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A comparative study of A1 pulley compliance

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Abstract

Background—Trigger finger is most common in the ring finger, but the reason for this is not known. We hypothesized that the compliance of the A1 pulley might be one of the factors responsible for this phenomenon. The purpose of this study was therefore to compare the compliance of the normal A1 pulley of the thumb, index, middle, ring and little fingers using human cadavers.

Methods—Eight normal thumbs, index, middle, ring and little fingers from eight fresh frozen human hand cadavers were used in this experiment. The compliance of the A1 pulley was measured by the resistance when passing a tapered metal rod through the A1 pulley. The slopes of the linear region of radial force/increasing area ratio curve were calculated and analyzed.

Findings—The mean slope of the linear region of the radial force/increasing area ratio curve was significantly different among the five digits ($p < 0.05$). Post hoc analysis indicated that the mean slope for the middle finger A1 pulleys was larger than the thumb and little finger A1 pulleys ($p < 0.05$).

Interpretation—The findings did not support our clinical hypothesis that A1 pulley stiffness would parallel the relative frequency of trigger finger by digit.

Keywords

Trigger digits; Tenosynovitis; Pulley; Hand; Human; Biomechanics

1. Introduction

A1 pulley is one of the palmar plate annular pulleys in the pulley system of a typical flexor tendon of the finger. The normal gliding motion of a flexor tendon is dependent on a “critical tendon sheath caliber tolerance” (Littler, 1977), which allows the passage of the flexor tendons through the A1 pulley in the region of the metacarpophalangeal (MCP) joint. Disturbances in this balance are common clinically, in the form of cases of stenosing tenosynovitis, or trigger finger, a condition characterized by a painful locking of the flexor tendons at the level of the A1 pulley during flexion and extension of the affected finger.

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While it is well known that triggering occurs at the A1 pulleys and that pulley release is usually curative, the exact cause of trigger finger is unknown (Freiberg et al., 1989). The ring finger is most commonly affected by triggering (Al-Qattan, 2007; Bonnici and Spencer, 1988; Fahey and Bollinger, 1954; Newport et al., 1990; Nimigan et al., 2006; Taras et al., 1998), but the reason for this predilection is also not known.

We hypothesized that the compliance of the A1 pulley might be one of the factors responsible for trigger fingers. If this is the case, then the compliance of the ring finger should be different from that of the other digits. The objective of this study therefore was to investigate the compliance of the A1 pulley of the thumb, index, middle, ring and little fingers by measuring the resistance when passing a tapered metal rod through the A1 pulley. The null hypothesis was that there were no significant differences in the compliance of the A1 pulleys of these digits.

2. Methods

Eight normal thumbs, index, middle, ring and little fingers from eight fresh frozen human cadavers (1 females and 7 males; age range: 70–93 years) were used in this experiment. This cadaver study was approved by our Institutional Reviewed Board.

2.1. Identification and dissection of A1 pulley

The fingers were prepared in full extension. The skin incision in volar part was made longitudinally from the proximal interphalangeal joint to the metacarpophalangeal (MCP) joint. After opening the skin, the entire A1 pulley was exposed. The A1 pulley is adjacent to the retinacular restraints of the MCP joint assemblage including the palmar plate and sagittal ligament. The A1 pulley is a band of fibers with distal and proximal edges. We carefully marked the edges with a marker pen and dissected without damaging the edges. After identification of the entire A1 pulley, the skin, subcutaneous tissue and the flexor tendons in the A1 pulley were removed from the specimens, leaving A1 pulley intact. The middle and distal phalangeal bones were also removed, leaving the proximal phalangeal bone, distal metacarpal, MCP joint and A1 pulley for testing (Fig. 1). The length and thickness of the A1 pulleys were measured with an electronic digital caliper.

2.2. Mechanical evaluation of A1 pulley compliance

The prepared specimen was mounted on a custom-made testing device. The measurement system consisted of one mechanical actuator with a linear potentiometer, a 25 lb load cell (Transducer Techniques, Inc., Temecula, California, USA) and a 6.0 cm long metal rod tapering from 2.5 to 14.5 mm diameter. The tangent of the angle of slope of the taper was 0.1. The tip of the metal rod was connected to the actuator through Green Spot Dacron trolling line (Cortland Line Co., Inc., Cortland, New York, USA) which passed through the A1 pulley. Therefore, the tapered metal rod was not constrained in order to achieve the best fit between the rod and A1 pulley during testing. The actuator pulled the tapered metal rod through the A1 pulley from proximal to distal. The starting position of the tapered metal rod was set to contact as much as possible of the A1 pulley entrance without any measurable load.

