The role of fracture reduction and plate position in the aetiology of flexor pollicis longus tendon rupture after volar plate fixation of distal radius fractures

David R. Selvan · David G. Machin · Daniel Perry ·
Claire Simpson · Phillipa Thorpe · Daniel J. Brown

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Abstract

Background Flexor pollicis longus (FPL) rupture has been described as complication following volar plating for distal radius fractures. It has been hypothesised that this is due to plate prominence. The aim of the study was to investigate the relationship between sub-optimal plate position and fracture reduction on plate prominence.

Methods Plate prominence was measured in two experimental models. In the first, the effect of plate position was investigated using 18 fresh frozen cadavers with prominence being measured using a micrometer. In the second study, the effect of fracture reduction on plate prominence was investigated using similar methodology with simulated mal-reductions on dry bone models.

Results The results of the first study showed a significant increase in lift-off for three plates (DVR, Synthes Universal and Acu-Loc), if the plates were moved distally or proximally from the anatomical position. Similar increases in prominence were also seen with rotational mal-positions.

The results of the second study showed a statistically significant effect on plate prominence for even a 5° mal-reduction ($p=0.001$) with worsening lift-off with increasing mal-reduction. These changes are significantly different from baseline and also significantly different to the lift-off recorded with mal-reductions 5° better and worse.

Mal-reductions also necessitate more proximal placement of the plate to avoid screw penetration of the articular surface, and each 5° increment is significantly different from baseline. **Conclusions** The results show a statistically and clinically significant effect of both plate position and fracture reduction

on plate prominence and support the theory that both contribute to the aetiology of post-operative FPL rupture.

Keywords Distal radius · Fracture · Flexor pollicis longus · Tendon rupture · Volar plating

Introduction

The use of volar locking plates for fractures of the distal radius is now routine practice in orthopaedic trauma surgery. Irritation and rupture of flexor tendons, most commonly flexor pollicis longus (FPL), is a well-recognised complication of this surgery. Numerous case reports and papers illustrate that this is a significant problem with FPL rupture rates of up to 12 % of patients following volar plating being reported [1–4, 10]. Further, the symptoms of tendon irritation or tendon rupture may present a considerable period after surgery [5, 8].

A recent study from our institution has shown that sub-optimal fracture reduction and sub-optimal plate position, as seen on post-operative radiographs, are both predictive of FPL rupture [12]. In our series, the most important factors that were predictive of FPL ruptures were the distance of the plate distal to the volar lip and mal-reduction of the radial tilt in respect to fracture reduction.

It is hypothesised in this and an earlier study that this is due to sub-optimal fracture reduction and sub-optimal plate position causing the distal edge of the plate becoming more prominent and allowing it to act as a mechanical irritant during FPL movement [2].

D. R. Selvan (✉) · D. G. Machin · D. Perry · C. Simpson ·
P. Thorpe · D. J. Brown
Department of Orthopaedics, Royal Liverpool University Hospital,
Prescot Street, Liverpool L7 8XP, UK
e-mail: daveselvan@doctors.org.uk

The purpose of this current study is to investigate this hypothesis further by investigating the effect of plate mal-positioning and fracture mal-reduction.

Materials and Methods

Study 1: the Role of Plate Position—a Cadaveric Study

Eighteen fresh frozen cadaveric wrists were examined. Each wrist (nine right and nine left) was from a different individual and had been preserved by freezing. Wrists were thawed before use. None of the cadaveric wrists showed evidence of abnormal anatomy of the distal radius such as evidence of previous trauma, surgery or bony pathology. The cadaveric wrists were prepared by removing the muscle and tendon from the volar surface leaving the ligaments and capsule intact.

