Strength Measurement and Clinical Outcome after Pulley Ruptures in Climbers

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ABSTRACT

SCHÖFFL V. R., F. EINWAG, W. STRECKER, and I. SCHÖFFL. Strength Measurement and Clinical Outcome after Pulley Ruptures in Climbers. *Med. Sci. Sports Exerc.*,Vol. 38, No. 4, pp. 637–643, 2006. **Purpose:** Ruptures of the finger flexor pulleys are the most frequent injuries in rock climbers. Whereas multiple pulley injuries demand a surgical reconstruction, single ruptures are mainly treated conservatively. Nevertheless, the question of the clinical outcome or a persisting finger strength deficit after conservative therapy arises. **Methods:** Twenty-one rock climbers (age 34 ± 9 yr) with a grade 2–4 pulley injury were reevaluated 3.46 (range: 0.25–18) yr after injury. The clinical evaluation followed a standard questionnaire in combination with an ultrasound examination in extension and forced flexion. In order to determine the finger strengths, the subjects hung with the respective finger in various postures on a ledge attached above a door frame, while standing on a force platform, which measured the relative release. **Results:** The 21 subjects had old (3.46 yr, range: 0.25–18) pulley injuries in 27 fingers (10 A2, 1 A3, 11 A4, 3 A2/3, 2 A3/4). The clinical outcome was excellent (Buck-Gramcko score of 3) in all cases; the subjects regained their climbing level within a year. There was no difference between the initial ultrasound examination and the follow-up during the study. For 17 finger pairs, data for the relative strength of the injured and the respective healthy finger could be gathered. The finger strength was not significantly different for the injured and the healthy finger in either the hanging or the crimping finger position. **Conclusions:** Nonsurgical treatment of single pulley ruptures is recommended. The clinical outcome was good to excellent, and no long-term strength deficit for the injured finger could be observed. **Key Words:** ROCK CLIMBING, FINGER INJURIES, FINGER STRENGTH, FLEXOR TENDON, STRENGTH MEASUREMENT, SPORT CLIMBING

Injuries to the finger flexor tendon pulley system are the most frequent injuries in rock climbers (8,10,11,19, 25,27,29,33–35). The pulley system of the second to the fifth fingers consists of five annular (A1–5) and three cruciform pulleys (C1–3) (Fig. 1); its main function is to maintain the flexor tendons close to the bone, thus allowing for the direct transfer of the translational force developed in the flexor muscle–tendon unit into a rotational moment of the phalanges. Without the pulleys, the tendon moves too far away from the bone in a flexed position, leading to a complete shortening of the muscle when the finger is not yet fully flexed. In addition, the tendons would move away from the fingers, causing a stretching of the skin visible from the exterior. These considerations can be observed after multiple pulley ruptures and are referred to as bowstring. With intact pulleys, the tendons still move away from the joints in a flexed position, especially over the A3 pulley, as this is the most flexible one and as a consequence of its positioning over the proximal interphalangeal joint (17), leading to a decrease in the angle between the pulley and tendon (26). Because the force acting on the concerned pulley increases with a decreasing angle (12), a finger position in which the fingers are maximally bent in the proximal interphalangeal joint (crimping position) will most likely lead to a pulley failure (Fig. 2). Therefore, the pulleys A2, A3, and A4 are most prone to rupture (16,18,20, 30,33,35,36). As a consequence of a pulley rupture, the flexor tendon moves away from the bone, which leads to clinically visible "bowstringing" if more than one pulley is missing (20). If only a single pulley is missing, the increased distance between tendon and bone (TB) can only be detected via ultrasound (13,21,22,35) and MRI (1,6). Klauser et al. (13) defined an increased TB distance with forced flexion of < 3.0 mm as an incomplete rupture of the A2 pulley and a TB of ≥ 3.0 mm as a complete rupture.

Since Bollen (2) and Tropet et al. (38) reported first about this injury in 1990, further reports have followed, giving various diagnostic and therapeutic recommendations (11,20). At present, a conservative therapy regimen has become standard practice for a single pulley rupture (6,7,31,33,35). Multiple ruptures, however, lead to an important bowstring that can become clinically visible and, as a consequence, the translational force developed in the flexor tendons cannot be transferred onto the bone, leading to a functional deficit when trying to flex the finger. In such a severe case, surgical repair is recommended (7,24,35). A grading system for pulley ruptures, and, based on that, a therapeutic and diagnostic algorithm with therapeutic guidelines, has been developed (35).

