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POSITIONING OF THE PULLEY MECHANISM WHEN RECONSTRUCTING DEEP FLEXOR TENDONS OF FINGERS

By

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In reconstructive surgery of deep flexor tendons of the fingers it is of considerable importance to leave or to reconstruct pulleys to ensure the correct alignment and run of the tendons. The literature seems to pay little attention to the question of what is the most favourable position for each pulley from the mechanical point of view.

We have tried to determine these positions mathematically.

We have assumed that:

1. The force which the muscle exerts on the tendon is independent of the positions of the pulleys.
2. There is no friction in the pulleys.
3. The tendon is long enough to allow complete extension of the finger.
4. The proximal pulley is always situated close to and on the proximal side of the metacarpo-phalangeal joint.
5. The two distal pulleys and the distal insertion of the tendon can be chosen at will.

Our goal has been to find a construction which makes it possible for the finger to act like a normal finger, *i.e.* to create a state where full range of movement is achieved with the smallest possible excursion of the muscle, and where the moments or torques about the joints are neither too great nor too small.

In the following we suppose that when a pulley is placed close to a joint it is flexible enough to turn in accordance with the joint and its direction bisects the angle of the joint.

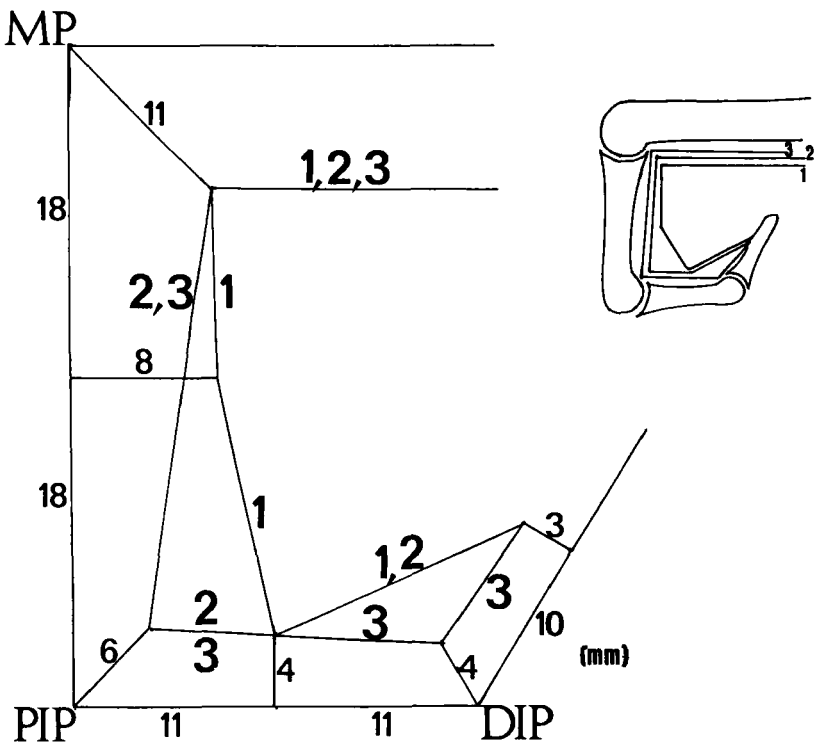

Figure 1. Three alternative pulley mechanisms.

In order to obtain results that are easy to compare with each other we have considered three given arrangements (Figures 1,1, 1,2, 1,3). We have not attempted to arrive at general formulae for the moments and tendon excursion as functions of the angles but rather to calculate their values in the extension (0°) and flexion states (by maximal flexion we mean in these calculations 90° except in the distal interphalangeal joint where 60° flexion is considered maximal). We are only discussing a typical finger and so we have used numerical values (Figure 2) throughout the calculations. We are only interested in comparing the different configurations, not in absolute values.

In calculations of the moment (M) of the tendon force (F) about a joint, the moment is defined as the force times the perpendicular distance (d) of its line of action from the joint: $M = F \cdot d$. Because the tendon is in equilibrium, the force (F) at any point (P) of the tendon is equal and opposite to the sum of all forces acting on the tendon at points distal to P. All we have to do, then, is to determine which pulley is closest to the joint on its distal side, and take as the line of action the direction of the tendon on the proximal side of the pulley (Figure 3).

