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The Effect of Circumferential Taping on Flexor Tendon Pulley Failure in Rock Climbers

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ABSTRACT

The purpose of this study was to determine whether circumferential taping of the base of the finger increases the A2 pulley's load to failure in a model simulating a rock climber's grip. Nine pairs of fresh-frozen cadaveric hands, 20 to 47 years of age, were rigidly mounted in a specialized jig that maintained the finger in the climber's "crimp" position. Two of the four fingers of each hand were reinforced over the A2 pulley with three wraps of cloth adhesive tape. The flexor digitorum profundus and superficialis tendons were distracted until pulley or tendon failure. Overall, A2 pulley strength was greater in male specimens than in female specimens, and the A2 pulley of the small finger was the weakest tested. The A2 pulley failed simultaneously with the A3 and A4 pulleys in 55% of the tests. In the remaining trials, a single pulley failed initially followed by the remainder of the sheath. Of the 72 fingers studied, complete data were available for comparison of 22 pairs of fingers. No statistically significant difference in load to A2 pulley failure was noted between the taped and untaped finger pairs. Based on our findings we do not support taping the base of the fingers as a prophylactic measure against flexor tendon sheath injury in the climbing athlete.

Over the past half century, advances in rock climbing equipment have allowed climbers to accomplish increasingly difficult climbs while the incidence of fall-related injuries has decreased. The increased "safety" of rock climbing has been a factor in its current popularity. The desire to climb at higher standards has led to aggressive training regimens on natural cliffs as well as in climbing gymnasiums. Elite climbers compete in World Cup events that require the dedication and discipline of any athletic pursuit. Similar to other athletes, climbers are increasingly affected by overuse injuries.[2,5,8,15,33]

Technical rock climbing is an activity that exposes the finger flexor tendon mechanism to tremendous stresses.[3–6,15,18,33,40,41] The upper extremities routinely support much of the climber's weight through as few as one or two fingers. In this population, injuries to the upper extremity, especially to the hand and wrist, predominate.[3–6,15,33,42,43] In addition to inflammatory conditions of the musculotendinous units, closed ruptures of the A2 pulley have occurred. The first case of A2 pulley rupture in a climber was reported in 1990,[4] and subsequently many more cases have been recorded.[3,6,14,17–19,25,27,40,42,43,45,46] This injury is painful and portends a prolonged convalescence, tendon "bowstringing" (volar displacement of the flexor tendons away from the phalanges), and fixed flexion contractures.[3–7,43] Complete A2 pulley rupture may require surgical repair or reconstruction.[14,45] If the A3 and A4 pulleys are torn also, surgical intervention is routine.[7,30]

Climbers often tape their fingers at the level of the proximal phalanx to prevent A2 pulley ruptures or to ameliorate symptoms of partial injuries.[15,33,40,41,43] It is not known if the application of tape increases the pulley's strength. If a model could demonstrate that applying tape strengthens the pulley, a case could be made for prophylactic taping. Our hypothesis was that circumferential taping of the base of the finger would significantly increase the A2 pulley's load to failure in a climbing model.

MATERIALS AND METHODS

Preparation of the Specimens

The properties of four different brands of cloth athletic tape were studied on a materials testing machine. The

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type with the greatest ultimate tensile strength and modulus of elasticity was selected for finger reinforcement (cloth athletic tape, white, Moore Medical Corp., New Britain, Connecticut). A power analysis with variation based on previous work on the flexor tendon sheath was performed.[34] This analysis yielded an estimated requirement for 23 pairs of fingers. Nine matched pairs (4 male and 5 female) of fresh-frozen cadaveric hands were obtained from donors 20 to 47 years old. The specimens were allowed to reach room temperature and then were dissected under loupe magnification via Bruner incisions. The annular pulleys were identified and marked with india ink. The specimens were kept moist with normal saline and tested in a predetermined randomized sequence. No specimens had finger deficiencies, upper extremity scars, or obvious arthritis. Thumbs were not studied. Two of the four fingers of each hand were reinforced with three circumferential wraps of 1.5-cm wide cloth tape, such that in each left-right pair of fingers only one finger was taped (Fig. 1). The incisions over the proximal phalanx of the fingers randomized to taping were closed with nylon sutures. Otherwise, the incisions were left open to allow for direct observation of pulley failure. The tape was applied with firm pressure with the proximal interphalangeal joint at 90° of flexion.

