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A1 PULLEY: AN ANATOMIC STUDY OF BIOMECHANICAL PROPERTIES WITH IMPLICATION IN TRIGGER FINGER RELEASE

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ABSTRACT

Purpose: Trigger finger is a common problem leading to hand incapacitation disproportionate to the pathology. The simple complete release of A1 pulley for triggering is based on the premise that its functionality is minimal, and sacrifice will lead to negligible drawbacks. This anatomical study objectively assesses A1 pulley function and evaluates biomechanical disadvantages of its sacrifice.

Methods: An anatomic study on fresh cadavers and amputated upper extremities was conducted to assess the role of A1 flexor pulley in digit function. With all pulleys intact, tendon excursion needed to attain complete finger flexion and force required to attain so were measured for each digit. These parameters were reassessed after partial 'functional' pulley release by the technique of 'N enlargement' plasty, and standard complete A1 pulley release. A statistical analysis of biomechanics of intact A1 pulley, and after the standard or 'N' plasty techniques is done.

Results: In five upper limbs, twenty-five digits were sequentially analyzed. The increased force and tendon excursion required after A1 pulley release is statistically significant compared to intact pulley or 'N' plasty partial release.

Conclusion: Complete finger flexion after standard release of A1 pulley, requires statistically significant increased force and tendon excursion than with the pulley intact or partially enlarged.

Clinical Relevance: A1 pulley has significant role in hand biomechanics and should be preserved whenever feasible. 'N' plasty is a simple and effective technique to enlarge A1 pulley while preserving significant function.

KEYWORDS

A1 pulley, Trigger Finger, Pulley release, Pulley biomechanics, Flexor pulley preservation, Stenosing tenosynovitis

INTRODUCTION:

Trigger finger is a common problem of the hand with incapacitation disproportionate to the pathology due to significant interference with digit function.[1] It is commonly caused by entrapment of the flexor tendon under the A1 pulley, resulting in increasing severity of resistance to digit flexor and subsequent locking.[2] Treatment approaches may be conservative using splints or steroid injections.[3,4] Surgical management, whether by percutaneous, endoscopic or open technique resorts to cutting open the A1 pulley to release the entrapped tendon which can then glide freely.[5,6,7,8] Pulley function, which provides direction and enhancement of power to the force applied, is invariably compromised through 'successful' surgery. Various studies employing biomechanical and anatomical models as well as clinical studies have addressed the relative importance of the A1 pulley in digit flexion.[9,10,11] Based on these studies opinions vary on the value of the A1 pulley in flexor tendon dynamics and the need to preserve it. Our anatomic study attempts to address the question of relative importance of A1 pulley function in terms of biomechanical advantage in digit flexion and consequences of its incomplete and complete sacrifice.

Anatomical basis & pathology

Nine digital flexor tendons pass though the carpal tunnel beneath the median nerve and are tethered to the metacarpals and phalanges by a series of retinacular pulleys. Their function is to provide direction to the muscle pull and increase the mechanical advantage by levering the tendon across joints. The flexor digitorum profundus and superficialis tendons enter a narrow fibro osseous tunnel formed by a groove in the palmar surface of the metacarpal neck and the annular ligament.[12]

Doyle and Blythe demonstrated that the flexor sheath in the finger is a double- walled, hollow, synovial-lined, connective tissue tube that encloses the flexor tendons.[13] A visceral component of the sheath covers each of the enclosed tendons, and a surrounding parietal layer creates a closed, fluid-filled system. There are 5 annular and 3 cruciate pulleys, the annular pulleys being thick and rigid. Some also claim a C 0 pulley between A1 and A2.

The thumb is enclosed in a similar double-layered synovial sheath, and its pulley system consists of two annular and one oblique pulleys.[14]

The second pulley (A2) and the fourth pulley (A4) are most important functionally. [15] It has been shown experimentally in some studies that section of only the first annular pulley (A1), as is done in surgical release of trigger finger or thumb, produces no loss of flexor function. However, division of both the A1 and A2 pulleys causes significant postoperative bowstringing and limitation of active flexion.[16] Recent bio mechanical analysis has questioned the veracity of above claims.[17]

PATIENTS & METHODS:

This is a prospective observational study performed on five upper limbs from Sep 2015 to Jun 2016 in order to study functional significance of A1 pulley. Among five upper limbs, four were from fresh cadavers employed for the anatomical study and one from a freshly amputated case. This study was conducted at a service medical institute from September 2017 to June 2018. None of the limbs were chemically treated or kept in hypothermic conditions. All dissections were conducted within 6 hours of demise or amputation. Donated cadavers with next of kin consent were included in study after due legal clearance from forensic and anatomy department. There were no ethical issues in the conduction of the study. None of the upper limbs had any history of injury or surgery in past.

