FLEXOR TENDON EXCURSIONS IN "NO-MAN'S LAND"

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SUMMARY

The excursions of the digital flexor tendons have been measured relative to the sheath and to one another at a point in no-man's land over the proximal phalanx, in fresh cadavers. Passive metacarpo-phalangeal joint movement produces no relative motion. Distal interphalangeal joint motion produces excursion of Flexor Digitorum Profundus on Flexor Digitorum Superficialis (a mean of 1 mm for ten degrees of flexion in the index finger). Proximal interphalangeal joint motion produces excursion of the Flexor Digitorum Superficialis and Flexor Digitorum Profundus together relative to the sheath (1.3 mm for ten degrees of joint flexion in the index finger).

The significance of these measurements is discussed in relation to the exploration of tendon injuries, the mechanism of failure after tendon repair, dynamic mobilisation and the anatomy of no-man's land.

INTRODUCTION

It has long been recognised that flexor tendon repairs in the distal palm and proximal finger do badly. Bunnell (1918) coined the term "no-man's land" for this area having skin boundaries extending from the distal palmar crease proximally to the proximal interphalangeal joint crease distally. This more or less corresponds to the flexor tendon sheath, which has been implicated as the major factor giving rise to problems.

Choosing a surface marking to classify deep injuries must however encompass tendon injuries over a greater length due to the excursion of the tendons through this area. Obviously the point of tendon injury must depend on whether the hand is in extension as in a protective wound or in flexion as when an assailant's hand slips down the dagger.

Surprisingly little attention has been paid to the magnitude of normal flexor tendon excursions.

Bunnell (reported by Boyes 1964) has made a few measurements in one cadaver and Kaplan (1965) has estimated total excursion at the metacarpo-phalangeal joint level alone. A more precise examination has therefore been undertaken to define the complex relationships of the three structures involved: the superficial and deep flexor tendons and the sheath.

MATERIALS AND METHODS

An experiment was devised to measure normal flexor tendon excursions. Fifty four fingers in fourteen hands were dissected in fresh cadavers. In every case the entire flexor apparatus was exposed by removal of skin from the distal palmar crease to the distal interphalangeal joint (Fig. 1). The tendons were exposed by partial excision of the sheath leaving sufficient pulleys to prevent bowstringing. All flexor tendons were tenotomised at the wrist to undo the rigor mortis position of balance.

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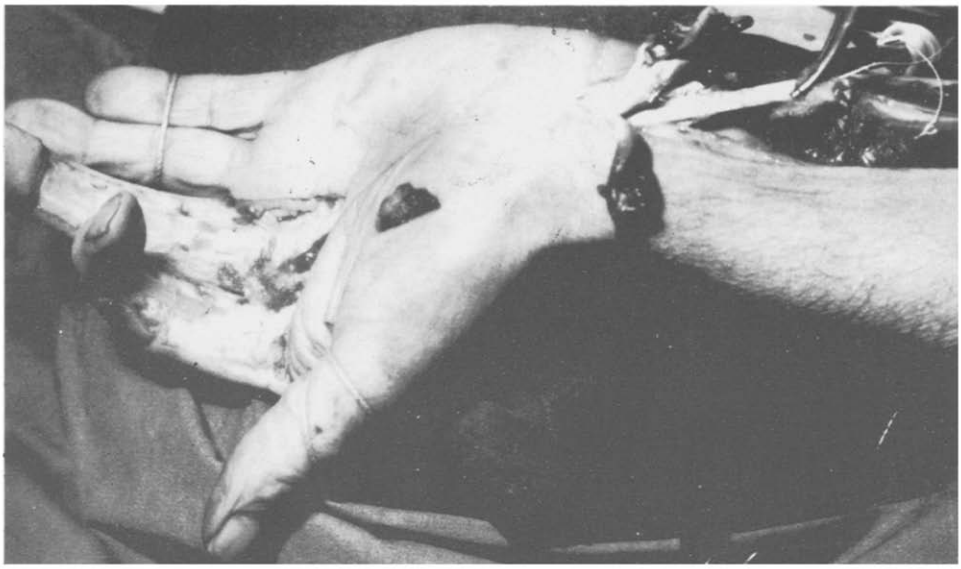

Fig. 1. Exposure of the flexor tendons. Simulated "active" tendon motion by traction on the Flexor Digitorum Profundus tendon.

