Kinematic Analysis of Six Different Insertion Sites for FDS Opponensplasty

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Abstract Six variations of opponensplasty were biomechanically studied to determine if there is a significant difference in the amount of opposition produced by altering the insertion site of the tendon transfer while keeping the tendon source and pulley location constant. Five cadaveric arms were used to simulate six described insertion sites for opponensplasty tendon transfers. The arms were mounted through the ulna onto a specially designed stand. The stand was equipped with a calibrated stylus which could be turned 90° in order to accurately measure points in *X*, *Y*, and *Z* planes. Metacarpal–phalangeal flexion and thumb abduction were measured before and after application of a 550-g load. Axial rotation (pronation) was mathematically calculated using reference points on the thumb which were measured with the stylus before and after application of the load. The Bunnell transfer insertion site provided the greatest amount of palmar abduction, the Brand transfer insertion site the greatest metacarpophalangeal flexion, and the Royle transfer insertion site the greatest rotation. Although each of these transfers produced the greatest motion in one plane, they performed relatively poorly in the other two. The Riordan transfer insertion site into the extensor pollicis longus in line with the abductor pollicis brevis was, in our study, the overall best transfer, providing the second greatest change in motion in each of the three planes measured.

Keywords Opponensplasty · Biomechanics · Kinematic analysis · Insertion sites for FDS

Introduction

Opposition of the thumb is arguably the most important motion of the hand, and its loss, whether through neurologic injury, traumatic local tissue loss, or disease process, represents a severe functional deficit. Given the importance of an opposable thumb, it is not surprising that numerous methods have been described in attempting to restore this motion. However, opposition is a complex motion, which is the result of the interaction of multiple muscle groups providing simultaneous mobilization and stabilization of several joints. It would be impossible to fully restore this motion through a single tendon transfer. Many different tendon sources, pulley location, and insertion sites have been described in attempts to confront this problem. The purpose of this study is to determine if there is a significant difference in the amount of opposition obtained in cadaveric specimens based on location of the insertion of the tendon transfers as described by Brand, Bunnell, Littler, Riordan, Royle, and Thompson [1, 3, 6, 7, 9, 10]. Illustrations of these insertion sites of the tendon transfers are depicted in Figs. 1, 2, 3, 4, 5, and 6. We studied six different tendon insertion sites as various types of opponensplasty by measuring the different effects on metacarpophalangeal (MP) joint flexion, abduction of the thumb, and pronation of the thumb.

Materials and Methods

Five fresh cadaveric arms, amputated above the elbow, were used for this study. In each arm, the flexor digitorum

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Figure 1 Brand tendon transfer.

superficialis (FDS) to the ring finger was transferred using a loop of the flexor carpi ulnaris (FCU) for a pulley. The tendon was passed through a subcutaneous tunnel to the dorsum of the thumb. The arm was mounted to a frame by transfixion pins placed through the ulna. The interphalangeal joint of the thumb was stabilized using a K-wire. Two additional K-wires were placed in the thumb and used for reference points: one in the proximal and one in the distal phalanx. Each of the two pins was left protruding approximately 1 cm from the skin. The FDS tendon was then secured to one of the six insertion sites to be tested.

In our experimental model, we chose to use the FDS to the ring finger as a tendon source and a FCU loop just proximal to the pisiform as a pulley. This combination was selected because it was felt to represent the method used in most situations for opponensplasty in low median nerve palsy. The donor and pulley location was kept constant for each trial.

Using a stylus mounted on a calibrated arm, X and Y coordinates for the ends of each reference K-wire were determined (Fig. 7). The calibrated arm could then be

Figure 2 Bunnell tendon transfer.

Figure 3 Littler tendon transfer.