Testing Apparatus

The hands were rigidly mounted in a specialized jig that maintained the fingers in the climber's "crimp" position (Fig. 2). This position was defined as flexion of 60° at the metacarpophalangeal joint, 90° at the proximal interphalangeal joint, and maximal hyperextension at the distal interphalangeal joint. The flexor digitorum profundus and superficialis tendons were divided at the musculotendinous junction and secured in a novel tendon clamp. The clamp was coupled to a load cell in series with a United SFM-1 computer-controlled linear actuator/materials testing system (United Calibration Corporation, Huntington Beach, California). Each finger was individually tested by distracting the clamp at 30 mm/min until the flexor sheath or the biomechanical system failed. Tendon loads, excursions, and deformation curves were captured by a personal computer with United Calibration software. The tests were videotaped using a 70° arthroscopic camera to record the sequence of pulley failure.

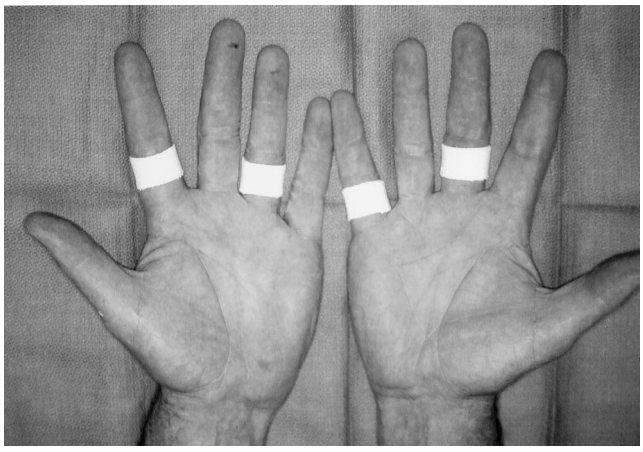

Figure 1. The taping sequence for five pairs of hands. The other four pairs of hands had the index and ring fingers of the right hand and the middle and small fingers of the left hand taped.

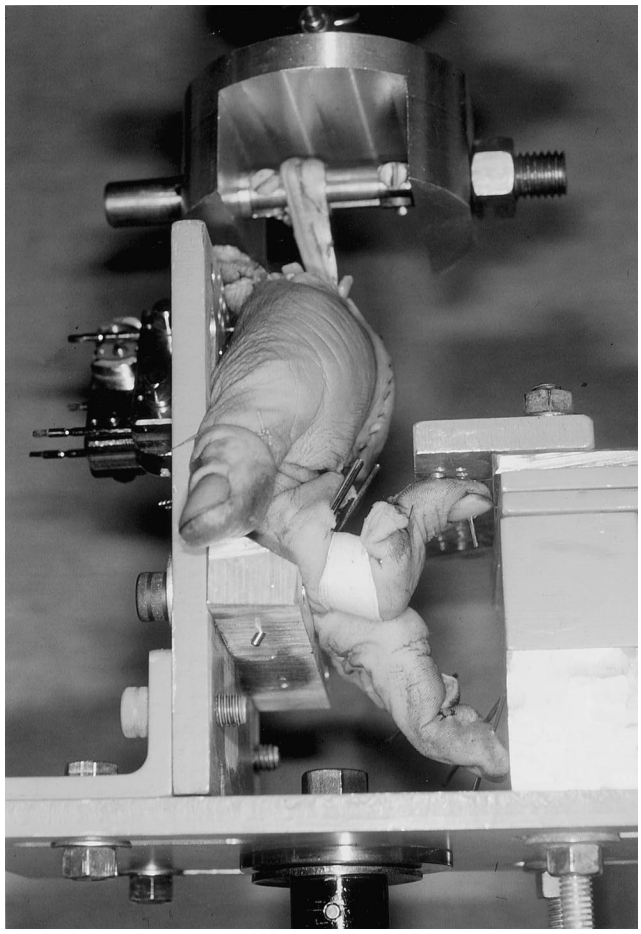

Figure 2. A taped right index finger prepared for testing in the climber's crimp position.