The noninvasive approach in the single pulley rupture is based on biomechanical analyses of the flexor tendon pulley

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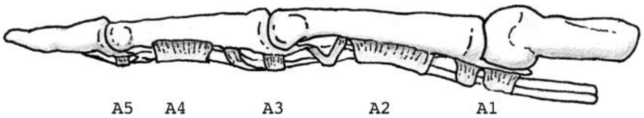

FIGURE 1 —The finger flexor pulley system (modified in accordance to Schmidt and Lanz (28)).

system (22,23) in addition to good clinical and functional results after a conservative functional therapy Some authors (39) recommend a surgical procedure for the single pulley rupture (A2 or A4), arguing that the climber will otherwise not be able to reach his or her former performance level. Our clinical results, however, suggest a nonsurgical approach (35). The question of a persisting strength deficit in the injured finger has never been assessed. The climbers observe a subjective deficit immediately after the injury (32). Should a persistent strength deficit be observed via strength analysis, the indication for a surgical repair, especially in highly competitive athletes, needs to be reconsidered.

Our hypothesis is that the initial strength deficit that can be observed immediately after a pulley rupture will resolve with time under conservative therapy and the climber will regain his sport-specific performance level and have a good clinical and functional outcome.

METHODS

Twenty-one rock climbers (age: 34 ± 9 yr, two female, 19 male with an average hand length on the dominant side male: 19.6 ± 0.6 cm, female: 18.4 ± 0.5 cm) with grade 2–4 pulley injuries (Table 1) (35) were reevaluated 3.46 (range, 0.25–18) yr after the initial injury. For the evaluation of the mean sport specific performance level (redpoint/onsight climbing level), the metric system described previously (32) was used. The average redpoint level (climbing a route that is known to the climber without rest) of the subjects was 8.53 ± 1.11 according to the Union Internationale des Associations d'Alpinisme grading scale, and the average onsight level (climbing a route unknown to the climber without rest) was 7.85 ± 1.05 (Table 2). The clinical evaluation followed a standard questionnaire and examination protocol (including Buck-Gramcko score (3), Table 3); the range of motion analysis was performed using a goniometer. Finger goniometry has a good reliability (4,5); nevertheless, three measurements were performed and the mean calculated. Ultrasound examination in extension and forced flexion (pressing the fingertips against the resistance of the examiners finger (13)) was performed using a Hitachi 8500 with a 10-MHz linear transducer in a water basin (supine position). Each examination was documented on hard copy printouts. The distance between the flexor tendons and the bone (TB) was gathered at the middle of the proximal phalanx for the A2 pulley and at the middle of the middle phalanx for the A4 pulley in longitudinal planes (21). For the A3 pulley, longitudinal and transverse planes were measured at the proximal portion of the PIP joint. TB > 2 mm for the A2, > 3.5 mm for the A3, and > 2 mm for the A4 pulley were defined as being a pulley rupture (9,13,33). Additional ultrasound findings were recorded using a standard examination protocol ("halo" phenomena, ganglions, bone spurs, etc.). If there was major pathology in connection with clinical symptoms, the finger was excluded from the strength measurement.

The finger strength was measured according to a protocol first described by Köstermeyer and Weineck (15). The subjects had had a sufficient rest after sport specific stress of > 48 h. A warm-up using finger exercise devices and hanging onto the test hold was performed for 10 min with a 10-min rest before starting the test. Strength

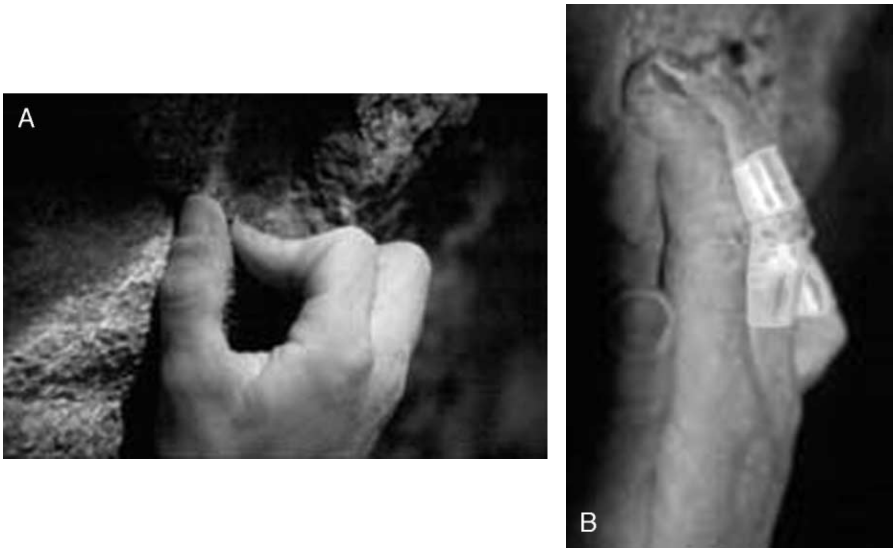

FIGURE 2—Two main hand and finger positions are used in rock climbing: the crimping (A) and hanging (B) positions.

