A2 and A4 Flexor Pulley Biomechanical Analysis: Comparison among Gender and Digit

Gregory Charles Mallo · Yury Sless ·
Lawrence C. Hurst · Kevin Wilson

Received: 2 April 2007 / Accepted: 30 May 2007 / Published online: 3 July 2007
© American Association for Hand Surgery 2007

Abstract Rock climbing has become increasingly more popular in the USA over the past two decades. Accordingly, with increased participation comes an increase in climbing-related injuries. Rooks et al noted that three-quarters of elite and recreational climbers will suffer upper extremity injuries, approximately 60% involving the hand or wrist and 40% divided evenly between the shoulder and elbow. Most of these injuries will be strains, microtrauma, and tendonitis; however, 30–50% represent trauma to the proximal interphalangeal region. The purpose of this study was to investigate the biomechanical properties of the A2 and A4 pulley and compare biomechanical properties among gender and digit. A specially designed materials testing machine, shown in the included figure, measured maximum breaking load, displacement and stiffness of the A2 and A4 pulleys of ten cadaveric hands using an S hook to apply a steady force until complete pulley rupture. The A2 and A4 biomechanical properties of breaking load, displacement, and stiffness did not significantly differ among the index, middle, ring, and little fingers. Additionally, there was no significant difference in A2 or A4 pulley biomechanics between male and female specimens. The A2 and A4 pulleys among differing digits and genders have similar biomechanical properties in regards to maximum breaking load, displacement, and stiffness.

Keywords A2 · A4 pulley · Flexor pulley · Hand · Mountain climbing · Gender differences between flexor pulleys · Rock climbing · Pulley rupture

Introduction

Over the last two decades, the sport of rock climbing has become increasingly more popular in the USA. The rock climbing community estimates that nearly 300,000 Americans have climbed a rock wall. In fact, climbing walls are sprouting up everywhere, from specialized training centers to luxury cruise ships and local county fairs. Accordingly, with increased participation comes an increase in climbing-related injuries. Rooks et al noted that three quarters of elite and recreational climbers will suffer upper extremity injuries, approximately 60% involving the hand or wrist and 40% divided evenly between the shoulder and elbow. Most of these injuries will be strains, microtrauma, and tendonitis; however, 30–50% represent trauma to the proximal interphalangeal region [1]. One such injury, known as climber's finger, representing closed traumatic rupture of the A2 pulley, was first documented in 1990 by Bollen and Tropet in two separate case reports [2, 3]. Since then, there has been a movement aimed at prevention and treatment of climber's finger.

Several methods for injury prevention such as stretching, supportive circumferential taping, and education of proper climbing technique have enjoyed variable success [4]. In addition, treatment options range from conservative measures to open surgical repair advocated in some instances for the elite climber.

Although a retrospective study by Logan showed no significant difference in incidence or type of injury among gender at the clinical level, this subject led to our investigation [5]. A biomechanical comparison of A2 and A4 pulleys among gender and digit was carried out to identify any gender specific susceptibility to A2 pulley rupture. Moreover, it is widely recognized that the middle and ring fingers are most commonly associated with

G. C. Mallo (✉) · Y. Sless · L. C. Hurst · K. Wilson
Department of Orthopaedics, T-18 Health Sciences Center,
State University of New York at Stony Brook,
Stony Brook, NY 11794-8181, USA
e-mail: gregory.mallo@gmail.com

traumatic A2 rupture. The purpose of this study was to investigate the biomechanical properties of the A2 and A4 pulley and compare biomechanical properties among gender and digit.

Materials and Methods

The study design involved dissection of four male and six female preserved cadaveric hands. Specimens were dissected and mounted on a material testing machine (MTM) with a specifically designed jig for phalangeal fixation (Fig. 1). The cadaveric A2 and A4 pulley of the index, middle, ring, and little finger was then loaded to failure, and absolute values for stiffness, yield displacement, yield load, ultimate displacement, and ultimate load to failure were recorded to allow for comparison of these properties among specimens. Although in vivo and fresh specimen pulleys would likely exhibit different biomechanical values than those obtained in this study, our comparison is based on absolute values used for relative comparison only among cadaveric specimens.

In total, 40 A2 and 36 A4 flexor tendon pulleys were tested. Notably, the A4 pulley in four female little finger specimens could not be meaningfully studied as the hook of the MTM was too large to slide beneath the pulley without rupture. The data collected for each pulley was grouped by specific finger and then separated into male and female specimens for relative value biomechanical comparison.