Figure 4 Riordan tendon transfer.

rotated 90° and locked in place to determine a Z coordinate of each of the two reference points. In doing this, a precise three-dimensional location for the tip of each reference pin was noted. These two points were referred to as A and B. A 550-g load was then applied to the FDS tendon through a pulley system setup to allow straight line pull. The X, Y, and Z coordinates for the two reference pins were again measured and are referred to as points C and D. Metacarpal–phalangeal flexions and abduction of the thumb were measured before and after transfer, while axial rotation (pronation) was mathematically calculated. The insertion of the FDS tendon onto the thumb was then changed to that of one of the remaining described insertion sites, and the process was repeated, taking measurements before and after application of the load. All six of the described transfers were performed on five fresh cadaveric arms.

The accuracy of our measurements using the stylus and calibrated arm was evaluated by taking repeated measurements of a fixed point. Error inherent to the system was then determined with an estimated precision error of 1.52%.

The amount of opposition produced by the 550-g load was calculated by the change in the location of the two reference points. A third reference point E was mathematically calculated using the equations:

$$X_E = (X_C - X_D) + X_B$$

$$Y_E = (Y_C - Y_D) + Y_B$$

$$Z_E = (Z_C - Z_D) + Z_B$$

This provided three points to create a plane. The change in rotation of the plane created by these points is represented as an angle and could then be determined by the following equations:

$$AB^2 = (X_A - X_B)^2 + (Y_A - Y_B)^2 + (Z_A - Z_B)^2$$

$$BE^2 = (X_C - X_B)^2 + (Y_E - Y_B)^2 + (Z_E - Z_B)^2$$

$$AE^2 = (X_A - X_E)^2 + (Y_A - Y_E)^2 + (Z_A - Z_E)^2$$

$$\cos B = \frac{AB^2 + BE^2 - AE^2}{2(AB)(BE)}$$

One-way analysis of variance (ANOVA) was used to compare these six different insertion points.

Results

Statistical significance was calculated using one-way ANOVA. The difference among these six insertion sites

Figure 5 Royle tendon transfer.

Figure 6 Thompson tendon transfer.

Figure 7 Photograph of the experimental setup depicting the method in which the arm was mounted and the stylus used to determine coordinate points.

Table 1 Metacarpal–phalangeal flexion.

One-way ANOVA	Mean change in angle (°)
Bunnell transfer insertion site	7.8
Thompson transfer insertion site	10.0
Littler transfer insertion site	19.6
Royle transfer insertion site	20.2
Riordan transfer insertion site	21.2
Brand transfer insertion site	23.0

in producing palmar abduction was not statistically significant.

There was a statistically significant difference between Bunnell transfer when compared with the Littler, Riordan, Brand, and Royle transfer insertion sites with respect to metacarpal–phalangeal flexion ($p < 0.05$). The Thompson transfer insertion site and Bunnell transfer insertion site had the lowest metacarpal–phalangeal flexion. Table 1 depicts the mean change in angle after metacarpal–phalangeal flexion for each of those six insertion sites.

The metacarpal–phalangeal flexion was statistically significant in the Thompson transfer insertion site when compared with the Brand transfer insertion site ($p < 0.05$).

Using one-way ANOVA, no statistically significant difference was found among those six different transfer insertion sites with regard to thumb palmar abduction.

A statistically significant difference was found between Bunnell transfer (mean change in rotation 38.7°) and Royle transfer (mean change in rotation 57.8°) in providing thumb axial rotation (Tables 2 and 3).

Insertion into the abductor pollicis brevis (APB), extensor pollicis longus (EPL), and dorsal hood (Brand) produced the greatest metacarpal–phalangeal joint flexion [3]. Insertion into the flexor pollicis brevis (FPB) and dorsal hood (Royle) produced the greatest rotation [9]. The best abduction was achieved by insertion into the dorsal ulnar base of the proximal phalanx (Bunnell) [1].

Table 2 Thumb palmar abduction.

One-way ANOVA	Mean change in abduction (°)
Royle transfer insertion site	32.6
Brand transfer insertion site	34.2
Littler transfer insertion site	36.4
Thompson transfer insertion site	36.6
Riordan transfer insertion site	39.6
Bunnell transfer insertion site	42.0

Table 3 Calculated thumb axial rotation.

