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ORIGINAL PAPER

A comparison of corrective osteotomies using dorsal and volar fixation for malunited distal radius fractures

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Abstract

Purpose This study aimed to compare clinical results and to restore radiographic parameters of corrective osteotomy for malunited distal radius fracture using a volar locking plate with a dorsal plate.

Methods We retrospectively studied 28 consecutive patients with symptomatic malunited distal radius fractures followed up for more than 12 months who underwent corrective osteotomy with a dorsal buttress plate ($n = 9$) or a volar locking plate ($n = 19$). Volar tilt (VT), radial inclination (RI), and ulnar variance (UV) were radiographically evaluated. Clinical examination parameters included pain, wrist and forearm ranges of motion (ROM), grip strength, and Mayo Modified Wrist Score (MMWS).

Results The volar group had a significantly greater VT undercorrection for − 9.4° than did the dorsal group for − 1.2° ($p < 0.001$). Major complications requiring plate removal occurred in six of nine patients in the dorsal group and two of 19 patients in the volar group. The complication ratio was significantly greater in the dorsal group than in the volar group ($p < 0.05$). Improvements in forearm and wrist ROM, grip strength, and MMWS did not differ significantly between groups.

Conclusions Opening wedge osteotomy of the radius using a volar locking plate is preferable to dorsal buttress fixation in terms of surgical and technical demands and frequency of complications, but VT correction is insufficient. Surgeons should be aware of the mismatch between the plate and the volar surface of the malunited distal radius.

Keywords Corrective osteotomy · Distal radius malunion · Three dimensional · Dorsal approach · Volar approach · Computer simulation

Introduction

Malunion with dorsal deformity is a common complication after distal radius fracture treated with closed reduction [1]. Malunion of the distal radius is often associated with complications such as wrist pain, restriction of range of motion (ROM), reduced grip strength, and subsequent osteoarthritis [2–5]. Restoration of the anatomical geometry of the distal radius improves wrist motion and preserves the normal kinematics of the wrist joint and load distribution over the articular surface and alleviates these symptoms [2, 6–8]. The traditional surgical technique is an opening wedge corrective osteotomy via a dorsal approach followed by dorsal buttress plate fixation [2, 4, 6, 9, 10]. Recently, satisfactory clinical results have been reported with corrective osteotomy using a volar approach and volar locking plates [7, 11–14].

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The present study aimed to retrospectively compare the clinical and radiographic outcomes of corrective opening wedge osteotomies using dorsal plates and volar locking plates. Each author certifies that his or her institution approved the human protocol for this investigation, all investigations were conducted in conformity with ethical principles of research, and informed consent was obtained from all study participants.

Materials and method

We retrospectively reviewed 43 consecutive patients with malunited distal radius fractures who underwent corrective osteotomies at our institution between February 2003 and June 2013. The inclusion criteria were the presence of a unilateral extra-articular dorsal extensional malunion of the distal radius treated with corrective osteotomy and followed up for more than 12 months. Patients with an articular malunion of the distal radius (one patient) or volar flexional deformity (four patients), those younger than 18 years (five patients), and those whose follow-up period was less than 12 months (five patients) were excluded. A total of 28 patients participated in this study.

We categorized the 28 patients into two groups based on operative procedure. Patients whose corrective osteotomies included a dorsal plate were assigned to the dorsal group ($n = 9$), and those who were treated using a volar locking plate were assigned to the volar group ($n = 19$). Our institution used the dorsal approach until December 2007, and the volar approach has been used since January 2008. The groups did not differ significantly with respect to patient's background (Table 1).

Table 1 Patients' demographic and clinical details

	Dorsal group	Volar group	*p* value
Age (years)	55.8	55.5	0.96
Man:woman (*n*)	1:8	3:16	0.74
Period from the initial injury (months)	11.4	14.3	0.49
Wrist ROM	82°	98°	0.09
Forearm ROM	128°	136°	0.58
Grip strength (%)*	38	51	0.12
VT**	− 37.1°	− 37.7°	0.92
RI**	− 12.2°	− 10.9°	0.70
UV** (mm)	3.4	4.4	0.26
MMWS	43	47	0.43

*Percentage of the contralateral limb

**Difference to the contralateral limb

ROM, range of motion; *VT*, volar tilt; *RI*, radial inclination; *UV*, ulnar variance; MMWS, Mayo Modified Wrist Score

Computer modeling

To plan for the surgeries, we simulated three-dimensional (3-D) corrections of the deformities using computer models of the bones. This technique has been described in detail previously [7, 8, 12, 15–17]. Both forearms of all patients were scanned with computed tomography (CT) using a low-radiation-dose technique [18]. We constructed 3-D surface models from CT data and performed pre-operative computer simulation of a corrective osteotomy.