The experiment set up is shown in Fig. 2. LabVIEW version 6 (National Instruments, Austin, Texas, USA) was used for a graphical programming environment optimized for data acquisition. The motor rate of the actuator was set at 1 mm/s and the sampling rate at 20 Hz. Because the lengths of A1 pulleys among five fingers are different, the displacement of the tapered metal rod to reach full engagement between rod and pulley was also different, being longer in a larger pulley and shorter in a smaller pulley. Based on preliminary testing the displacement was set at 12 mm for thumbs and little fingers and a distance of 18 mm for the index, middle and ring fingers. Throughout testing, the specimen was kept moist by spraying with phosphate-buffered saline. Each specimen was tested five times and the means of the five tests were used for data analysis. The radial force, F' , acting on the wall of the A1 pulley was deduced from the applied longitudinal force. The test set up is shown in Fig. 3. F is the longitudinal force recorded from the load cell. The tangent angle, θ , of the tapered metal rod is calculated from the length and diameter of the rod. Since the rod is 6.0 cm long, tapering from 2.5 to 14.5 mm diameter, the tangent of the angle of slope of the taper was 0.1. The radial force, F' , was then calculated, as $F \tan \theta$. c is the radius of the small side of tapered metal rod. The cross-sectional area, A , at a given length, a , along the tapered metal rod is similarly derived from the formula $A = \pi (c + a \tan \theta)^2$.

2.3. Data analysis

The increasing area ratio (InAR) was calculated from the absolute increasing cross sectional area of the inner wall of the A1 pulley during the test divided by the its original area at the initial zero-stress state. The InAR was defined as follows:

$$InAR = \frac{A - A_o}{A_o} = \frac{\Delta A}{A_o}$$

where: A : cross sectional area of the inner wall of A1 pulley; A_o : cross sectional area of the inner wall of A1 pulley at zero-stress state.

Custom-made MATLAB programs were used to calculate the slopes of the linear part of the curves between the radial force and InAR.

2.4. Statistical analysis

Statistical analyses were performed with SPSS 13.0 (SPSS Inc., Chicago, Illinois, USA) software. The results were expressed as mean (standard deviation, SD). One way analysis of variance (ANOVA) was used to compare the means of the values of radius of the A1 pulley initial inner wall, length and thickness of the A1 pulleys among thumb, index, middle, ring and little fingers, followed by post hoc analysis with least significant difference for individual comparisons.

The mean slopes of the linear region of the curves between the radial force and InAR among thumb, index, middle, ring and little fingers were tested by using analysis of variance (ANOVA) with repeated measures. Mauchly's test was conducted to test the equality of variances of the differences between levels of the repeated measures factor and the Greenhouse–Geisser correction was applied for violations of sphericity. If significance

existed, post hoc comparison was conducted on the means by using least significant difference pairwise multiple comparison tests. Differences were considered significant at a $p < 0.05$ level.

3. Results

There was very little difference in the results when comparing the five runs for each digit, with standard deviations being $< 1\%$ of the mean value. The radius of the A1 pulley inner wall, length and thickness of the A1 pulleys in the five digits are shown in Table 1. A significant difference was shown in the mean of initial inner wall A1 pulley radius ($p < 0.05$). In post hoc comparison tests, the mean in the middle fingers was the largest ($p < 0.05$). The mean of the length of the A1 pulley among five fingers were significantly different ($p < 0.05$). Post hoc analysis indicated that the means of A1 pulley length in thumb and little finger are shorter than index, middle and ring fingers ($p < 0.05$). There was no significant difference between the length of thumb and little finger. The means of the lengths of the index, middle and ring fingers were not significantly different. There was a significant difference shown in the mean of thickness of A1 pulleys ($p < 0.05$). The mean thickness of thumb and little finger were significantly smaller than that of index, middle and ring fingers ($p < 0.05$). However, there was no significant difference between the thickness of thumb and little finger. The means of thickness of index, middle and ring fingers were not significantly different.

Representative curves from the radial force vs. increasing area ratio are shown in Fig. 4. A significant difference was shown in the mean slope of the linear region of the radial force/InAR curve among the five digits ($p < 0.05$). In post hoc comparison tests, the mean slope for the middle finger A1 pulleys was larger than the thumb and little finger A1 pulleys ($p < 0.05$). No significant differences were shown between thumb A1 pulleys and index finger A1 pulleys, between index A1 pulleys and middle finger A1 pulleys, between index A1 pulleys and ring finger A1 pulleys and between middle finger A1 pulleys and ring finger A1 pulleys. Fig. 5 shows the results for the dependent variables with significant differences.

4. Discussion

In this study we found that the means of the A1 pulley lengths in the thumb and little finger were shorter than those in the index, middle and ring fingers, and that there was no significant difference between the length of the pulleys in the thumb and little finger. These findings are consistent with the study of Jongjirasiri (Jongjirasiri, 2009), who found that the length of the A1 pulley in the thumb and little finger are shorter than in the other three fingers. We also found that the middle finger A1 pulleys had greater stiffness (less compliance) than the thumb and little finger. These findings are consistent with the work of Lin et al (Lin et al., 1990), who noted that the middle finger A1 pulley had a higher breaking strength than that of the other fingers. We were unable to find any references which compared the breaking strength of the thumb A1 pulley to the digits. The results of this study did not support our hypothesis that compliance of the normal pulley is correlated with the risk of developing trigger finger.

