Recent Developments Are Changing Extensor Tendon Management

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Learning Objectives: After reviewing this article, the participant should be able to: 1. Start early protected movement at 3 to 5 days after surgery with relative motion extension splinting for zone 5 extensor tendon lacerations over the hand. 2. Allow patients to resume regular activities much sooner than the conventional 3 to 4 weeks of splinting after extensor tendon repair. 3. Improve the rehabilitation of boutonniere deformities with relative motion splinting.

Summary: This article focuses on surgery and rehabilitation of extensor tendon injuries from the proximal interphalangeal joint (boutonniere) to the wrist. Relative motion flexion and extension splinting and wide awake, local anesthesia, no tourniquet surgery have revolutionized the management of these lesions, with early protected movement, sooner return to regular activities, and improved rehabilitation. This article explains and illustrates these new advances in extensor tendon management. (*Plast. Reconstr. Surg.* 145: 617e, 2020.)

THE THREE MOST IMPORTANT RECENT ADVANCES IN ZONES 3, 5, AND 6 EXTENSOR TENDON INJURY OF THE HAND

Three of the most important recent innovations in extensor tendon management are (1) relative motion extension (RME) orthoses (splints) that permit early active motion and functional use at 3 to 5 days after extensor tendon repair and reconstruction over the hand dorsum; (2) relative motion flexion (RMF) orthoses for boutonniere management; and (3) the use of local anesthesia with epinephrine instead of the tourniquet and sedation for wide awake extensor tendon surgery. This article focuses on these developments and how they are improving the management of extensor tendon injury (Fig. 1).

RATIONALE FOR WIDE AWAKE, LOCAL ANESTHESIA, NO TOURNIQUET SURGERY FOR EXTENSOR TENDON REPAIR AND RECONSTRUCTION

Eliminating the tourniquet avoids the severe pain it causes as well as the need for sedation and ischemic paralysis from motor blocks. This permits comfortable, clear-headed functional active movement and observation of that motion by the surgeon and patient during surgery.

In extensor tendon repair or reconstruction over the dorsum of the hand, the surgeon can simulate relative motion flexion or extension splinting during the operation with a sterile tongue depressor or ribbon retractor. The surgeon can study and safely adjust the sutured tendons moving at the patient's command. In complex reconstruction such as tendon transfer for extensor tendon rupture, in situations such as caput ulnae,[1] the moving patient can verify whether the initial sutures have restored the necessary delicate balance or not.

The surgeon can also assess the extensor tendon repair with full fist flexion and extension during the operation. The surgeon can see if the relative motion extension orthosis is keeping a repaired tendon slack enough to permit early active protected movement in a relative motion splint at 3 to 5 days, with or without the addition of a wrist splint.

The patient can see and remember that the relative motion orthosis protects the repair, so the patient will be able to actively return to activities

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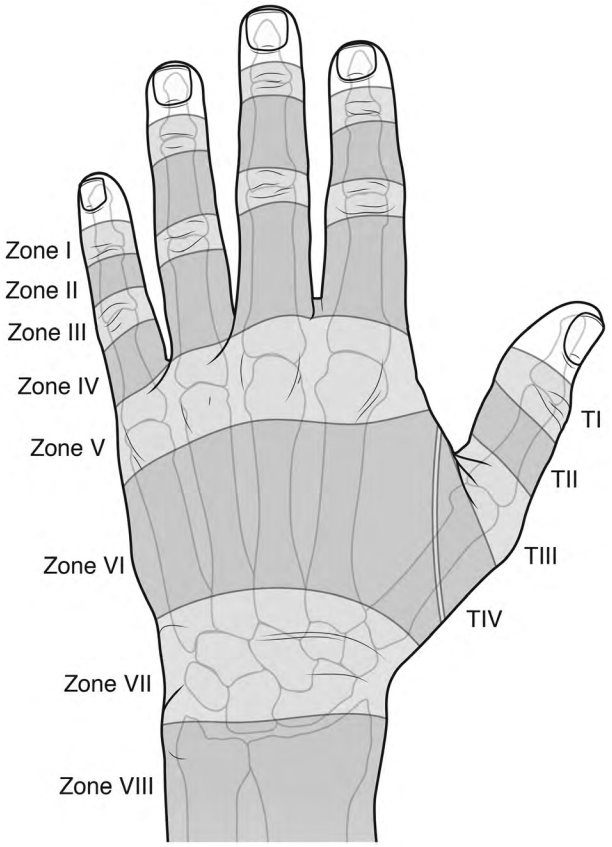

Fig. 1. Zones of extensor tendon injury in the hand. This article focuses on extensor tendon injury and management of zones 3, 5, and 6.

wearing the splint. The surgeon can explain to the patient about how the splint works during the operation. The clear-headed, unsedated patient will remember how important it is to wear the orthosis as he or she starts early protected movement after surgery.

In complex reconstruction, such as boutonniere deformity repair, the moving patient can verify whether the necessary delicate intrinsic-extrinsic balance is restored or not. The relative motion flexion orthosis is simulated with a tongue depressor, so the surgeon can see that both proximal interphalangeal extension and distal interphalangeal flexion are maintained without rupture of the repair.

RATIONALE FOR RELATIVE MOTION EXTENSION SPLINT TO PROTECT ACTIVE MOVEMENT AFTER EXTENSOR TENDON REPAIR OVER THE HAND (ZONES 5 AND 6): THE QUADRIGA EFFECT

A relative motion extension splint keeps the injured finger more extended at the metacarpophalangeal joint than the adjacent uninjured fingers (Figs. 2 and 3). When the repaired finger extensor digitorum communis tendon is placed in 15 to 20 degrees greater extension at the metacarpophalangeal joint than its neighboring uninjured finger extensors, it has more slack than the other tendons due to the quadriga effect.