Three widely used, commercially available, plates were fixed sequentially in the position of best anatomical fit onto each wrist—choosing the most appropriately sized implant where multiple sizes were available. The plates used were the Synthes LCP distal radius system (Solothurn, Switzerland), the Hand Innovations DVR plate (Miami, FL) and the Acumed Acu-Loc plate (Beaverton, OR). The Synthes plate (Fig. 1) is sided and less anatomical. The DVR plate (Fig. 2) is sided and is an anatomical plate designed to sit behind the

Fig. 1 Radiograph showing the Synthes LCP distal radius system (Solothurn, Switzerland)

Fig. 2 Radiograph showing the Hand Innovations DVR plate (Miami, FL)

‘watershed line’. The Acu-loc plate (Fig. 3) is sided and is an anatomical plate designed to sit on the watershed line and offers more support to the radial styloid.

Each plate was aligned parallel to the long axis of the radial shaft to avoid rotation of the plate. The contour of the plate was aligned with the volar flare of the distal radius so that it sat

Fig. 3 Radiograph showing the Acumed Acu-Loc plate (Beaverton, OR)

in the pronator fossa. This position of best fit was then confirmed radiographically using an image intensifier.

In this anatomical position, the distance between bone and plate was measured at the distal end of each plate using a Starrett precision measuring gauge (Athol, MA) (Fig. 4). This was measured at the radial, middle and ulna aspects of the plate and the mean of these results calculated. The plate thickness was subtracted from this to calculate plate ‘lift-off’. Lift-off is defined as representing the distance between the distal edge of the plate and the bone and is demonstrated in Fig. 5. We define lift-off as the distance from the cortex of the bone to the bone facing side of the plate in millimetres.

This ‘best fit’ position of the plate was marked on the bone. The plate was then repositioned 5 mm proximally, and the lift-off was recalculated. The same process was repeated moving the plate 5 mm distally. Each plate was then again repositioned by angulation through 10° from the position of best fit. The plate was rotated about the midpoint of the plate in a radial direction and then subsequently in an ulna direction. The lift-off was again recorded.

Study 2: the Role of Fracture Reduction—a Saw Bone Study

Sixteen identical saw bone distal radii (Pacific Research Laboratories Inc., Vashon, WA, USA) were used. A wide Acumed Acu-Loc plate (Beaverton, OR) was used, as this best matched the anatomy of the saw bone model.

The plate was placed onto each saw bone in the best anatomical position. Once the best position was confirmed, a K-wire was passed through the middle screw hole in the distal row in order to mark this position. Lift-off was measured in this position in an identical way as in the above study. The bones were then split into four groups. Using custom cutting blocks, a closing dorsal wedge was removed to simulate a fracture being fixed in varying degrees of mal-reduction. Group 1 had a 5° wedge removed, group 2 a 10° wedge, group 3 a 15° wedge and group 4 a 20° wedge. The osteotomy was closed, initially held with a bone clamp and subsequently with K-wires. Lift-off was again measured.

As the screw holes on this plate (and the wire holes) are fixed-angle, a mal-reduced fracture in dorsal angulation causes the screws on a previously anatomically positioned

Fig. 4 Anatomically positioned volar locking plate

Fig. 5 Proximally positioned volar locking plate. The arrow indicates the ‘lift-off’ measured in each case

plate to enter the joint. Mal-reduction necessitates the plate be moved more proximally to prevent the distal screws breaching the joint. The plate was therefore repositioned in the most distal position possible with the distal screws still within the bone and the position marked with a K-wire as above. The distance between the original K-wire hole and this one was measured to give a value for how far the plate needed to be moved proximally when the fracture was fixed with a mal-reduction.

Statistical Analysis

In both studies, the mean lift-off across each plate was calculated and the 95 % confidence interval for each established. In the first study, results were compared between the differing plate positions using a two-tailed Wilcoxon signed-rank test. A p value of <0.05 was considered statistically significant. In the second study, as well as the lift-off with differing degrees of mal-union, the amount of obligated proximal migration of the plate was also analysed. A two-tailed Wilcoxon signed-rank test was again used. In the second study, as well as comparing the results with the position of best fit, the results were also compared with a 5° better and worse mal-union.