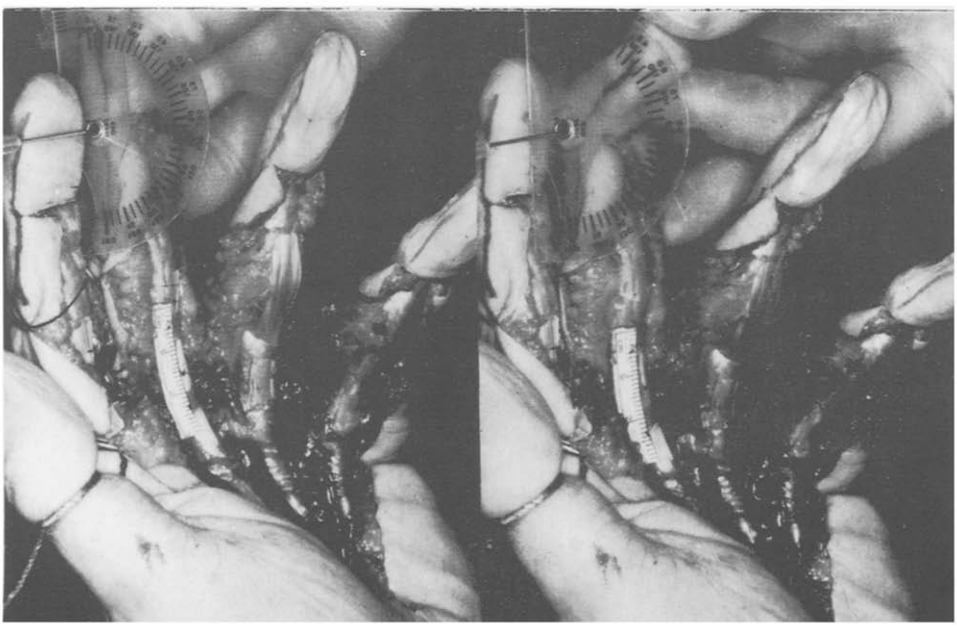

Fig. 2(a). Passive positioning of the distal interphalangeal joint in 10 degrees of flexion (middle finger left hand).

Fig. 2(b). The distal interphalangeal joint flexed 50 degrees. The excursion of the Flexor Digitorum Profundus (distal suture) relative to the apex of the Superficialis decussation (proximal suture) can be measured.

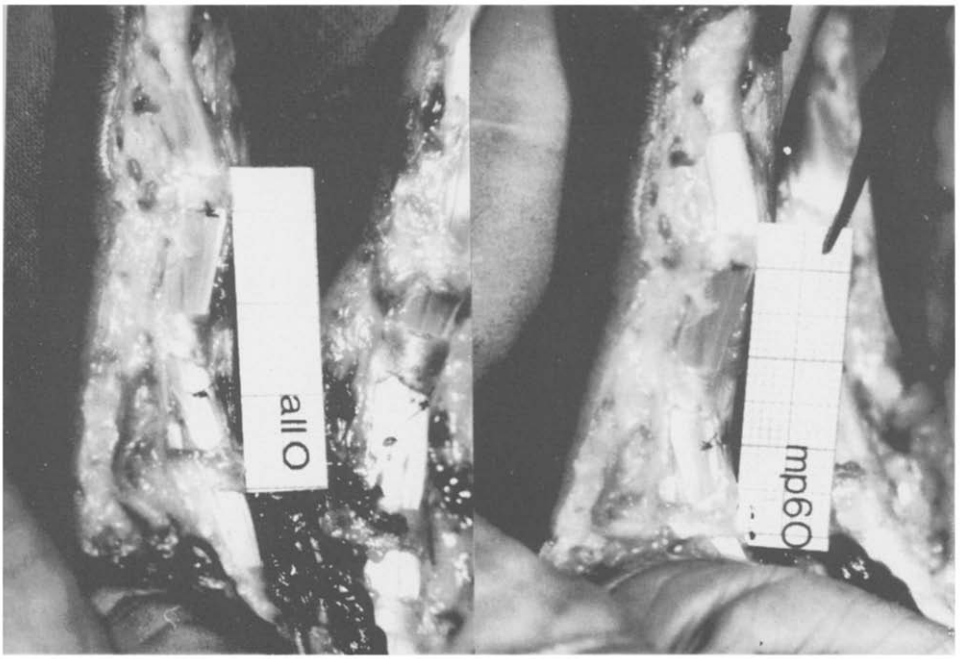

Fig. 3(a). The positions of the sutures on the Flexor Digitorum Profundus (distally) and on the Flexor Digitorum Superficialis and sheath (at the same level, proximally) with the metacarpo-phalangeal joint extended.

Fig. 3(b). With the metacarpo-phalangeal joint flexed 60 degrees, there is no relative movement of the sutures.

This allowed free passive motion of the finger joints. The deep and superficial flexor tendons for the fingers under examination were gripped with artery forceps at the wrist. Simulated "active" motion of the finger joints could then be achieved by pulling on the tendons at the wrist (Fig. 1). In practice to allow movement of only one joint at a time the joints were passively positioned and the tendons tensioned by pulling at the wrist to remove slack.

A marking suture was placed in the superficial flexor tendon at the apex of the decussation (Figs. 2 and 3). This was generally over the proximal phalanx at the level of the proximal finger skin crease, but some variation was noted.

A second suture was placed in the sheath at the same level as the first suture with the finger extended (Fig. 3). A third was placed far enough distally in the profundus tendon to be still visible distal to the decussation throughout the full range of motion (Fig. 3). Joint measurement was made by a protractor located by transfixing its axis at the joint centre transversely by a hypodermic needle (Fig. 2).

First, the excursion of the profundus tendon relative to the superficial tendon was measured. The relative distance between the tendon sutures was measured in full extension and in every 10 degrees of distal interphalangeal joint flexion (Fig. 2) to 60 degrees, the other joints being held straight. Sixty degrees was the maximum flexion that could generally be achieved without also flexing the proximal interphalangeal joint.