Results

The mean values for the biomechanical properties of the A2 and A4 pulley were ranked and compared. In general, the values for the A2 pulley of the middle and index finger were higher than the other digits for all parameters.

Figure 1 Specimens were dissected and mounted on a material testing machine with a specifically designed jig for phalangeal fixation.

A2 Pulley Mechanics Comparison Among Digits

The A2 pulley values for the middle digit ranked highest in four of the five parameters tested and that of the index ranked second highest in three of five. With respect to stiffness, the index ranked first ahead of the middle. The ring finger was consistently the lowest ranked digit according to all parameters except stiffness where only the little finger was less stiff. The above-noted trends suggest subtle differences in the properties among digits, although these differences were not statistically significant (Table 1).

A2 Pulley Between Gender

According to gender, the female A2 pulley of the middle, ring, and little finger ranked ahead of the respective male pulley. The male index ranked ahead of the female index in stiffness, yield load, and ultimate displacement. These differences were not statistically significant (Table 1).

A4 Pulley

In general, the index ranked ahead of all digits in each parameter tested except stiffness where the middle ranked first. The middle and ring finger each ranked second in two of the parameters tested. The A4 pulley of the little finger was not included in the ranking as measurements were technically difficult to perform. The values for each parameter tested were not statistically different (Table 2).

A4 Pulley Between Gender

According to gender, the female A4 pulley of the index and middle ranked ahead of the respective male pulley in every parameter tested. The male ring finger ranked ahead of the female in yield displacement and yield load. These gender differences were not statistically significant (Table 2).

Discussion

In the general population, injuries to the flexor tendon pulley system are relatively rare, although they are very common among rock climbers. In fact, Logan reported on the experience of 545 climbers and reported that 8% had been diagnosed with specific A2 pulley ruptures [5]. Several studies have described the biomechanical properties of the A2 and A4 pulleys which are regarded as the most important for preventing bowstringing and providing mechanical advantage during finger flexion, leading to our analysis of these pulleys [6–8].

It is widely accepted that the middle and ring fingers are most susceptible to A2 pulley rupture in the setting of rock climbing

Table 1 Mechanical properties of A2 pulley.

	Stiffness	Yield Displacement	Yield Load	Ultimate Displacement	Ultimate Load
Index (rank)	1	3	2	2	2
Male	54.79 (36.1)	4.21 (2.2)	172.2 (120.8)	4.93 (1.6)	183.38 (115.4)
Female	46.46 (24.0)	4 (1.5)	147.35 (60.5)	5.85 (2.4)	204.75 (88.8)
All	49.79 (27.8)	4.08 (1.7)	157.19 (84.0)	5.48 (2.0)	196.20 (94.6)
Middle (rank)	2	1	1	1	1
Male	46.53 (27.7)	4.82 (1.5)	156.23 (87.4)	5.91 (0.90)	186 (96.1)
Female	45.37 (24.1)	5.3 (1.5)	188.1 (77.8)	7.34 (1.5)	226.86 (80.1)
All	45.81 (24.1)	5.11 (1.6)	175.33 (77.9)	6.77 (1.7)	210.51 (77.4)
Ring (rank)	3	4	4	4	4
Male	37.24 (10.9)	3.01 (0.70)	110.7 (35.7)	4.2 (2.3)	136.42 (57.9)
Female	41.83 (31.9)	2.94 (1.8)	127.97 (103.9)	4.23 (1.5)	169.71 (108.2)
All	39.99 (24.0)	2.97 (1.4)	121.06 (77.6)	4.21 (1.9)	156.39 (87.7)
Little (rank)	4	2	3	3	3
Male	28.68 (15.8)	4.52 (2.1)	125.24 (79.0)	4.81 (2.3)	136.79 (89.5)
Female	40.15 (16.1)	5.25 (1.5)	164.5 (62.2)	5.64 (1.5)	180.65 (61.1)
All	35.56 (16.2)	4.95 (1.7)	148.79 (68.1)	5.31 (1.8)	163.10 (72.5)

Mean A2 pulley data separated by gender and finger. Standard deviations noted in parenthesis. No statistically significant difference in recorded values

[5, 9]. This is likely due to differing forces exerted on the A2 pulleys of differing digits as a result of traditional grip and climbing technique; however, there is limited data directly comparing the biomechanical properties of these pulleys against one another. Additionally, the vast majority of documented A2 pulley rupture occurs in men. This can be expected as rock climbing tends to be a predominantly male activity. Nevertheless, it is worthwhile to explore possible inherent biomechanical differences in the pulleys across gender.

