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ORIGINAL STUDY

Breakage of volar locking plate system for distal radius fractures

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The purpose of this study was to elucidate the causes of implant breakage of the volar locking plate system for distal radius fractures and to propose measures for its prevention. Medical data of patients without and with implant breakage were retrospectively compared. Postoperative reduction loss significantly affected implant breakage and should lead to close monitoring of these patients. Moreover, the absence of a distal locking screw aiming at the radial styloid and plate fixation with a gap formation of 2 mm or greater from the volar surface of the distal radius were significantly associated with breakage of distal locking screws and should be avoided.

Keywords: Distal radius fracture ; volar locking plate ; implant breakage.

INTRODUCTION

Distal radius fracture is a common fracture of the wrist. In the treatment of distal radius fractures, sufficient reduction and maintaining a satisfactory anatomical position are required because malunion of the fractures lead to poor functional outcome *(8)*, for which surgical treatment tend to be chosen *(5,17)*.

Closed reduction and external fixation is an option for the surgical treatment. However, external fixation can cause a disability associated with the external fixator and delay of joint movement. Furthermore, there is a risk of several complications related to the inserted pin such as pin tract infection, pin loosening, skin adhesion, and irritation of a superficial branch of radial nerve *(13-14,23)*. Thus, the volar locking plate system for distal radius fractures, which provides sufficient stability to allow early range of motion through the use of multidirectional distal locking screws, was introduced and open reduction and internal fixation with the system has rapidly become more and more popular in last decade; however, several complications, such as flexor tendon rupture, extensor tendon rupture, and median nerve neuropathy, have been reported with this procedure *(1,16,21)*. Although implant breakage following this procedure is rare complication, it may require second surgery for correction and alleviation of accompanying symptoms *(2,4,6,10,12,25)*. The cause of implant breakage, however, remains unclear.

We have experienced implant breakage as a postoperative complication associated with the volar locking plate system. Thus, we aimed

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to elucidate the cause of implant breakage in order to propose measures for its prevention by retrospectively comparing medical data of patients with and without implant breakage following treatment for distal radius fracture.

PATIENTS AND METHODS

During the 1-year period from January, 2014 to December, 2015, surgery using the volar locking plate system was performed to treat 40 wrists with distal radius fractures in 39 cases at our hospital. Postoperative implant breakage was observed in 3 wrists (2 patients). The medical backgrounds and radiographs of the 39 patients were retrospectively reviewed to identify differences between wrists without (group A) and with implant breakage (group B).

First, data regarding age, sex, body mass index (BMI), affected side, fracture type based on the AO classification, plate system used, and duration of postoperative immobilization were examined from patient medical records.

Next, multiple radiographic assessments were conducted. Radial inclination (RI) and volar tilt (VT) were measured using wrist radiographs of the affected side at the day of surgery and at 1 month, 3 months, 6 months, and 1 year postoperatively. In addition, RI and VT of healthy wrists were measured in 35 wrists whose preoperative wrist radiographs of the unaffected side were available. The extent of surgical reduction relative to healthy wrists and postoperative reduction loss were assessed using these measurements. Additionally, the maximum distance between the plate and volar cortex of the distal radius (P-Rd1) and the distance between the distal end of the plate and most volar prominent portion on the watershed line of the radius (P-Rd2) were measured using the lateral wrist radiographs of the affected side at the surgery date to assess the immediate postoperative plate position in the volar-dorsal direction and proximal-distal direction, respectively. Locking plates with a 2 mm gap from the bone reduced construct fatigue life (20). Consequently, P-Rd1 of 2 mm or greater was defined as significant gap formation between the plate and distal radius. Finally, to assess the stability of a fixation by distal locking screws, the usage rate of distal locking screw holes was calculated as follows:

(number of used distal locking screw holes)/(the number of total distal locking screw holes) × 100

To assess whether both distal and proximal row of distal locking screw holes had been used or not and to assess the presence or absence of a distal locking screw aiming at the radial styloid, we examined postoperative radiographs.

Data were statistically compared between group A and group B using the Mann–Whitney and $\chi 2$ test; p -values < 0.05 were considered significant. Statistical analyses were performed using SPSS 20 statistical computer software.