TABLE 1. Pulley injury score (35).

Grade	Injury
I	Pulley strain
II	Complete rupture of A4 or partial rupture of A2 or A3
III	Complete rupture A2 or A3
IV	Multiple ruptures (A2/A3, A2/A3/A/4) or single rupture (A2 or A3) combined with Mm. lumbricalis or collateral ligament trauma

was measured using a 15-cm-long and 2-cm-strong wooden horizontal edge with a rounded margin that was screwed above a door frame as the test hold. The size of the test hold was designed so that it could only be held with the first finger. The test subject was standing straightforward in an erect position perpendicular to the test hold on the center of a force platform (Erbse®, Germany, sampling rate: 1 per millisecond), which measured the relative release (body weight minus the applied finger strength). The subject needed to pull as much as possible on the test hold over a period of 5 s. After each test, the subject rested for 3 min. The graph representing the force measurement over time was then analyzed for determining the 2 s, during which the subject pulled at his or her maximum. We tested the index, middle, and ring fingers of both hands first isolated and then all three together in the crimping and the hanging positions. The strength data were processed in the percentage of total body weight for comparison among the subjects. We believe that a direct comparison of the injured and uninjured fingers is not sufficient because the handedness of the subjects may have influenced the results. Therefore, we processed the data further. An example is included to clarify the procedures. In the example, the patient has a pulley rupture on the fourth finger of the right hand, which is also his stronger hand. The data on the noninjured fingers as well as the data on the three fingers combined were used to determine the mean strength of the right hand (R) and the left hand (L), respectively. In a second step, we processed these values further by subtracting the mean strength value for the injured hand (I) from the mean strength value for the uninjured hand (U). Thus, R becomes I and L becomes U if R is the injured hand, as is the case in our example. Then the difference ($D_{U\text{-}I}$) between the uninjured and injured hands is calculated as $D_{U\text{-}I} = U - I$.

This gave us the mean strength difference between the injured and noninjured hand, which was positive if the stronger hand was also the noninjured hand and negative if the stronger hand included the injured finger. In our example, the patient would have a negative value for $D_{U\text{-}I}$ because his injury is on his stronger hand. Then we used the data for the finger with the pulley rupture (R) and the contralateral healthy finger (H) and subtracted the injured from the healthy one: $D_{H\text{-}R} = H - R$.

In our example, the strength of the fourth finger of the right hand is subtracted from the strength of the fourth finger of the left hand. Finally, we compared the difference between dominant and nondominant hand ($D_{U\text{-}I}$) with the difference between injured and noninjured finger ($D_{H\text{-}R}$). A significant difference ($D_{U\text{-}I}$ vs $D_{H\text{-}R}$) indicated that the difference in strength between injured and healthy finger was not due to handedness. In our example, there would be a difference if the injured finger was stronger than the contralateral healthy finger and significantly more so than the right hand was already.

To assess a possible time after injury–related strength difference of the injured compared with the healthy finger, the patients were also grouped according to the time that had passed since the injury (group 1 (11 subjects): time interval since injury > 1 yr; group 2 (six subjects): time interval since injury < 1 yr). All subjects gave written informed consent to the examinations and test, and the study was approved by the ethics committee.

Statistical analysis was performed using Microsoft Excel 2000® for data collection and SPSS 12.0® (SPSS Inc., Chicago, IL) in cooperation with the Institute of Medical Physics, University Erlangen-Nuremberg. All measured values are reported as means and SD. The Kolmogorov–Smirnov test was used to check for normal distribution. Homogeneity of variance was investigated using Levine's *F*-test. For normally distributed variables, differences within and between groups were assessed with paired and unpaired *t*-tests; otherwise, the Wilcoxon or the Whitney–Mann *U*-test were used. All tests were two tailed; a 5% probability level was considered significant.

RESULTS

Clinical findings. The 21 long-time (>5 yr of rock climbing) rock climbers taking part in the study presented

TABLE 2. Evaluation of the subjects.