"Quadriga" is the name Romans gave their two-wheeled chariot with equidistant reins to control four horses by the charioteer. The term "quadriga effect" was coined by Verdan[2] as a metaphor to bring attention to the complication that occurs when the long extensor tendon is sutured to the profundus tendon over a digital amputation stump, with resultant loss of full flexion of the adjacent uninjured digits. This is due to the relative shortening of the amputated digit's profundus tendon, which restricts contraction of the common flexor muscle, causing loss of flexion in the adjacent digits.

After extensor tendon repair over the hand, the quadriga of the three "reins" of the three uninjured extensor tendons are tight, and the "rein" of the injured extensor tendon is loose due to the relatively extended metacarpophalangeal joint with the relative motion extension splint. With full fist flexion, the extensor digitorum communis muscle is pulled distally by the tendons of the metacarpophalangeals that are more flexed, maintaining laxity of the repaired tendons. With full extension, the splint keeps the hyperextended injured tendon in a slack position. This is easily demonstrated in the cadaver shown in Video 1. [**See Video 1 (online)**, which demonstrates a slack extensor tendon with a single 6-0 nylon suture. The repair does not come apart in full metacarpophalangeal flexion because of the relative motion extension orthosis.]

This is also easily seen in the clinical setting in the awake patient. Place a sterile tongue blade beneath the proximal phalanx of a repaired digit and on top of adjacent fingers to simulate a relative motion extension splint. Then ask the patient to flex and extend after placement of a single 6-0 nylon suture repair of the tendon. It will be seen that the single 6-0 nylon suture holds the tendon together without rupture using this simulated splint despite full flexion and extension. This also reassures the surgeon that splint protection will be adequate to safely allow early protected movement after surgery. A more formal secure repair is then performed, and the patient is splinted in the user-friendly functional orthosis for 6 weeks.

The relative motion extension splint not only holds the tendon repair in a slack position with

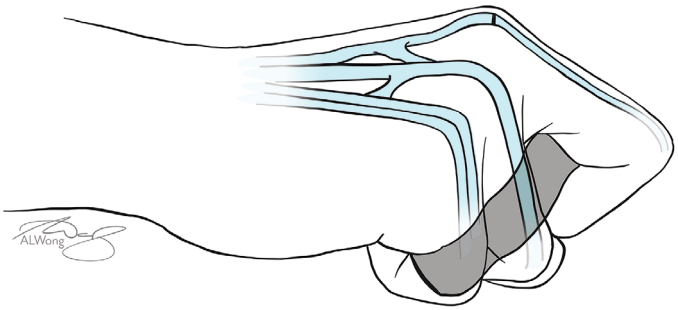

Fig. 2. Finger extension in relative motion extension splint after extensor tendon repair. This splint keeps the injured long finger more extended at the metacarpophalangeal joint than the adjacent uninjured fingers after an extensor tendon repair over the dorsum of the hand (*lateral view*).

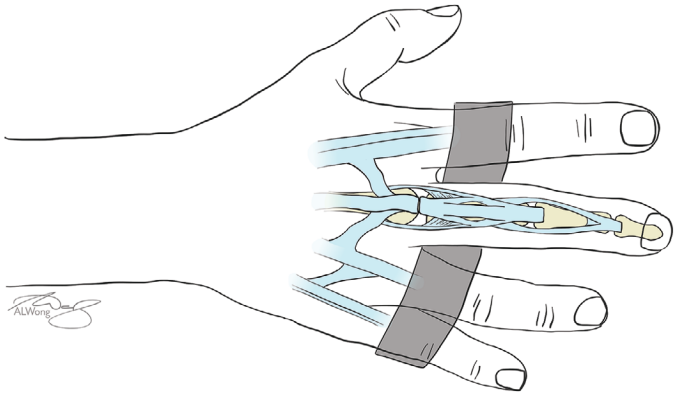

Fig. 3. Full fist flexion in relative motion extension splint after extensor tendon repair (*dorsal view*). This relative motion extension splint keeps the injured long finger extensor tendon slack even with full metacarpophalangeal flexion. It also decreases the injured extensor tendon excursion during active movement as seen in wide awake surgery.

the finger in full flexion but also decreases the excursion of the repaired tendon. It is suggested that 5 mm of active tendon excursion is enough movement to prevent tendon adhesions.[3] Observation under local anesthesia shows that a normal 12 mm of extensor excursion can diminish to 6 mm of active excursion in a relative motion extension splint. [**See Video 2 (online)**, which demonstrates a repair of extensor tendon over the index finger metacarpophalangeal joint. With full fist flexion and extension in the awake patient at surgery, the tendon not only is slack with a relative motion extension splint but also has a reduced glide of 6 mm with the splint and 12 mm without.] Relative motion extension splinting therefore not only decreases the tension on the repair, it also decreases the excursion. The tendon can move enough to avoid getting stuck, but it will not move enough to come apart. Both those factors allow safe active protected movement in the orthosis, and yet allow enough excursion to decrease adhesions.

This explains how relative motion splinting eases rupture-free earlier range of motion, with an average return to work time of 17 days[4] compared with 3 to 4 months[5] with immobilization. In the 375 cases reviewed by Hirth et al.,[6] there were no ruptures and no development of chronic pain syndromes in patients treated for long extensor repair and sagittal band rupture using relative motion extension orthoses. However, some patients have difficulty wearing this orthosis at night. Those individuals get a static gutter splint to wear while they sleep, maintaining the repaired tendon at rest in 15 to 20 degrees of greater extension at the metacarpophalangeal joint than uninjured fingers.

