MANAGEMENT OF THE STIFF PROXIMAL INTERPHALANGEAL JOINT

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The stiff digit occurs most frequently after posttraumatic injuries and as a postsurgical complication. The identification and precise participation of the structures involved may be difficult. A step-wise algorithmic approach trying to minimize morbidity may help to obtain the best results. A review of the literature reveals that a midaxial approach is versatile, can accommodate skin deficiencies, and offers appropriate volar and dorsal exposure. Sequential joint release is achieved by complete capsular incision, collateral ligament excision, and volar plate release or partial excision. Tenolysis also may be required for full passive range of motion. Neuroleptoanalgesia is important in proving reconciliation of active and passive discrepancies. Severe cases may require staged reconstructive efforts and represent a higher risk for neurovascular complications. A ray resection may be an appropriate alternative in these individuals. Dedicated rehabilitation including a tendon acceleration program should maintain the motion accomplished during surgery.
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Patients acquire stiff digits for many reasons. Posttraumatic stiffness and postsurgical stiffness are usually the most limiting in terms of measurable degrees of motion.[1-6] Stiffness from slowly evolving osteoarthritis or rheumatoid arthritis may be more painful but often preserves a better range, and patients tend to adapt to their deficits. The underlying etiology may direct attention to certain anatomic structures as the most responsible for the stiffness. However, the anatomic basis for stiffness is not always clear. When passive range of motion at the proximal interphalangeal (PIP) joint is preserved but an active-passive discrepancy exists, then tendon adherence definitely is present.[7,8] When passive range of motion at the PIP joint is lost then joint involvement is confirmed, but the degree of tendon involvement now is masked and becomes unknown.[9] With severe flexion contractures, deficiencies of skin, nerve, and vessels, may prohibit achieving full extension even if the joint and tendons are addressed adequately. Surgical management of these cases involves more complex recon-

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struction and poses a significant risk for ischemia. Three components enter into the planning of operations to correct a stiff digit: the surgical approach, the deep tissues targeted for release, and the planned rehabilitation program. The planning considerations realized during this analysis may lead to the conclusion that the stiff digit release should be performed in stages. Two of the most common stage separations are to achieve soft-tissue envelope expansion before releasing deep structures or to achieve passive joint range before attempting tenolysis or tendon reconstruction. Finally, surgery should be undertaken only when tissue equilibrium has occurred. This point is determined by physical examination, not by the calendar. It usually does not occur until at least 10 to 12 weeks after the last trauma experience or surgical intervention and should correlate with a sustained plateau in therapy progress.

TECHNICAL BACKGROUND

The PIP joint is the critical site that serves as the foundation for movement within the digit. As a bicondylar joint with excellent inherent stability, extensive capsulectomy can be performed here without creating instability.[10,11] Eaton et al[12] have shown that new collateral ligaments reform within 3 weeks after capsulectomy. Even though extensive scarring around this joint may exist preoperatively, the joint itself should never be the limiting factor in achieving restoration of motion. The usual culprits that make correction of the stiff digit so difficult are the tendon systems. Extensor zone 3 is short, but contact is close between the central slip and the dorsal surface of the head of the proximal phalanx (P1). Only a limited range of excursion exists here, and it is difficult to prevent postoperative adhesions. Extensor zone 4 is characterized by a large surface area for potential adherence between the sheet-like extensor apparatus and the dorsum of P1. Preoperative physical examination may indicate intrinsic tightness, extrinsic tightness, or an extensor lag.[13,14]

The flexor system is equally problematic for other reasons. The exposure to P1 is not nearly so great, but differential adhesions within the fibro-osseous canal make restoration of a gliding interface quite difficult.[15,16] Preoperative examination may indicate a flexor lag (active-passive discrepancy) or tenodesis that prevents full extension in either the flexor digitorum

superficialis, the flexor digitorum profundus, or both. The heavier the scarring on the flexor side, the higher the probability that scarring will exist around the proper digital nerves and arteries.[8,17] This situation is compounded if a former surgical approach or traumatic open wound occurred volarly. The scar that lies around the neurovascular bundles may prohibit achieving full extension without sustaining damage to these structures. As the degree of pathology becomes more complex, it becomes more difficult for the preoperative examination to target the definitive anatomic basis for stiffness. At the end of this spectrum lies the frozen digit, for which any and all structures may play a role in the limited motion.