	N	Maximum	Mean	Minimum	SD
Height	21	1.93	1.78	1.68	0.05
Weight	21	86.00	72.19	52.00	9.86
Age	21	59	34	22	9
BMI	21	27.9	22.8	18.4	2.5
Climbing years until injury	21	27.00	10.79	2.00	7.11
Climbing years after injury	21	18.00	3.46	0.25	4.14
Climbing level (onsight) at time of injury	21	9.50	7.85	6.00	1.05
Climbing level (redpoint) at time of injury	21	10.30	8.53	6.70	1.11

Twenty-one subjects (2 female, 19 male).
BMI, body mass index.

TABLE 3. Buck-Gramcko score (3).

Measurement of digits II–V	Points
Fingertip-palmar crease distance/complete flexion	
0–2.5 cm/≥200°	6
2.5–4 cm/≥180°	4
4–6 cm/≥150°	2
>6 cm/<150°	0
Extension deficit	
0–30°	3
31–50°	2
51–70°	1
>70°	0
Range of motion	
≥160°	6
≥140°	4
≥120°	2
<120°	0

Grading: 14–15 points, excellent; 11–13 points, good; 7–10 points, fair, 0–6 points, poor.

TABLE 4. Clinical examination.

	No. of Pathologic Cases
Reduced range of motion	
PIP extension	10 (37%)
PIP flexion	1 (3.7%)
DIP extension	0
DIP flexion	0
MCP extension	0
MCP flexion	0
Reduced extension of the fingertip to the horizontal	1 (3.7%)
Reduced distance fingertip to the distal palmar crease	0
Soft-tissue swelling at the site of the injured pulley	1 (3.7%)
Soft-tissue decrease at the site of the injured pulley	1 (3.7%)
'Bowstring' visible	0
'Bowstring' palpable	3 (11.1%)

PIP, proximal interphalangeal joint; DIP, distal interphalangeal joint; MCP, metacarpophalangeal joint.

27 (10 A2, 1 A3, 11 A4, 3 A2/3, 2 A3/4) old pulley injuries. The ring finger (18/27) was most affected, second was the middle finger (7/27), and then the index and small fingers (each 1/27). Twelve of 27 ruptures were on the left hand, and 15 of 27 were on the right hand. Twenty of 21 subjects were right-handed. Eleven (41%) pulley ruptures were grade 2, 11 (41%) were grade 3, and five (19%) were grade 4 injuries. All subjects with grade 4 injuries either refused surgical therapy before or were not treated according to the score. Four climbers had more than one pulley injury from different accidents and on different fingers. Nine (33%, 9/27 pulley ruptures) climbers reported not having warmed up properly when they injured themselves, 15 (56%) had warmed up, and one climber had already been exhausted after a long climbing day. The injury patterns were as follows: crimping a small edge in 12 incidents (44%), crimping an undercling in two (7%), crimping and holding a one- or two-finger pocket in six (22%), crimping and slipping off a foothold at the same time in two (7%), "fatigue" rupture after chronic tenosynovitis and local cortisone injection in two (7%), and pulling on a large hand hold while the edge of it was pressing onto the A2 pulley in one (4%) case. In 18 (67%) cases, a doctor was consulted within 8 d (mean, range 0–35). In 14 (52%) cases, adequate therapy was conducted, and climbing with taping as pulley protection (all subjects) was started 6 wk after the injury (mean, ± 6 wk) (range, 0–27 wk). Taping was performed for 26 wk (mean, range: 1 d–5 yr) after the injury; six climbers were still using tape regularly as a pulley protection. The climbers stopped taping after 26 ± 30 wk, seven (33%) were still using tape when climbing very hard. Eight (30%) climbers reported having occasional trouble because of the old injury while climbing, but only two (7%) complained about occasional problems during daily life. Onsight and redpoint climbing level was regained within 1 yr for every climber. Two of the five subjects with "younger" injuries regained their climbing level after 4–6 months.

In the clinical examination, 16 of 27 (59%) of the once-injured fingers showed free range of motion, and 11 of 27 (41%) showed decreased range of motion in the proximal interphalangeal joint (PIP). The decreased range of motion was a 5–10° extension deficit for the PIP in 10 fingers and a 20° flexion deficit in one finger (in comparison with the contralateral healthy finger). For further evaluation, see Table 4. According to the Buck-Gramcko score (3), all injured fingers showed an excellent result (fingertip–palmar–crease distance of 0–2.5 cm, extension deficit < 30°, and total finger range of motion > 160°).

