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Volar locking plate removal after distal radius fracture: a 10-year retrospective study

Jun-Ku Lee[1] · Younghun Lee[2] · Choongki Kim[1] · Minwook Kim[2] · Soo-Hong Han[2]

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Abstract

Introduction Distal radius fracture (DRF) is the most common upper extremity fracture. After the introduction of volar locking plate (VLP) fixation, treatment has shifted from conservative management to more operative management. The implant removal rate after VLP fixation in patients with DRF varies and the reasons for removal and associated patient characteristics have not been clearly defined. This study aimed to compare the characteristics of patients who underwent VLP with and without subsequent implant removal. Second, the rate of implant removal according to the implant position and type was investigated. Finally, we summarized clinical outcome with implant removal, the reasons for, and complications associated with implant removal.

Methods In this retrospective study, patient data were collected between January 1, 2008, and December 31, 2017. The study population was divided into two groups based on subsequent implant removal. Data on patient characteristics, such as age, sex, comorbidities, side of the fractured arm, the AO Foundation and Orthopaedic Trauma Association classification of the DRF, plate position grade based on the Soong classification type, type of inserted plate, insurance coverage, and treatment costs were collected. Furthermore, we investigated the reason for implant removal, clinical outcomes, and post-removal complications.

Results After applying the exclusion criteria, 806 patients with a total of 814 DRFs were included in the study. Among the 806 patients who underwent VLP fixation for DRF, 252 (31.3%) patients underwent implant removal. Among the patients undergoing implant removal, the mean age was 50.8 ± 14.0 years, 94 (37.3%) were male. The average time to implant removal from the fracture fixation was 12.1 ± 9.2 months (range 1–170 months). When comparing groups, patients who underwent implant removal were significantly younger and had fewer cases of diabetes, hypertension, and cancer history. According to the Soong plate position grade, the most common position was G1 in both groups. Although there was no significant difference ($p = 0.075$), more G2 cases were found in the removal group (15.0%) than in the retention group (10.2%). About 66.5% of the patients with implant removal had other health insurance as well as the national service, compared with 47% of the patients with implant retention. In total, 186 patients (73.8%) underwent implant removal despite being asymptomatic after the bony union. The patient satisfaction scores improved from 4.1 to 4.4 after implant removal, and 93% of the patients answered that they would choose implant removal again. Only 10% of the patients who underwent removal reported minor complications. No major complications were reported.

Conclusion Although the implant removal was conducted without clinical symptoms in the majority of patients, overall patients presented improved functional outcomes with implant removal. The evidence is inconclusive regarding its necessity, however, implant removal after VLP fixation for DRF is not a challenging procedure and is not associated with major complications.

Level of evidence Level IV.

Keywords Distal radius · Fracture · Volar locking plate · Implant removal · Complication

✉ Soo-Hong Han
hsoohong@daum.net

Extended author information available on the last page of the article

Introduction

Distal radius fractures (DRFs) accounts for approximately 16% of all fractures treated by orthopaedic surgeons [1]. They are the most commonly encountered fracture in the emergency department, and more than 640,000 are reported annually in the United States alone [2]. Although the majority of DRF management strategies involve non-operative methods, a significant trend towards surgical treatment has been noted [3–5], largely explained by the introduction of volar locking plate (VLP) fixation which is associated with benefits including stable fixation, short immobilization period, and few complications [6, 7]. However, after plate fixation of the distal radius, adverse outcomes may include infection, tendon irritation, articular violation, or nerve irritation and most of these events require removal of the inserted VLP [8–10]. In the absence of complications, many surgeons have insisted that the inserted VLP does not need to be removed [11, 12]. Nevertheless, site-specific removal rates vary greatly from 0 to 100% [13–17]. In some cases, plate removal is performed at the patient's request or the surgeon's discretion in the absence of any clinical symptoms [18, 19].

This study aimed to compare characteristics of patients who underwent VLP fixation with and without subsequent implant removal. Second, the rate of implant removal according to the implant position and type was investigated. Finally, we summarized clinical outcome after implant removal, the reasons for removal, and the associated complications.

Materials and methods

Study design, setting, and participants

This retrospective single-centre cohort study was performed in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [20]. The study design was approved by the local institutional review board. The patient data were collected between January 1, 2008, and December 31, 2017. A highly experienced hand surgeon, according to levels of experience previously defined, conducted all surgeries [21]. During the procedure, the surgeon performed VLP fixation for DRFs using a modified Henry approach to the fractured distal radius in-between the flexor carpi radialis (FCR) and the tendons of the brachioradialis. Regarding the inserted VLP, only one manufacturer (DePuy Synthes Co., Solothurn, Switzerland) was used, but different types of plates were used depending on the fracture patterns per the surgeon's discretion.