Many different surgical approaches have been advocated for treatment of the stiff digit. Dorsal approaches have used a straight midline or a curvilinear incision. If previous wounds have created a volar skin scar contracture, Z-plasty or other tissue rearrangement may be necessary to overcome this restriction. If such constraints do not exist, the surgical approach may be chosen based on its own merits. Neutral tension lines exist in the digit along the midaxial plane or connecting volarly between points defined by the intersection of a digital flexion crease and the midaxial line. Incisions placed here will not result in postoperative contractures and thus are appropriate for use in surgery designed to improve motion.[18-20] The extensor mechanism in zone 4 presents a broad surface for adherence to any dorsally based incision. Even when there is an indication that the extensor system plays a significant role in the contracture, it is difficult to justify stimulating new adhesion formation between the healing edges of a surgical wound and the extensor mechanism. Significant work on the flexor tendons also is difficult to perform from a dorsal approach. A volar approach allows skin contracture correction, easy management of the flexor tendons, reasonable ease of PIP capsulectomy, but makes addressing extensor problems quite difficult.[21] Even in the case of skin shortness, midaxial incisions are the most versatile and have proven to be useful in cases requiring skin augmentation.[19,22,23] They provide the most direct access to the PIP joint and both flexor and extensor tendon systems can be addressed easily. The incision is fully extensile both proximally and distally. When the pathology is concentrated in the region of the PIP joint, shorter incisions allow an equal amount

of work to be performed compared with the other 2 approaches.

The next consideration in planning is to identify the deep structures targeted for release. This is a process that begins with physical examination in the office but usually is completed intraoperatively.[9] Intraoperative examination after each critical structure released must be capable of reproducing the delicate balance of dynamic forces during active motion, only truly possible with the patient's active participation.[8] Neuroleptoanalgesia is the technique of choice that allows active flexion and extension by the patient.[20,24-26] Traction assessment by the surgeon using a proximal incision to pull on the tendon in question is an alternative, although less desirable in our hands. A traction maneuver cannot truly approximate the complete effect of a cortically generated signal transmitted through the peripheral nervous system to the muscle belly, onto the tendon, ultimately resulting in active joint movement. The local anesthesia or distal regional block given to accompany the analgesia must not paralyze the intrinsics because this will disrupt the dynamic balance being tested.[8,20]

The final step in strategic planning involves choosing the method of rehabilitation. The 2 primary goals are to maximize end range and afford the patient good active control over the newly acquired total range of motion.[27] To accomplish the first goal, effective exercises and splints must ensure that both flexion and extension end points are reached every 24 hours. Failure to do so will result in a progressive loss of motion compared with the gains at the time of surgery. The second goal requires an effective set of exercises to be performed by the patient that will accomplish true active excursion of the tendons through the available range and break down new adhesions as they form during the period of aftercare.[15] The placement of incisions determines where points of splint contact will be tolerated. The deep tissues released determine how much emphasis is given to each type of motion exercise. When well integrated, the surgical approach, the deep tissue releases, and the rehabilitation program can make an effective solution for the stiff digit.[28-30]

SURGICAL TECHNIQUE

The surgical strategy begins with patient counseling before entering the operating room. The patient is shown the type of motions he or she will be expected to show, and the principles of neuroleptonalgesia are explained. Stiffness confined to the digit allows the regional block to be performed in the distal palm, equally effective for single or multiple digits. Injection given higher in the form of a wrist block paralyzes the intrinsic muscles. Likewise, ischemic muscle paralysis dictates that a digital tourniquet be used whenever possible. Forearm or brachial level tourniquets will affect the extrinsic motors.[8,17] If a brachial or forearm tourniquet must be used, application should be less than 30 minutes, and appropriate reperfusion time should be allowed for muscle recovery before testing.