One-way ANOVA	Mean change in rotation (°)
Bunnell transfer insertion site	38.708
Thompson transfer insertion site	40.074
Littler transfer insertion site	42.624
Brand transfer insertion site	45.142
Riordan transfer insertion site	46.356
Royle transfer insertion site	57.770

As expected, those transfers which provided the best motion in one plane often provided poor motion in other planes. The Bunnell transfer gave the best abduction but the worst MP flexion and axial rotation. The Royal transfer was the best at providing rotation but the worst at abduction, whereas transfer into the EPL in line with the APB, as proposed by Riordan, provided the second-best result in each of the three different planes of motion that were measured [7].

We concluded that insertion into APB (Littler) produced as much rotation as some of the more complicated insertions [6]. MP flexion was shown to be directly affected by tendon insertion. Those inserting onto the APB and EPL (Riordan), the EPB and EPL (Bunnell), and the APB, EPL, and dorsal hood (Brand) produced greater extension, while insertion onto the FPB (Royle) produced much greater MP flexion.

Discussion

Loss of thumb opposition represents a significant functional deficit to the hand. Given the importance of restoring opposition of the thumb, it is not surprising that many different tendon sources, pulley locations, and transfer insertion sites have been described in attempts to confront this problem. The objective of this study was to evaluate various insertion sites with a constant tendon source and pulley location, to determine if there is a significant difference in the amount of opposition that is provided.

The motion of thumb opposition is actually a combination of thumb abduction, flexion, and pronation (axial rotation). When one considers the complex interaction of the intrinsic and extrinsic muscles involved in producing opposition, it is not reasonable to expect any one tendon transfer to accurately reproduce this motion. Our results demonstrate that changes in the insertion site did vary in the amount of flexion, abduction, and rotation for each specific transfer as compared to the other insertions. Our study of the kinematics of opponensplasty revealed that

none of the insertion sites could maximally reproduce more than one of the individual motions involved in opposition.

Cooney et al. also attempted to determine the best tendons and insertions for opponens transfer [2]. They found that, based on cross-sectional muscle anatomy, transfer of the FDS to the long finger or extensor carpi ulnaris muscles was capable of generating 60% of the required strength to produce opposition, providing maximal abduction and near full thumb rotation. In their study, abduction was the greatest with either FDS from the ring or long fingers, while the FDS and EIP transfers provided the greatest rotation.

Roach biomechanically evaluated thumb opposition transfer and found that insertion into the FPB and radial dorsal extensor hood insertion site, or APB insertion site, provided the best overall opposition [8]. They used the FDS of the ring finger as a donor tendon.

Axial rotation in our study was mathematically calculated based on accurate reference points. We also tried to focus on the amount of opposition produced by various insertion sites while eliminating other variables such as different tendon sources and pulley locations by keeping them constant.

The choice of FCU pulley in our study was to produce the greatest palmar abduction. Similar biomechanical findings of the pulley location were reported by Lee [5]. They biomechanically studied not only the pulley location but also two insertion sites. They concluded that the choice of pulley may depend on the type of transfer and that the palmar radial insertion site into the abductor pollicis brevis produced better thumb opposition, MP joint abduction, and MP joint flexion.

Our results suggest that transfer into EPL tendon in line with the pull of the APB as proposed by Riordan may be the most physiologic insertion site. This would make sense given the importance that the APB is the most important muscle in providing opposition of the thumb [1, 4]. Although other insertion sites were able to produce greater motion in any one plane, they could not reproduce motion as well in the other two planes. The Riordan transfer was able to consistently reproduce good motion in all three measured planes, placing second best in each of MP flexion, abduction, and axial rotation. It should be noted that it is sometimes difficult to directly correlate results of an experimental model with the clinical setting. While laboratory models are useful in isolating variables, they cannot take into account associated soft tissue trauma or joint contracture which is often present, nor can they predict changes which occur over time because of progressive laxity in a joint as a result of constant pull from an unbalanced tendon source.

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