RESULTS

Group A comprised 37 wrists (16 right and 21 left wrists) in 37 cases (26 females and 11 males), with a mean age of 65 (range, 34–96) years and a mean BMI of 23.3 (range, 19.6–36.8) kg/m2. AO fracture types were A2 (n = 2), A3 (n = 5), B3 (n = 2), C1 (n = 15), C2 (n = 10), and C3 (n = 3). All volar plate systems were manufactured by the DePuy Synthes company. Variable Angle LCP® Two-column Volar Distal Radius Plate 2.4 (TCP DRP) was used in 34 wrists, LCP Distal Radius System 2.4 Juxta-articular LCP DRP in 2 wrists, and Variable Angle LCP® Volar Rim Distal Radius Plate 2.4 (Volar Rim DRP) in 1 wrist. All wrists, except for one, were immobilized until a mean postoperative day 19 (range, 0–34).

Group B comprised 3 wrists in 2 cases. One case (Figure 1) was a 70-year-old male with a BMI of 24.5 kg/m2 and a previous history of thyroid disease and schizophrenia. He had bilateral distal radius fractures (type A3 in the right and type C1 in the left wrist) and a lumbar vertebra fracture as a result of injury due to fall. His wrists were surgically treated using TCP DRP and immobilized using short arm splints until postoperative day 19. On postoperative day 44, he complained of left wrist pain, with wrist radiograph showing breakage of the distal locking screws in both wrists. He had frequently been placing weight on his wrists because of difficulty in ambulation due to the accompanying

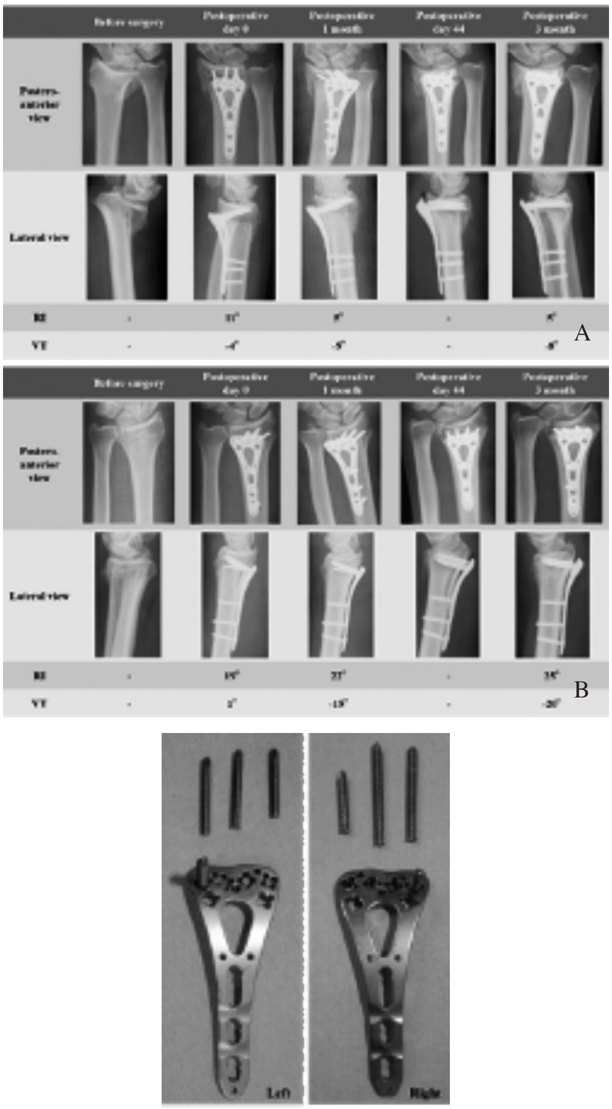

Fig. 1. — Radiographic change in a case of distal locking screw breakage in both wrists: right (A) and left (B). Red arrowheads indicate implant breakage. The removed implant systems were found to have breakage of the distal locking screws at the locking head–shaft junction (C)