Step 1: PIP Joint Capsulectomy

Midaxial incisions are made 15 mm in length on both sides of the PIP joint (Fig 1). Dorsal branches from the proper digital nerves usually pass proximal and dorsal to this area but should be sought and protected to avoid painful neuroma formation. The lateral digital fascia is encountered, blending with the transverse retinacular ligaments. The volar edge of the conjoined lateral band is identified, and the retinacular ligament is incised along this line. This allows dorsal retraction of the extensor mechanism. Complete exposure of the collateral ligament system and joint capsule is now available. When limitation of passive range of PIP joint motion exists, capsulectomy is necessary.[8,11,17,19,22,29-31] Although it is possible to merely incise the capsule or to excise only certain portions until full range is achieved, complete capsulectomy of the proper and accessory collaterals allows
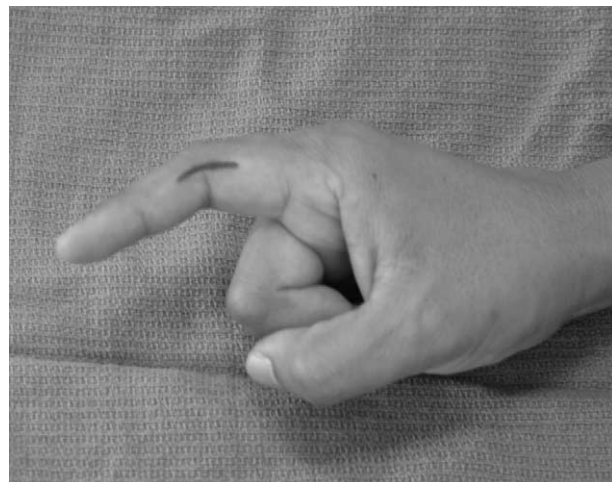

FIGURE 1. Midaxial approach on nondominant side.

the inherent articular congruity to become the prime determinant of the path of postoperative motion.[9,10,32] Retained portions of capsule (even if they do not formally prevent achieving full range of motion) may steer the joint out of alignment by creating uneven tension and will serve as a nidus for recurrent scar formation.[10,12]

Step 2: Volar Plate Release Versus Excision

If tension-free full extension is not yet restored, the check-rein ligaments of the volar plate should be released. This maneuver is accomplished by sliding a tenolysis elevator along the inside of the A2 pulley deep to the volar plate on both sides. At the same time, the subcapital recess volar to the neck of P1 is cleared of any obstructing scar tissue that prevents full flexion. If significant thickening and scarring of the volar plate and check reins is observed to prevent smooth gliding or folding of these structures during the passive range of motion, excision should be considered as described by Mansat et al[33] and Abbiati et al.[11] Before entertaining the prospect of a complete excision of both the volar plate and collateral ligaments, verification of the articular congruity and tendon systems should have been performed thoroughly. A more prudent approach is to excise only a portion of the proximal volar plate sufficient to allow unimpeded motion while allowing the distal portion to help balance and control the pathway of motion (Fig 2A and 2B). At this point, any further resistance to achieving full passive motion will come from the tendons themselves. With the current limited exposure, testing of tension in both tendon systems is performed to ascertain at which level proximal to distal and from which side, radial to ulnar, the majority of the remaining limitation appears to be coming. If necessary, one of the 2 midaxial incisions can be extended as far as necessary to address these points of adhesion.[19,22,23]