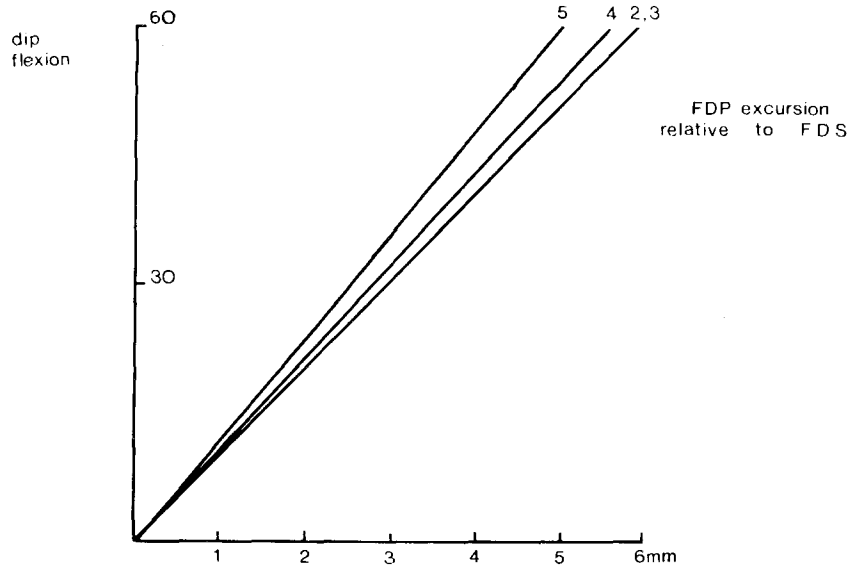

Fig. 4. The excursions of the Flexor Digitorum Profundus (FDP) relative to Flexor Digitorum Superficialis (FDS) (and therefore relative also to the sheath) on flexion of the distal interphalangeal joint alone. Index 2, Middle 3, Coincide; Ring 4; Little Finger 5.

Next, the excursion of the superficial tendon was measured relative to the sheath, for every ten degrees of proximal interphalangeal flexion from full extension to ninety degrees of flexion (Fig. 7).

Thirdly, the excursion of the profundus tendon was measured relative to the sheath for a wind up of both interphalangeal joints (i.e. 60 degrees distal interphalangeal and 90 degrees proximal interphalangeal flexion). (Fig. 7c).

RESULTS

It must be emphasised that pure metacarpo-phalangeal joint motion produces no passive excursion of the tendons at the point of examination over the proximal phalanx as shown in Figure 3. The 20mm gap between the tendon sutures in full extension (Fig. 3a) remains unchanged in 60 degrees of metacarpo-phalangeal flexion (Fig. 3b) i.e. there is no relative motion of the tendons or sheath distal to the metacarpo-phalangeal joint and therefore in most of "no-man's land" when that joint moves.

Distal interphalangeal joint motion produces excursion of the profundus on superficialis as shown in the graph in Fig. 4. The relationship between flexion and tendon excursion is more or less linear. This was surprising as mathematical analysis assuming the joint to be a hinge had predicted a curve. The interphalangeal joint is not a pure hinge however, since the tendon attachment on the distal phalanx migrates proximally as the distal phalanx glides around the head of the middle phalanx giving a more or less linear relationship.

Table 1 gives mean values of tendon excursion.

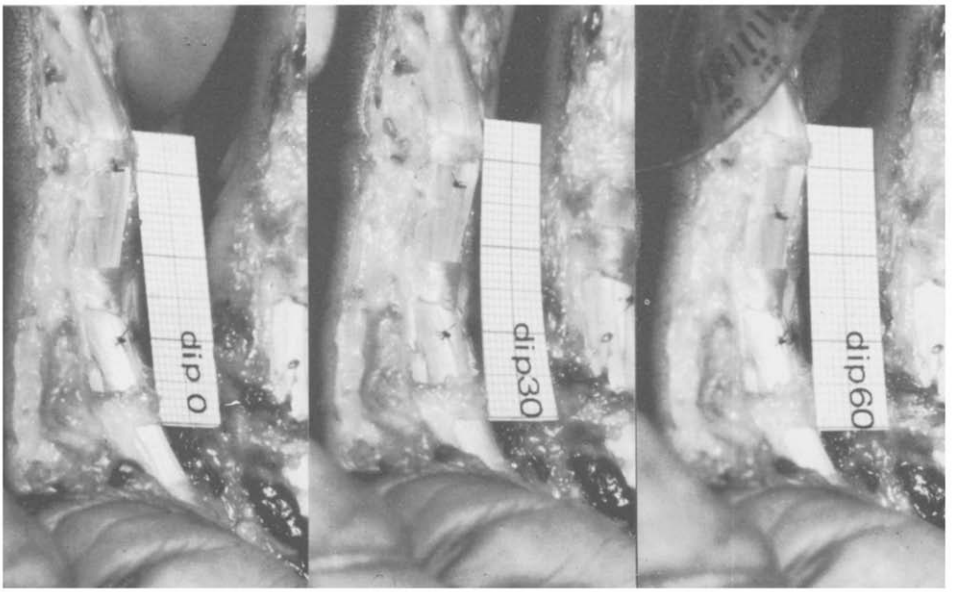

Fig. 5(a). With the distal interphalangeal joint extended, the distance between the tendon sutures is 20mm.