The entire skin over the palm and digits was excised except over the terminal phalanx, exposing the entire flexor tendon and pulley mechanism. The forearm skin and fascia was also excised to expose all flexor muscles and tendons. The flexor retinaculum at the wrist was left intact. With the wrist in neutral position, the wrist joint line was marked for subsequent measurements. The Flexor Pollicis Longus and Flexor Digitorum Profundus slips to the fingers were identified and looped.

Exposed tissues were kept moist with saline. Baseline recording was done by marking fixed points on each tendon where they could be securely held in a haemostat and where they crossed the wrist joint at rest. All haemostat application and traction sites were at similar distance of 5cm proximal to the wrist. A haemostat was applied securely across the tendon so that it's tip extended a cm beyond the tendon. This allowed balanced traction without angulation and also permitted hooking of the digital force recording meter across the tendon and haemostat. Employing traction by the hemostat, the concerned digit was brought into full flexion with fingertip just touching the palm. The tendon excursion proximal to the wrist was marked and recorded in mm. A portable digital weight recording device was then looped around the haemostat and tendon and traction reapplied to achieve the same degree of flexion. The force needed to do was as recorded and average of 3 readings taken.

With the flexor retinaculum and all pulleys intact, the initial measurements were recorded as baseline.

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In the first cadaver, we incised and released the A1 pulley of all digits of both hands employing 'N' plasty. The 'N' Plasty approach employs pulley delineation and release using fine iris scissors or reversed No 11 blade. Opposing and overlapping incisions are made across the pulley as demonstrated in Fig.1. Care is taken to ensure overlapping of the incisions to adequately widen the pulley and create additional space between the tendon and pulley.

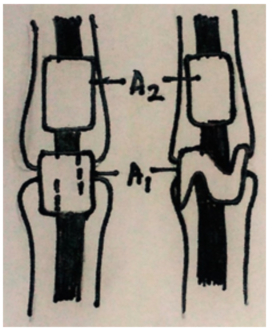

Fig 1 N plasty

Adequate release is confirmed by free insertion of an angular dental probe of graduated width under the A1 pulley. Free passage of the probe till its base of 3 mm width is ascertained. An adequate release easily permits insertion of a mosquito artery forceps tip between the tendon and released pulley. The relevant FDP tendon was again pulled proximally to achieve full finger flexion into the palm and excursion and force recorded. Thereafter standard A1 pulley release was done and measurements repeated. The evaluation was sequentially continued after 'N' plasty and standard release of the A2 pulley.

In the second cadaver, we performed 'N' plasty release in all A1 and A2 pulley of all digits of the right hand whereas standard complete release was done in the A1 and A2 pulley of the left hand for comparison. This enabled direct comparison between similar pulley releases by different techniques in matching digits. (Fig. 2 - 8).