lumbar vertebra fracture. During implant removal surgery, all distal locking screws, except for the one fixed at the most ulnar screw hole, were broken at the locking head–shaft junction (Figure 1C). The other case (Figure 2) was a 74-year-old female with a BMI of 21.3 kg/m2 and a previous history of chronic renal failure and left hemiplegia. She had right distal radius fractures (type C1) due to a fall. She had received a Volar Rim DRP without any plate bending procedures, with a short arm cast applied for 14 days postoperatively. However, on postoperative day 14, right wrist pain developed, and breakage of the plate was identified on wrist radiograph. Accordingly, the short arm splint was applied for 15 more days. She had frequently been shifting her weight onto the affected wrist during her daily life, despite immobilization, due to hemiplegia of the uninjured side. Her removed implant revealed that the plate was broken at an unused distal locking screw hole in the proximal row at the fracture site (Figure 2B).

For all wrists in both groups, plate systems had been implanted by orthopedic surgeons who were not specialized in hand surgery and had a mean experience of 3 years (range, 1–13) via the trans flexor carpi radialis approach without bone grafting; digit exercise was allowed immediately postoperatively. Regarding medical record data, implant breakage was not found to be associated with age, sex, BMI , affected side , fracture type , plate system type , and postoperative immobilization duration .

The mean RI at the day of surgery (27.3° in healthy wrists) was 23.9°(range, 15–30) in group A and 17° (range, 11–21) in group B ($p = 0.98$). The mean VT (16.8° in healthy wrists) was 10.5° (range, −15 to 33) in group A and −6° (range, −15 to 1) in group B ($p = 0.16$). Postoperative reduction loss significantly affected implant breakage ($p = 0.02$; $\varphi = 0.46$). Although only 8 wrists (21.6%) had postoperative reduction loss in group A, all wrists in group B had postoperative reduction loss. A mean VT loss of 2.5° (range, 1–4) in 4 wrists and a mean RI loss of 2.9° (range, 2–3) in 7 wrists at 1 month postoperatively, a VT loss of 6° in 1 wrist at 3 months postoperatively, and an RI loss of 2° in 1 wrist at 6 months postoperatively were observed in group A. A mean VT loss of 11.7° (range, 1–20) and a mean RI loss of 7.7° (range, 3–14) at 1 month postoperatively were observed in group B (Figure 1A, B, and 2A). Additionally, although a progress in reduction loss was not observed in group A, the progress could be observed in all wrists of group B after implant breakage between 1 and 3 months postoperatively, with a mean VT loss of 4° (range, 3–5) in 2 wrists and a mean RI loss of 3° in 2 wrists (Figure. 1A, B, and 2A).

There was no wrist for which plate was fixed beyond the most volar prominent portion on

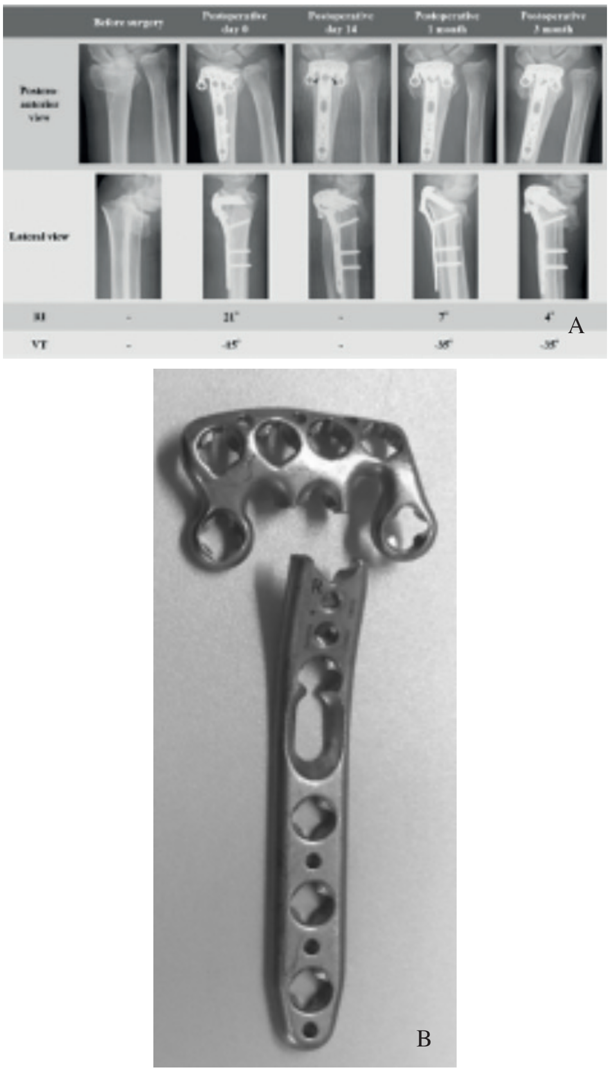

Fig. 2. — Radiographic change in a case of plate breakage (A). Red arrowhead indicates the breakage. The removed plate was found to have breakage at a distal locking proximal screw hole (B)

