A modification of the Kleinert orthosis providing early controlled mobilization following flexor tendon repair is presented in the article. Ongoing evaluations of the efficacy of the splint are described and implications for use in treatment are reviewed.

The views expressed in this paper are those of the authors and do not reflect official United States Army or U.S. Department of Defense Policy.

Throughout the history of tendon repair, surgeons, therapists, and patients have been plagued by adhesion formation. In 1948 Pulvertaft noted, “It is not difficult to suture tendons and prepare the ground for sound union. The real problem is to obtain a freely sliding tendon capable of restoring good function.” (1, p 82) One method of dealing with or preventing adhesion formation following tendon repair has been early motion.

The concept of early motion following tendon repair is not new. In 1911 Lexor (2) stated that adhesions could be avoided by mobilization as early as six days after surgical repair. This idea was challenged by Mason and Allen in 1941 (3), who stated that early motion, especially early active, unrestricted motion leads to marked reaction and adhesion formation. They recommended complete im-
mobilization followed by protective rehabilitation. Since that time, numerous studies have revealed much about the tendon structure, vascularization, and the healing process following tendon repair (4-7).

Based on these studies, Duran and Houser reported, “It would appear from experimental and clinical observations that 3 mm to 5 mm of extension motion of the tendon anastomosis in a passive exercise program is sufficient to prevent firm adherence of a repaired flexor tendon.” (8, p 105)

In the first focused study on the benefits of early controlled mobilization, Strickland and Glogovac (9) supported the assumptions of Duran and Houser (8) with statistically significant results.

Kleinert and associates (10) have used a dynamic splint to provide early controlled mobilization. A dorsal plaster splint is applied with the wrist in flexion and the digit at zero degrees. Dynamic rubberband traction applied to the fingernail holds the digit in flexion but permits active extension to zero degrees (see Figure 1).

Presently, occupational therapists in several Army medical facilities are employing a modification of the Kleinert orthosis in rehabilitation following tendon repair. The modification includes a palmar pulley that allows passive motion of the interphalangeal joints of the digits. The palmar pulley changes the direction of the fingernail traction, pulling the digits into the palm and flexing the interphalangeal joints fully rather than pulling the digits toward the distal forearm and only providing minimal interphalangeal flexion. The purpose of the modification is to maximize flexor tendon excursions through full finger flexion, improve digital function with increased digit mobility, and demonstrate that advancement of the pulley into the palm of the hand does not overstress the repair (11).

Results following use of the splint modification are being compiled and evaluated at Silas B. Hays Army Community Hospital at Ford Ord, California, Brooke Army Medical Center in San Antonio, Texas, and Walter Reed Army Medical Center in Washington, D.C.

The purpose of this article is to describe the modified orthosis and the preliminary positive results following use of the splint.

Procedures

The three Army hospitals follow the same basic postoperative procedure outlined in the following paragraphs.

Following Zone II flexor tendon repair, the hand is placed in a bulky compression dressing, and traction is begun with a dorsal plaster splint positioning the wrist at 20 degrees less than full flexion, the metacarpophalangeal joints at 20 degrees of flexion, and the interphalangeal joints at zero de-
degrees. Following surgery, a proximal pulley (safety pin) may be placed in the palm (11). Within the first three postoperative days, the bulky compression dressing and plaster splint are removed, and a dorsal thermoplastic splint is fabricated.

The thermoplastic dorsal splint is constructed with the wrist maintained at approximately 20 degrees short of full flexion. A metacarpophalangeal stop maintains the metacarpophalangeal joint (MCP) at 20 degrees of flexion. The splint may or may not extend to the fingertips with the interphalangeal joints (IPs) fully extended. Some therapists have stated that this splint continuation over the IPs may prevent flexion contractures by providing sensory feedback when the patient actively extends his or her digits. In our experience at Fort Ord, this continuation did not appear to make a difference in the end result if the therapist could periodically reinforce full active extension. Only the affected digit(s) are included in the splint.

The splint contains a palmar piece with a pulley in the appropriate position for full digit flexion and a forearm piece as a traction base (see Figure 2). The palmar

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Figure 2
Modified splint with palmar pulley
piece should fit the metacarpaltransverse arch accurately and allow the metacarpophalangeal joints to flex to 90 degrees. The splint also should retain the normal axis of movement. (Note that the digits normally point to the navicular when flexed.) The palmar and forearm pieces may be constructed from thermoplastic material or from safety pins and straps.

A wire foam splint that uses the same concept of a palmar pulley with controlled mobilization post-flexor tendon repair is available on the market; however, no documented research has been found to support the use of a palmar pulley. As with all prefabricated splints, the principal advantages are in the time and personnel resources saved. However, individually fitted splints often function better than prefabricated splints. In terms of design of the prefabricated splint, some difficulties with the extended wrist angle, the location of the palmar bar, and the interference of the opponens bar have been noted.

At time of surgery, a 0 to 2-0 nylon monofilament is usually sutured through the tip of the affected digit's nail. This is the site for the distal attachment of the rubber band. A fingernail hook also works well. The nylon monofilament is necessary for smooth gliding through the palmar pulley. The rubber band attached to the monofilament should allow full active extension, but should be strong enough to return the digits to full flexion. This traction should be maintained constantly for the first three weeks.