In the following we denote the moments of the flexor profundus force (F) about the metacarpo-phalangeal (MP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints by M_{MP}, M_{PIP} and M_{DIP} respectively. By the excursion

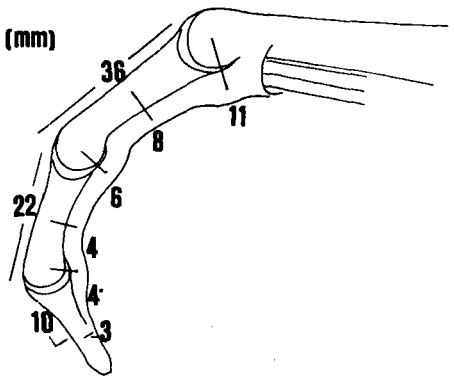

Figure 2. Measurements of bones of a normal finger.

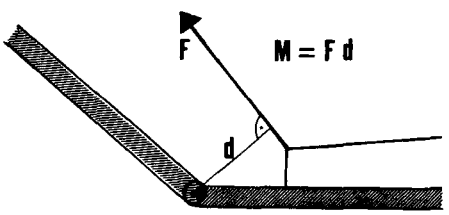

Figure 3. Calculation of the moment of the flexor tendon force about a joint.

Δl we understand the difference in length in the extension and flexion states of the portion of the tendon which lies in the finger (*i.e.* the excursion in the MP joint). All lengths are measured in millimetres. The values have been found graphically.

Alternative 1 (Figure 1,1).

The pulleys are placed in the middle of the proximal and middle phalanges.

Results

	Extension	Flexion
M_{MP}	11 F	7.5 F
M_{PIP}	6 F	11.5 F
M_{DIP}	3.5 F	8 F
Δl		36.5 mm

Alternative 2 (Figure 1,2).

The proximal pulley is placed just at the PIP joint, the distal one in the middle of the middle phalanx.

Results

	Extension	Flexion
M_{MP}	11 F	8.8 F
M_{PIP}	6 F	4.3 F
M_{DIP}	3.5 F	8 F
Δl		30 mm

Alternative 3 (Figure 1,3).
Both pulleys are placed at the interphalangeal (IP) joints.

Results

	Extension	Flexion
M_{MP}	11 F	8.8 F
M_{PIP}	6 F	4.3 F
M_{DIP}	3 F	3.5 F
Δl		28 mm

In the normal finger (Figure 4) the moments are remarkably constant for all angles.

M_{MP}	11 F
M_{PIP}	6 F
M_{DIP}	4 F

For the flexion state the moments are likely to be slightly smaller. The excursion is somewhat smaller than in alternative 3.

From the results above we may conclude that for all alternatives the moments in extension are approximately equal to those of the normal finger. With flexion the moment about the MP joint decreases slightly more in alternative 1 than in 2 and 3. In the normal finger M_{MP} is greater than in any of the cases 1, 2, 3, but the difference is small. The main difference between the three alternatives is that

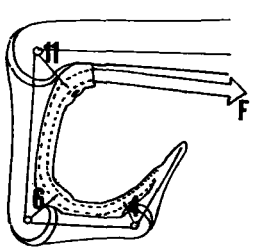

Figure 4. Deep flexor tendon of a normal finger.

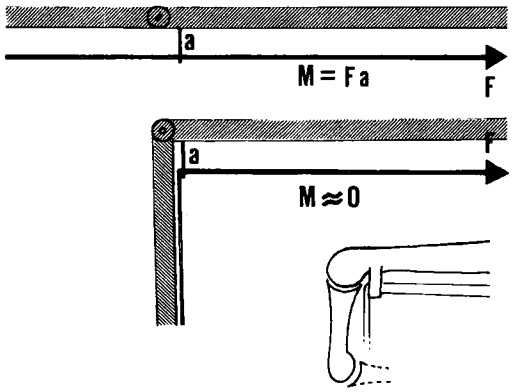

Figure 5. A rigid pulley close to a joint results in very small flexion moment.

the moment tends to grow very big about a joint which is without a pulley. Thus, in alternative 1, for example, M_{PIP} and M_{DIP} are twice as big as in the normal finger. This situation may upset the equilibrium of the finger and prevent complete extension. Particularly in alternative 1 the amplitude of excursion necessary for the complete range of movement of the finger is considerably greater than in the normal case. Alternative 3 seems to be the one most nearly resembling the normal situation; the excursion is shortest and there are no excessive moments. The moments are in fact smaller than in normal, which, particularly in the PIP joint, might cause some trouble with flexion.