Statistics

Statistical analysis was accomplished with the VAX BMDP package program (SPSS Inc., Chicago, Illinois). Repeated measures analysis of variance tests were used to account for potential sources of variation. The level of significance for each test was set at $P \leq 0.05$.

RESULTS

Of the 72 fingers studied, 23 tests were complicated by proximal interphalangeal joint fracture or dislocation (14), metacarpal fracture (3), tendon failure at the clamp (3), tendon avulsion (2), or proximal phalanx fracture (1) before pulley compromise. Overall, the A2 pulley failed at the same time as the A3 and A4 pulleys in 55% of the

successful tests (Fig. 3). In the remaining trials, a single pulley failed initially (A2 in 27% of specimens [13 fingers], A4 in 16% [8 fingers], and A3 in 2% [1 finger]), followed by the remainder of the sheath (A2–4) (Fig. 4). The sequence of pulley failure was not affected by the presence of circumferential tape. The A1 pulley failed in only three small fingers and the A5 pulley was never compromised. Repeated measures analysis of variance simultaneously accounted for all identified potential sources of variation in the threshold force required for A2 pulley rupture. Results of this analysis are as follows with notation of unadjusted means ± standard error of the mean in newtons: A statistically significant difference in A2 pulley strength was noted between the female (414 ± 28 N) and male (569 ± 39 N) specimens ($P < 0.01$). The A2 pulley was weaker in the small finger (373 ± 47 N) than in the other fingers (527 ± 31 N) ($P < 0.01$). The A2 pulley data were available for comparison in 22 pairs of fingers (Table 1). No statistically significant difference in mean load to failure was found in the matched pairs between the taped (516 ± 35 N) and untaped (482 ± 33 N) condition ($P = 0.53$).

DISCUSSION

The anatomy and function of the finger flexor tendon sheath have been thoroughly studied.[1,9–13,20,22,28,29,34,38,44] The sheath holds the digital flexor tendons close to the phalanges to maximize joint excursion and provides mechanical stabilization for the transfer of forces.[9,38] Sheath integrity is also important for tendon nutrition.[32] The A2 pulley is considered the most important component of this sheath, as its absence is associated with the greatest loss of joint motion.[12,28,38] In the past, the A2 pulley was thought to be weaker than the A1 and A4 pulleys.[34] Since then, the A2 pulley has been definitively shown to be the strongest pulley, followed in order of strength by the A1, A4, and A3 pulleys.[29]

Failure of the A2 pulley is a common problem among elite climbers.[3,4,6,14,17,18,25,27,45,46] In one series, 26% of the climbers (17 of 67) in a national level competition had sustained this injury in at least one digit.[6] A survey of recreational climbers found evidence of A2 pulley rupture in 19% (7 of 36).[42] Closed ruptures of the A2 pulley have also been reported from windsurfing, weightlifting, and falls.[7,27] In each case, a violent extension force was applied against a tightly closed hand.[7] Several of these patients had associated ruptures of the A3 and A4 pulleys. Interestingly, many of the patients delayed seeking treatment until they had worsening proximal interphalangeal joint flexion contractures. Two mechanisms seem to occur

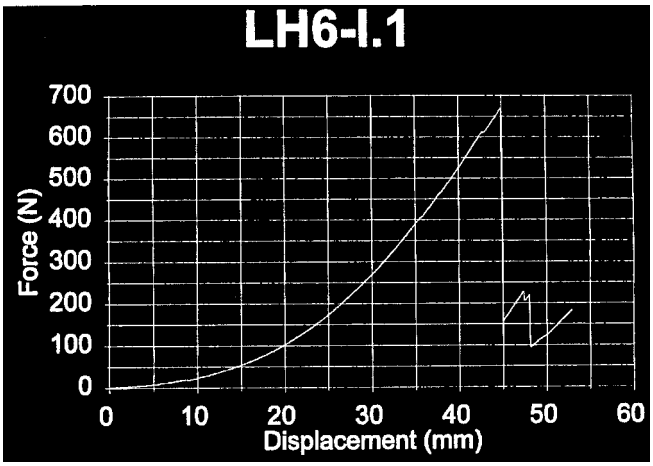

Figure 3. A force-displacement curve demonstrating simultaneous rupture of the A2, A3, and A4 pulleys at 670 N. The curve deflection at 48 mm represents an avulsion of the flexor digitorum superficialis tendon at its insertion.