Ultrasound examination. The earlier diagnosed pulley ruptures could be confirmed according to our criteria in all subjects. In addition to the pulley rupture, bone spurs (osteoarthrosis radiographically confirmed), tenosynovitis, ganglions, and "halo" phenomena were found (Table 5). TB in the pathologic cases was 2.8 ± 0.6 mm for the A2, 4.4 ± 0.9 mm for the A3, and 2.4 ± 0.3 mm for the A4 pulley (Table 5). A comparison with ultrasound images dating from directly after the injury was possible in 14 subjects. In one case, the diagnosis needed to be changed from an initial A2 pulley rupture to an A2/A3 pulley rupture because of an earlier misdiagnosis. Diagnosis has become more accurate due to better ultrasound equipment and more practice. The analyses for TB were in all cases for A2, A3, and A4 within a range of ± 0.3 mm in the control ultrasounds compared with the initial examination.

Strength measurement. Data for the injured and the respective healthy finger in 17 finger pairs were gathered. The other 10 pulley rupture strength measurements could not be evaluated because the subjects either had pulley ruptures on the same finger on both sides or had other complaints on the contralateral side (e.g., tenosynovitis, lumbrical shift syndrome). The finger strength was not significantly different for the injured and the healthy finger in either the hanging or crimping finger position (healthy finger vs injured finger hanging: $P = 0.29$; healthy finger vs injured finger crimping: $P = 0.95$; $D_{U\text{-}I}$ vs $D_{H\text{-}R}$ hanging: $P = 0.38$; $D_{U\text{-}I}$ vs $D_{H\text{-}R}$ crimping: $P = 0.98$) (Fig. 3, Table 6). Although the means of all subjects (Fig. 3) are negative, and this implies that the injured hand was generally the stronger hand and that the injured finger was stronger than the uninjured finger, the values are extremely small. This, in combination with the large error bars, indicates that there was great interindividual variability and explains why the values did not reach significance; that is, even though the mean values of the subjects were negative, there were also a lot of positive values annihilating each other with negative values of

TABLE 5. Ultrasound findings.

	No. of Pathologic Cases	Distance (mm) (Mean ± SD)
Tendon–bone distance (TB)		
TB A2 pulley	13	2.8 ± 0.6
TB A3 pulley	6	4.4 ± 0.9
TB A4 pulley	13	2.4 ± 0.3
Other findings		
Bone spurs	1 (3.7%)	
Ganglion A2 pulley	1 (3.7%)	
Ganglion A3 pulley	1 (3.7%)	
'Halo' phenomena (tenosynovitis)	1 (3.7%)	

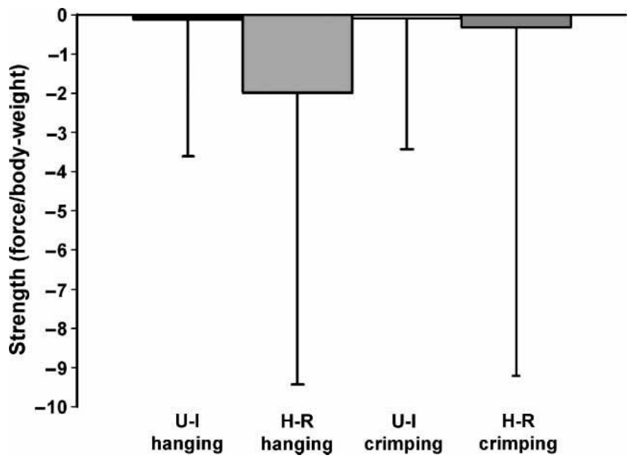

FIGURE 3—Strength measurement.

other subjects. The time interval after the injury (groups 1 and 2) was of no significance for the strength difference between the injured and the healthy finger for the crimping (P = 1.0) and the hanging position (P = 0.4).

DISCUSSION

As expected, most pulley injuries were on the ring finger, which is in accordance with the literature (35). Neither the right nor the left hand was more prone to injury, nor was there any relationship between the injured side and the dominant side in comparison with the nondominant side. Because we only evaluated patients with nonreconstructed pulley ruptures, the single rupture was most common. A direct link between the accident and the fact that the subjects had not warmed up properly, as proposed by Schweizer et al. (37), could not be drawn because most of the injuries (>50%) occurred after warming up. The theory that pulley ruptures most often occur when the foot slips off a hold (24,35), thus applying peak forces on the pulley system, could not be sustained because only 7% of the injuries occurred this way. Still, crimping a small edge proved to be the most dangerous finger posture for a pulley rupture, a finding in several previous studies (11,20,24,25,35,36). It is remarkable that only 67% of the climbers sought a physician's advice, a peculiarity also observed by Bollen (2). The good clinical outcome of our patients is in accordance with the results of other studies (6,20,24,35); nevertheless, it is remarkable for the five subjects who had multiple ruptures and should have had a surgical repair (35). However, none of these patients had a rupture of all three important pulleys (A2, A3, A4), and neither a highly limited range of motion nor clinically evident bowstringing was found.