Step 3: Tendon Limitations to Passive Range of Motion

The extensor system is relatively straightforward when causing limitation of passive flexion. If intrinsic tightness exists, a distal intrinsic release can be performed. A triangular piece of tissue is excised consisting of the intrinsic tendon distal to the sagittal bands and proximal to the conjoined lateral band.[34] A similar but less frequently needed release referred to as a
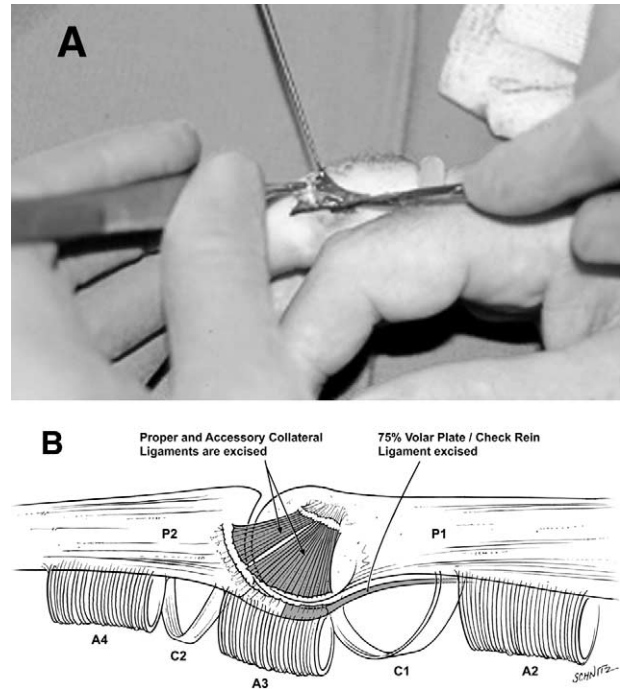

FIGURE 2. (A) Capsulectomy should include complete proper and collateral ligament excision. Consideration for volar plate release versus partial excision should be done according to existing scar and to prevent excessive scar formation. (B) Diagramatic representation of capsulectomy.

distal extrinsic release may be performed by dividing the digitorum communis tendon in extensor zone 4. Other than these procedures, the search is strictly for surface adhesions on either the deep surface to bone or periosteum or on the superficial surface to skin. If at all possible the adhesion should be excised completely rather than just divided. The chance of early recurrence is thus minimized. The surgeon should always be conscientious with respect to the amount of new raw collagen surface exposure that is being created, especially in areas with deficient gliding tissues such as subcutaneous fat or periosteum (Fig 3).

The flexor system is slightly more complex when causing limitation of passive extension. Adhesions form between 2 tendons and a tubular fibro-osseous sheath. The 3-dimensional anatomy of scarring is more difficult to visualize and release. Furthermore, the surgeon must work retrograde back into the A2 pulley from access at its distal end. If adhesions are extensive enough, a counterincision may need to be made in the palm at the A1-A2 junction to allow antegrade passage of the tenolysis elevators. This incision does not need to be connected to the midaxial
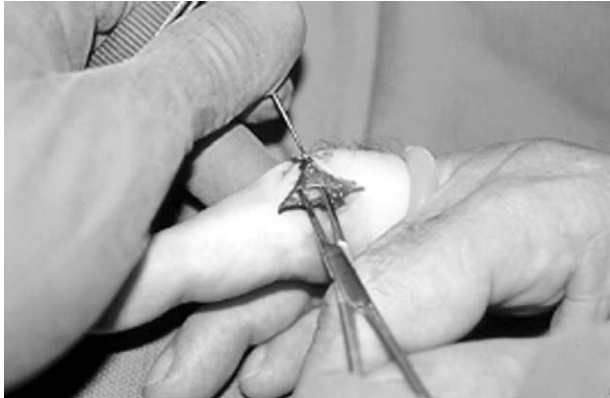
FIGURE 3. Flexor and extensor tendon adhesions may be resolved through the midaxial approach. Extension of the incision can be performed as required.

incision but can be joined easily if the surgeon wishes to observe the progress looking through the wall of the sheath.[19,22,23]