Results

Study 1: the Role of Plate Position

Three different sizes of DVR plate were used—small ($n=1$), medium ($n=13$) and large ($n=4$). The Synthes plate is of universal size, and consequently, one size was used for all cadavers ($n=18$). Two different sizes of Acu-Loc plate were used—medium ($n=13$) and large ($n=5$).

Comparing the most commonly used plates (medium DVR, medium Acu-Loc and universal Synthes plate), a similar and significant change was seen with each plate when translated proximally and distally and when rotated in a radial and ulna direction (Tables 1 and 2).

Mean lift-off in the DVR plate increased significantly from 0.83 mm (95 % confidence interval (CI) 0.58–1.08 mm) in the anatomical position to 2.11 mm (95 % CI 1.73–2.49 mm,

Table 1 Degree of lift-off associated with proximal and distal translation of the plate

Plate	<i>n</i>	Mean ‘lift-off’ across plate (mm) in differing positions (95 % confidence intervals)		
		Anatomical	Distal positioning	Proximal positioning
DVR (small)	1	0.09	0.73	2.19
DVR (medium)	13	0.83 (0.58–1.08)	2.11 (1.73–2.49) $p<0.001$	2.05 (1.56–2.54) $p<0.001$
DVR (large)	4	0.94 (0.07–1.80)	2.60 (0.05–5.14) $p=0.13$ -NS	2.45 (2.02–2.87) $p=0.13$ - NS
Synthes Universal	18	1.89 (1.56–2.22)	2.61 (2.33–2.89) $p<0.01$	2.51 (2.08–2.95) $p<0.05$
Acu-Loc (medium)	13	0.68 (0.41–0.94)	1.81 (1.56–2.05) $p<0.001$	2.67 (2.24–3.09) $p<0.001$
Acu-Loc (large)	5	0.87 (0.23–1.52)	3.33 (2.60–4.06) $p=0.06$ -NS	2.61 (1.81–3.41) $p=0.06$ -NS

Table showing the mean lift-off for each plate in their anatomical position, distal and proximal positions. The confidence interval for each is included, and the p value for mean lift-off for distal and proximal positions compared to the anatomical position for each plate is shown. p is significant if <0.05
 NS not significant

$p<0.001$) when repositioned 5 mm distally and 2.05 mm (95 % CI 1.56–2.54 mm, $p<0.001$) when repositioned 5 mm proximally. Radial angulation similarly produced an increase in plate lift-off ($p<0.001$), as did ulnar angulation, but this failed to reach statistical significance.

Mean lift-off in the universal Synthes plate increased from 1.89 mm (95 % CI 1.56–2.22 mm) in the anatomical position to 2.61 mm (95 % CI 2.33–2.89 mm, $p<0.01$) when repositioned 5 mm distally and 2.51 mm (95 % CI 2.24–3.09 mm, $p<0.05$) when repositioned 5 mm proximally. Ulnar angulation similarly produced an increase in plate lift-off ($p<0.01$), as did radial angulation although this failed to reach statistical significance.

Mean lift-off in the Acu-loc plate increased from 0.68 mm (95 % CI 0.41–0.94 mm) in the anatomical position to 1.81 mm (95 % CI 1.56–2.05 mm, $p<0.001$) when repositioned 5 mm distally and 2.67 mm (95 % CI 2.24–3.09 mm, $p<0.001$) when repositioned more 5 mm proximally. Both radial and ulnar angulation similarly produced an increased in plate lift-off ($p<0.01$).

Similar trends can be seen in the table for the DVR small and large plates and the Acu-loc large plate, but with a small numbers of plates, the results failed to reach statistical significance.