As all climbers regained their sport-specific performance level within a year, we do not see an indication for surgery in single pulley ruptures, as suggested elsewhere (24,39). The argument that the climbers will not regain their initial climbing level even after a single (A2 or A4) pulley rupture, if not surgically repaired, seems incorrect. The good functional results and the positive strength values obtained in the patients with grade 4 ruptures (A2/3 or A3/4) suggest that there is a nonsurgical option for uncomplicated grade 4 ruptures and that the algorithm may need to be reconsidered.

As discussed earlier, the pulley system enables us to bend our fingers and to develop forces in a flexed finger position. Following a pulley rupture, the tissue does not grow back together, leading to an increased TB, which has been demonstrated in pulley ruptures in rock climbers by ultrasound evaluation (6,13,24,33,35). Our own ultrasound follow-ups in this study show the same results. Our findings for TB distances are in the same range as those of Klauser et al. (13,14). As the pulleys deflect the flexor tendons, they convert translational force into torque of motion. As moment is strength × lever arm, an increase of the lever arm will lead to a higher moment with the same force. After pulley rupture, the tendons move away from the bone, thus leading to an increase of the lever arm. This implies that after a pulley rupture, the finger would theoretically be stronger than before. However, after a pulley rupture, the missing pulley causes a shorter distance for the tendon–muscle unit from its origin to its insertion. Because the tendon length is the stable parameter in this consideration, the muscle body therefore needs to shorten. The muscle cannot be shortened as much as before during contraction, which explains the initial strength deficit (active insufficiency), which can be observed immediately after the injury. Through reorganization, the muscle's active parts, the actin and myosin filaments, will recapture their contractile ability and resolve the initial strength deficit. Nevertheless, these are only theoretical considerations that are limited to single pulley ruptures. In a multiple rupture, the force developed in the tendons can no longer be transferred onto the phalanges, resulting in a flexion deficit.

TABLE 6. Strength measurements results in percentage of body weight (see text for explanation).

TP	U-I Hanging	U-I Crimping	H-R Hanging	H-R Crimping	Grade of Injury
1	−4.8	0.6	−1.7	−3.5	3
2	0.9	0.4	−0.3	2.8	3
3	0.4	1.7	−1.4	−1.4	4
4	−5.3	1.4	−4.0	−15.7	2
5	1.6	0.1	−5.8	−2.5	4
6	0.2	−1.0	10.6	−0.2	3
7	0.2	−0.4	2.4	0.2	4
8	−0.9	−1.4	0.2	18.8	4
9	0.1	−1.0	−0.2	−12.9	2
10	−9.1	6.9	−3.1	0.8	3
11	1.4	−1.7	−9.1	0.7	2
12	1.5	0.3	5.2	−5.3	2
13	4.8	1.7	−6.1	7.6	2
14	2.0	−7.1	3.2	13.0	3
15	1.7	4.8	0.9	4.2	3
16	4.6	−6.8	0.2	2.3	3
17	−1.3	−0.1	−24.8	−14.3	3
Mean	−0.1	−0.1	−2.0	−0.3	
SD	3.5	3.4	7.5	8.9	

TP, test person; U, mean strength value for the uninjured hand for the two healthy fingers and the three fingers together; I, mean strength value for the injured hand for the two healthy fingers and the three fingers together; R, mean strength value for finger with pulley rupture; H, mean strength value for contralateral healthy finger.

There are no data on strength analysis of fingers with conservative therapy. Only on reconstructed pulleys in multiple pulley ruptures, Gabl et al. (7) reported on a pinch grip improvement from 28 to 56 N. These results are difficult to compare because grip strength measured through a pinch gauge is a standard procedure in follow-up examinations after hand surgery, but is difficult to compare interindividually. In their report, Gabl et al. (7) do not compare the pinch grip strength of the healthy and injured sides, and, in addition, hand grip strength proved to have a weak association to rock climbing performance because it lacks specificity with most of the hand positions used while climbing (40). Consequently, we conducted a strength measurement of the injured finger and the respective healthy finger using a sport-specific measuring device. We did not observe any strength deficit of the injured finger in comparison with the healthy one. This observation undermines the theoretical considerations. In the analyses of the influence of the time interval on the finger strength between the two groups, the fact that no significance could be observed is probably due to 1) the small number in both groups, making a statistical evaluation difficult, and 2) some climbers regaining their full climbing level soon after a pulley rupture (especially after A4 pulley rupture) (35). One difficulty with our examination protocol was the fact that the crimping position with a single finger is a complex task that may lead to decreased strength values in this position.

