cut), and intact conditions. Elongation values greater than 3 mm represent substantial gapping past the maximum range of the differential variable reluctance transducer sensor.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

This study did not include live human subjects.

Declaration of Conflicting Interests

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