We planned an ulnar-shortening osteotomy to avoid delayed bone union and excessive tightness of soft tissues only if the shortest distance between the distal and proximal fragment was more than 3 mm in the 3-D simulation to restore the ulnar variance to the same level with the contralateral normal side. In the dorsal group, the amount of correction was determined by matching the affected radius to the mirror image of the normal contralateral radius. In the volar group, the radial length and inclination of correction were referenced from the mirror image of the normal radius, but the volar angulation was determined by fitting the slope of the volar locking plate using computer-aided design (CAD) data. The differences in the values of volar tilt (VT), radial inclination (RI), and ulnar variance (UV) in the simulation results and the normal radius were compared between the groups using the 3-D bone models.

To reproduce the pre-operative simulations during the operations, we designed patient-matched instruments (PMIs) based on the pre-operative simulations. The PMIs were embodied as plastic models made of medical-grade resin (USP class VI), which was passed the tests for cytotoxicity, dermal irritation, and delayed-type hypersensitivity, with rapid prototyping technology. PMI was shaped to fit the bone surface and had osteotomy slits and drill holes. As previously reported, the accuracy of corrective osteotomy using a PMI is within 1.0 mm and 1.0° [19, 20]. The total cost is approximately US $1000 for planning and manufacturing a PMI.

Procedures

In the dorsal group, a dorsal approach to the distal radius through the third and fourth extensor compartment was used. The PMI was fitted to the dorsal aspect of distal radius and fixed with two sets of paired Kirschner wires through the guides of the PMIs, which had a 3-D deformity angle. The bone was divided through the slit on the PMI between the two sets of Kirschner wires. After removing the PMI, the bone fragments were corrected by making the sets of wires parallel to each another. A correction guide was used to maintain the parallel position of the wires. After the insertion of an autogenous corticocancellous iliac crest graft in four cases, an artificial bone graft in two cases, and a combination graft in three cases, the bone fragments were temporally fixed by cross-pinning with two Kirschner wires, each 2.0 mm in diameter.

Finally, the correction guide was removed, and internal fixation was achieved using a dorsal plate (Fig. 1). A non-locking dorsal plate (Matrix Distal Radius Planting System; Stryker, UK), a locking dorsal plate (Matrix SmartLock Polyaxial Locking System; Stryker), and locking dorsal radius plates with L and straight shapes (DRP; Synthes, Solothurn, Switzerland) were used in six, two, and one case, respectively. Wedge-shaped corticocancellus iliac crest graft and 3-D-shaped artificial bone graft were used in the cases fixed with non-locking plates. After the fixation, the extensor retinaculum flap based on radial side was divided transversely. The proximal flap was placed on the tendons and the distal flap under the tendons to protect the tendons from plate irritation [21].

In the volar group, the volar surface of the distal radius was exposed using a conventional volar approach, and the PMI was fitted onto the volar surface. Then, we predrilled through the guiding holes in the PMI into the distal radius and the shaft of the radius. The holes had been calculated on the basis of the preoperative simulation using CAD data from the plate. Then, we osteotomized the radius through the slit. The brachioradialis tendon was cut and the dorsal periosteum was released by an elevator from radial side enough to mobilize the distal fragment. The volar locking plate was fitted to the distal radius fragment by inserting distal locking screws into the predrilled screw holes. Thereafter, the proximal part of the plate was pushed against the stem of the radius, and the screw was fixed in the predrilled screw hole in the proximal radius. This manipulation led to angular correction of the distal radial fragment along the volar locking plate (Figs 2 and 3). An Alliance plate system (Newclip Techniques SAS, La Haye-Fouassiere, France), DVR anatomic volar plating system (Depuy Synthes, West Chester, PA, USA), and OSR plate (Kyocera Medical Corporation, Osaka, Japan) were used in 13, four, and two cases, respectively. Autogenous iliac corticocancellous bone in ten cases, artificial bone in four cases, and a combination of both in five cases was grafted into the open osteotomy site from the radial space loosened after releasing brachioradialis muscle. Ulnar-shortening osteotomy of 3 and 7 mm and fixation with a 3.5-mm diameter five-hole locking plate was performed in two patients.