CONCLUSION

With our reevaluation of conservatively treated pulley injuries, we could justify nonoperative management of grade 1–3 injuries. The clinical outcome was good to excellent; the ultrasound follow-ups demonstrated a constant TB distance and a high reliance of the initial diagnosis. The climbers regained their initial climbing level, and the strength measurements demonstrated no strength deficit for the injured finger. The good results of the five conservatively treated grade 4 injuries suggest that in cases of A2/A3 or A3/A4 injuries, without clinical bowstringing or initially limited range of motion, a conservative approach is possible. Nevertheless, a secondary reconstruction must be performed in cases with constant complaints. For highly active climbers, as well as all other grade 4 injuries involving clinical bowstringing, we still favor the surgical reconstruction.

REFERENCES

1. Bodner, G., A. Rudisch, M. Gabl, W. Judmaier, P. Springer, and A. Klauser. Diagnosis of digital flexor tendon annular pulley disruption: comparison of high frequency ultrasound and MRI. *Ultraschall. Med.* 20:131–136, 1999.
2. Bollen, S. R. Injury to the A2 pulley in rock climbers. *J. Hand Surg. [Br].* 15:268–270, 1990.
3. Buck-Gramcko, D., F. E. Dietrich, and S. Gogge. Evaluation criteria in follow-up studies of flexor tendon therapy. *Handchirurgie* 8:65–69, 1976.
4. Ellis, B., and A. Bruton. A study to compare the reliability of composite finger flexion with goniometry for measurement of range of motion in the hand. *Clin. Rehabil.* 16:562–570, 2002.
5. Ellis, B., A. Bruton, and J. R. Goddard. Joint angle measurement: a comparative study of the reliability of goniometry and wire tracing for the hand. *Clin. Rehabil.* 11:314–320, 1997.
6. Gabl, M., C. Rangger, M. Lutz, C. Fink, A. Rudisch, and S. Pechlaner. Disruption of the finger flexor pulley system in elite rock climbers. *Am. J. Sports Med.* 26:651–655, 1998.
7. Gabl, M., C. Reinhart, M. Lutz, G. Bodner, P. Angermann, and S. Pechlaner. The use of a graft from the second extensor compartment to reconstruct the A2 flexor pulley in the long finger. *J. Hand Surg. [Br].* 25:98–101, 2000.
8. Hamman, J., A. Ali, C. Phillips, B. Cunningham, and D. P. Mass. A biomechanical study of the flexor digitorum superficialis: effects of digital pulley excision and loss of the flexor digitorum profundus. *J. Hand Surg. [Am].* 22:328–335, 1997.
9. Hauger, O., C. B. Chung, N. Lektrakul, et al. Pulley system in the fingers: normal anatomy and simulated lesions in cadavers at MR imaging, CT, and US with and without contrast material distention of the tendon sheath. *Radiology* 217:201–212, 2000.
10. Hochholzer, T., and V. R. Schöffl. Epiphyseal fractures of the finger middle joints in young sport climbers. *Wilderness Environ. Med.* 16:139–142, 2005.
11. Holtzhausen, L. M., and T. D. Noakes. Elbow, forearm, wrist, and hand injuries among sport rock climbers. *Clin. J. Sport Med.* 6:196–203, 1996.
12. Hume, E. L., D. T. Hutchinson, S. A. Jaeger, and J. M. Hunter. Biomechanics of pulley reconstruction. *J. Hand Surg. [Am].* 16:722–730, 1991.
13. Klauser, A., F. Frauscher, G. Bodner, et al. Finger pulley injuries in extreme rock climbers: depiction with dynamic US. *Radiology* 222:755–761, 2002.
14. Klauser, A., F. Frauscher, M. Gabl, and V. Smekal. High frequency sonography in the detection of finger injuries in sports climbing. *Sport Orthop. Sport Trauma* 21:24–30, 2005.
15. Köstermeyer, G., and J. Weineck. Necessity of one-finger-training for the increase of performance in climbing. Comparison of force development between one-and four-finger maximum contraction. *D. Z. Sportmed.* 46:356–362, 1995.
16. Lin, G. T., P. C. Amadio, K. N. An, W. P. Cooney, and E. Y. Chao. Biomechanical analysis of finger flexor pulley reconstruction. *J. Hand Surg. [Br].* 14:278–282, 1989.
17. Lin, G. T., W. P. Cooney, P. C. Amadio, and K. N. An. Mechanical properties of human pulleys. *J. Hand Surg. [Br].* 15:429–434, 1990.
18. Lister, G. Indications and techniques for the repair of the finger flexor tendon sheath. *Hand Clin.* 1:85–95, 1985.
19. Logan, A. J., N. Makwana, G. Mason, and J. Dias. Acute hand and wrist injuries in experienced rock climbers. *Br. J. Sports Med.* 38:545–548, 2004.
20. Marco, R. A., N. A. Sharkey, T. S. Smith, and A. G. Zissimos. Pathomechanics of closed rupture of the flexor tendon pulleys in rock climbers. *J. Bone Joint Surg. Am.* 80:1012–1019, 1998.
21. Martinoli, C., S. Bianchi, M. Nebiolo, L. E. Derchi, and J. F. Garcia. Sonographic evaluation of digital annular pulley tears. *Skeletal Radiol.* 29:387–391, 2000.
22. Mitsionis, G., J. A. Bastidas, R. Grewal, H. J. Pfaeffle, K. J. Fischer, and M. M. Tomaino. Feasibility of partial A2 and A4 pulley excision: effect on finger flexor tendon biomechanics. *J. Hand Surg. [Am].* 24:310–314, 1999.

