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Flexor Subzone II A–D Range of Motion Progression during Healing on a No-Splint, No-Tenodesis Protection, Immediate Full Composite Extension Regimen

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Background: The objective was to study the hypotheses that an advanced zone II flexor tendon rehabilitation protocol would avoid rupture, achieve a high range of excursion, and minimize interphalangeal contracture during both the early phases and at the conclusion of healing. We also proposed the null hypothesis of no difference between any two of the zone II subdivisions.

Methods: Fifty-one consecutive adult patients with zone II flexor tendon repairs of a single finger were retrospectively evaluated on an active contraction rehabilitation protocol with no splint, no tenodesis protection, and immediate full composite extension. There were 38 males and 13 females with a mean age of 39 years (range 18–69) involving 15 index, 7 long, 6 ring, and 23 small fingers. Repairs were located in flexor subzone IIA for 8 fingers; subzone IIB, 14; subzone IIC, 19; and subzone IID, 10. Differences in outcome between any two subzones were compared by T-test with $p < 0.05$.

Results: Mean active arcs of motion in degrees at 3 weeks post repair were PIP 1-93; DIP 0-44; and total active motion (TAM) 221. At 6 weeks PIP 2–98; DIP 1–51; and TAM 236. At 10–12 weeks PIP 1–101; DIP 1–56; and TAM 246. Final TAM by flexor subzone IIA was 243; IIB, 251; IIC, 246; and IID, 246. There were no significant differences between any two subzones. Mean final DASH score was 5. There were no ruptures.

Conclusions: The results support the hypotheses. Outcomes of the therapy protocol demonstrated the lack of interphalangeal joint flexion contractures, high range of total active motion achieved early and sustained, and no ruptures. No differences were identified between and two of the flexor subzones.

Keywords: *Flexor, Tendon, Laceration, Repair, Rehabilitation*

INTRODUCTION

As surgical techniques for zone II flexor tendon repair have improved, commensurate evolution in therapy methods has followed. Modern repairs involve 4–8 strands that lock tendon fibers and avoid gap formation.[1-8] The historical desire to preserve as much tendon sheath as possible has given way to venting the sheath throughout the path of repair site excursion.[9-14] The fear of rupture has decreased as supported by a low published incidence.[13,15-20] Stronger repairs with low rupture rates encouraged the transition from passive to active motion rehabilitation programs.[10,21-24] Current practice ranges from more restrictive regimens where motion is performed in a splint to those that come out of a splint but utilize limited arcs or compensatory tenodesis unloading.[16,20,25-27] We observed that patients who were noncompliant with our former in-and-out of splint, tenodesis-protected, active motion program obtained better

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results than compliant patients. The study objective was to test the hypothesis that a different formal therapy program (designed to capture the beneficial aspects of the non-compliant patients' behavior) would optimize motion outcomes while still avoiding rupture (Table 1). A secondary hypothesis was that immediate unlimited motion, including composite extension, would minimize the development interphalangeal joint flexion contractures. The tertiary hypothesis was that no difference would be seen between any two subdivisions of flexor zone II.

METHODS

Fifty-one adult patients were retrospectively identified by searching the database of a practice specializing in hand and wrist trauma using the CPT codes 26356 and 26357 for zone II flexor tendon repairs of a single finger. Inclusion required a minimum follow-up of 8 weeks and adherence to the specific therapy protocol but permitted associated digital nerve and artery lacerations and repairs. Excluded were flexor pollicis longus repairs (different joint measurements), associated fractures, and pre-existing motion limitations from prior trauma or osteoarthritis. After applying inclusion and exclusion criteria, all patients from April 2016 to April 2018 were studied. There were 38 males and 13 females with a mean age of 39 years (range 18–69) involving 15 index, 7 long, 6 ring, and 23 small fingers. Repairs were performed for 49 flexor digitorum profundus (FDP) tendons, 19 flexor digitorum superficialis (FDS) tendons, 33 digital nerves, and 21 digital arteries. Repairs were located in flexor subzone IIA for 8 fingers, subzone IIB for 14 fingers, subzone IIC for 19 fingers, and subzone IID for 10 fingers. Differences in outcome between any two subzones were compared by T-test with $p < 0.05$. Comparisons were tested as subzone A vs. B, A vs. C, and A vs. D. We tested subzone B vs. C and B vs. D. Testing subzone C vs. D completed all possible combinations to identify any difference between two subzones. Ranges of motion were measured using a goniometer by the patient's therapist for individual joint motions as well as total active motion (TAM) = the sum of the active arcs of motion for the metacarpophalangeal, proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints.