Step 4: Assessment of Active-Passive Discrepancy

Once passive range of motion has been restored fully, the next step is to ensure complete active range of motion and eliminate any discrepancy. This is accomplished by first having the patient show the amount of active range possible (Fig 4A and 4B).[8,13,17,29,30] The anesthesiologist must be informed far enough in advance of when this critical moment in

the procedure is to occur to have brought the patient to a lucid state, capable of following commands. Proper counseling in the preoperative holding area will now pay off because patient participation is critical to this step. After having performed the releases necessary to achieve full passive range, the patient often will have had the same adhesions that were limiting active range freed. No further steps are thus necessary. Alternatively, there will still be a few critical adhesions remaining that must be addressed. Extensor tendon adhesions prevent full active extension. Flexor tendon adhesions prevent full active flexion. Extension of one of the midaxial incisions on the more limited side or nondominant side of the digit allows as much exposure as needed for extensile release of both flexor and extensor systems. Furthermore, the healing dermal scar that follows will be lateral rather than over the newly released tendon structure. Sheath access for the flexors is accomplished as described earlier. The additional adhesions responsible for active motion limitations are then preferably excised rather than simply released. When complete active motion has been restored, some patients will wish to see their own hand move when elevated over the edge of the drapes.

Step 5: Reconstructive Procedures

Skin deficiencies usually are corrected in advance by a separate procedure of local flaps, regional flaps, free

FIGURE 4. (A and B) Under neuroleptoanalgesia, the patient shows active flexion and extension.

tissue transfer, or skin grafting. Treatment of limited deficiencies by Z-plasty can accompany the release procedure in select cases. The final consideration is with respect to damaged pulley systems and scarred neurovascular bundles. All patients are counseled preoperatively regarding the complexity that these issues add to the already difficult problem of a stiff digit. The patients are asked to commit to a course of action of either a full reconstructive effort or to instruct the surgeon to limit the surgical steps at a certain level.[35-37] If the patients request a full reconstruction, it is with the knowledge of significantly increased complexity after surgery. An extended duration of rehabilitation will occur. The complication rate increases,[38] and with scarred neurovascular structures, this includes the possibility of digital ischemia and loss. Fingers with poor neurovascular support might be better served by arthrodesis or amputation.[16,17]

During the tenolysis process, the surgeon must determine whether enough of the critical A2 and A4 pulleys remain to support proper gliding function of the tendons. The basic quality of the tendons themselves also must be evaluated. In the setting of severe damage from prior surgery or trauma, a homogenous mass of scar without tissue planes may need to be excised completely. Reconstruction then proceeds with stage 1 tendon rod placement and pulley reconstruction.[35-37] Lister[39] has indicated that extensor retinacular tissue from the wrist or ankle offers advantages over free tendon strips for pulley reconstruction. Alternatives include flexor tendon tissue that is excised or the palmaris longus. Circumferential pulley reconstruction is the standard.[40,41] The loop is placed under the extensor tendon at the level of P1 and most often over the extensor at the level of P2 (the loop may be placed under the extensor at the level of P2 if the surgeon's observations indicate an advantage to this routing). When scarring is extensive enough in the volar aspect of the digit to warrant this method of reconstruction, the neurovascular bundles likely will be encased heavily in scar as well. Direct dissection of the bundles risks injury to them and creates additional planes of tissue dissection that will scar during rehabilitation. Previous investigators and conventional hand surgery wisdom both indicate that the neurovascular bundles along with the scar encasing them should be protected as far away as possible from the plane of dissection used to perform tendon reconstruc-

tion.[8] Shortness in the neurovascular structures may preclude full digit extension. Damage to both proper digital arteries may exist preoperatively in a digit surviving on communicating branches from the dorsal digital arteries continuing the flow of the dorsal metacarpal arteries. As additional bulk is added to the digit with loops to recreate pulleys, compression of the fine caliber communicating branches may occur. This problem may occur immediately or may develop through the course of several days after surgery in a digit showing full perfusion at the conclusion of the procedure. Progressive swelling after surgery and the stresses of motion rehabilitation combine to cause delayed occlusion of the communicating branches. It is because of the potential for complications such as this, as well as the diminishing potential for functional return, that has led to the recommendation of ray resection as a primary treatment for the severely stiff isolated digit.[16]