A distal shift of the insertion of the profundus tendon increases M_{DIP} and excursion in alternative 1 and 2 but has no noticeable effect in alternative 3. If we consider a case where the pulley remains orthogonal to the phalanx even during complete flexion (90°), we find that at this angle the moment becomes vanishingly small (Figure 5), provided that the pulley is close enough to the joint. Thus it seems to us that if the pulley is so strong that it withstands the torque which the tendon exerts on it, it should be placed at some distance from the joint. On working out the effect of this position of the pulleys, we were somewhat surprised to find that, from the mechanical point of view, there is no difference between a construction in which the pulley lies some distance proximally of the joint and one in which it is situated equally far distally of the joint (assuming that the tendon is approximately parallel to the phalanx) (Figure 6). As is to be expected, this construction is intermediate between alternatives 1 and 3. The moments can be made roughly equal to those of a normal finger

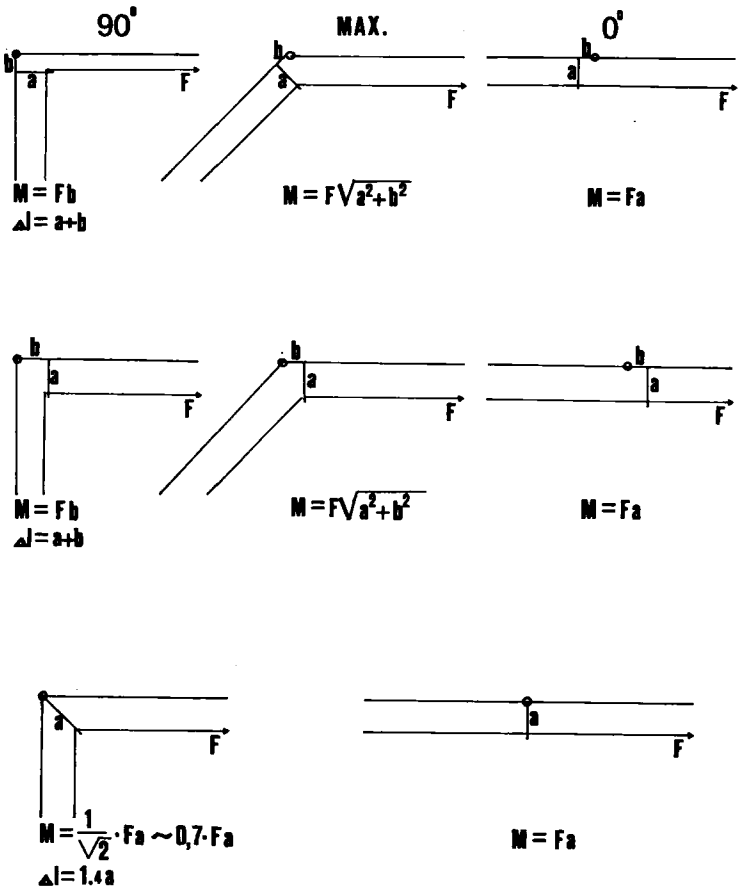

Figure 6. Moments and excursions when the pulley is situated distally, proximally or just at a finger joint.