Each patient completed a separate specific consent form for inclusion in the research. The study was submitted to the hospital ethics committee for institutional review. The study conforms to the ethical guidelines of the 1975 Declaration of Helsinki and HIPAA privacy protections. We have implemented the items from the Strengthening the Reporting of Observational Studies in Epidemiology checklist for cohort studies that apply to

Table 1. Comparison of Different Therapy Protocols

	Other protocols	Our previous protocol	Current study protocol
Splint design and use	Splint formed with wrist in flexion; Hinged splint kept on during motion rehabilitation; Splint only removed to perform motion rehabilitation.	Wrist extended intrinsic-plus splint; Splint only removed to perform motion rehabilitation.	Wrist extended intrinsic-plus splint; Splint only worn defensively in specific risk environments, otherwise no splint worn.
Extension phase	Composite extension avoided prior to healing; Wrist flexed when interphalangeal joints extended; Metacarpophalangeal joints partially flexed when interphalangeal joints extended.	Composite extension avoided prior to healing; Wrist flexed when interphalangeal joints extended; Metacarpophalangeal joints extended along with interphalangeal joints.	Immediate composite extension of wrist, metacarpophalangeal and interphalangeal joints, including use of passive force if necessary to reach position.
Flexion phase	Flexing the fingers with the wrist in flexion; Limiting the range of flexion during the initial weeks of motion rehabilitation; Avoiding full effort active pull through, always providing assist force; Passive flexion phase with no active contraction at all.	Wrist relaxes into extension as fingers flex full range; Low force active contraction, but using guided assist force to reach flexion if any resistance encountered; Standard fist formation only.	Wrist relaxes into extension as fingers flex full range; Active contraction to maximum capacity, avoiding reliance on external assistance unless absolutely necessary; Formation of both standard fist and hook fist flexion postures; Multiple relax-contract cycles at end range of flexion.

The Journal of Hand Surgery (Asian-Pacific Volume) • Vol. 24, No. 4, 2019 • www.jhs-ap.org

this specific project.

Therapy protocol

Patients were given extensive pre-operative instructions regarding all aspects of flexor tendon injury, repair, rehabilitation, and healing by the surgeon. Therapy was prescribed to begin 72 hours after surgery under direction of a certified hand therapist, but actual initiation times varied from the prescription by up to a week. Patients were provided with a protective intrinsic-plus splint to be used as a defensive shield only in particularly dangerous environments. When at home or in their offices, patients were instructed to leave the splint off and freely move all fingers through the maximum excursion range. Protection against rupture was accomplished through the strict instruction to never contract the repaired tendon against added external force such as grasping or holding onto an object.

The excursion cycle begins with the wrist and fingers in full composite extension, specifically avoiding the compensatory tenodesis unloading of wrist flexion opposite digital extension (Fig. 1). If passive force was needed to achieve absolute full extension, patients were instructed to use the other hand to bring the repaired finger all the way out to prevent any flexion contracture developing. From the full composite extension starting position, patients are taught to actively contract to form both a standard fist and to form a hook fist position, allowing the wrist to relax into comfortable extension while doing so (Fig. 2). They are taught to recognize and avoid co-contraction so that full active flexion can be achieved early, before adhesions form (Fig. 3). Co-contraction is a mal-adaptive behavior on the part of the patient, often witnessed during the initial phases of hand rehabilitation. At the same time as the intentional contraction of the agonist muscle groups (digital flexors/wrist extensors), the patient also subconsciously contracts (co-contracts) the antagonist muscle groups (digital extensors/wrist flexors) that then resist and compete against the agonist muscle groups. In the case of attempted active digital flexion, motion is resisted and higher force is required when patients simultaneously co-contract digital extensors (both extrinsic and intrinsic), less so wrist flexors. If despite best efforts, pure active motion has not resulted in full flexion, patients are taught to lightly assist with the other hand but to continue pulling actively the whole time. Once a full fist has been reached, they repeat short arc relax-contract cycles to reinforce the end range of active flexion before returning out into full composite extension and repeating.