REHABILITATION

There are 2 goals in rehabilitation, maximizing the end ranges of movement and attaining active control over that range.[27,42-44] The surgical procedure creates a starting point for rehabilitation with full releases of previous adhesions but also creates raw collagen surfaces in proximity to future adhesions. The rehabilitation plan must be constructed in the context of these intraoperative observations. Three-point splinting (either dynamic or static progressive) is a very effective tool for maintaining end-range extension and should be applied nightly with a variable amount of daytime use. Flexion strapping and manual active-assist exercises concentrating on holding the end point serve to maximize the opposite end range.[6,28-30] As effective as these techniques are in making a good end range of motion available, they do little to help the patient actively reach these points when starting from a midrange position. This task is frequently the most difficult for patients to achieve. Immediately after surgery, pain from the surgical site and acute swelling limit the patient's capacity to pursue aggressive active motion. Early edema control with carefully applied coban wraps facilitates motion and decreases scar formation by eliminating inflammatory transudates and dead space.[8] Within several days, the process of adhesion formation begins on the surface of the flexor and extensor tendons. The job of
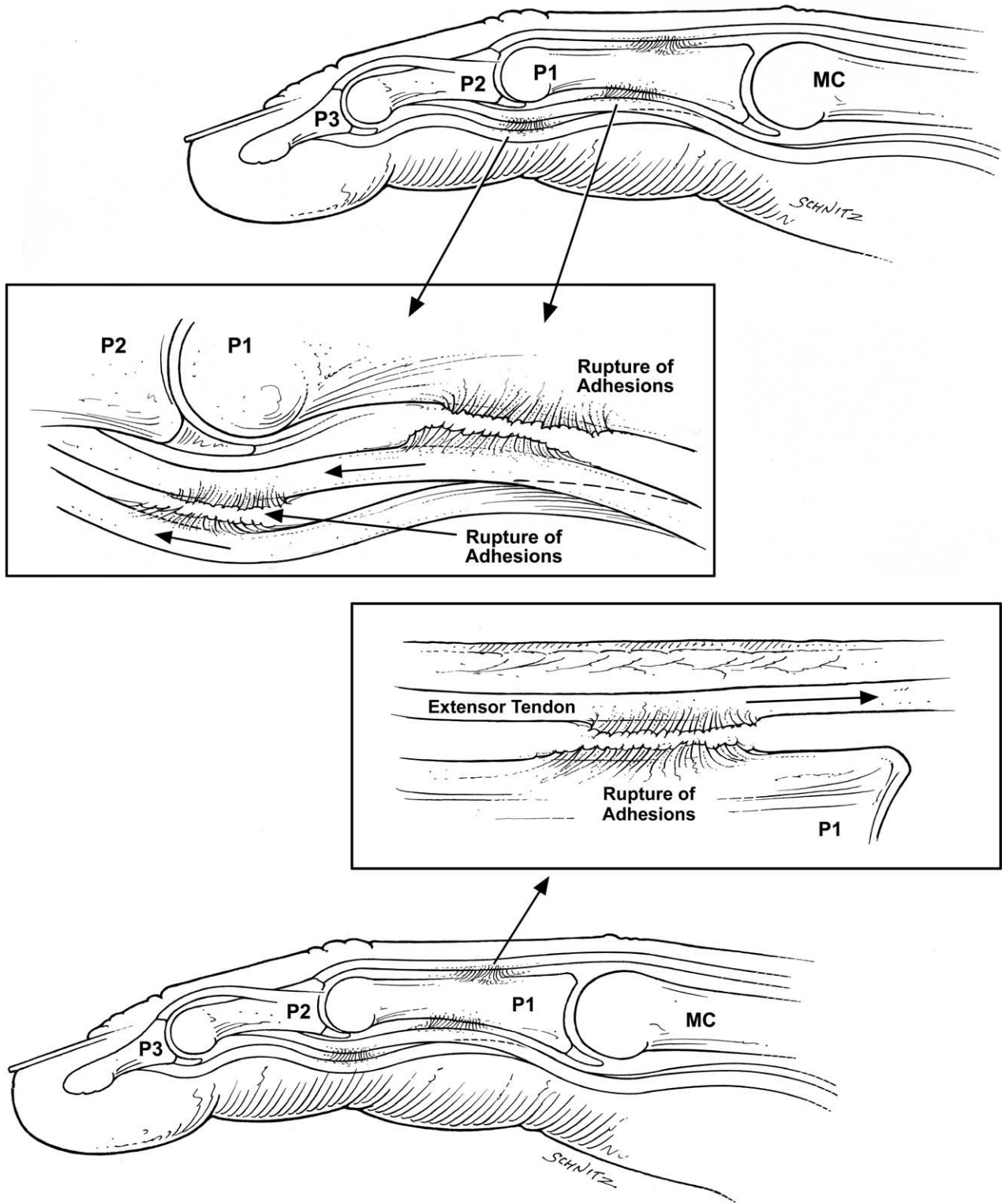
FIGURE 5. Artistic representation of the mechanism by which a tendon acceleration program allows disruption of newly forming adhesions.