Fig. 5(b). In 30 degrees distal interphalangeal flexion the tendon sutures are 17mm apart, and

Fig. 5(c). In 60 degrees distal interphalangeal flexion, 14mm apart. i.e. a total excursion of 6mm for 60 degrees flexion.

For the index finger the mean profundus excursion is of the order of 1 mm for ten degrees of flexion. An example is shown in Fig. 5.

In full extension the distance between the tendon sutures is 20mm (Fig. 5a). In thirty degrees of distal interphalangeal joint flexion the gap is 17mm (Fig. 5b) and in sixty degrees flexion 14mm (Fig. 5c) giving a total excursion of 6mm for sixty degrees of distal joint flexion.

TABLE 1
MEAN VALUES OF TENDON EXCURSION

	index	middle	ring	little
Excursion of FDP relative to FDS (and sheath)——for 10° dip flexion	1.0 ±0.4	1.0 ±0.15	0.95 ±0.25	0.84 ±0.3
Excursion of FDS relative to sheath——for 10° pip flexion	1.3 ±0.2	1.4 ±0.4	1.2 ±0.4	1.0 ±0.2
Total profundus excursion (full ext. to 90° pip and 60° dip flexion)	16.0 ±6.0	17.6 ±4.8	16.7 ±4.8	15.0 ±5.2

There is no statistically significant difference between the flexor digitorum profundus excursions in the different digits. The flexor superficialis excursions are significantly different ($1\% < p < 0.1\%$) and the difference between profundus and superficialis is significant ($p > 1\%$). These values concur with the anatomical arrangement.

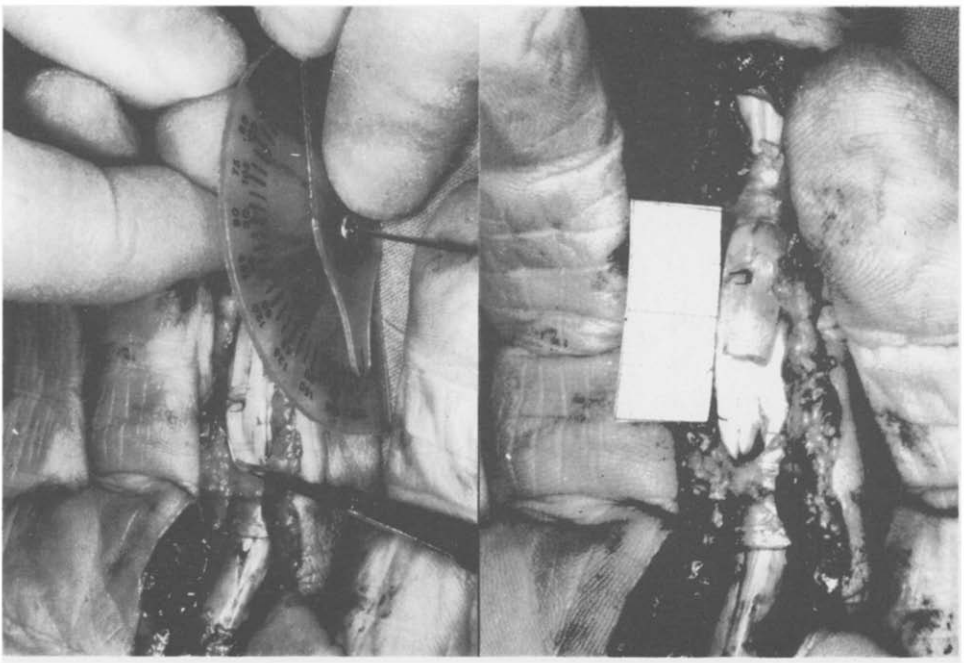

Fig. 6(a). The Flexor Digitorum Profundus divided with the distal interphalangeal joint in 60 degrees of flexion.

Fig. 6(b). On extending the distal joint the Flexor Digitorum Profundus retracts 6mm.

These figures were confirmed by another experiment (Fig. 6) in which the flexor profundus tendon was cut transversely over the midpoint of the proximal phalanx with the distal interphalangeal joint in sixty degrees of flexion and the flexor retraction on fully extending the finger was 6mm.

When we consider excursion of the superficialis tendon we see that pure proximal interphalangeal joint motion produces excursion of the superficialis relative to the sheath as in the Fig. 8 and Table 1.

Again a more or less linear relationship of the order of 1.3mm for ten degrees of joint flexion of the index finger.

An example is shown in Fig. 7. There is no gap between the superficialis and sheath sutures at rest (Fig. 7a). On flexing the proximal interphalangeal joint 90 degrees (Fig. 7b) both profundus and superficialis travel 12mm relative to the sheath.

On further flexing the distal interphalangeal joint 60 degrees (Fig. 7c) the relationship between sheath and superficial tendon remains unchanged but the profundus moves a further 7mm relative to the superficial tendon.