the watershed line of the radius. Radiographic assessments did not reveal any significant difference between group A and B regarding plate system fixation. A P-Rd1 greater than 2 mm was observed in 7 wrists (18.9%) in group A and in 2 wrists (66.7%), with breakage of distal locking screws, in group B ($p = 0.12$). The mean P-Rd2 was 2.7 mm (range, 0–6) in group A and 3.7 mm (range, 2–5) in group B ($p = 0.29$). The mean occupation rate of the distal locking screw holes was 71.4% (range, 50–100) in group A and 63.5% (range, 57.1–66.7) in group B ($p = 0.10$). Compared to no wrist with surgical fixation with the distal locking screw aimed at the radial styloid or with distal locking screws in both the distal and proximal rows of distal locking screw holes in group B, they were observed in 31 (83.8%; $p = 0.61$) and 7 (18.9%; $p = 0.56$) wrists in group A, respectively. Two factors were found to be significantly associated with breakage of distal locking screws: the absence of a distal locking screw aiming at the radial styloid ($p = 0.004$, $\varphi = -0.81$) and plate fixation with a gap formation of 2 mm or greater from the volar surface of the distal radius ($p = 0.04$, $\varphi = 0.43$).

DISCUSSION

Our findings corroborate those of previous reports on postoperative implant breakage of the volar locking plate system and associated break patterns (Table 1) *(2,4,6,10,12,25)*. Breakage of distal locking screws occurred at the locking head–shaft junction both in our and in previously reported cases *(2,6)*. Mechanical weakness at this junction has been demonstrated by biomechanical studies *(3,11)*. Kamei et al. compared the stability of five volar locking plate systems using cadaveric distal radius fracture models and reported bending or breakage around the junction in four of the five evaluated plate systems *(11)*. The present statistical analysis revealed two factors to be significantly associated with breakage of the distal locking screw: absence of a distal locking screw targeting the radial styloid, also reported in previous cases *(2,6)*; plate fixation with a gap of 2 mm or greater from the volar surface of the distal radius. Iba et al. evaluated the stability of a volar locking plate system fixation with or without radial styloid screws using six cadaveric distal radius fracture models *(9)*. They reported that the mean ultimate strength at failure of volar plate fixation with radial styloid screws was significantly higher than that without radial styloid screws. Rotne et al. investigated the mechanical stability of a locking plate with 0 mm and 2 mm gaps from bone in biomechanical experiments using 6 pairs of adult canine femora *(20)*. They reported that mechanical properties of the plate when applied at 0-mm gap were significantly greater than those when applied at 2-mm gap. Hence, these two factors may lead to increased mechanical stress on distal locking screws, particularly at the locking head–shaft junction of the mechanical weak point, leading to decreased stability of the plate system and consequently, breakage of the distal locking screws. Conversely, plate breakage at unused proximal row screw holes for distal locking screws, as in the present study, was reported by all four previous studies *(4,10,12,25)*. Proximal row screw holes tended to be located at the fracture site as a result of design, and screw holes not filled with screws expose the adjacent metal portions to strong mechanical stress. A previous biomechanical study demonstrated unfilled screw holes at the fracture site as a site of weakness in the volar locking plate system *(22)*. Additionally, Mehling et al. compared the biomechanical properties of distal locking screw locations in the volar locking plate in distal radius fracture cadaver models *(18)*. They reported that the stiffness of the plate with distal locking screws only in the distal row was significantly lower than that of the plate with distal locking screws filling all screw holes both in the distal and proximal rows. They also reported plate deformation at the fracture site as the most frequent failure type. Therefore, plate fixation with sufficient contact of plate with the volar cortical surface of the distal fragment, distal locking screws directed at the radial styloid, and using screws in both distal and proximal row screw holes may provide stronger fixation and prevent abnormal mechanical stress leading to the breakage of the volar locking system (Fig. 3).