Two separates orthopaedic surgeons collected the data. During the study period, 1455 patients were diagnosed with DRF and treated operatively. Only patients with VLP fixation were included, and those with other treatment modalities, such as closed pinning, external fixation, dorsal plate fixation, and screw-only fixation, were excluded. The patients aged < 18 years were also excluded. During data analysis, the patients with insufficient information due to loss of medical records, those for whom data were not consistently recorded, and those with missing data regarding confirmation of medical comorbidities were excluded. Patients who were lost to follow-up before the bony union was achieved were also excluded.

Implant removal

The same surgeon performed implant removal after administration of anaesthesia (general, brachial plexus block, or bier block). Using a previously reported approach, the inserted plate was extracted under tourniquet inflation. A simple soft dressing was applied postoperatively, and immediate range of motion (ROM) exercises were allowed. Intravenous or oral antibiotics were routinely prescribed for less than 1 week.

Variables, data sources and measurement

The study population was divided into two groups based on subsequent implant removal. Data on patient characteristics, such as age, sex, side of the fractured arm, and comorbidities (diabetes, hypertension, angina or myocardial infarction, nephropathy or dialysis history, hypo- or hyper-thyroidism, and cancer) were collected from medical data base. For the radiologic evaluation, the AO Foundation and Orthopaedic Trauma Association (AO/OTA) classification of the DRF was assessed based on plain X-ray or computed tomography. For plate prominence grading associated with the watershed line in postoperative lateral plain X-ray, the Soong classification system was used [22], and the product name of the inserted plate was obtained. The insurance coverage for the DRF treatment was attempted to be investigated in all included patients.

Depending on groups, we attempted to compare regarding basic characteristics, comorbidity, AO/OTA classification, Soong grade, plate types, and insurance coverage.

Further investigation into the implant removal group was conducted. For functional evaluation, the patients with subsequent implant removal were assessed with the Disabilities of the Arm, Shoulder, and Hand (DASH) score prior to the operation. The DASH score was assessed again

after implant removal during the outpatient follow-up before the end of treatment.

The treatment cost for implant removal was also investigated. When possible, the patient was contacted by phone, and further follow-up was conducted by two different orthopaedic surgeons during study investigation period. The reason for implant removal, clinical outcomes, and post-removal complications were investigated.

The reasons for implant removal were investigated from the medical chart review and through follow-up conducted via telephone. The reasons were classified into seven categories, including removal without clinical symptoms, nerve-related issues, tendon-related issues, implant-related issues, problems with osteosynthesis, part of another procedure, and others.

From the telephone phone survey, the personal satisfaction of each patient was assessed through two questions. First, ''How would you describe the overall result of your treatment considering how you felt before implant removal and now, after implant removal??''. The possible responses were ''very satisfied (5)'', ''satisfied (4)'', ''average (3)'', ''poor (2)'', and very poor (1)". The second question was, ''Would you undergo implant removal again in the same situation?'' The possible answers were ''yes'' or ''no''.

Finally, we investigated any complications associated with implant removal and classified them as major and minor complications. The major complications included failure to remove a plate despite an attempt, refracture, tendon and neurovascular damage, decrease in the wrist ROM after implant removal, and deep infection. The minor complications included broken screws that remained at the implant site, superficial infection, post-operative pain, tenosynovitis, neuritis-like transient tingling sensation, and dissatisfaction with the operative scar.

Statistical analysis

The summary statistics are presented as mean ± standard deviation (SD) or numbers and percentages. Pearson's chi-square test and Fisher's exact test were used to compare the categorical variables and Student's *t* test was used for comparison of continuous variables between groups. Before Student's *t* test was performed, a normality test (Shapiro–Wilk test) was performed. The paired Student's *t* test or Wilcoxon signed-rank test were performed in cases of paired continuous variables depending on normality tests result. A *p* value of less than 0.05 was considered statistically significant. With software R (v. 3.1.0; The R Foundation, Vienna, Austria), the statistical evaluation was conducted.

Results

Finally, 806 patients with a total of 814 DRFs were included in the study with a minimum postoperative follow-up duration of 4 months (Fig. 1).

Among the 806 patients who underwent VLP fixation for DRFs, 252 (31.3%) patients underwent implant removal. The average time to implant removal from the initial open reduction and internal fixation (ORIF) was 12.1 ± 9.2 months (range 1–170 months). The mean operation time for implant removal was 28.8 ± 9.9 min. The average hospital stay was 2.2 ± 1.9 days and the average medical cost per patient was 616.6 USD (range 0–1594 USD) from admission to discharge.

All implants were manufactured by the same company (Depuy Synthes Co., Solothurn, Switzerland) with five different types of titanium plates used, including the 3.5-mm locking compression plate (LCP) T-plate, 2.4-mm variable angle LCP (VA-LCP) two-column volar distal radius plate, 2.4-mm LCP distal radius system (LDRS)/extra-articular, 2.4-mm LDRS/juxta-articular, and 2.4-mm VA-LCP volar rim distal radius plate.