Surgeons have traditionally held repaired extensor tendons immobilized in extension

without movement for 4 to 6 weeks.[7] This is often followed by additional weeks out of work to alleviate the stiffness and loss of flexion. Relative motion splinting permits significantly earlier range of motion and return to work[8,9] and preserves 98.5 percent of the contralateral hand flexion after 6 weeks of splinting.[10]

We teach patients during the surgery that the hand is "on strike" for the first 3 to 5 days after surgery. They keep their hand elevated and immobilized in a temporary traditional full hand splint. This decreases the risk of postoperative bleeding in the wound, which would increase scar formation. It also allows the swelling and the work of tendon movement to decrease before collagen formation starts at day 3. In addition, the author D.H.L. recommends to awake patients during surgery that they get off all painkillers by 3 to 5 days so that they can listen to their body and start pain-guided therapy and pain-guided healing.

In the first years of this technique, the senior author (W.H.M.) felt wrist splinting in 20 to 30 degrees of extension was also advisable, in addition to relative motion extension splinting for the first 3 to 4 weeks followed by continuing the splint alone for a total of 6 weeks. However, in a scoping review of 375 patients treated with relative motion orthoses, Hirth, Howell, and O'Brien[6] pointed out that 188 reported cases were managed with no wrist component, and there were no reported ruptures. It may be that the wrist part of splinting is not necessary.

The author D.H.L. examines the repair with intraoperative active movement with a tongue blade simulating the relative motion extension splint. If the repair looks stressed with composite flexion or extension testing under local anesthesia, he adds the additional wrist splint to the relative motion extension splint for the first 3 to 4 weeks.

Video 3 demonstrates how to make relative motion orthosis. [**See Video 3 (online)**, which displays how to build a relative motion orthosis.] Some surgeons who have no access to hand therapists use tape to simulate relative motion splinting. [**See Video 4 (online)**, which displays how Dr. Caio De Souza uses tape for relative motion flexion splinting to treat this boutonniere deformity in Brazil.]

TREATMENT OF SAGITTAL BAND RUPTURE (ZONE 5)

Patients with acute closed sagittal band rupture, less than 2 to 3 weeks after injury, can usually centralize the tendon and experience pain relief when the injured finger metacarpophalangeal joint is tested in a relatively extended position with a pencil, keeping the injured finger more extended than the others. In Video 5, we present a patient in whom the lesion was just proximal to that, for whom the pencil test solved the snapping problem and the pain with the finger in a more flexed position. [**See Video 5 (online)**, which tells the story of a patient who did not need surgery after a tear of the sagittal band with snapping subluxation of the extensor tendon over the metacarpophalangeal joint.] With typical sagittal band ruptures, patients resume function in a relative motion extension splint for 4 to 10 weeks (usually 6 weeks), monitored by a hand therapist. These patients are splinted in a manner similar to that used for long extensor repairs with the same rationale,[11] but with no wrist component. The patient is encouraged to fully flex (minus the 15 to 20 degrees at the metacarpophalangeal joint) and should be pain-free without subluxation during the weeks of splinting. It remains questionable how late after injury one can manage these patients, and we have succeeded as late as 8 weeks if there is still inflammation and discomfort to indicate an active wound-healing process.

Peelman et al.[12] notes a success rate of 95 percent if splinted before 3 weeks and 57 percent if splinted after 6 weeks using a relative motion extension splint. The popular use of buddy splinting for sagittal band rupture has been associated with persistent discomfort as late as 1 year afterward.[13]

Some cases of subluxating snapping extensor tendons can also be managed with relative motion flexion splinting. [**See Video 6 (online)**, which displays a case of a painful subluxating extensor tendon. The pencil test showed that relative motion flexion splinting took away the pain and the snapping. The patient went on to heal the tendon snapping with only relative motion flexion splinting. The pencil test determines the type of splint to use by which position the pencil relieves the snapping and pain.] **Video 6** illustrates the pencil test which indicates which type of relative motion splint to use. Placing a pencil under or over the proximal phalanx of the affected finger and asking the patient to flex and extend the fingers several times will determine whether a flexed or extended position of the metacarpophalangeal joint alleviates the symptoms.[14]

Chronic sagittal band rupture surgery involves reconstruction of the ruptured side (usually radial) with tendon slips, grafts, or direct repair to centralize the tendon[15] [**See Video 7 (online)**, which

displays wide awake, local anesthesia, no tourniquet reconstructive surgery with a follow-up result.]

Another useful technique is the use of a tendon graft to make a pulley at the metacarpal head.[16] [**See Video 8 (online)**, which demonstrates a pulley reconstruction to centralize the extensor tendon in an awake patient. This technique is very useful when the local tissues are not adequate for other types of reconstruction.] Regardless of the surgical technique, we recommend early protected motion with relative motion extension splinting for 6 to 8 weeks as monitored by the therapist. A tendon graft pulley decreases the concern about the quality of the extensor hood tissues, especially in patients with connective tissue disease, previous infection, Ehlers-Danlos syndrome, or concern whether the tendon was adequately centralized. The graft is simply a strong tendon placed in the central position with its suture line rotated into the bone. Its value can be easily confirmed with wide awake approach. This postoperative management could be utilized with any of the various reconstructive techniques, but we prefer the tendon graft pulley method because it secures centralization of the tendon and does not rely on the quality of remaining connective tissue adjacent to the rupture. Various tissues for tendon graft have included juncturae tendinum, one-half of the extensor indicis proprius, a strip of extensor retinaculum, palmaris longus graft, and one-half of the extensor flexor radialis, with the latter two seeming preferable (W.H.M.).

We recommend relative motion extension splinting rehabilitation to avoid stiffness. Full activity and hand use is encouraged in the orthosis, and full recovery of flexion without subluxation is the usual outcome.