All of the patients were evaluated clinically and radiographically before surgery and during the final follow-up session. The union was considered complete when the osteotomy line disappeared on the plain radiographs. VT, RI, and UV were determined from the radiographs and compared between the affected side and the normal contralateral side.

Patients were clinically assessed for pain, wrist and forearm ROM, and grip strength. Pain at the wrist joint was graded as none (no pain), mild (occasional pain with excessive use of the hand), moderate (persistent but endurable pain), or severe (pain necessitating analgesic control). Grip strength was recorded as a percentage of that on the normal contralateral side. Total function was assessed using the Mayo Modified Wrist Score (MMWS) rating system [22]. The level of complications was classified into major or minor. Cases that required additional surgical treatment including removal of plate to recover symptoms were defined as major complication. Cases that did not require surgical intervention were defined as minor complication.

Statistical analysis

We performed power analysis before the study. We identified that a sample size of nine cases in each group would provide a power of 90% to detect 8.0° difference in VT and RI and 2-mm difference in UV at the 0.05 confidence level. This means that we had enough patients to detect a difference of graphic parameters between groups. The differences between the preoperative and post-operative radiographic values, ROM, grip strength, and MMWS in each group were determined using the Wilcoxon signed-rank test. The differences between the groups with respect to post-operative radiographic values and clinical functions were determined using the Wilcoxon

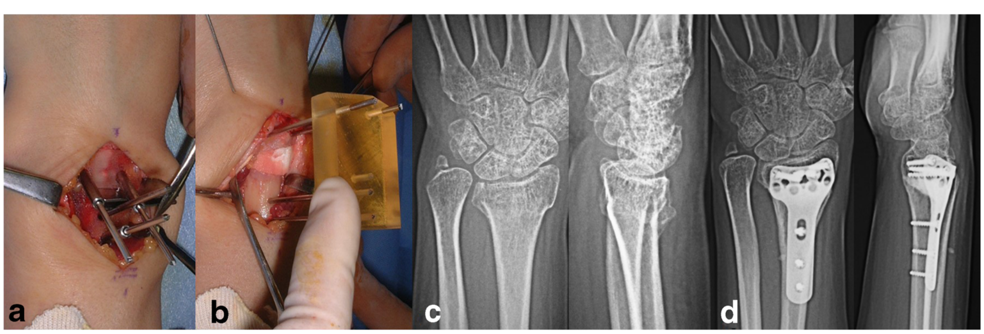

Fig.. 1 In the dorsal approach, a patient-matched instrument (PMI) is fitted onto the dorsal surface of the distal radius and fixed with two sets of paired 2-mm Kirschner wires that have a three-dimensional deformity angle calculated from the computer simulation. A bone saw is used to divide the bone through the cutting slit between the sets of wires in the PMI (**a**). The bone segments are reduced with the sets of Kirschner wires parallel to each other. A reduction guide is used to maintain the parallel position of the wires, and the artificial bone graft is inserted (**b**). The anteroposterior and lateral views of the preoperative (**c**) and postoperative (**d**) plain radiograph are shown