Study 2: the Role of Fracture Reduction

Mean lift-off with the Acu-loc plate on the saw-bone model was 0.78 mm, which is comparable with the findings on the cadaveric bone (mean 0.68 mm, 95 % CI 0.41–0.94), and confirms that the saw-bone model is appropriate for this purpose.

Mean lift-off increased significantly with even a 5° mal-reduction to 3.14 mm ($p=0.001$). Further amounts of mal-reduction increased lift-off even further with a 20° mal-reduction creating lift-off of 6.96 mm (Table 3). These increasing lift-off measurements with increasing 5° steps of mal-reduction are not only significantly different than baseline, but also significantly different to the lift-off recorded with mal-reductions 5° better and worse (see Table 3).

Table 2 Degree of lift-off associated with radial and ulnar angulation of the plate

Plate	<i>n</i>	Mean ‘lift-off’ across plate (mm) in differing positions(95 % confidence intervals) p value		
		Anatomical	Ulnar angulation	Radial angulation
DVR (small)	1	0.09	0.99	0.83
DVR (medium)	13	0.83 (0.58–1.08)	0.99 (0.76–1.24) $p=0.31$ -NS	1.32 (1.01–1.63) $p<0.001$
DVR (large)	4	0.94 (0.07–1.80)	1.11 (0.44–1.78) $p=0.63$ -NS	1.60 (0.48–2.72) $p=0.13$ -NS
Synthes	18	1.89 (1.56–2.22)	2.23 (1.86–2.59) $p<0.01$	2.02 (1.15–2.32) $p=0.70$ -NS
Acu-Loc (medium)	13	0.68 (0.41–0.94)	1.12 (0.82–1.41) $p<0.01$	1.01 (0.76–1.26) $p<0.01$
Acu-Loc (large)	5	0.87 (0.23–1.52)	2.46 (1.28–3.65) $p=0.06$ -NS	1.35 (0.67–2.03) $p=0.06$ -NS

Table showing the mean lift-off for each plate in their anatomical position, ulna and radial angulations. The confidence interval for each is included, and the p value for mean lift-off in ulna and radial angulation compared to the anatomical position for each plate is shown. p is significant if <0.05

NS not significant

Table 3 Degree of lift-off associated with simulated mal-union of a fracture

Reduction	Lift-off			
	Mean	SD	P1	P2
Anatomical	0.78	0.49	–	
5° mal-union	3.14	0.66	=0.001	=0.001
10° mal-union	5.34	0.97	<0.001	<0.001
15° mal-union	7.48	0.99	<0.001	<0.001
20° mal-union	6.96	1.86	<0.001	=0.04

Table showing the effect of mal-union on plate lift-off (measured in mm). P1 represents the level of significance compared with anatomical. P2 represents the level of significance compared with a 5° greater or lesser mal-union

Mal-reductions also necessitate more proximal placement of the plate in order to avoid screw penetration of the articular surface. This proximal migration increases with the amount of mal-reduction with 3.71-mm movement required with a 5° mal-reduction and 7.7 mm with a 20° mal-reduction. Again, each 5° increment is significantly different from baseline and significantly different from the next increment with the exception of the 5–10° increment which nears significance (see Table 4).

Discussion

We have recently demonstrated that imperfect plate position and fracture reduction, as seen on post-operative radiographs, were predictive of FPL rupture and hypothesised that this was due to an increased plate prominence with sub-optimal plate position or fracture reduction [12]. This hypothesis has also been put forward by other authors [2, 3, 9, 13]. The results of this study seem to support this argument with both statistically

Table 4 Amount of enforced proximal migration of a plate caused by a simulated mal-union

Reduction	Proximal plate movement			
	Mean	SD	P1	P2
5° mal-union	3.71	0.41	<0.001	
10° mal-union	4.38	0.52	<0.001	=0.07
15° mal-union	5.91	1.07	<0.001	=0.02
20° mal-union	7.7	1.02	<0.001	=0.03

Table showing the effect of mal-union on enforced proximal plate movement required to avoid the screws penetrating the joint surface (measured in mm). P1 represents the level of significance compared with anatomical. P2 represents the level of significance compared with a 5° greater or lesser mal-union

and clinically (mechanically) significant increases in lift-off, our measure of prominence, seen with both sub-optimal plate position and sub-optimal fracture reduction. The studies presented seem to provide evidence to support this hypothesis, with the suggestion that FPL ruptures may be caused by attrition rupture over prominent metalwork.