HOW A RELATIVE MOTION FLEXION ORTHOSIS REBALANCES THE BOUTONNIERE DEFORMITY (ZONE 3): "WINSLOW'S DIAMOND"

A relative motion flexion splint keeps the metacarpophalangeal joint of the injured finger in a 15- to 20-degrees more flexed position than the uninjured fingers. Both senior surgeons (W.H.M. and D.H.L.) regard the relative motion flexion splint as the most important development in the management of both unoperated and operated boutonnieres (Figs. 4 and 5). A boutonniere deformity provides the unique opportunity for a simultaneous beneficial quadriga effect in both extensor and flexor systems with relative motion flexion orthoses. [**See Video 9 (online)**, which displays how the relative metacarpophalangeal flexion generated by the splint tightens the long extensor pull on the lateral bands to pull them dorsally, while the intrinsics relax to let them go dorsally. **See Video 10 (online)**, which displays how the relative metacarpophalangeal flexion splint reverses the boutonniere deformity in a central (ring finger) digit as well as in a border (index finger) digit.]

First, on the dorsal extensor surface, the dynamic, somewhat complex relationship between the long extensor and intrinsic mechanism—described by Jacob Winslow (1669 to 1760) as "a tendinous rhomboideus"[17] and later known as "Winslow's diamond"[11]—is accomplished by the trifurcation of the long extensor proximal to the proximal interphalangeal joint, with the central slip inserting onto the base of the middle phalanx while the two lateral slips attach into the combined interossei and lumbrical tendons to form the lateral bands. This results in the rhomboid shape encirclement surrounding the proximal interphalangeal joint, rejoining distally to form the single conjoined tendon, and crossing the distal interphalangeal joint to insert into the distal phalanx.

Distal to the proximal interphalangeal joint, the lateral bands are connected to one another across the dorsum by the triangular ligament of Winslow and proximally by the oblique and horizontal arciform fibers of the extensor hood. Cadaver experiments[13] clearly demonstrated that all three of these structures (central slip, arciform hood fibers, and triangular ligament) must be divided to experimentally create a boutonniere deformity.

Winslow pointed out that when the normal proximal interphalangeal joint flexes, the lateral bands move laterally and volarly (Fig. 6), where they are restrained above the proximal interphalangeal joint axis of rotation by the triangular ligament and hood arciform fibers. This volar lateral position provides the necessary lateral band laxity to permit distal interphalangeal joint flexion because of the proximal attachment and tethering of the lateral slips to the intact central slip of the extensor digitorum communis where they trifurcate. With disruption of the central slip, this lateral band laxity is lost, increasing extensor tension on the distal interphalangeal conjoined tendon and weakness of proximal interphalangeal extension, which is noted when the proximal interphalangeal joint is held in a flexed position (evidenced by the Elson test and visible with the modified Elson test).

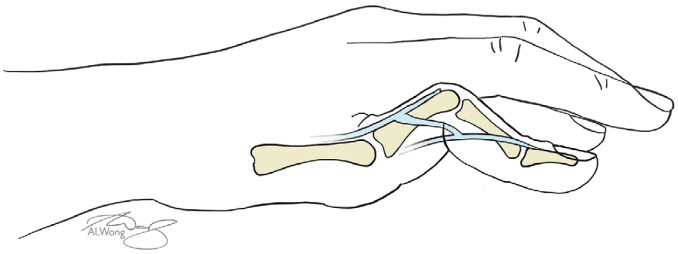

Fig. 4. The boutonniere deformity: simplified. The rupture of the central slip and the triangular ligament of Winslow allow the lateral bands to migrate volarly. Metacarpophalangeal extension tightens the lateral bands which pull volarly, and loosens the lateral slips of the long extensor upward pull on the lateral bands.

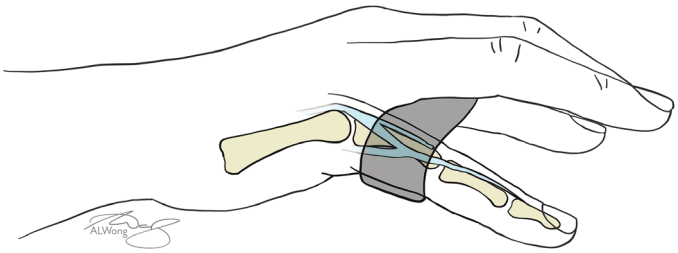

Fig. 5. Boutonniere deformity corrected with relative motion flexion splint. The splint keeps the metacarpophalangeal joint flexed, and the flexion loosens the intrinsic lateral band tightness and allows the bands to migrate dorsally. The lateral slips of the long extensors get tight with metacarpophalangeal flexion. They pull the lateral bands dorsally in metacarpophalangeal flexion. This is demonstrated in the cadaver in Videos 9 and 10.

Winslow also pointed out that with extensor digitorum communis extension, the lateral band encircling "diamond" normally moves medially in a "cinching" fashion as the central slip extends the proximal interphalangeal joint, and the lateral bands relocate medially from the combined pull of the extensor digitorum communis and lumbrical attachments to the lateral bands as they extend the distal interphalangeal joint (Fig. 7). It is well known that the extensor digitorum communis central slip insertion into the middle phalanx alone is not essential for proximal interphalangeal extension by those doing the Fowler procedure for chronic mallet deformity, carefully dividing the central slip insertion without injury to the triangular ligament or arciform hood fibers, to rebalance the system.[14] This then heals without the boutonniere deformity developing. The relative motion flexion orthosis permits proximal interphalangeal and distal interphalangeal extension by means of the extensor digitorum communis lateral band attachment following acute boutonniere rupture of the central slip, because the relative flexed metacarpophalangeal position increases tension on the lateral slips of the extensor digitorum communis tendon and corrects the lag caused by retraction of the central slip.