Comparison between implant removal and retention

The patients who underwent implant removal were significantly younger (50.8 ± 14.0 years) compared to those who retained their implant (62.0 ± 13.4 years, $p < 0.001$). In the group with the implant removal, the male ratio was 37.3%, which was higher than the male ratio of 30.7% in the retention group, but there was no statistical difference. There were no differences between the two groups in terms of the fractured arm (Table 1).

When comparing the comorbidities between the two groups, patients who underwent implant removal presented with a significantly lower rate of diabetes ($p = 0.001$), hypertension ($p < 0.001$), and any type of cancer ($p = 0.004$) than those who retained the implant. In the radiologic comparison, there was no difference in the AO/OTA classification between the groups. In terms of plate prominence according to Soong classification, the most common type was G1 in both groups. Although there was no statistical difference ($p = 0.075$), the G2 type tended to be more common in the removal group (15.0%) compared to the retention group (10.2%) (Table 2).

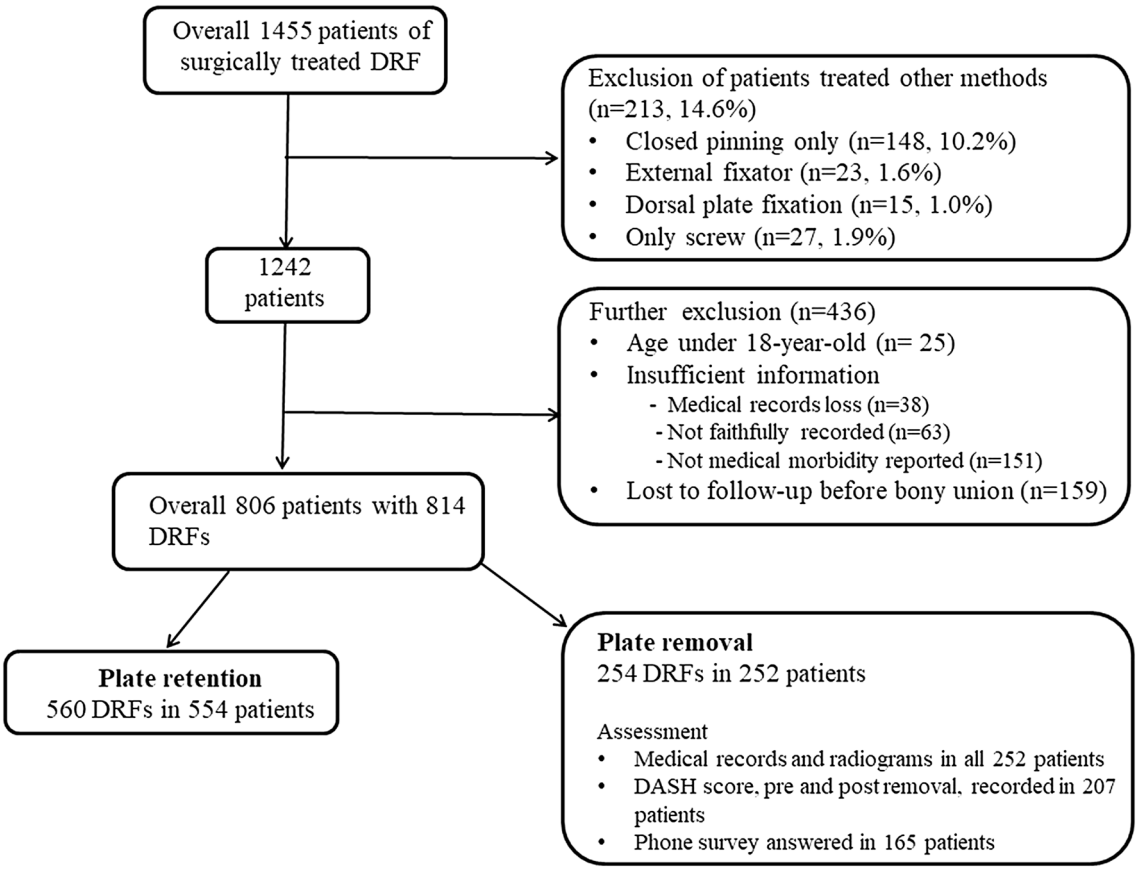

Fig. 1 Flow diagram for patient selection

Comparison depending on plate type

There was a statistical difference in the implant removal rate depending on plate design (Table 3).