Surgical methods

This study is not investigating surgical methods; techniques are provided as a point of reference only because method of rehabilitation is inseparable from surgery. Core sutures employed a cross-locking 4-strand repair with 3-0 non-absorbable braided suture, independently pre-tensioning each cross- lock. The zone for excursion of the repair junction itself was marked, and all

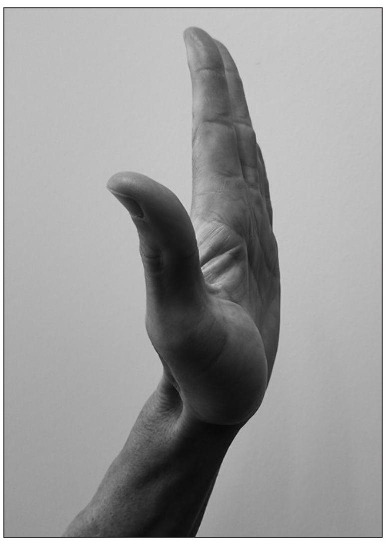

Fig. 1. The excursion cycle begins with all three finger joints in full composite extension, along with the wrist in neutral to slight extension (not the compensatory tenodesis of wrist flexion).

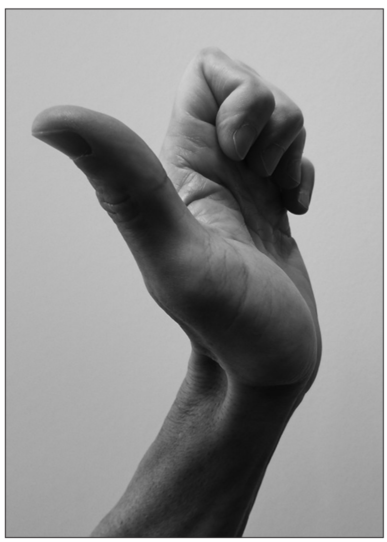

Fig. 2. The hook fist position emphasizes active interphalangeal flexion. It is a useful training position particularly for those patients who tend to overemphasize metacarpophalangeal flexion at the expense of interphalangeal flexion.

pulleys in this zone were fully divided except A2. If the repair junction traveled through the majority of A2 during excursion, then reduction of sheath contents rather than pulley modification was used to reduce drag and work of flexion. In these cases, if FDS was also fully lacerated, it was excised. If FDS was partially lacerated or intact, then half the FDS was excised.

RESULTS

Mean active ranges of motion post-repair for PIP extension, PIP flexion, DIP extension, DIP flexion, and TAM at 3 weeks, 6 weeks, and 10–12 weeks are recorded in Table 2. Final TAM measurements, in degrees (+/− standard deviation), were flexor subzone IIA, 243 (+/− 18); subzone IIB, 251 (+/− 24); subzone IIC, 246 (+/− 23); and subzone IID, 246 (+/− 29). There were no statistically significant differences in outcome between any of the two flexor subzones. Mean final DASH score was 5. There were no ruptures. No tenolyses were performed.