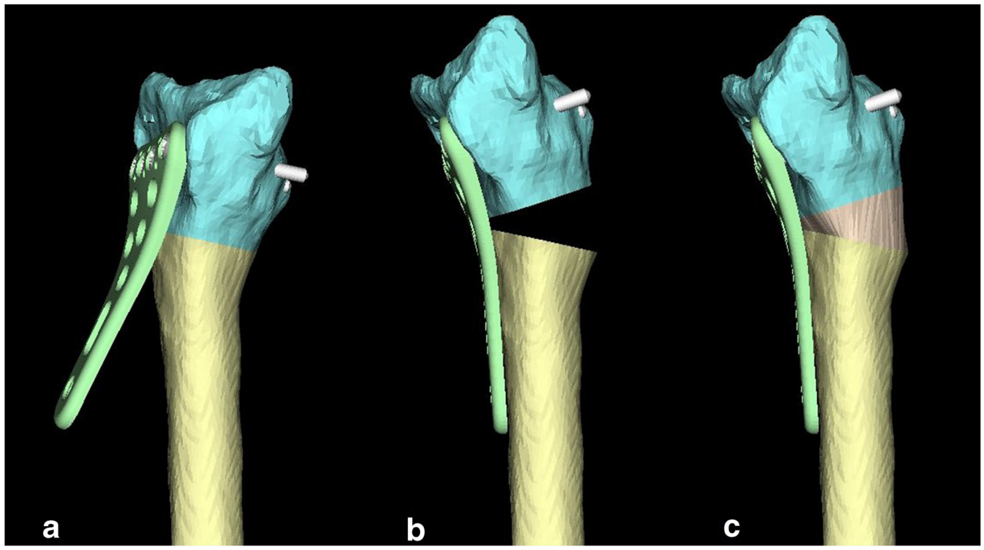

Fig. 2 The volar locking plate is fitted to the distal radius fragment in the simulation (**a**). The deformity is automatically reduced along the shape of the anatomical plate via fixation of the proximal stem of the plate to the radius (**b**, **c**)

signed-rank sum test. The differences among the three types of grafting bones with respect to time to bone union were determined using the Tukey-Kramer test. A p value of < 0.05 was considered statistically significant.

Results

Table 2 summarizes the post-operative results. We found no significant difference in the time to bone union between the groups. With respect to bone graft materials, the time to bone union in 14 cases with autogenous bone, seven cases with artificial bone, and seven cases with combinations of bone materials was 9.7, 18.0, and 8.7 weeks, respectively. Bone union was significantly delayed with artificial bone compared with autogenous bone ($p < 0.001$) or bone material combinations ($p < 0.001$). There was no significant difference in the time to bone union between autogenous bone and mixed autogenous and artificial bone. The difference of UV between the affected side and the contralateral normal side improved from 3.4 to −0.1 mm in the dorsal group, and 4.4 to 0.4 mm in the volar group. The average improvement of UV which indicated lengthening of radius was 3.7 mm in both group excluding two cases with ulnar shortening. The maximum lengthening of radius without ulnar shortening was 9.0 mm.

Forearm and wrist ROM increased by 30° and 39°, respectively, in the dorsal group and by 26°and 34°, respectively, in the volar group. The grip strength ratios improved from 38 to 83% in the dorsal group and from 51 to 84% in the volar group. MMWS improved from 43 to 76 in the dorsal group and from 47 to 79 in the volar group. The post-operative those clinical evaluations did not differ significantly between the groups.

In the dorsal group, major complications were observed in six patients. One patient had residual pain in the dorsal wrist, one patient developed extensor adhesion, and four patients reported dorsal wrist discomfort. These six patients had their plates removed with resection of synovitis around extensor tendons. In the volar group, major complications were observed in two of 19 patients. Plates were removed in these

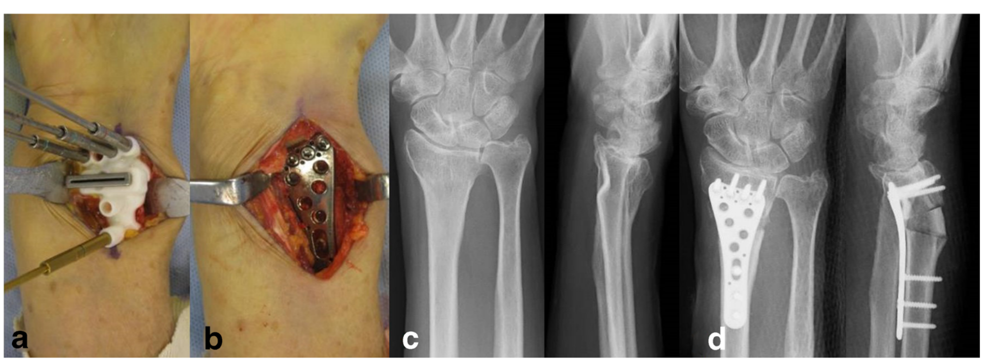

Fig. 3 A PMI is fitted onto the volar surface of the distal radius. Holes are predrilled into the subchondral bone of the distal radius and into the shaft of the radius through the guiding holes in the PMI calculated on the basis of the pre-operative simulation (**a**). The deformity is automatically reduced by inserting the locking screws into the predrilled holes in the radius (**b**). The anteroposterior and lateral views of the pre-operative (**c**) and post-operative (**d**) plain radiographs are shown