Therefore, where the distal interphalangeal joint is fixed both tendons are moving more or less together relative to the sheath. There is just a little relative movement to allow for their having different arcs of circles, but this is less than

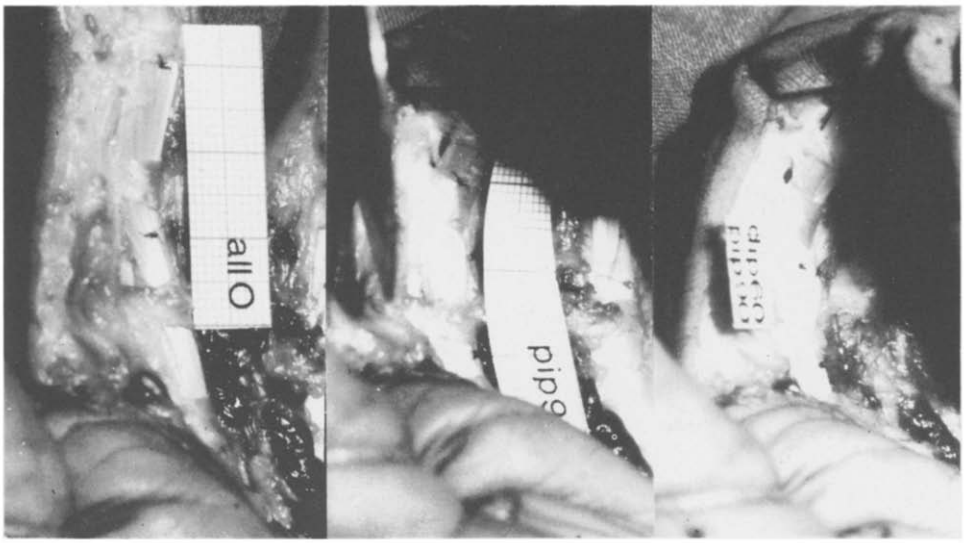

Fig. 7(a). The tendon suture positions with the proximal interphalangeal joint fully extended.

Fig. 7(b). When the proximal interphalangeal joint is flexed to 90 degrees, both flexor tendons move 12mm proximally, but they remain 20mm apart.

Fig. 7(c). When the distal interphalangeal joint is now flexed 60 degrees, the Flexor Digitorum Profundus travels a further 6mm relative to the Superficialis.

1mm for the proximal interphalangeal joint range. Therefore the only factor accounting for movement of the profundus on the superficialis is flexion of the distal interphalangeal joint. Conversely, if the tendons adhere over the proximal phalanx they will act as a mass proximal interphalangeal joint flexor.

Again, the accuracy of these measurements of superficial tendon excursion can be shown by cutting the tendons over the middle of the proximal phalanx with the proximal interphalangeal joint in flexion (Fig. 9). Here the superficial tendon is seen to retract 10mm for ninety degrees of flexion. Incidentally, the profundus has retracted a further 5mm for sixty degrees distal interphalangeal flexion, indicating a total excursion of 15mm relative to the sheath in this case. The average index profundus excursion relative to the sheath was 16mm for sixty degrees distal interphalangeal and ninety degrees proximal interphalangeal flexion.

CASE REPORT

These measurements are confirmed by the following case report:—

A fourteen year-old girl presented with a foreign body attached to her deep flexor tendon visible by blanching of the overlying skin; (Fig. 10a) metacarpophalangeal flexion did not move it (Fig. 10b), proximal interphalangeal flexion did not move it, (Fig. 10c) distal interphalangeal flexion moved it (Fig. 10d) 8mm for 80 degrees (Fig. 10e) agreeing with our experimental findings. Further measurements in operative cases with divided tendons have also confirmed these findings.

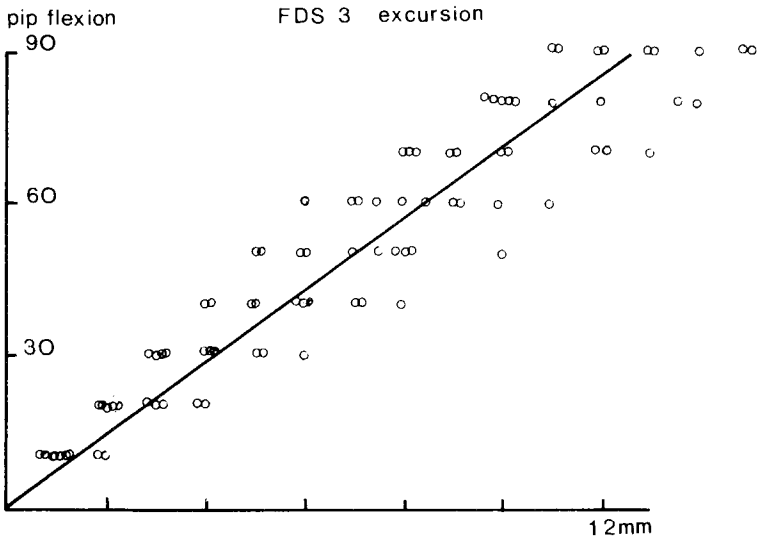

Fig. 8(a). The values of Flexor Digitorum Superficialis excursion in the middle finger (3) are shown for 10 subjects.