Previous studies reporting on plate breakage were conducted among varied patient populations regarding sex, age, fracture type, and plate system, as the present study (Table I). Two of these reported cases *(4,21)* included obese patients, with postoperative weight bearing on the affected wrist observed in three wrists *(4,21,25)*, including the obese cases. In the present study, all cases in group B had placed weight on their affected wrist postoperatively, although no significant difference in BMI was observed between groups A and B. These findings indicate that the volar locking plate system for fractures of distal radius, which is usually an unloaded bone, is unable to bear repetitive weight, despite the capability to bear a stress of 250 N during the wrist and digit motion *(18-19)*. Moreover, implant breakage was identified

Fig. 3. — Ideal fixation of the volar locking plate system to prevent breakage. The fixation includes sufficient contact between the distal part of the plate and the distal radius (red-dashed line), a distal locking screw directing toward the radial styloid (blue arrow), and distal locking screws in both the distal and proximal row screw holes (red circles)

on radiographs within 7 weeks postoperatively in the present series and within 14 weeks postoperatively in previous reports *(2,4,6,10,12,25)*. The mean reported times to union of distal radius fractures following implantation of the volar locking plate system in previous studies range between 6.7–12.4 weeks *(7,15,24)*. Thus, to avoid implant breakage, it may be important for clinicians to advise patients not to place their weight on affected wrists during the early postoperative period when the fractures are not completely healed.

Finally, implant breakage of the volar locking plate system may be misdiagnosed due to its rarity. Postoperative reduction loss before breakage has been previously reported only in one case *(4)*. However, we found the presence of postoperative reduction loss to be significantly associated with implant breakage. The present study results indicate that patients with postoperative reduction loss should be closely monitored for the possibility of implant breakage during the postoperative period.

The present study has some limitations. The number of patients in group B was much

Table 1. Cases with Postoperative Implant Breakage of the Volar Locking Plate System in Previous Reports

Authors	Age	Sex	Obesity	Fracture type	Plate system	Broken part	Time detected after surgery	Distal locking screw in proximal row	Distal locking screw to radial styloid	Postoperative weight bearing	Postoperative reduction loss
Dellaere, et al.[11]	58	Female	+	Type I (Fernandez classification)	Locking Compression Plate, Mathys Medical Ltd	Plate/Unused proximal distal locking screw hole	14weeks	-	-	+	+
Imaeda, et al.[10]	56	Male	nd	C2 (AO classification)	Matrix Locking Plate, Stryker	Plate/Unused proximal distal locking screw hole	1week	-	-	nd	nd
Yukata, et al.[15]	82	Female	nd	C2 (AO classification)	The Matrix SmartLock, Stryker Leibinger	Plate/Unused proximal distal locking screw hole	12weeks	-	-	+	nd
Khan, et al.[14]	30	Male	nd	C2 (AO classification)	3.5mm Locking Compression Plate, Synthes	Plate/Unused proximal distal locking screw hole	6weeks	-	nd	nd	nd
Cao, et al.[20]	40	Female	+	A3 (AO classification)	Aculock, Acumed	Distal locking screws/Locking head-shaft junction	10weeks	-	-	+	nd
Foo, et al.[12]	80	Female	nd	A3 (AO classification)	2.4mm Locking Compression Plate, Synthes	Distal locking screws/Locking head-shaft junction	12weeks	-	-	nd	nd

nd; no date

smaller than that of patients in group A because the breakage of the volar locking plate system was a rare complication in distal radius fracture cases. Furthermore, breakage was multifactorial, including biological, patient, and biomechanical factors *(12)*. Thus, our study results may not apply to all cases in an actual clinical situation. However, we believe that these findings will help avoid volar locking plate system breakage following distal radius fracture treatment.

In summary, significant factors were plate fixation with a gap of 2 mm or greater between the plate and distal radius or without a distal locking screw aiming at the radial styloid for distal locking screw breakage and a postoperative reduction loss for implant breakage.

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