Table 2 The patients' post-operative results

	Dorsal group	Volar group	*p* value
Wrist ROM	121°	132°	0.30
Forearm ROM	158°	162°	0.78
Grip strength (%)*	83	84	0.85
MMWS	76	79	0.55
Bone union (weeks)	11.1	11.7	0.78
VT**	− 1.2°	− 9.4°	0.001 >
RI**	− 1.0°	− 1.5°	0.69
UV** (mm)	− 0.1	0.4	0.35
Complication rate	6/9	2/19	0.05 >

*Percentage of the contralateral limb

**Difference to the contralateral limb

ROM, range of motion; *MMWS*, Mayo Modified Wrist Score; *VT*, volar tilt; *RI*, radial inclination; *UV*, ulnar variance

patients owing to wrist discomfort. An additional four patients wished to get the plate removed despite the absence of symptoms of the wrist. These four patients were excluded from the major complication category.

VT, RI, and UV improved in line with expectations set by pre-operative simulations performed (Table 3). The errors between the simulation and post-operative results for VT, RT, and UV, which were less than 1.0 mm and 1.0°, were not significantly different between the groups. The post-operative differences in RI and UV between the simulation and affected sides relative to the normal contralateral sides were − 1.9 ± 2.8° and − 1.0 ± 1.8°, and − 0.4 ± 0.7 mm and − 0.1 ± 1.1 mm, respectively in the dorsal group, and − 1.8 ± 3.0° and − 1.5 ± 3.6°, and 0.5 ± 1.5 mm and 0.4 ± 1.9 mm, respectively, in the volar group. These differences were not significant. However, in the volar group, post-operative VT was accurately corrected in the simulation, but undercorrection occurred in both the simulation and the post-operative result relative to the normal contralateral radius (simulation, − 8.6 ± 3.8°; post-operative result, − 9.4 ± 4.9°). This undercorrection was significant greater than that in the dorsal group ($p < 0.001$) (simulation, − 1.7 ± 3.3°; post-operative result, − 1.2 ± 2.4°); (Fig. 4). No significant differences in VT, RT, or UV between the simulation and the post-operative results occurred in either group regardless of the type of the plate used.

Table 3 The parameters of distal radius

	Dorsal group		Volar group	
	Simulation	Post-op	Simulation	Post-op
VT	− 1.7 ± 3.3°†	− 1.2 ± 2.4°††	− 8.6 ± 3.8°†	− 9.4 ± 4.9°††
RI	− 1.9 ± 2.8°	− 1.0 ± 1.8°	− 1.8 ± 3.0°	− 1.5 ± 3.6°
UV	− 0.4 ± 0.7 mm	− 0.1 ± 1.1 mm	0.5 ± 1.5 mm	0.4 ± 1.9 mm

† $p < 0.001$

†† $p < 0.001$

Discussion

Previously, corrective osteotomy for malunited distal radius fracture with dorsal deformity was treated using a dorsal buttress plate. The dorsal approach is often difficult and requires technical skills in correction, fixation, and proper management of soft tissues. Recently, corrective osteotomy with a relatively simple technique, using volar locking plate, became a treatment option. However, the results of the present study revealed that VT undercorrection was significantly greater in the volar group than in the dorsal group even though the correction was achieved accurately according to pre-operative simulations in both groups.

The main reason for the greater VT undercorrection in the volar group may be associated with differences in the pre-operative planning of the procedures. The VT insufficiency in the simulation results, which had no significant differences from the post-operative results, was greater in the volar group than in the dorsal group. In the latter, corrective osteotomy was achieved by mirroring the normal contralateral radius, which was considered the goal model and by accurately correcting the dorsal deformity using a PMI during the surgery. On the contrary, in the volar group, the corrective osteotomy was planned using CAD data from the volar locking plate, and the deformity was corrected along the plate. Therefore, the amount of correction achieved depended on the shape of the plate. However, volar locking plates do not always fit the volar surface of the corrected distal radius appropriately because the anatomical slope of the volar radial surface changes during malunited healing. Thus, mismatches between the shape of an anatomical volar plate and that of the non-anatomical distal radius after a malunion can lead to undercorrection. The other reason for VT undercorrection in the volar group would be the insufficient screw stabilization in poor bone quality and the lack of bone support on the dorsal open side [23].