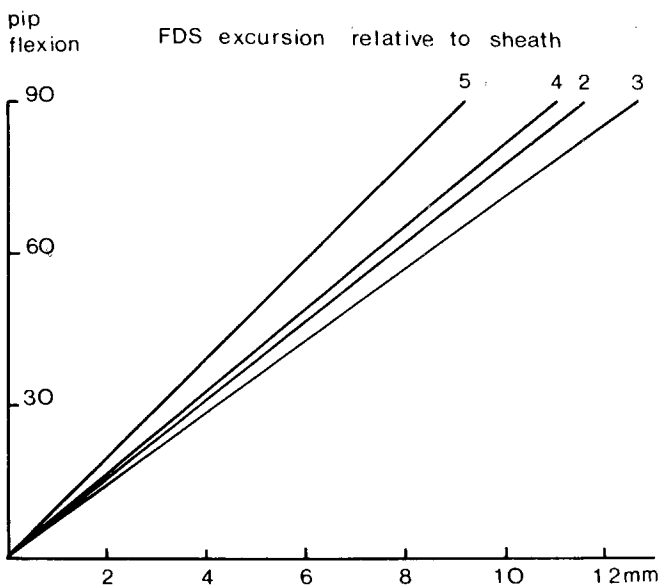

Fig. 8(b). The mean excursions of Flexor Digitorum Superficialis shown for the index (2), middle (3), ring (4) and little (5) fingers for flexion of the proximal interphalangeal joint to 90 degrees. The Flexor Digitorum Profundus has an almost identical excursion relative to the sheath in the proximal segment on flexion of the proximal interphalangeal joint alone.

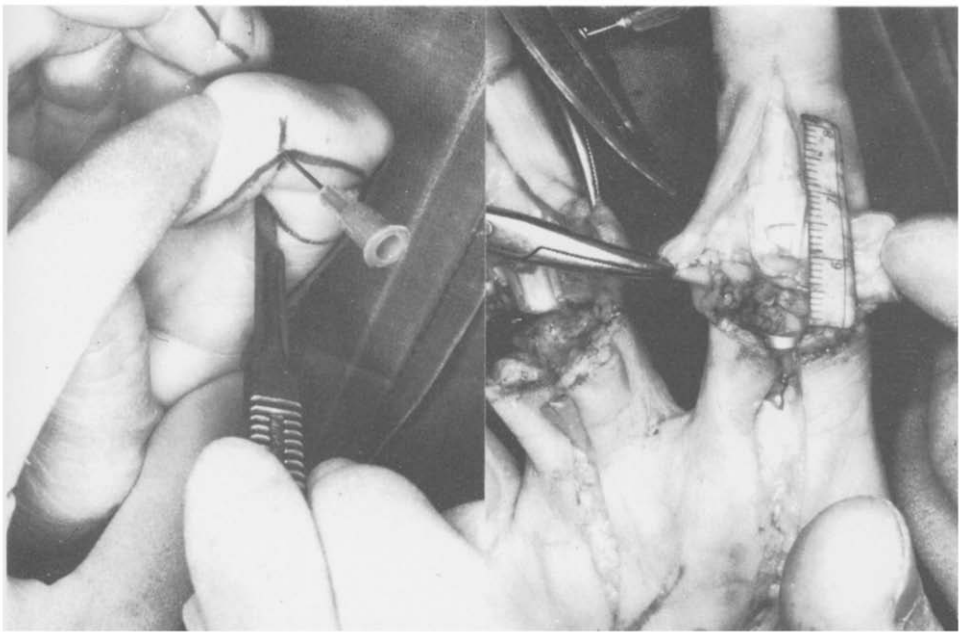

Fig. 9(a). Both tendons being divided with the proximal interphalangeal joint flexed 90 degrees, and the distal interphalangeal joint flexed 60 degrees.

Fig. 9(b). On extension in this case the Flexor Digitorum Superficialis is seen to retract 10mm and the Profundus a further 5mm.

DISCUSSION

The flexor tendon excursion found was less than anticipated. Although most surgeons have a mental picture of the amount of flexor tendon excursion this may be erroneously judged from the observed retraction of the proximal ends after division. The true excursion can of course only be measured by the residual length of the distal ends.

An application of the excursion measurements is the ability to predict how far the tendon ends will be found distal to the wound when the tendons are cut in flexion. If a finger is cut in extension the distal ends will be found at the wound but if cut in flexion the distal ends will retract by 16mm in the case of the flexor profundus for 60 degrees distal interphalangeal and ninety degrees of proximal interphalangeal joint wind up. This information gained at the start of repair will allow more logical planning in extension of the wound.

Classification of tendon injuries by skin boundaries or even by tendon sheath landmarks is inaccurate due to the tendon excursions and is denying the importance of the level of tendon division. A new look at tendon injuries with more accurate recording of the precise level of tendon divisions (i.e. is the superficial tendon one tendon or two, anterior, lateral or posterior to the profundus), whether they are cut in flexion or extension and how much the repairs are offset, may illuminate anatomical situations of particular difficulty.