Second, the quadriga effect on the volar surface is provided by the flexor profundi because of the lumbrical muscles arising from the radial side of the profundi tendons. Although controversial,[18] Kaplan,[19] Brand,[20] and Zancolli[21] regarded the lumbrical as the principal interphalangeal joint extensor. While not as powerful as the interossei, the lumbrical has four times more excursion, is more volarly positioned as it passes from beneath the transverse metacarpal ligament, and may provide sensory feedback regarding interphalangeal positioning.[19] Zancolli's electromyographic nerve conduction studies[20] confirm that the lumbrical remains active throughout digital extension, whereas the interossei has intermittent activity and is most notably active during forced powerful extension of the interphalangeal joints, stabilizing the metacarpophalangeal joint to prevent hyperextension while the interphalangeal extension is

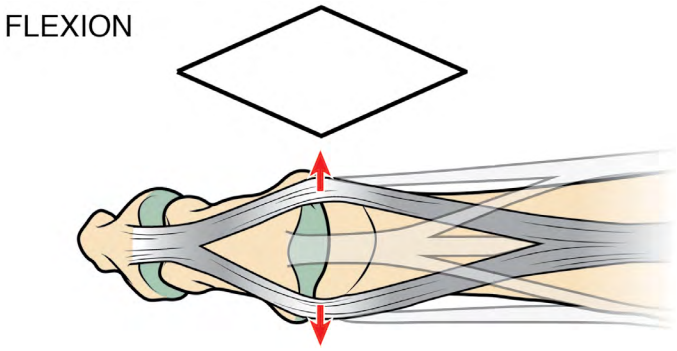

Fig. 6. Winslow's diamond in flexion in the normal finger. When the normal proximal interphalangeal joint flexes, the lateral bands move laterally and volarly, where they are restrained above the proximal interphalangeal joint axis of rotation by the triangular ligament and hood arciform fibers.

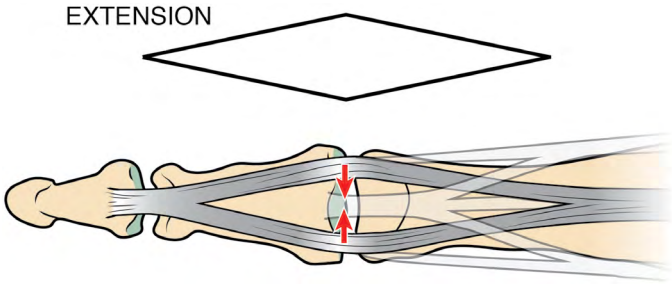

Fig. 7. Winslow's diamond in extension in the normal finger. With extensor digitorum communis extension, the lateral band encircling "diamond" normally moves medially in a "cinching" fashion as the central slip extends the proximal interphalangeal joint and the lateral bands relocate medially from the combined pull of the lateral slips of the extensor digitorum communis and lumbrical attachments to the lateral bands as they extend the distal interphalangeal joint.

accomplished with extensor digitorum communis and lumbrical muscle combined activity.

Because lumbricals arise from the profundi, placing a metacarpophalangeal joint in 15 to 20 degrees greater flexion relaxes that profundus compared to its neighbors due to their common muscle, which subsequently also relaxes that lumbrical muscle. In a developing boutonniere deformity with a disrupted central slip, the lumbrical appears to be the principal deforming force, pulling the lateral bands below the proximal interphalangeal axis of rotation by attenuating the residual weakened and injured horizontal and oblique extensor hood fibers and triangular ligament of Winslow. When the lateral bands become abnormally positioned below the proximal interphalangeal axis of rotation, extensor digitorum communis and lumbrical muscular contraction in attempting to extend the interphalangeal joints actually causes proximal interphalangeal flexion and metacarpophalangeal and distal interphalangeal hyperextension. Once they become adherent in this position with fixed proximal interphalangeal flexion contracture, holding the proximal interphalangeal joint in maximum extension will tighten distal interphalangeal hyperextension so that passive flexion is limited or absent, but with flexion of the proximal interphalangeal joint, the distal interphalangeal can easily be fully flexed when it is still passively mobile (as evidenced by the Boyes test[22]).

TREATMENT OF ACUTE BOUTONNIERE INJURY

Patients frequently have an initial normal range of motion for several days after boutonniere

extensor hood and central slip disruption, because it may take a while for the proximal interphalangeal extensor hood and triangular ligament to completely disrupt and create the full-blown deformity. However, most patients will be aware that something is amiss, despite a normal range of motion on initial examination. They often complain of pain, weakness, or proximal interphalangeal joint instability. It behooves the initial treating physician to consider this possibility and know the clinical tests needed to recognize the disorder.

First, the proximal interphalangeal joint is usually swollen. The Elson test is a good early test (Fig. 8).[23] It is performed by placing the flexed proximal interphalangeal joint at the edge of a table and comparing the amount of extension force present at the proximal interphalangeal joint, which is weakened due to the absence of the extensor digitorum communis central slip attachment. The extension force at the distal interphalangeal joint (which does not normally extend at all in this position) may be felt in the boutonniere deformity due to the untethered pull through the lateral slips, especially when they are volarly displaced. Visible confirmation is by the modified Elson test (Fig. 9)[24]; the injured digit and its normal counterpart are placed in full proximal interphalangeal flexion, with the dorsum of each middle phalanx firmly against each other. If the injured side has visibly better distal interphalangeal extension than the uninjured counterpart, boutonniere disruption is likely. The Boyes test (Fig. 10) may also be positive, though it can be subtle in acute deformity if the bands have not repositioned volarly. When boutonniere deformity is suspected, magnetic resonance imaging or ultrasound can show the disruption of the central slip.

The best treatment for boutonniere deformity is to prevent the deformity. Once fixed deformity occurs, treatment becomes far more difficult, so early diagnosis and treatment are of paramount importance.