the rehabilitation program is to prevent these adhesions from restricting full excursion of the tendons. The details of the exercises performed determine to what degree the forming adhesion will move with the tendon during each cycle of motion.[5,16]

Passive motion creates the least amount of differential excursion and consequently has the least effect in preventing adhesion formation. The tendon fibers are being pushed along their course and a degree of compression and crimping occurs. Active motion pulls the tendon along its course and stretches the tendon fibers. Two factors come into play with active motion, speed, and kinetic force. The forming adhesion is a viscoelastic structure and as such experiences time-dependent behavior in response to loading.[5] The combined effect of speed and preload on breaking down the tendon to adhesion interface can be understood most easily by looking at the 2 extremes of time. If the tendon is moving at the slowest possible rate, the adhesion is allowed to creep as it is pulled along with the tendon. The adhesion's bond to the tendon surface is not stressed or disrupted. At the opposite end of the spectrum, if the tendon were moved instantaneously relative to the adhesion, the developing bond here would be suddenly disrupted (Fig 5). Complete excursion of the tendon's full range of motion in zero time obviously is not possible, but it is the ideal model for motion to approximate. The smaller the fraction of time in which the tendon is moved through its range, the more effective the action of disrupting the forming surface adhesion bond because that bond
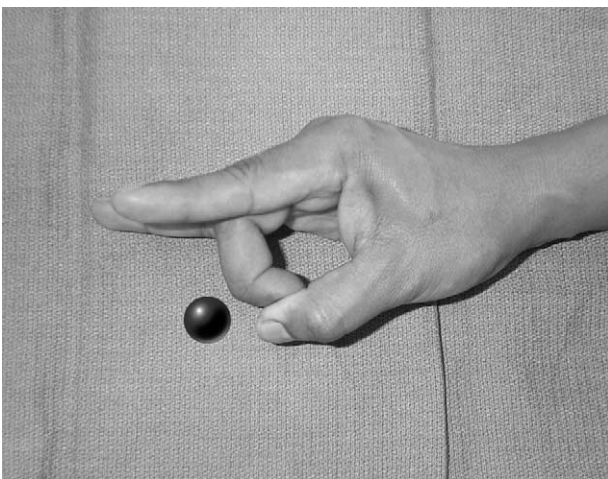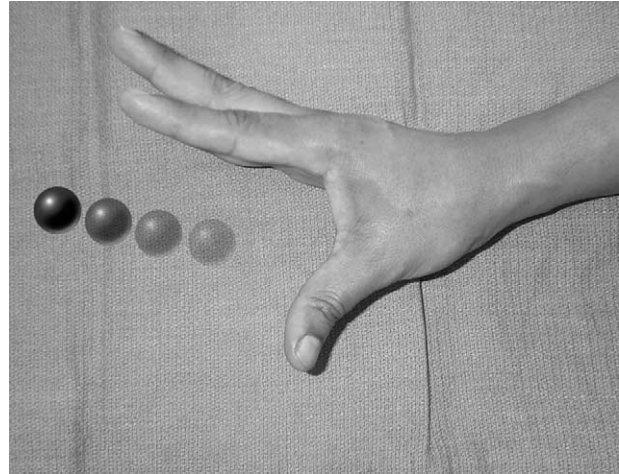