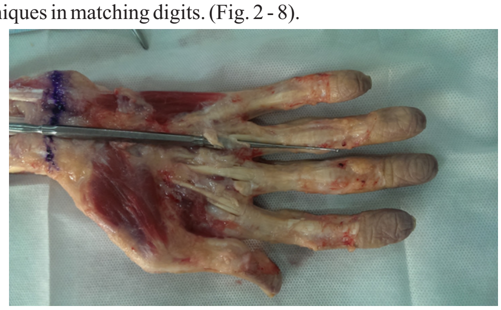

Fig 3 N plasty of A1 pulley

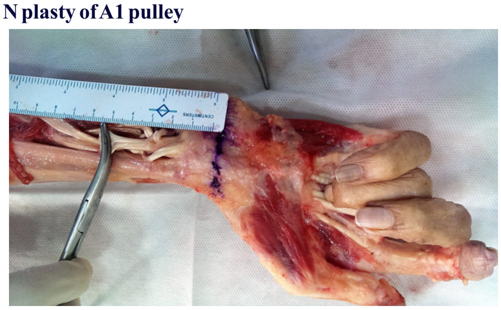

Fig 4 Excusion measurement post N plasty

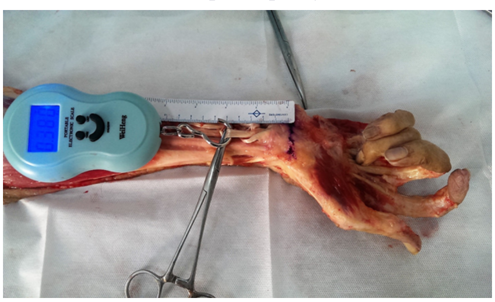

Fig 5 Force measurement post N plasty

Fig 6 Standard plasty A1 pulley

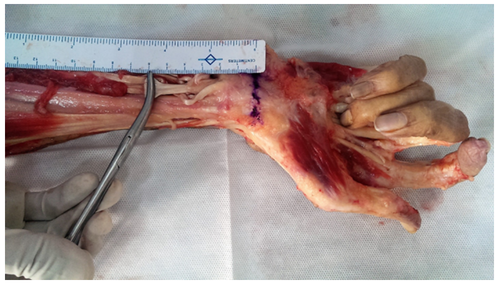

Fig 7 Excursion measurement in standard plasty

Fig 8 Force measurement in standard plasty

Paired T test technique was used for statistical analysis to compare difference excursion of flexor tendon and force required to achieve complete finger flexion in cases of standard A1 pulley release and 'N' plasty. Few digits were analysed for A1 + A2 pulley release vs 'N' plasty of A1 + A2 pulley in similar way.

RESULTS:

This anatomic study was performed on five upper limbs and twenty-five digits were analyzed. Total nineteen digits were studied for flexor tendon excursion and force required for complete flexion of digit as control, after performing 'N' plasty and finally after standard plasty of A1 pulley. As extended part of study 'N' plasty was performed in A1 + A2 pulley in six digits and compared with standard release of A1 + A2 pulley in fourteen digits.

Force Requirement for complete finger flexion

In control group (n=19) mean force was 250.8 gm (S.D.+/-89.32). When 'N' plasty was performed on A1 pulley in respective digits, (n=19) mean force required was more with 334.73 gm (S.D. +/-125.19). When A1 pulley was completely transected by standard plasty the force required to achieve full flexion of digit was 481.32 gms (S.D.+/-229.22). Table No.1 presents the force requirement trend. Difference of force requirement when compared in N plasty and standard plasty was found to be statistically significant by paired T test (p=0.0001).

Release of A1 + A2 pulley when compared by N plasty and standard complete pulley release in terms of force requirement was 285.83gms (S.D. +/-126.19) and 600gms (S.D.+/-187). The difference of force requirement in two groups is statistically significant (p=0.0008). (Table 1) (Fig 9)

Force Requirement For Complete Finger Flexion
Table 1 Force Requirement for Complete Finger Flexion

	No. Of Patients (n)	Mean Force In GMS	Standard Deviation	Min	Max
Control	19	250.79	89.32	100	400

N Plasty A1 Pulley	19	334.74	125.19	15	565
Control	19	266.32	96.6	100	400
Standard Plasty A1 Pulley	19	481.32	229.22	165	1090
Control	6	253.33	78.33	135	330
N Plasty A1+a2 Pulley	6	385.83	126.19	180	510
Control	14	273.57	88.57	100	395
Standard Plasty A1+a2 Pulley	14	600.71	187	250	860

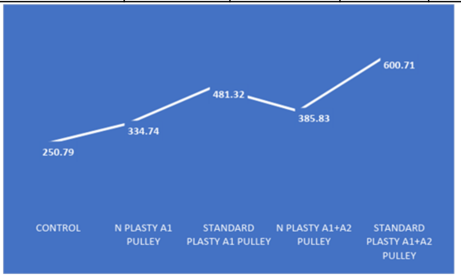

Fig 9 Force requirement in GMS

Flexor Tendon Excursion

Similar trend was seen when flexor tendon excursion was quantitatively analyzed. In nineteen digits mean excursion was 43.84mm (S.D.+/-13.79) for control group (n=19). For N plasty and standard plasty it was 46mm (S.D.+/-14.49) and 51.42mm (S.D.+/-16.16) (Table 2). Excursion required and compensation by increase force increases with extent of pulley release. The difference in N plasty and standard plasty group for excursion is statistically significant (p=0.0002). Similar observations are seen with simultaneous release of A1+A2 pulley by N plasty and standard plasty. Difference in excursion in both groups is not statistically significant (p=0.10). Shows comparison of control, N plasty and standard plasty groups (Fig. 10).