When an acute closed injury has developed a boutonniere deformity, placement of a pencil or even examiner finger pressure over the dorsal proximal phalanx may then allow recovery of full proximal interphalangeal active extension when the injured digit metacarpophalangeal joint is in approximately 15 to 20 degrees greater flexion than the uninjured finger metacarpophalangeal joints. The diagnosis is best supported by clinical tests (Elson, Boyes, modified Elson), magnetic resonance imaging, or ultrasound, because with a pseudo-boutonniere deformity (flexor volar pulley or volar plate injury), the proximal interphalangeal joint will not maintain extension in the orthosis.

Relative motion flexion splinting can reverse the acute deformity by rebalancing the forces while maintaining metacarpophalangeal flexion during all activities of daily living. With metacarpophalangeal flexion, lumbricals, long flexors, and interossei relax and let the lateral bands migrate dorsally. With metacarpophalangeal flexion, the long extensor gets tighter and pulls lateral bands dorsally via lateral slips (Fig. 11). Keeping the metacarpophalangeal joint relatively flexed closes Winslow's diamond to bring the lateral bands more dorsal.

When the pencil test simulation of a relative motion flexion splint lets the patient completely extend the proximal interphalangeal joint, we build the splint and verify complete joint extension when the patient goes through a full range of motion while wearing the splint. In such a case, full-time wearing of the splint for 6 to 12 weeks can allow useful function and then recovery of a full range of motion. [**See Video 11 (online)**, which displays how to manage chronic boutonniere cases.]

If the relative motion flexion splint does not generate and maintain full proximal interphalangeal extension with active movement, we treat the patient as we would for chronic boutonniere deformity, but we first confirm there is no pseudo-boutonniere diagnosis using magnetic resonance imaging or ultrasound.

For repair of an acute open boutonniere injury, the wide awake, local anesthetic, no tourniquet technique is preferable to accurately assess the delicate balance of the repaired extensor mechanism. This is best assessed with the patient's intraoperative cooperation and the intraoperative simulation of a relative motion flexion splint with a sterile tongue depressor or ribbon retractor. After surgery, the hand is elevated and the injured finger is immobilized in 15 to 20 degrees greater metacarpophalangeal flexion than the uninjured fingers. After 3 to 5 days, the hand is fitted for a relative motion flexion splint for a 6- to 10-week interval and monitored by the therapists.

CHRONIC BOUTONNIERE DEFORMITY

Chronic fixed boutonniere deformity has been a conundrum that often defied any acceptable correction with surgical or nonsurgical techniques. It has traditionally been treated with serial casting followed by 6 weeks or more of immobilization