The time to bone union was unrelated to the surgical approach but related to the type of bone graft material. Compared with using autogenous bone with or without artificial bone, the use of artificial bone alone delayed mean time to bone union by four weeks. UV in 26 cases, excluding two cases with ulnar shortening, improved by 3.7 mm and the maximum change between pre-operative and post-operative UV was 9.0 mm. In the two cases, which were combined with ulnar shortening, the total amount of radial lengthening and ulnar shortening was 11 and 12 mm, respectively. According to the results, UV could be corrected up to 9.0 mm in the corrective osteotomy of radius without ulnar shortening and good bone union could be expected. Srinivasan et al. reported

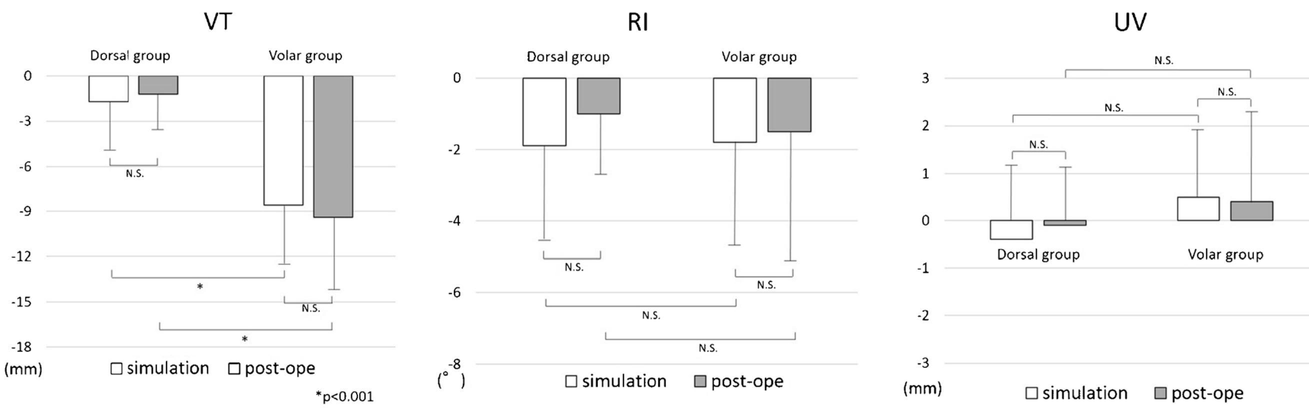

Fig. 4 The errors between the simulation and post-operative results of volar tilt (VT), radial inclination (RI), and ulnar variance (UV) did not differ significantly between the dorsal and volar approach groups. No significant differences were found between the groups with respect to UV or RI in either the simulation or the post-operative results. The undercorrection of VT in both the simulation and the post-operative results in the volar group was significantly greater than that in the dorsal group ($p < 0.001$)

good clinical outcomes of isolated ulnar-shortening osteotomy for distal radius malunion without severe extensional deformity [24]. However, they also mentioned that isolated ulnar-shortening osteotomy for distal radius malunion may not be indicated for patients who have dorsal tilt (DT) greater than 20°. In our series, the average DT was 23.9° and 16 of 28 patients had more than 20° DT. Therefore, both angular correction and adjustment of length were considered to be important in the cases with severe deformity of distal radius.

With regard to complications, the incidence of tendon irritation that required the removal of the hardware was higher in the dorsal group than in the volar group. In terms of the surgical procedure, a more complex technique was required in the dorsal group and involved correction of angulated deformity, lengthening of the radius, and plate fixation. Residual deformity of the distal radius after corrective osteotomy through the dorsal approach has been reported [5, 25]. Dorsal plate fixation while holding the corrective position of distal fragment accurately is difficult even if a PMI is used. On the contrary, achieving rigid fixation is easier with the volar locking plate, and the procedure is less complex. After osteotomy of the distal radius, volar locking plate fixation to the distal fragment followed by proximal screw fixation to the radial diaphysis, referred to as a condylar-stabilizing technique [26], automatically brings about correction along the shape of volar locking plate.