The following timetable for Kleinert traction was adapted following the first three weeks in tractions:

1. During the third to fourth week, the patient is allowed out of traction during clinic treatment sessions and allowed active range of motion (AROM) with no resistance. The dorsal splint remains on during all nonclinic periods.

2. In the fourth to fifth week, the patient is allowed light hand activity, for example, picking up light objects that are close to the weight of a checker. The patient may start gentle flexion of the re-paired digit over a finger or thumb.

3. During the fifth to sixth week, the patient may continue using the hand in object manipulation and can begin light activities of daily living (ADL). Gentle digit flexion over a finger or thumb is increased, and the patient is allowed to remove the dorsal splint during periods of protected activity, for example, watching television or light clinic activities.

4. In the sixth to seventh week, ADL and clinic activities are continued with the splint removed. The gentle digit flexion over a finger or thumb discontinued. Evaluation of AROM of the digit(s) and determination of the splinting needed are required at this point.

5. After the seventh week, full use of the hand should be allowed in all activities except those that are extremely heavy. If flexion or extension contractures are present (for example, proximal interphalangeal joint flexion contractures), it will be necessary to splint. Patient may be returned to a full workload.

Discussion
Tendon healing has been a topic of much controversy. Following his experiments with dogs, Potenza (5) stated that the tendon heals by cellular activity of the sheath and surrounding tissue, and he noted that the tendon is quite passive in the healing process. In 1975, Caplan, Hunter, and Merklin (7) demonstrated the presence of an intrinsic vascularity of tendons. This gave support to the idea of end-to-end tendon healing. The findings of Lundborg and Rank (4) strongly indicated that tendons possess an intrinsic potential for repair if they receive a nutritional supply sufficient to satisfy the increased demand required for cellular proliferation and collagen synthesis. The idea of end-to-end healing was further supported by Becker, Graham, Cohen, and Diegelmann (6) who demonstrated that tendon fibroblasts are active cells able to proliferate and migrate from the cut edge of a tendon. With the information from previous studies, Matthews and Richards (12) demonstrated intrinsic tendon healing when a partially divided tendon is isolated from the sheath incision or when constant motion is maintained.

Occupational therapists are concerned with all aspects of human function. Hand use is an essential component of functioning, and many therapists have developed special interests in the evaluation and treatment of hand dysfunction. Therapists involved in rehabilitation following surgical repair of tendons should familiarize themselves with the physiological processes occurring in tendon healing.

Therapists have the greatest impact on the outcome of the tendon repair during the postoperative care period. The idea of controlled mobilization has been supported and emphasized as important in tendon healing in recent lit-
erature. It has been strongly suggested that adhesion formation is reduced or prevented through the use of early controlled mobilization; however, uncontrolled early active flexion may disrupt the tendon repair (13). Mason and Allen (3) demonstrated that early motion may be expected to lead to a rapid increase in tensile strength of the union. Electromyographic studies (13) have demonstrated that contraction against resistance of one group of muscles results in synergistic relaxation of its antagonists. This means that there is a minimum of stress placed on the tendon repair site when controlled mobilization is used. Perhaps the most significant benefit following early controlled mobilization is the speed at which function is recovered (13).

The goal of the ongoing evaluations at the three Army hospitals is to expand the idea of controlled mobilization by improving digital function through tendon excursion in the Kleinert splint with the insertion of a pulley at the level of the palm (11). These evaluations also address the statement by Lister and associates (13) against having the digits flex into the palm, because they felt this might overstress the hand. The results to date have not supported this statement.

Evaluation of results following the use of the splint modification at Fort Ord and Brooke Army Medical Center have been based on the criteria proposed by Kleinert (10) (see Table 1).

The splint modification has been used in six cases at Ford Ord and, to date, has demonstrated 100 percent good to excellent results at eight to twelve weeks post-Zone II flexor tendon repair. At Brooke Army Medical Center, the splint has been used with ten patients and has produced 87 percent good to excellent results (11)

<table>
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<th>Criteria for Evaluation of Results</th>
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<tr>
<td>Excellent</td>
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<td>Flex within 1 cm of distal palm</td>
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<td>crease with less than $15^\circ$ loss of extension</td>
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| Good                               |
|   Flex within 1.5 cm of distal palm crease with less than $30^\circ$ loss of extension |

| Fair                               |
|   Flex within 2 to 3 cm of distal palm crease with more than $30^\circ$ loss of extension, but less than $50^\circ$ |

| Poor                               |
|   Greater values of distance to distal palm crease, extension loss or both, or tendon rupture |

This report has discussed a modification of the Kleinert orthosis presently in use and has reviewed some of the physiological mechanisms accompanying tendon re-
pair and the use of early controlled mobilization. The hand is an essential tool required for daily functioning and work, which is a key concept in occupational therapy. Early controlled mobilization has demonstrated some definite benefits with more rapid resumption of function. This resumption of function is important to therapists, patients, employers, families, and society-at-large. The preliminary results of ongoing evaluations suggest that use of the modified orthosis produces more effective results and perhaps a better quality functional level in the end.

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REFERENCES