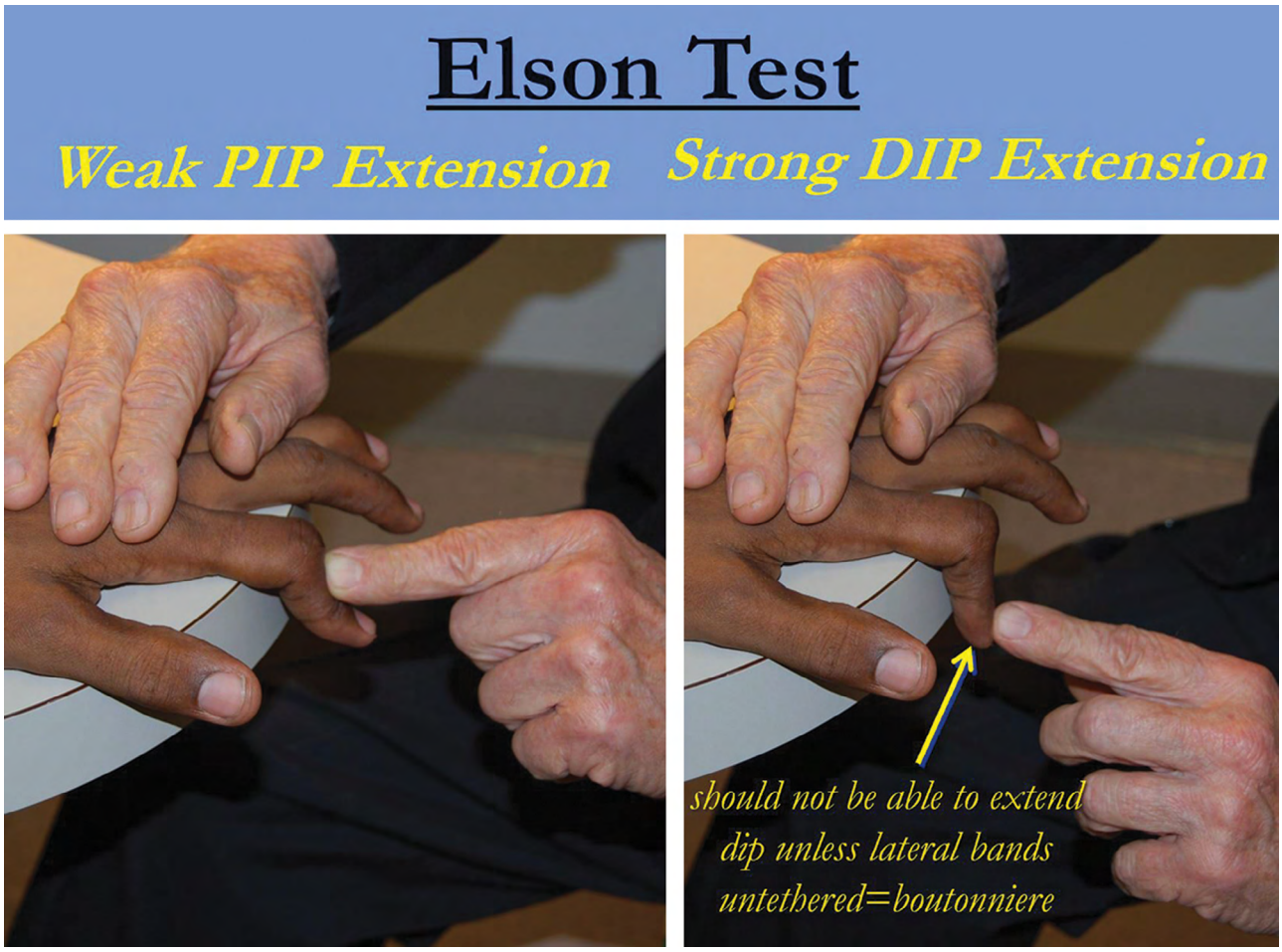

Fig. 8. Elson test for boutonniere deformity. With the finger in proximal interphalangeal (*PIP*) flexion at 90 degrees off the side of a table, proximal interphalangeal extension force is weak and distal interphalangeal (*DIP*) extension force is strong in the boutonniere finger. In a normal finger, proximal interphalangeal extension force is strong and distal interphalangeal extension force is weak.

in extension, which has often failed. Surgical correction has been attempted with a variety of techniques with such poor results it is not recommended unless the proximal interphalangeal contracture is greater than 30 degrees.[25] Relative motion flexion splinting has revolutionized management in these injuries.

The first goal is to restore passive extension with serial casting of the proximal interphalangeal joint into as close to full extension as possible (at least –20 degrees) to correct the volar joint capsule contracture. We sometimes combine serial casting and proximal interphalangeal extension splinting with the relative motion flexion splint in order to rebalance the proximal quadriga forces described above. Once the proximal interphalangeal is at –20 degrees (or better) and the distal interphalangeal is able to actively flex, relative motion flexion splinting is initiated for 2 to 4 months as monitored by the therapist. If distal interphalangeal joint hyperextension is present, it is necessary to block this in neutral extension to achieve and maintain full proximal interphalangeal extension in the relative motion flexion orthosis.

Therapy is initially directed toward recovering full flexion while monitoring to be sure proximal interphalangeal extension is maintained in the orthosis. If it is not, one should confirm the diagnosis is not pseudo-boutonniere deformity from a volar plate or flexor pulley injury. Once flexion is achieved, full functional use is encouraged during the months of splinting. It is useful to provide a spare splint during this prolonged interval because breakage may occur.

Surgical options are many.[26–28] This may be because none of them work reliably and consistently well. We believe conservative management with relative motion flexion orthoses should be attempted first. Our results with conservative

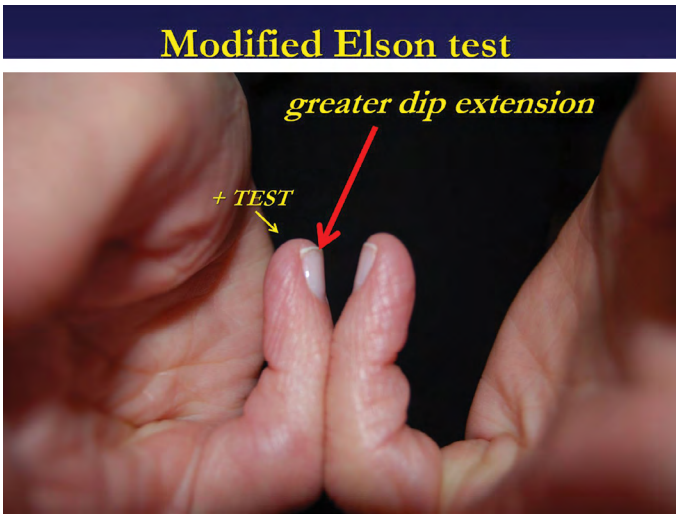

Fig. 9. Modified Elson test for boutonniere deformity. The modified Elson test is performed by placing the injured digit and its normal counterpart in full proximal interphalangeal flexion, with the dorsum of each middle phalanx firmly against each other. If the injured side has visibly better distal interphalangeal (*dip*) extension than the uninjured counterpart, boutonniere disruption is likely.