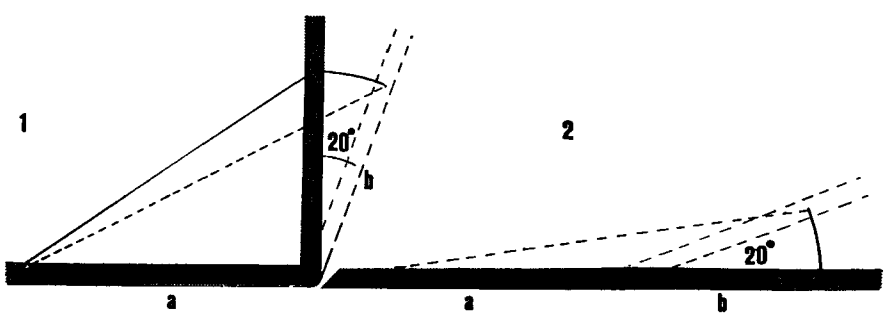

Figure 7. Demand for full flexion is uneconomical (cf. text).

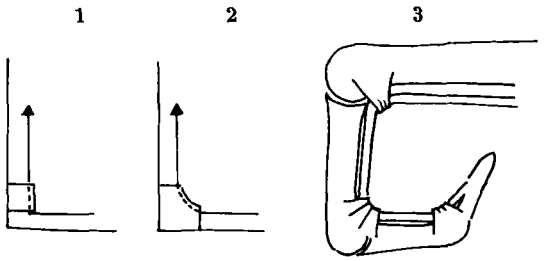

Figure 8. A broad pulley at the joint secures a good glide for the tendon.

by placing each pulley at a distance of approximately 0.8 times the height of the pulley from the centre of the joint. This gain in moment, however, has to be paid for by a corresponding demand for increase in the excursion of the tendon.

It should be emphasized that it is very "uneconomical" with regard to the excursion to demand full flexion. Let us consider the theoretical example of figure 7. If we want to bring the two rods the last 20° to full flexion (Figure 7,1) and the last 20° to full extension (Figure 7,2) respectively, we shall find that the flexor excursion needed in Figure 7,1, $\Delta l_1 = 0.34 \cdot \frac{ab}{\sqrt{a^2+b^2}}$ and that needed in Figure 7,2, $\Delta l_2 = 0.06 \cdot \frac{ab}{a+b}$. If a = b, this gives $\Delta l_1 = 8 \cdot \Delta l_2$.

When talking about the tendon excursions in the alternatives reviewed above, however, we must bear in mind that the excursion of the muscle is longer than we have calculated. The reason is that we have omitted the excursion in the wrist. The relative differences in excursion in the various alternatives are therefore not so great as they would seem to be from the above calculations.

As regards the frictional effects in the pulleys, we would point out that the pull of the tendon tends to turn the pulley in such a way as to make gliding as smooth as possible. If the pulley withstands the torque, however, the tendon will turn sharply at one edge of the pulley (Figure 8, 1) instead of turning equally at both edges. This will increase the friction. Physically the best arrangement seems to be one with broad pulleys at the joints (Figure 8, 2). This will greatly reduce the sharp angles, increase the moment and lessen the need for excursion. Such an arrangement would result in action fairly similar to that of a healthy finger (Figure 8,3).

CONCLUSIONS

Mechanical considerations indicate that a pulley mechanism which makes it possible for the finger to act like a normal finger will be obtained by placing the pulleys at the IP joints. This is only the case, of course, if the other necessary conditions are met. If it is important at the same time to retain complete extension, this is the construction to aim at. If it is obvious that the muscle has lost some of its ability to contract and if active maximal flexion is held to be most important, one has to consider whether to place both or one of the distal pulleys proximally of the IP joint. It will be difficult, if not impossible, to obtain full extension when full flexion is secured with this construction.

SUMMARY

Based on mathematical considerations it is concluded that from the mechanical point of view the most favourable position for each pulley of deep flexor tendons of fingers is at the interphalangeal joints. Physically best are broad and pliable pulleys.

RESUME

En se basant sur des considérations mathématiques, il est conclu que d'un point de vue mécanique la position la plus favorable pour chaque «pulley» des tendons fléchisseurs profonds des doigts est l'articulation interphalangienne. Physiquement, les meilleures sont les «pulleys» larges et souples.

ZUSAMMENFASSUNG

Durch mathematische Betrachtung ist festgelegt, dass vom mechanischen Standpunkt aus die günstigste Stelle für jede „Pulley" der tiefen Flexorsehnen der Finger an den Interphalangealgelenken ist. Physikalish am besten sind breite und nachgiebige „Pulleys".