FIGURE 7. Sudden release of kinetic force will result in instantaneous acceleration and subsequent disruption of adhesions.

must behave in a viscoelastic manner. The combination of friction, drag, hydrostatic forces, and pain all make achieving speed of excursion difficult because the tendon must accelerate from a standstill to maximum velocity. Preloading the tendon enhances the patient's ability to instantly accelerate the tendon (Fig 6). Tensioning the tendon against resistance without movement occurring is analogous to the racecar driver spinning the wheels with the brakes fully applied. When the signal is given, it is far easier to merely release the brakes than it is to bring all the mechanisms responsible for acceleration into play immediately (Fig 7). Likewise, active contraction of a tendon is a process that begins with a cortical signal transmitted through the peripheral nervous system to the motor end plate resulting in a contraction within the muscle cells that develops first tension then excursion in the tendon. When preload against resistance is first applied, all of these steps have been completed except the final one, excursion. In other words, it is far easier to accelerate the tendon to an excursion velocity that the adhesion cannot keep pace with through this method than it is to attempt the same goals with just a standard active contraction from a resting starting point. It also is easier to set the starting point at a specific angle with the preload acceleration method. This has the advantage of being able to intentionally work on breaking down adhesions whose effect has been targeted to a specific range.

Although not as completely effective, the rapid contraction achieved with electrical muscle stimula-

FIGURE 6. Patient shows preloading phase of tendon acceleration program.

tors approximates the benefits of tendon acceleration exercises. The stimulator, however, does not require nearly as much concentration or effort by the patient and can be used daily at home for both the flexor and extensor systems. The final step in rehabilitation design is to assign a schedule to the patient of a fixed number of minutes or repetitions and frequency of performance for each exercise or splint. These assignments will be different for each patient based on the individual features of the stiffness. The anatomic systems that originally were most responsible for the preoperative stiffness are important but not as important as the areas most directly involved in postoperative new adhesion formation. Rehabilitation begins within 48 hours of surgery and continues throughout the period of scar maturation that lasts around 12 to 20 weeks. Attendance at outpatient therapy visits should be 5 times per week for the first few weeks tapering to 2 to 3 times per week afterward. The assigned proportionate schedule for the various exercises and splints likely will change as rehabilitation progresses. Decision making regarding these issues requires a skilled and experienced hand therapist.

CONCLUSION

The evaluation and treatment of the stiff digit is relatively complex in most cases. The process begins in the office with a systematic examination of passive and active motion limitations and discrepan-cies. The most likely deep tissues responsible for the limitations are identified, and a baseline surgical strategy is constructed. If a volar skin deficiency exists, the approach must include an appropriately staged plan to compensate for this deficiency. In all other cases, an initial midaxial approach offers a versatile starting point that can be expanded easily to handle any problem identified intraoperatively. During surgery, passive motion is restored first through a complete PIP joint capsulectomy and volar plate release, and then by any additional flexor or extensor tendon system releases. Once passive motion has been restored, active motion is assessed through patient active contraction under neuroleptoanalgesia. Additional tendon releases are made until any active-passive discrepancy has been resolved. Rehabilitation is then structured to target those tendon systems expected to undergo the most vigorous scar formation during the aftercare period. The maximum attainable final function is pursued through the combined use of end-range adjustable splints, edema and pain control, active tendon acceleration exercises, blocking exercises, and electrical muscle stimulation. Patients with a severe degree of stiffness may be expected to have extensive scarring and should be counseled regarding the need for more elaborate staged reconstructions as well as the potential for significant complications. Arthrodesis and ray resection should be considered as options for the isolated severely stiff digit.

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