The studies demonstrate that plate prominence is relatively intolerant of minor errors in both plate position, distance of plate from joint and rotation from long axis of the radius and sub-optimal fracture reduction, with as little as a 5° loss of position leading to a fourfold increase in plate prominence.

In our cadaveric study of plate position, and contrary to the work of Soong et al., this does not seem to be plate-specific [14]. The plates chosen here represent an anatomical plate designed to sit on the watershed line (the Acu-loc plate), an anatomical plate designed to sit behind the watershed line (the DVR plate) and a less anatomical plate (the Synthes plate) [11].

With both the DVR and the Acu-loc plates, there is very little lift-off when the plates are situated appropriately but a marked (and similar) increase in lift-off when positioned sub-optimally. The effect seems to hold for different plate sizes, although the numbers in the groups are too small to confirm this statistically.

A difference in plate lift-off was less evident in the Synthes plate, which, we hypothesise, may be because this plate is less ‘anatomical’ and, therefore, has notable lift-off even when positioned in position of best fit. The prominence of the plate when sub-optimally situated is, however, similar to the others. Newer Synthes plates are more anatomical and, therefore, are likely to have less lift-off in their optimal position. It is also noted that an ‘original’ Acu-loc plate was used in this study. This is similar to the new ‘distal’ Acu-loc 2 plate in terms of its shape and positioning, whereas the ‘proximal’ Acu-loc 2 sits in position similar to the DVR. As our hypothesis is that this is not a plate-specific problem but will affect all volar distal radial plates, we would still anticipate a significant increase in lift-off in badly positioned plates and badly reduced fractures.

It is result of this opinion that this is not a plate-specific effect and that we only tested one plate in the second study, and it is our assertion that the results would have been comparable had we repeated this with the other plates.

In the paper by Soong et al., they suggest that the prominence of the plate can be graded by the position of the plate with reference to the watershed line as seen on lateral radiographs [14]. We would suggest that this is a function of the design of the plate. Some are designed to sit more distally, providing more support to distal fragments and will therefore always be graded, using their system, as 2. Others are designed to sit behind the watershed line and will be graded 0. It is our hypothesis that this is not the major issue regarding plate prominence. Instead, it is a badly positioned plate, a badly

reduced fracture or a combination of the two which cause an anatomical plate to lift-off the bone and present a prominent edge to irritate the tendons that pass over it.

Conclusion

This study strongly supports the belief that sub-optimal plate position and sub-optimal fracture reduction are both key to the development of FPL ruptures following volar plating of distal radial fractures. Furthermore, post-operative radiographs highlighting these variables are predictive of FPL rupture. As other authors have shown, volar locking plates are extremely efficient at maintaining fracture reduction [7, 11]. It therefore can be assumed that intra-operative radiographs are also predictive of post-operative rupture. We strongly recommend that at the time of surgery, strict attention to detail is required to optimise both plate position and fracture reduction. Although there are several papers that suggest that this is not essential for long-term functional outcome, it appears necessary to minimise the risk of rupture to the FPL tendon [6, 7].

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Conflict of Interest Daniel J. Brown (senior author) is a consultant for Acumed and receives royalties for the Acu-Loc 2 plate. None of the other authors David R. Selvan, David G. Machin, Daniel Perry, Claire Simpson and Phillipa Thorpe have any conflict of interest to declare.

Statement of Human and Animal Rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent No informed consent was required for this work.

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