Table 2 - Excursion Requirement for Complete Finger Flexion

	No. Of Patients (n)	Mean Excursion In Mms	Standard Deviation	Min	Max
Control	19	43.84	13.79	22	60
N Plasty A1 Pulley	19	46	14.49	22	63
Control	19	45.79	14.52	22	71
Standard Plasty A1 Pulley	19	51.42	16.16	28	80
Control	6	45	17.47	22	60
N Plasty A1+a2 Pulley	6	50.33	18.98	24	68
Control	14	47	14.34	27	71
Standard Plasty A1+a2 Pulley	14	56.43	17.41	31	86

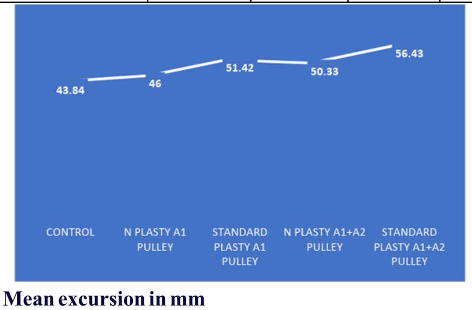

Fig 10 Mean excursion in mm

Thumb Analysis

When force and length requirement was calculated after N plasty and Standard plasty , results were glaring, showing significant increase in force and excursion requirement after standard palsy (0.000 and 0.025 respectively) (Table 3).

Table 3 Force and Excursion requirement of thumb

	No. Of Patients (n)	Mean Force In GMS	Standard Deviation
N Plasty A1 Pulley	05	150	123.8
Standard Plasty A1 Pulley	05	505	238.00
	No. Of Patients (n)	Mean Excursion In MMS	Standard Deviation
N Plasty A1 Pulley	05	4.8	4.43
Standard Plasty A1 Pulley	05	9.4	6.18

DISCUSSION

The Twenty-two extrinsic tendons crossing the wrist provide a unique combination of power and dexterity in the hand. Division or rupture of a critical retinacular ligament, or *pulley*, will allow the tendon to drift away from the joint's centre of rotation and consequently increase the moment arm for force production but effectively lengthen the tendon and limit excursion of the joint. The mechanism of trigger fingers is still unknown. Furthermore, hand function and load changes occur along with compensation effects. It is essential to understand trigger fingers as a biomechanical aspect.

There has been little literature regarding trigger release while preserving pulley function. This is apparently because of the presumption that A1 pulley sacrifice does not adversely affect digit function along with the surgical difficulty of reconstructing an enlarged pulley.

The efficiency of flexor tendon system was examined in a human cadaver model by Rispler et al.[18] Pulleys were randomly sectioned, and the results were evaluated on the basis of the tendon excursion, force generated at the fingertip and the work (force multiplied by distance) involved, as compared to the intact pulley system. When a single minor pulley (A1 or A5) was cut, there was no statistical difference in work efficiency or excursion from controls. Cutting one of the major pulleys (A2, A4) resulted in significant changes in efficiency, but what was unexpected was to find an 85% loss of both work and excursion efficiency for the loss of A4 but only an excursion difference of 94% for the loss A2. Our study has found a linear correlation between the number of pulleys sectioned and the increased excursion and force required for flexion.

A biomechanical muscle model of trigger fingers was developed by Chin et al to provide quantitative descriptions.[19] To investigate the efficiency difference among different extent of pulley release, total joint ROM per unit of tendon excursion was analyzed in human cadavers. Results showed that joint rotation per unit of tendon excursion decreased with increasing extent of pulley release. Our results demonstrate that complete pulley release at A1 or combined A1 and A2 level imposes significantly more force requirement and tendon excursion than corresponding incomplete (and functional pulley) release by 'N' plasty.

Boretto et al conducted a prospective study in 19 patients with trigger thumbs to define the anatomy of the A1 pulley and to evaluate biomechanical parameters of the thumb after complete division of the A1 pulleyTheir clinical data showed that there is no deficit with respect to motion and strength of the thumb after complete sectioning of A1 pulley.[20] Based on our results, there is evident derangement of biomechanical parameters after A1 release. These may be apparently compensated by greater use of force and longer excursion and hence not evident in clinical outcome differences. Our subset analysis of complete thumb A1 pulley release reveals marked worsening of mean force and excursion compared to controls and 'N' plasty which is highly significant. Since majority of trigger thumbs are congenital, we strongly feel that pulley sacrifice by complete release is avoidable if full trigger release is achieved by 'N' plasty release.