23. Mitsionis, G., K. J. Fischer, J. A. Bastidas, R. Grewal, H. J. Pfaeffle, and M. M. Tomaino. Feasibility of partial A2 and A4 pulley excision: residual pulley strength. *J. Hand Surg. [Br].* 25:90–94, 2000.
24. Moutet, F. Flexor tendon pulley system: anatomy, pathology, treatment. *Chir. Main.* 22:1–12, 2003.
25. Rohrbough, J. T., M. K. Mudge, and R. C. Schilling. Overuse injuries in the elite rock climber. *Med. Sci. Sports Exerc.* 32: 1369–1372, 2000.
26. Roloff, I., V. Schöffl, L. Vigouroux, and F. Quaine. Biomechanical Model for the determination of the forces acting on the finger pulley system. *J. Biomech.* 39:915–923, 2005.
27. Rooks, M. D. Rock climbing injuries. *Sports Med.* 23:261–270, 1997.
28. Schmidt, H. M., and U. Lanz. In: *Chirurgische Anatomie der Hand [Surgical Anatomy of the Hand].* Stuttgart: Hippokrates Verlag, 2003, pp. 186–187.
29. Schöffl, V., and I. Schöffl. Finger pain in rock climbers-reaching the right differential diagnosis. *J. Sports Med. Phys. Fitness,* 2006 (in press).
30. Schöffl, V., and I. Schöffl. Injuries to the finger flexor pulley system in rock climbers—current concepts. *J. Hand Surg. (Am)* (in press).
31. Schöffl, V., and I. Roloff. Understanding tendon pulley ruptures in rock climbers [Concepts actuels de ruptures des poulies chez les grimpeurs]. *Chir. Main* 24:113, 2005.
32. Schöffl, V., T. Hochholzer, and A. Imhoff. Radiographic changes in the hands and fingers of young, high-level climbers. *Am. J. Sports Med.* 32:1688–1694, 2004.
33. Schöffl, V., T. Hochholzer, H. P. Winkelmann, I. Roloff, and W. Strecker. Pulley injuries in sport climbers. *Handchir. Mikrochir. Plast. Chir.* 36:224–230, 2004.
34. Schöffl, V., T. Hochholzer, H. P. Winkelmann, and W. Strecker. Differential diagnosis of finger pain in sport climbers. Differentialdiagnose von Fingerschmerzen bei Sportkletterern. *D. Z. Sportmed.* 54:38–43, 2003.
35. Schöffl, V., T. Hochholzer, H. P. Winkelmann, and W. Strecker. Pulley injuries in rock climbers. *Wilderness Environ. Med.* 14: 94–100, 2003.
36. Schweizer, A. Biomechanical properties of the crimp grip position in rock climbers. *J. Biomech.* 34:217–223, 2001.
37. Schweizer, A., O. Frank, P. E. Ochsner, and H. A. Jacob. Friction between human finger flexor tendons and pulleys at high loads. *J. Biomech.* 36:63–71, 2003.
38. Tropet, Y., D. Menez, P. Balmat, R. Pem, and P. Vichard. Closed traumatic rupture of the ring finger flexor tendon pulley. *J. Hand Surg. [Am].* 15:745–747, 1990.
39. Voulliaume, D., A. Forli, O. Parzy, and F. Moutet. Surgical repair in flexor tendon pulley rupture in high level rock climbing. *Chir. Main* 23:243–248, 2004.
40. Watts, P. B. Physiology of difficult rock climbing. *Eur. J. Appl. Physiol.* 91:361–372, 2004.