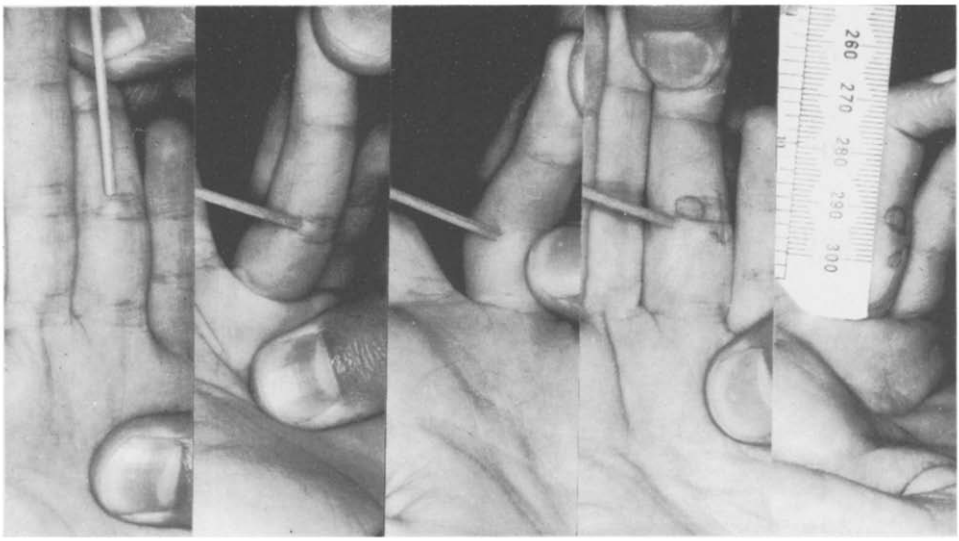

Fig. 10(a). Foreign body attached to Flexor Digitorum Profundus seen by blanching of the overlying skin at the tip of the orange stick.

Fig. 10(b). On metacarpo-phalangeal joint flexion, there is no excursion.

Fig. 10(c). On proximal interphalangeal joint flexion there is again no movement as the foreign body lies distal to the joint line.

Fig. 10(d). On distal interphalangeal joint flexion the blanched area migrates proximally, as indicated by the arrow.

Fig. 10(e). The maximum excursion is 8mm for 80 degrees of distal interphalangeal joint flexion.

Failure of tendon repair is due to *Dehiscence* or *Adhesion*. Most agree that dehiscence is less frequent with a good technique and failures are therefore generally due to adhesions. In view of the small excursions the occurrence of adhesion failure is not at all surprising. The smallest excursion is between the profundus and superficialis and on purely mechanical grounds this would therefore seem to be most vulnerable to adhesion. This would seem particularly likely to happen where the two cut tendons are lying side by side in the resting position when the suture lines may never be more than half of the total relative excursion distance apart.

The excursion between superficialis and sheath suggests that these structures would be the next most likely to adhere. The profundus seems least likely to stick to the sheath in the proximal segment assuming full joint mobility. However, if the profundus were to adhere to the superficialis first then the whole profundus-superficialis complex would have an excursion relative to the sheath the same as the superficialis alone, and adhesions of the entire system might follow. How failure occurs is somewhat speculative, but these mechanical factors are certainly working to the surgeon's disadvantage, and the traditional view of a piston sticking in a cylinder is rather too simple.

Mechanically excision of the superficialis would seem likely to lessen the chances of adhesion failure in the proximal segment of the finger since the two remaining structures, flexor digitorum profundus and the sheath have a good

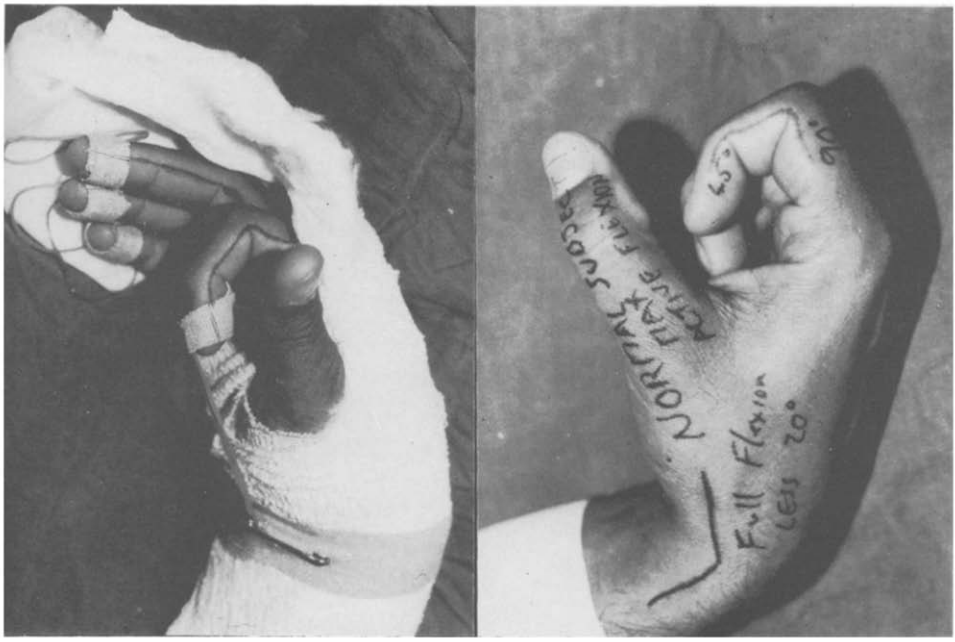

Fig. 11(a). A Kleinert dynamic splint (normal uninjured subject) to show the maximum passive flexion.