Previous studies have reported abnormalities in the A1 pulleys of patients with trigger fingers. Sampson et al. noted that primary trigger fingers have fibrocartilaginous metaplasia within the A1 pulley and on the palmar surface of the finger flexors (Sampson et al., 1991). Sbernardori et al. reported that the inner portion of the A1 pulley changes in trigger digits and becomes a dense, irregular connective tissue (Sbernardori and Bandiera, 2007; Sbernardori et al., 2007). Drossos et al. (2009) reported that the histologic features in the A1 pulley of trigger digits were correlated with the severity of the clinical symptoms. As the disease becomes more severe, the gliding surface begins to wear and is gradually replaced by a secondary invasive hyperplasia from the outer layer. Thickening and hyper-vascularization of the A1 pulley were also found in patients with trigger fingers on sonography (Guerini et al., 2008).

The cause of these pathological changes is unknown, as is the etiology of trigger finger in most cases (Moore, 2000). One of the common hypotheses is that repetitive activity somehow causes a non-inflammatory degeneration in the tendon and/or pulley (Moore, 2000). In this study we looked for one possible correlate to support that hypothesis, namely that trigger digits would be more prevalent in fingers in which the pulley was less compliant. As this hypothesis was not supported, unfortunately we are no further in understanding why some digits, and some individuals, develop trigger fingers. Other hypotheses, for example is that triggering develops in ischemic tendons (Amadio et al., 1982), could be the subject of a future study.

There are two principal limitations in this study. First, our method assumes that the canal of the A1 pulley is round and perfectly matches the shape of the rod. This may not be true. However, since we calculated the mean slope from the linear portion of the radial force/InAR curves, when full rod/pulley contact was achieved, the effect of this limitation may be small. Second, there might be some visco-elastic behavior with repeated tests that we did not consider and it might possible that the first test plastically deformed the A1 pulley tissue. We could not identify a reference that describes the compliance or visco-elastic properties of A1 pulleys. However, we did find that the rod testing for A1 pulleys was repeatable.

5. Conclusions

This study compared the compliance of the A1 pulleys from normal human cadavers. While the findings allowed us to reject the null hypothesis, the findings did not support our clinical hypothesis that the findings on A1 pulley stiffness would parallel the relative frequency of trigger finger by digit. Thus we conclude that it is unlikely that A1 pulley stiffness is a causative factor in trigger finger. We do believe that our findings provide a useful database of A1 pulley mechanical properties.

Acknowledgments

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Fig. 1.
A: Thumb; B: Index finger; C: Middle finger; D: Ring finger; E: Small finger; F: Tapered metal rod. Arrows indicate A1 pulley.

Fig. 2.

A: Testing apparatus, including 1) mechanical actuator with a linear potentiometer; 2) cable to connect actuator and tapered metal rod; 3) specimen; 4) tapered metal rod, and 5) testing frame. B: Initial position of the A1 pulley and tapered metal rod before testing. C: Ending position of the A1 pulley and tapered metal rod after testing.

Fig. 3.

(A) Calculation of the radial force acting on the A1 pulley and the cross-sectional area along the tapered metal rod. “ b ” is part of the taper radius at the level of the pulley distal edge. The radius at this level is equal to $c+b$. Here, c is the radius of the taper end, which is known. b was calculated by tangent θ , ($\tan \theta$) multiplied by a , which is the distance between taper end to the pulley edge. The area, A , is the cross-sectional area of the tapered metal rod at the level of the distal pulley edge. (B) Anatomic sketch corresponding to the schematic drawing in Fig. 3A.

Fig. 4.
Representative curves from the radial force vs. InAR.

Fig. 5.

Mean slope of the linear region of the radial force/InAR curve among the five digits.

Table 1

Means (SD) of initial inner wall A1 pulley radius, length and thickness of A1 pulleys in thumbs, index, middle, ring and little fingers at the initial, zero-stress state.

	Thumb (N=8)	Index (N=8)	Middle (N=8)	Ring (N=8)	Little (N=8)
Inner wall radius (mm)	1.70 (0.30)	1.96 (0.40)	2.29 (0.31)	2.00 (0.24)	1.93 (0.26)
Length of A1 pulley (mm)	6.78 (0.88)	9.49 (1.02)	10.73 (2.79)	9.16 (1.63)	7.44 (1.55)
Thickness of A1 pulley (mm)	0.24 (0.05)	0.34 (0.07)	0.40 (0.05)	0.36 (0.07)	0.21 (0.06)

N=sample size