Investigation of the overall A2 pulley strength among varying digits showed that the ring finger was consistently

the weakest and least stiff with rare exception (Table 1). Evaluation of overall A4 pulley strength among varying digits showed the index was consistently stronger and stiffer than all other digits with rare exception (Table 2). Although parameter differences in this study were not statistically different, investigators have demonstrated that the ring and middle finger are most prone to injury during climbing [5, 9]. A follow-up study with a larger sample size might bear out the observed trend of A2 ring finger pulley weakness and further explain why the ring finger is so prone to injury.

Table 2 Mechanical properties of A4 pulley.

	Stiffness	Yield Displacement	Yield Load	Ultimate Displacement	Ultimate Load
Index	2	1	1	1	1
Male	46.37 (18.2)	4.38 (0.9)	148.72 (55.7)	4.51 (1.0)	155.43 (58.5)
Female	57.21 (31.9)	5.62 (0.8)	194.81 (98.6)	5.8 (0.8)	213.45 (111.3)
All	52.87 (5.13)	5.13 (1.0)	176.37 (83.7)	5.28 (1.1)	190.24 (94.4)
Middle	1	3	2	3	2
Male	37.84 (21.3)	3.09 (1.1)	113.31 (78.0)	3.43 (0.9)	74.54 (76.9)
Female	67.93 (35.7)	4.11 (0.9)	174.93 (74.6)	4.28 (1.0)	188.6 (81.5)
All	60.41 (34.2)	3.85 (1.0)	159.53 (75.2)	3.94 (1.0)	142.98 (95.6)
Ring	3	2	3	2	3
Male	32.83 (16.8)	4.38 (2.0)	151.08 (93.9)	4.02 (2.6)	137.91 (103.7)
Female	46.27 (17.9)	4.03 (1.3)	136.67 (44.5)	4.2 (1.3)	146.11 (48.4)
All	40.89 (17.8)	4.15 (1.4)	141.47 (59.2)	4.13 (1.8)	142.83 (70.0)
Little	—	—	—	—	—
Male	27.82 (9.0)	4.14 (0.4)	116.29 (35.8)	5.47 (1.1)	135.67 (23.2)
Female	32.98 (16.5) ^a	4.76 (2.5) ^a	134.18 (59.5) ^a	5.9 (4.1) ^a	174.06 (95.3) ^a
All	31.26 (13.7)	4.55 (2.0)	128.22 (49.7) ^a	5.76 (3.2)	161.27 (77.1)

Mean A4 pulley data separated by gender and finger. Standard deviations noted in parenthesis. No statistically significant difference in recorded values

^a A4 technically difficult to measure

With respect to gender, the female A2 pulley of the middle and ring ranked ahead of the respective male pulley, whereas the male index ranked ahead of the female in most categories (Table 1). The female A4 pulley of the index and middle ranked ahead of the respective male pulley in every parameter tested (Table 2). Although parameter differences were not statistically significant, further investigation may demonstrate a biomechanical gender difference in the A2 and A4 flexor tendon pulley system.

References

1. Rooks MD. Rock climbing injuries. *Sports Med* 1997;23(4):261–70, Apr.
2. Bollen SR. Injury to the A2 Pulley in rock climbers. *J Hand Surg* 1990;B:268–70.
3. Tropet YD, Menez P, Balmat RP, Vichard PH. Closed traumatic rupture of the ring finger flexor tendon pulley. *J Hand Surg* 1990;15A:745–7.
4. Warne WJ, Brooks D. The effect of circumferential taping on flexor tendon pulley failure in rock climbers. *Am J Sports Med* 2000;28:674–8.
5. Logan AJ, Makwana, Mason, Dias. Acute hand and wrist injuries in experienced rock climbers. *Br J Sports Med* 2004;38:545–8.
6. Marco RA, Sharkey NA, Smith TS, Zissimos AG. Pathomechanics of closed rupture of the flexor tendon pulleys in rock climbers. *J Bone Jt Surg Am* 1998;80(7):1012–9, Jul.
7. Bowers WH, Kuzma GR, Bynum DK. Closed traumatic rupture of finger flexor pulleys. *J Hand Surg [Am]* 1994;19(5):782–7, Sep.
8. Manske PR, Lesker PA. Strength of human pulleys. *Hand* 1977;9(2):147–52, Jun.
9. Injuries to the finger flexor pulley system in rock climbers: current concepts. *J Hand Surg* 2006;31(4):647–54, April.