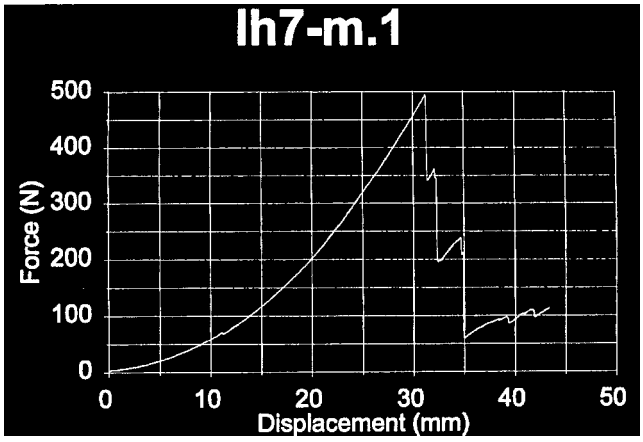

Figure 4. This curve represents a failure of the A3 and A4 pulleys at 494 N followed by A2 pulley failure at 362 N. Terminally, the flexor digitorum superficialis tendon avulsed at 35 mm of displacement.

TABLE 1
Forces Measured at the Moment of A2 Pulley Failure in Successful Tests in Paired Hands

Specimen	Age	Sex	Finger[a]	Force (in newtons)	
				Taped	Untaped
1	34	F	IF	408.3	310.3
1	34	F	RF	427.0	233.3
2	42	F	IF	506.2	442.7
2	42	F	RF	385.1	343.2
3	20	F	RF	484.5	661.0
4	42	F	RF	463.6	464.4
5	37	M	IF	527.2	670.0
5	37	M	MF	991.5	588.5
5	37	M	RF	704.4	747.8
5	37	M	SF	492.8	453.1
6	42	M	IF	448.7	516.0
6	42	M	MF	569.0	361.9
6	42	M	RF	787.4	404.5
6	42	M	SF	320.0	347.7
7	45	M	IF	709.6	664.8
7	45	M	MF	516.7	798.6
7	45	M	RF	642.3	556.3
7	45	M	SF	395.6	449.4
8	47	F	IF	421.0	406.0
8	47	F	MF	451.6	457.6
8	47	F	RF	399.3	488.3
8	47	F	SF	296.9	226.6

[a] IF, index finger; MF, middle finger; RF, ring finger; SF, small finger.

in climbers: When the body is supported by one or two fingers in the crimp position, a slip of the foot can cause acute loading of the digit(s).[3,4,6,46] Additionally, when the climber dynamically moves either to or from a small hold, the flexor tendon sheath can be overloaded (Refs. 3 and 6; H. Florine, personal communication, 1997).

We specifically used young specimens to better approximate the ages of persons involved in rock climbing and the relative strengths of their tissues. Despite the relatively young age of the specimens, many failed because of proximal interphalangeal joint fracture or dislocation. Retrospectively, we noted that this mode of failure occurred in hands that appeared unaccustomed to heavy work. No hands that were heavily callused failed in this manner. This may represent an oversight in our exclusion criteria because hypertrophic changes in muscles, tendons, ligaments, and bones have been noted on MRI scans of climbers' hands.[17]

Logistical constraints precluded using fresh hands, so fresh-frozen specimens were obtained. Tendons preserved by freezing have been compared with fresh tendons.[36] The frozen tendons demonstrated similar stress-strain limit cycles but had a lower modulus of elasticity. We believed that the flexor tendon sheath would demonstrate similar resiliency to freezing and would yield useful data.

The ring finger is the finger most commonly affected by closed pulley ruptures, followed in frequency by the middle finger.[3,6,7,17,27] The reason for this is unclear, but it probably relates to the preference of climbers to use the middle and ring fingers on holds or in pockets that will accommodate only two digits. The other digits, excluding the thumb, have been similarly compromised but are at a decreased risk.[6,7,27,42] The small finger A2 pulley was significantly weaker than the other fingers, as noted earlier. The reason that the small finger is not more commonly injured in the climber is that it is rarely used in power moves or used alone.