The effect of the extent of A1 pulley release on the force required to flex the digits was examined in a cadaver study on the thumb, middle and ring fingers by Low et al. The A1 pulley was released distally in consecutive stages by 25%, 50%, 75% and 100% of its length. The force required to fully flex the digit at each stage was recorded. The force decreased with more extensive A1 pulley release and this became significant when more than 50% of the pulley was released. These changes were probably due to loss of friction force rather than bowstringing of the tendon.[21] Clinical application from this inference appears to be limited.

The pulley system of the thumb has been evaluated in an anatomic and biomechanical study by Bayat et al. The biomechanical study was done on 8 limbs by using linear strain transduction techniques. The analysis showed that the strain in the oblique pulley was greater in extension than in flexion of the thumb. This statement remains true even after division of either the A1 or Av pulley and after section of both pulleys. The oblique pulley does not prevent bowstringing of the flexor pollicis longus when A1 and Av pulleys have been sectioned. These studies challenge current concepts of both the anatomy and mechanics of the thumb pulley system with implications for clinical procedures such as trigger thumb release and pulley reconstruction.[22]

Multiple recent reports also suggest a correlation between carpal tunnel release and trigger finger (TF) as they often coexist in the same hand through the relationship between the two conditions and their exact cause is not clear.[23,24]

The increased incidence of triggering after carpal tunnel release is possibly due to greater friction at the A1 pulley due to the increased entrance angle of the tendons. It is suggested that biomechanically, the flexor tendons displace anteriorly after division of the carpal tunnel, creating a bowstringing which results in an increase in the entrance angle of the flexor tendons to the A1 pulley. This leads to a deterioration of the boundary lubrication mechanism of the tendon and pulley system. Comprehensive forces increase and a fibrocartilagenous metaplasis of the connective tissue becomes possible at the side of increased compression which leads to triggering.[24]

The available evidence clearly indicates the need to preserve pulley function as loss of any pulley over a period of time leads to overloading of the next distal one. The drawback to pulley preservation was the lack of a simple procedure which permits release of above objectives to be achieved.

Schoffl studied the development of chronic tenosynovitis after pulley rupture.[25] It is regarded as a consequence of higher friction between the remaining pulleys and tendon because of the diminished angle between pulley edge and tendon. It also attests to the importance of pulley function in preventing chronic tenosynovitis.

Through studies claim A1 pulley function to be relatively unimportant compared to the more important A2 pulley, considered in isolation, A1 pulley also serves a useful purpose. A successful N plasty and functional pulley will continue to provide leverage and improved gradient while still preventing greater loading of distal pulleys and reduce tenosynovitis.

Despite studies suggesting that A1 pulley function can be sacrificed with indifference, many unconvinced surgeons continue to perform complex pulley reconstructions with an aim to restore its function while not compromising tendon movement. Kapandji enlargement plasty of A1 pulley with 5 yr follow up was done in 15 trigger fingers by Migaud et al.[25] They retrospectively studied the enlargement plasties of the A1 pulley performed for trigger finger in a university orthopaedic department. Patients were reviewed after 5 years of follow-up (2-8 years) by an observer who did not participate in the surgery. Authors found that after surgery, all symptoms resolved and no recurrence was observed during the follow-up period. The authors recommend this procedure, which does not lead to recurrence despite closure of the enlarged A1 pulley. Technically more demanding than simple A1 pulley opening, the authors concluded that this procedure was safe despite participation of junior surgeons.Though the relative function and importance of various pulleys is different, as attested to by various studies, it stands to reason that any procedure which delivers standard outcomes while preserving function should be more appealing than one which sacrifices it. It is apparent from our anatomic study that A1 pulleys sacrifice imposes greater force and excursion requirement on the muscles for attaining full digit function. This may be clinically compensated with no apparent flexion deficit, but nonetheless imposes greater load and excursion liability on the muscle. 'N' plasty is a simple modification to existing pulley release surgery, accomplished in a minute or so of additional surgical time, and offers significant advantages in mechanical efficiency by attaining pulley release without function sacrifice.

Clinical studies indicate an early flexion lag after complete A1 pulley release, which improves over time, corroborating our conclusions. Statstical analysis seems to indicate a higher degree of compensatory mechanisms in play after standard release, commensurate with available literature. Our study is limited in sample size but suggests that A1 pulley function leads to significant reduction in compensation in terms of force and excursion. This is most remarkable in the thumb, where complete A1 pulley release in childhood is less desirable due to the much greater biomechanical advantage sacrifice.

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