The advantages and disadvantages of the approaches reviewed in this study include superior VT reduction in the dorsal group. Otherwise, there were no significant differences between the groups with respect to clinical function. Given the high rate of complications in the removal of hardware and the complex technical demands of dorsal plate fixation, surgical correction using a volar locking plate appears to be superior. The small fragment-specific fixation plates shaped to exactly fit the distal radius also could be one of the option for treating corrective osteotomy of distal radius malunion, especially intra-articular osteotomy, from the view of few complications [27].

Our study has the following limitations: The use of different types of plates in both groups may have affected the results. Furthermore, several surgeons performed the corrective osteotomies; therefore, the clinical results might have been influenced by surgical skill. However, the specialized hand surgeons had more than ten years of experience each and the effect of surgical skill on the results was likely minor. The functional outcome was evaluated with MMWS, because this retrospective study included old cases. It is a simple scoring system and it might be insufficient to evaluate the level of cases with respect to activities and work. The sample size was relatively small to evaluate the functional outcome and post-operative complication though in radiographic evaluation, sample size provided a power of 90%.

Conclusions

We conclude that opening wedge osteotomy of the radius using a volar locking plate is preferable to dorsal buttress fixation in terms of surgical and technical demands and frequency of complications, but VT correction is insufficient. Furthermore, autologous with or without artificial bone grafts have an advantage in early bone union. However, surgeons should be aware of the incompatibility of the volar locking plate with the volar surface of the malunited distal radius.

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Compliance with ethical standards

Each author certifies that his or her institution approved the human protocol for this investigation, all investigations were conducted in conformity with ethical principles of research, and informed consent was obtained from all study participants.

Conflict of interest O.K. received funding in support of this research from the Japan Society for the Promotion of Science (JSPS). T.M. received funding in support of this research from the Japan Agency for Medical Research and Development (AMED). All the other authors have no conflict of interest.