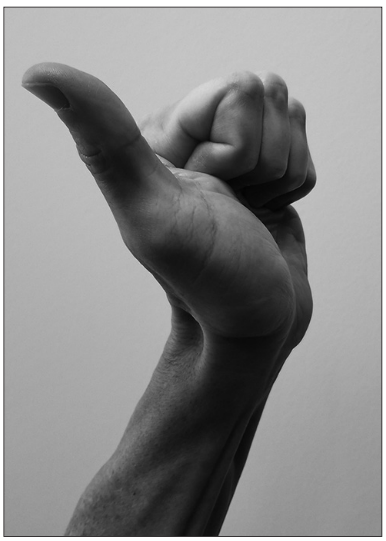

Fig. 3. The standard fist position of full composite flexion is the target objective to achieve using active only contraction, minimizing reliance on external assist forces.

DISCUSSION

The study affirmed all three hypotheses. A high range of excursion was achieved early and maintained without rupture. Interphalangeal flexion contractures were avoided, and no differences were seen between any of the two subzones. Zone II flexor tendon repair and rehabilitation is one of the most complex topics in hand surgery with multiple interactive variables affecting outcome. Over time, thoughtful research from around the world has progressively revealed better practices and the particular combinations of variables that work well together. The numerous variables include the joint angles of the resting splint, whether the splint is fully removed during motion, the range allowed at different time points of healing, whether the wrist is flexed when the fingers extend (tenodesis unloading protection), and allowance for any passive extension force.[9,10,16,19,23,24] Authors have reported different combinations of these variables and others, but nearly all previously reported programs require some form of restraint to motion during the early stages of healing.[15,17,20,21,26-28]

The theoretical reason for imposing restraint is to prevent tensile loading from exceeding force thresholds that lead to rupture or repair site gapping over 2 mm.[2,3,6,8,12,29,30] The degree of restraint, however, has been disproportionate to the low reported rupture rates of 0–7.1%.[13,15-20] Compared to studies specifically addressing rehabilitation methods, a greater amount of flexor tendon research has focused on the many details of repair technique. Much of this research has been directed at maximizing strength sufficient to support active rehabilitation methods.[4,5,7,16,31-33] Flexor tendons have been shown to experience 14 N loading with passive motion, 27 N with active motion, and 50 N with added resistance.[34,35] A 4-strand, cross-locking repair similar to the one employed in the current study demonstrated 62 N to 2 mm gap formation and 72 N load to failure.[30] To safely support active motion rehabilitation programs, a repair should use a 3-0 braided core suture with at least 4 strands crossing the repair site and use cross-locks rather than grasping loops capturing at least a 2 mm cross sec-

Table 2. Active Ranges of Motion in Degrees (+/– Standard Deviation)

	PIP extension	PIP flexion	DIP extension	DIP flexion	TAM
3 weeks post-repair	1 (+/– 4)	93 (+/– 7)	0 (+/– 1)	44 (+/– 11)	221 (+/– 21)
6 weeks post-repair	2 (+/– 4)	98 (+/– 7)	1 (+/– 2)	51 (+/– 13)	236 (+/– 25)
10–12 weeks post-repair	1 (+/– 3)	101 (+/– 8)	1 (+/– 2)	56 (+/– 14)	246 (+/– 24)

PIP: proximal interphalangeal joint, DIP: distal interphalangeal joint, TAM: total active motion = active arcs of motion metacarpophalangeal + PIP + DIP joints.

tion of longitudinal tendon fibers a centimeter from the junction.[1-3,7,8,20,29-32] In pursuit of maximum strength, some advocates have recommended 6 and 8-strand repairs, but the comprehensive performance of a repair encompasses more than just resistance to tensile load.[5,16,17] Certain patterns of cross-locking 4-strand repairs are as strong as other patterns of 6 and 8-strand repairs but demonstrate better overall performance according to author designated metrics for construct efficiency and quality.[1,2,4,6,7] Focused epitenon alignment sutures yield less gliding resistance than either no epitenon suture or a fully circumferential epitenon suture, as does full venting of the sheath throughout the zone of excursion without a clinically evident decrement in flexion efficiency from bowstringing.[6,9-14,33,36,37] The design of the repair technique described in the methods section was based on these findings and other cumulative evidence from the literature.[4,8,19,20,32,38]