A recent model for flexor tendon pulley rupture was used to define the pathomechanics of injury in climbers.[35] Using a strain rate of 30 mm/min, the authors found the force in the ring finger flexor digitorum profundus tendon to be significantly less than that in the index or middle fingers at the time of initial pulley failure. In their specimens, the A4 pulley failed first in 14 of 17 digits. Our data did not show the ring finger A2 pulley to be significantly weaker than that of the index or middle fingers, although a larger sample size may have confirmed this. In our tests, the A4 pulley failed in concert with the A2 and A3 pulleys in 55% of the successful tests, and failed first in only 8 of 49 digits (16%). The A2 pulley was the first to fail in 13 fingers (27%), and the A3 pulley failed first only once (2%).

Although failure of multiple contiguous pulleys has been reported,[7,27] isolated A2 pulley ruptures seem to be more commonly reported in climbers.[3,4,6] However, in these articles isolated A2 pulley injuries were reported as such based on the physical finding of bowstringing alone. Other elements of the sheath may have been ruptured as well and were unrecognized. Some degree of bowstringing should be evident with the loss of any annular pulley,[30] yet it is not known how many pulleys must be compromised for bowstringing to be clinically recognized. One case has been reported where an isolated A2 pulley was detected by clinical examination before surgical repair.[45]

Diagnosis of annular pulley rupture is facilitated after 30° of proximal interphalangeal joint flexion is exceeded,[28] especially with resisted flexion. Imaging studies including computed tomography,[27] MRI,[14,17,18,25] ultrasound,[23] and tenography[7] have been used to define the extent of the flexor tendon sheath rupture. Isolated A2 pulley tears in climbers have been documented by MRI[17,18] and at surgery[45] in a few case reports.

The short-term natural history of less-extensive injuries of the flexor tendon sheath is relatively normal function, allowing the patient to return to unimpaired climbing after a period of rest.[4] Surgical intervention is usually not required unless function is impaired by multiple contiguous pulley ruptures or by ensuing flexion contractures.[7,27] Many climbers, and some investigators, believe that circumferential tape around the base of the finger protects against A2 pulley injury.[6,14,31,37,40,42] To our knowledge, this is the first study designed to evaluate the efficacy of taping with regard to protecting the flexor tendon sheath in the climber. Most of the previous studies that investigated the merits of taping involve the ankle or knee. However, in a recent study of football players, a cohort who routinely taped their fingers and wrists underwent handgrip dynamometer testing.[39] No improvement of grip strength was identified in the taped condition. We detected no significant effect of circumferential taping at the base of the finger. Although taping does not appear to lend any biomechanical advantage to the pulley system, there may be proprioceptive and placebo benefits that are not known.

The "crimp" grip is preferred by climbers because it allows wrist extension, which lends the flexors a mechanical advantage.[41] It is understood that the grip that allows the most secure hand-hold will be used in a competition or on an actual climb. Since pulley injuries are largely acquired as a function of the finger position, the most significant prophylactic intervention that can be made is to avoid using the crimp grip in repetitive training exercises and when an open grip will suffice. Several investigators have recommended alternative training techniques to decrease the incidence of pulley injury.[14,24,40]

Although stretching may be helpful in preventing injuries at the musculotendinous junction,[16] its efficacy in preventing injuries of the tendon sheath or tendon insertion has been questioned.[21,26] It is not known if the wearing of broad metal rings can prevent these injuries. The wearing of a ring while crack climbing could result in a finger avulsion in the event of a fall. This type of injury would far outweigh any prophylactic measure afforded against pulley compromise. Further trials using rings of sufficient rigidity but constructed of a more forgiving material than metal may show an increase in the pulley's load to failure. Ideally, such a study should use specimens from young cadavers with work-hardened hands to more closely approximate the population at risk.

A human cadaveric model of A2 pulley failure in the climbing configuration was able to detect differences in

sex and finger type. Nevertheless, comparison of paired fingers with and without circumferential cloth athletic tape reinforcement disclosed no statistically significant increase in load to failure of the A2 pulley. These results do not support external taping as a prophylactic measure against flexor tendon sheath injury in the climbing athlete.

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