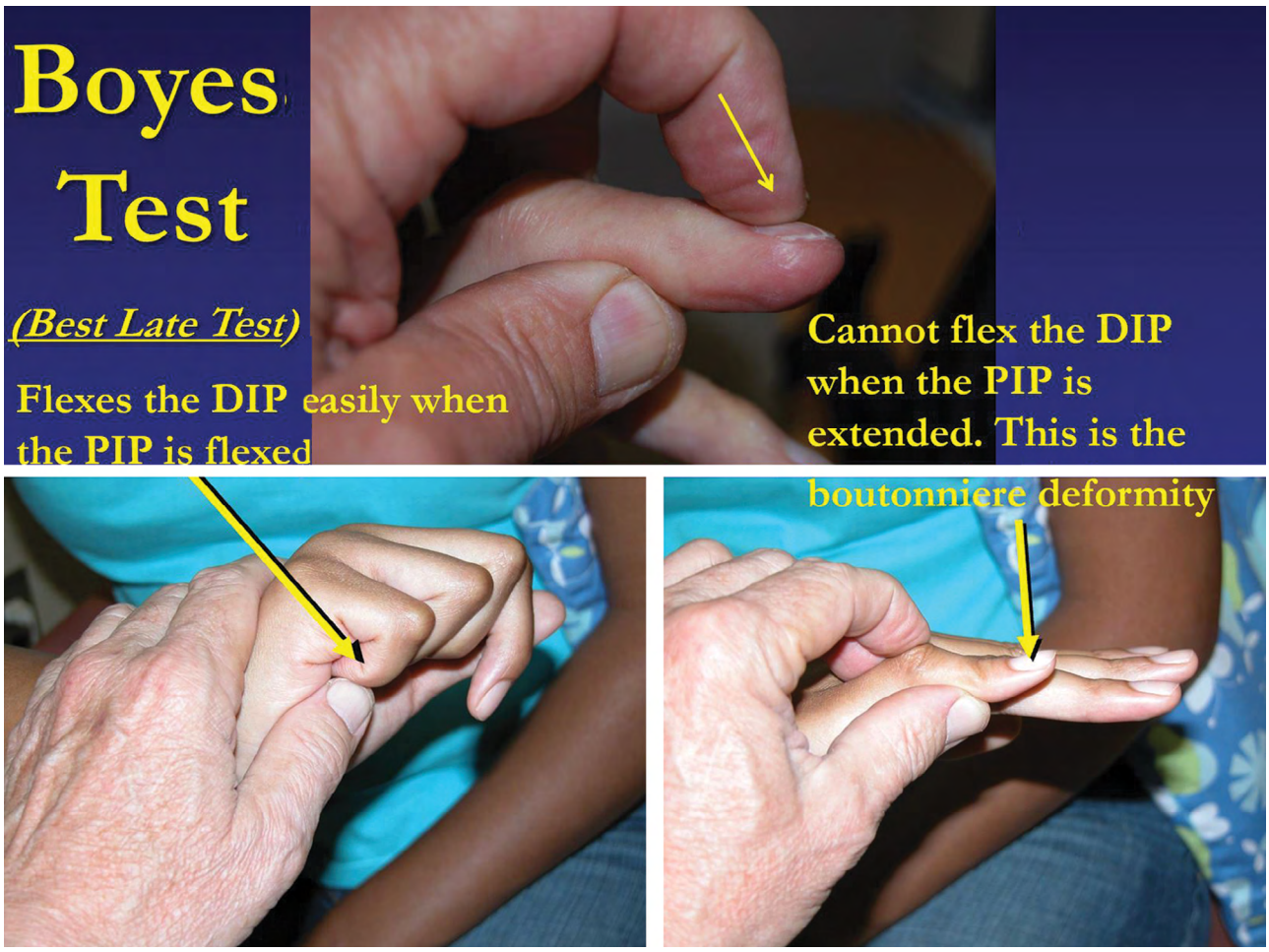

Fig. 10. Boyes test. With the proximal interphalangeal (*PIP*) held in passive extension, there is resistance to passive distal interphalangeal (*DIP*) flexion. With the proximal interphalangeal held in passive flexion, the distal interphalangeal is easily passively flexed.

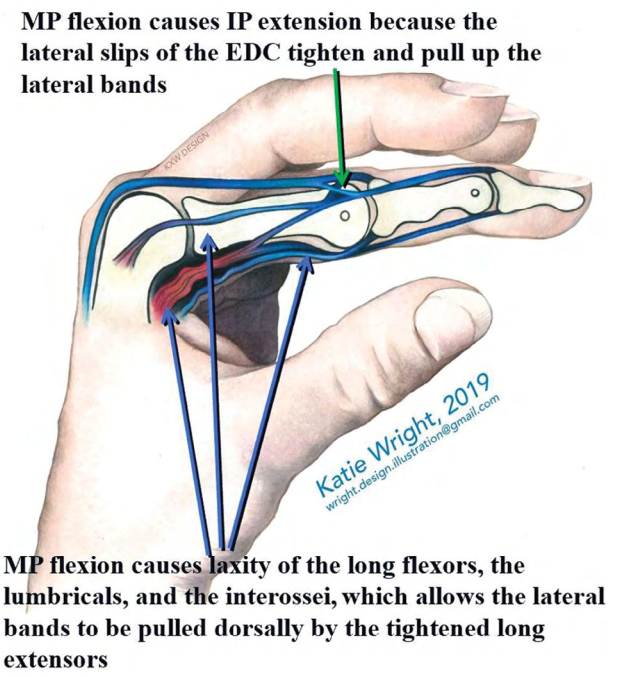

Fig. 11. Metacarpophalangeal (*MP*) flexion with relative motion flexion splinting encourages proximal interphalangeal (*IP*) extension in boutonniere deformity. With metacarpophalangeal flexion in the relative motion flexion splint, lumbricals, interossei, and long flexors slacken to allow dorsal migration of the lateral bands. With metacarpophalangeal flexion, the long extensor gets tighter and pulls the lateral bands dorsally via lateral slips. *EDC*, extensor digitorum communis. Reproduced with permission from Katie Wright 2020/wright.design.illustration@gmail.com.

management thus far most often fit into the Strickland-Steichen classification of "excellent" for chronic boutonniere deformity.[25] The success of this method lies in the fact that it creates only minimal impairment to the patient's function during the 3 months of healing.[29] [**See Video 12 (online)**, which displays how to prevent boutonniere deformity with relative motion flexion splinting in acute central slip avulsion injury.] If surgery is necessary, relative motion flexion splinting postoperative management should be used.

PROXIMAL INTERPHALANGEAL EXTENSOR LAG AFTER FINGER FRACTURE OR DUPUYTREN'S CONTRACTURE

Relative motion flexion splinting is also a very helpful method to restore proximal interphalangeal extension after finger fractures, Dupuytren's surgery, or collagenase injection.[14] The relative motion flexion splint flexes the metacarpophalangeal joint, which increases the extension force to the proximal interphalangeal joint. With these orthoses, patients exercise while they are living instead of stopping living to exercise, because they open and close their fingers hundreds of times per day.

SUMMARY

Relative motion splinting permits safe early active motion without adherence or rupture to avoid stiff fingers. The wide awake, local anesthetic, no tourniquet approach facilitates the surgical rebalancing of the complex relationship between the extrinsic and intrinsic tendon systems in extensor injuries. These two innovations have produced a paradigm shift in the management of extensor tendon surgery.

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