Range of motion outcomes following zone II flexor tendon repair may be the indirect consequence of surgical technique, but they are the direct consequence of the quality of motion rehabilitation performed throughout the healing phase. Studies designating the rehabilitation method as the independent variable while controlling for surgical technique have demonstrated superior outcomes with active motion compared to passive motion.[21,24,28] Amongst active motion programs, superiority of one particular combination of details is less clear.[15,19,20,22,25,27] Past studies report TAM of 230 degrees or less and DASH scores of 11–18.[5,9,13,15,17,18,21,23,28,39] The final mean TAM in the current study was 246 degrees with a mean DASH score of 5. Despite these favorable results with a reasonably sized sample, as an observational cohort study without a control group, it is not possible to state that this particular rehabilitation program is necessarily better than any other. Recognizing that shortcoming, the primary purpose of this initial observational study was to reveal any rupture rate and document the amount of motion that could be achieved with a less restrictive protocol while controlling for other variables: surgical technique, surgeon experience, single finger, and no associated fracture. The next step in studying an advanced rehabilitation protocol would be a randomized controlled trial. Unfortunately, in order to achieve sufficient power such studies lose control of the other surgical and patient variables, most often yielding the typical result of no statistically significant difference in the dependent variable, even when truly different treatments have been rendered.

The secondary and tertiary purposes of the study were to examine for differences between any two of the subzones and catalog specific individual joint ranges at measured time points throughout the healing phase. Past research has demonstrated inferior results for flexor subzone IIC, but that was not our finding.[13,23] Final TAM in flexor subzone IIC was 246 degrees and for the entire cohort 246 degrees. Testing each combination of one subzone vs the other three did not find statistically significant differences with $p < 0.05$. Our past experience using in-and-out of splint, tenodesis-protected, active contraction rehabilitation methods yielded an early tendency towards developing PIP (and sometimes DIP) joint flexion contractures that has also been previously reported by others.[33] Our hypothesis was that by bringing the finger into true composite full extension with each motion cycle (even if passive force was required to do so), development of PIP and DIP joint flexion contractures would be minimized. This indeed proved true with a maximum mean PIP flexion contracture of 2 degrees at the 6-week assessment, DIP of 1 degree.

In summary, a well-repaired flexor tendon should, on a daily basis, be actively moved through the longest possible composite excursion pathway under sufficiently low forces to avoid gap formation or rupture. When patients spend too much total time per day in a restrictive splint, local segments of scar tissue progress and mature that lead to specific motion deficits, most frequently at the PIP joint. Our protocol differs from others in that we now only have patients wear the splint in particularly dangerous and unpredictable environments, leaving it off at other times to encourage free range full motion of the hand. When patients use tenodesis unloading, even though individual joints are moving well, the same segment of tendon travels a limited distance, allowing local adhesions to develop. Our protocol differs from others in that we now have the patient come all the out into full composite extension of the wrist and fingers simultaneously from the very first therapy session. In other protocols that fully extend the DIP and DIP joints but with compensatory tenodesis, the flexor tendon to surrounding tissue relationship is the same as our patients from the proximal phalanx and distal. But, the tendons proximal to the proximal phalanx progressively form local adhesions at a reduced length, leading to interphalangeal flexion contractures when the patient eventually attempts a composite extension posture at a later time point. Our protocol differs from others in that we now have the patients actively contract without hesitation through the full range of flexion, as long as they are not contracting the repair against external resistance. Protocols that limit active pull-through early in the training do not reach full excursion; meanwhile local adhesions are forming. Although the design of this therapy protocol originated from observations on previous 'non-compliant' patients who didn't wear their splints and moved freely, ongoing predictable success requires compliant patients who can be counted on to not exert excessive forces with an unconstrained hand. The high frequency of direct surgeon to patient interactive training sessions may be an important variable in meeting these objectives.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this study.

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The Journal of Hand Surgery (Asian-Pacific Volume) • Vol. 24, No. 4, 2019 • www.jhs-ap.org

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