References

1. Cooney WP 3rd, Dobyns JH, Linscheid RL (1980) Complications of Colles' fractures. The Journal of bone and joint surgery American 62(4):613–619
2. Fernandez DL (1982) Correction of post-traumatic wrist deformity in adults by osteotomy, bone-grafting, and internal fixation. The Journal of bone and joint surgery American 64(8):1164–1178
3. Jupiter JB, Fernandez DL (2002) Complications following distal radial fractures. Instr Course Lect 51:203–219
4. Ladd AL, Huene DS (1996) Reconstructive osteotomy for malunion of the distal radius. Clin Orthop Relat Res 327:158–171
5. Prommersberger KJ, Van Schoonhoven J, Lanz UB (2002) Outcome after corrective osteotomy for malunited fractures of the distal end of the radius. J Hand Surg Br 27(1):55–60. https://doi.org/10.1054/jhsb.2001.0693
6. Athwal GS, Ellis RE, Small CF, Pichora DR (2003) Computer-assisted distal radius osteotomy. J Hand Surg Am 28(6):951–958
7. Miyake J, Murase T, Moritomo H, Sugamoto K, Yoshikawa H (2011) Distal radius osteotomy with volar locking plates based on computer simulation. Clin Orthop Relat Res 469(6):1766–1773. https://doi.org/10.1007/s11999-010-1748-z
8. Murase T, Oka K, Moritomo H, Goto A, Yoshikawa H, Sugamoto K (2008) Three-dimensional corrective osteotomy of malunited fractures of the upper extremity with use of a computer simulation system. J Bone Joint Surg Am 90(11):2375–2389. https://doi.org/10.2106/JBJS.G.01299
9. Fernandez DL (1988) Radial osteotomy and bowers arthroplasty for malunited fractures of the distal end of the radius. The Journal of bone and joint surgery American 70(10):1538–1551
10. Jupiter JB, Ring D (1996) A comparison of early and late reconstruction of malunited fractures of the distal end of the radius. The Journal of bone and joint surgery American 78(5):739–748
11. Malone KJ, Magnell TD, Freeman DC, Boyer MI, Placzek JD (2006) Surgical correction of dorsally angulated distal radius malunions with fixed angle volar plating: a case series. J Hand Surg Am 31(3):366–372. https://doi.org/10.1016/j.jhsa.2005.10.017
12. Oka K, Murase T, Moritomo H, Goto A, Sugamoto K, Yoshikawa H (2010) Corrective osteotomy using customized hydroxyapatite implants prepared by preoperative computer simulation. The international journal of medical robotics + computer assisted surgery: MRCAS 6(2):186–193. https://doi.org/10.1002/rcs.305
13. Osada D, Kamei S, Takai M, Tomizawa K, Tamai K (2007) Malunited fractures of the distal radius treated with corrective osteotomy using volar locking plate and a corticocancellous bone graft following immediate mobilisation. Hand Surg 12(3):183–190. https://doi.org/10.1142/S0218810407003560
14. Wijffels MM, Orbay JL, Indriago I, Ring D (2012) The extended flexor carpi radialis approach for partially healed malaligned fractures of the distal radius. Injury 43(7):1204–1208. https://doi.org/10.1016/j.injury.2012.04.002
15. Murase T (2016) Surgical technique of corrective osteotomy for malunited distal radius fracture using the computer-simulated patient matched instrument. J Hand Surg Asian Pac Vol 21(2):133–139. https://doi.org/10.1142/S2424835516400051
16. Murase T, Oka K, Moritomo H, Goto A, Sugamoto K, Yoshikawa H (2009) Correction of severe wrist deformity following physeal arrest of the distal radius with the aid of a three-dimensional computer simulation. Arch Orthop Trauma Surg 129(11):1465–1471. https://doi.org/10.1007/s00402-008-0800-x
17. Oka K, Moritomo H, Goto A, Sugamoto K, Yoshikawa H, Murase T (2008) Corrective osteotomy for malunited intra-articular fracture of the distal radius using a custom-made surgical guide based on three-dimensional computer simulation: case report. J Hand Surg Am 33(6):835–840. https://doi.org/10.1016/j.jhsa.2008.02.008
18. Oka K, Murase T, Moritomo H, Goto A, Sugamoto K, Yoshikawa H (2009) Accuracy analysis of three-dimensional bone surface models of the forearm constructed from multidetector computed tomography data. The international journal of medical robotics + computer assisted surgery : MRCAS 5(4):452–457. https://doi.org/10.1002/rcs.277
19. Oka K, Murase T, Moritomo H, Goto A, Nakao R, Sugamoto K, Yoshikawa H (2011) Accuracy of corrective osteotomy using a custom-designed device based on a novel computer simulation system. Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association 16(1):85–92. https://doi.org/10.1007/s00776-010-0020-4
20. Omori S, Murase T, Kataoka T, Kawanishi Y, Oura K, Miyake J, Tanaka H, Yoshikawa H (2014) Three-dimensional corrective osteotomy using a patient-specific osteotomy guide and bone plate based on a computer simulation system: accuracy analysis in a cadaver study. The international journal of medical robotics + computer assisted surgery: MRCAS 10(2):196–202. https://doi.org/10.1002/rcs.1530
21. Williamson SC, Feldon P (1995) Extensor tendon ruptures in rheumatoid arthritis. Hand Clin 11(3):449–459
22. Cooney WP, Bussey R, Dobyns JH, Linscheid RL (1987) Difficult wrist fractures. Perilunate fracture-dislocations of the wrist. Clin Orthop Relat Res 214:136–147
23. Martinez-Mendez D, Lizaur-Utrilla A, de Juan-Herrero J (2018) Prospective study of comminuted articular distal radius fractures stabilized by volar plating in the elderly. Int Orthop. https://doi.org/10.1007/s00264-018-3903-1
24. Srinivasan RC, Jain D, Richard MJ, Leversedge FJ, Mithani SK, Ruch DS (2013) Isolated ulnar shortening osteotomy for the treatment of extra-articular distal radius malunion. The Journal of Hand Surgery 38(6):1106–1110. https://doi.org/10.1016/j.jhsa.2013.03.015
25. von Campe A, Nagy L, Arbab D, Dumont CE (2006) Corrective osteotomies in malunions of the distal radius: do we get what we planned? Clin Orthop Relat Res 450:179–185. https://doi.org/10.1097/01.blo.0000223994.79894.17
26. Kiyoshige Y (2002) Condylar stabilizing technique with AO/ASIF distal radius plate for Colles' fracture associated with osteoporosis. Tech Hand Up Extrem Surg 6(4):205–208
27. Babikir EME, Al-Maqdassy ED, Hasan K, Abdul Hameed S, Alhammoud A, Al-Dosari MMA (2017) Efficiency of fragment specific fixation plates in the treatment of comminuted distal radial fractures. Int Orthop 41(9):1763–1769. https://doi.org/10.1007/s00264-017-3516-0