Fig. 11(b). With the wrist held in the same position, the maximum possible active flexion is as shown.

relative movement, but Lister (1977) has suggested in a small number of cases that the results are poorer and other factors may therefore be more important, e.g. damage to the blood supply in excision of the superficial tendon.

Kleinert's (1979) approach has been to avoid adhesions by early motion or at least to encourage long lax adhesions loose enough to allow motion. Let us consider what tendon motion occurs in a Kleinert splint. Applied as recommended (Lister, 1977) we have found the splint to produce ranges of joint motion in normal subjects of 33 degrees at the distal interphalangeal and 74 degrees at the proximal interphalangeal joints (Mean of 12 digits).

These were normal subjects without oedema or pain presumably achieving the best possible range of motion that can be achieved. The calculated ranges of tendon excursions in the proximal digital segment are correspondingly 3.25mm of Flexor Digitorum Profundus relative to superficialis and 9.6mm of superficialis relative to the sheath.

These excursions are small and it appears that the Kleinert splint alone is a poor nobiliser of the distal interphalangeal joint and therefore cross union between the tendons would be expected to be a problem. These small excursions are hardly surprising when it is considered that with the wrist in Kleinert's position (i.e. full flexion less 20 degrees) and the metacarpophalangeal joints flexed the maximum active finger flexion that can be achieved is ninety degrees at the proximal interphalangeal joint and 45 degrees at the distal interphalangeal joint (Fig. 11b) although there is individual variation.

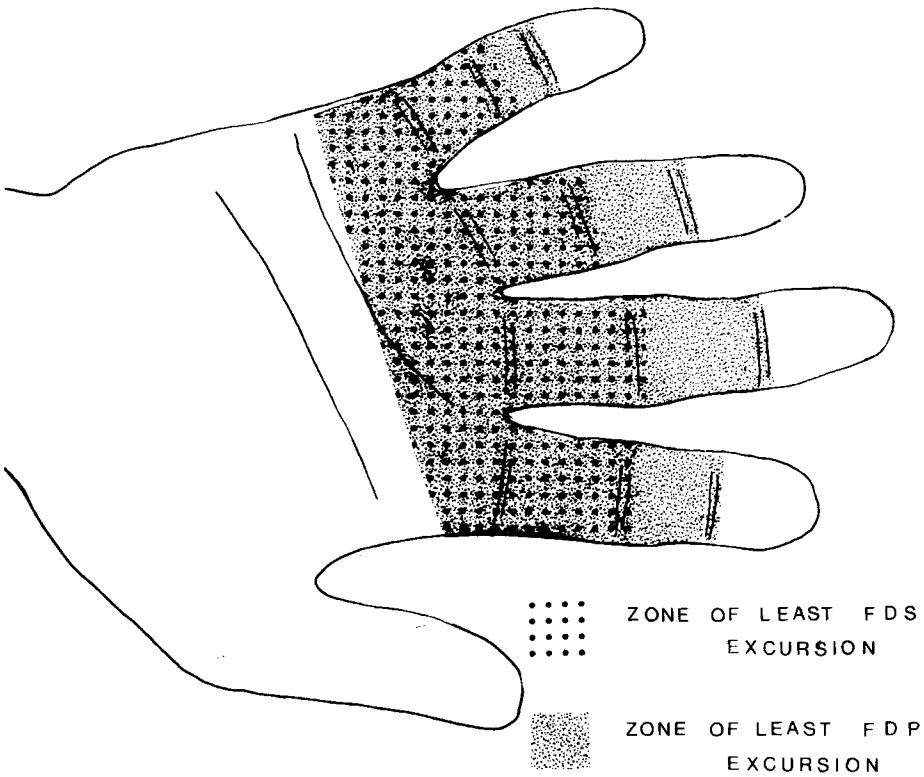

Fig. 12. The zones of least flexor tendon excursion. The Flexor Digitorum Profundus has a poor excursion relative to Superficialis and the latter has a poor excursion relative to the sheath in an area corresponding to No-man's Land, i.e. from the metacarpo-phalangeal joint to the Superficialis insertion. Proximal to the metacarpo-phalangeal joint both tendon excursions are much greater.

Where the distal interphangeal joint is flexed at the time of injury the profundus division will lie further distally than that of the superficialis on finger extension. The static night position of flexion in the Kleinert splint will then produce apposition of the tendon suture lines. Perhaps we should be positioning the finger to avoid this, e.g. a finger cut in flexion should perhaps be immobilised overnight in extension to offset the healing tendon suture lines.

Finally if we consider the distal palm and the zones of least tendon excursion, it will be seen that there is an area of poor superficialis excursion from the metacarpophalangeal joint to its insertion (Fig. 12). If one superimposes on this the zone of poor profundus excursion, relative to superficialis (i.e. from the metacarpophalangeal joint to the profundus insertion the two zones of poor excursion are seen to more or less correspond to Bunnell's no-man's land!

The sheath is important, as is the tendon blood supply but simple mechanical factors must not be overlooked.

ACKNOWLEDGEMENTS

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