A relatively lower implant removal rate was observed for patients who received the 2.4-mm LDRS/extra-articular plate (21.6% [16 out of 74]) compared to those who received the other types of plates. In contrast, higher removal rates were observed in patients with the LDRS/juxta-articular plate (51.4% [18 out of 35]) and the VA-LCP volar rim plate (100% [2 out of 2]). Given the overall average time to implant removal, 12.1 months, between fracture fixation and implant removal, the average time in patients with the LDRS/juxta-articular plate and VA-LCP volar rim plate was shorter with 249.4 and 244.0 days, respectively.

Insurance coverage

In total, insurance coverage was verified for 185 of the 252 patients (73.4%) with plate removal and 332 of the 560 patients (59.9%) with plate retention. Comparing the insurance coverage for which patients were benefited, there was statistically different between groups ($p < 0.001$) (Table 4). Among plate removal patients, 46.5% disclosed that they had private health insurance which would cover the entire cost for implant removal compared to 31.0% in the patients with implant retention. In contrast, 53.0% of the patients with plate retention declared that they only had national health insurance coverage compared with 33.5% in the plate removal group. Industrial accident insurance coverage paid for implant removal cost in 11.9% of the total implant removal cases compared to coverage in 2.4% of the patients with plate retention.

Reasons for implant removal

Eighteen reasons for implant removal were identified and assigned to one of the seven defined categories. Overall, 186 (73.8%) patients (73.8%) underwent implant removal without clinical symptoms after bony union. The other reasons reported were carpal tunnel syndrome ($n = 13$ patients, 5.2%), combination with removal of other implants ($n = 13$ patients, 5.2%), unclear source of discomfort or pain ($n = 12$ patients, 4.8%), and foreign body sensation ($n = 8$ patients, 3.2%) in orders of ratio (Table 5). Among 13 patients with

Table 1 Comparison of patients between implant removal (group 1) and retention (groups 2)

	Group 1 ($N=252$)	Group 2 ($N=554$)	p
Basic characteristics			
Age	50.8 ± 14.0	62.0 ± 13.4	**< 0.001**
Gender			0.076
Men	94 (37.3%)	170 (30.7%)	
Women	158 (62.7%)	384 (69.3%)	
Fractured arm			0.634
Right	118 (46.8%)	251 (45.3%)	
Left	131 (52.0%)	295 (53.3%)	
Both	3 (1.2%)	8 (1.4%)	
Comorbidity			
Diabetes			**0.001**
None	244 (96.8%)	498 (89.9%)	
Yes	8 (3.2%)	56 (10.1%)	
Hypertension			**< 0.001**
None	228 (90.5%)	395 (71.3%)	
Yes	24 (9.5%)	159 (28.7%)	
Angina or myocardial infarction			0.350
None	246 (97.6%)	532 (96.0%)	
Yes	6 (2.4%)	22 (4.0%)	
COPD or asthma			0.733
None	249 (98.8%)	544 (98.2%)	
Yes	3 (1.2%)	10 (1.8%)	
Thyroid disease			0.825
None	247 (98.0%)	540 (97.5%)	
Yes	5 (2.0%)	14 (2.5%)	
Rheumatoid arthritis			0.585
None	252 (100.0%)	551 (99.5%)	
Yes	0 (0.0%)	3 (0.5%)	
Dialysis			0.417
None	252 (100.0%)	550 (99.3%)	
Yes	0 (0.0%)	4 (0.7%)	
Cancer			**0.004**
None	252 (99.2%)	525 (94.8%)	
Yes	2 (0.8%)	29 (5.2%)	

COPD chronic obstruction pulmonary disease

carpal tunnel syndrome, carpal tunnel release was performed together with implant removal in 11 (4.4%) patients.

Clinical outcomes

In 207 (82.1%) of the 252 patients who underwent implant removal, the pre- and post-operative DASH scores were obtained. The post-operative DASH scores were assessed on average 5.5 weeks after implant removal (range 2 weeks–15 months). The average pre-operative DASH score of 16.1 (range 0–70.8) improved to 5.1 at the final follow-up after implant removal (range 0–43.3; $p<0.001$). Among the 252 patients, 165 (66%) completed a follow-up phone survey. Among 165 respondents, the satisfaction score average was 4.1 ± 0.9 (range 1–5) immediately preceding the implant removal and 4.4 (range 1–5) at the time of the phone survey, which indicates a significant improvement ($p<0.001$). Among the 165 patients questioned, 153 (93%) patients answered "yes'' when asked if they would undergo implant removal again under the same conditions.

Table 2 Comparison of AO Foundation and Orthopedic Trauma Association (AO/OTA) classification between implant removal (group 1) and retention (groups 2)

	Group 1 ($N=254$)	Group 2 ($N=560$)	p
AO/OTA classification			0.676
A			
A2	13 (5.1%)	31 (5.5%)	
A3	21 (8.3%)	38 (6.8%)	
B			
B1	2 (0.8%)	2 (0.3%)	
B2	18 (7.1%)	41 (7.3%)	
B3	9 (3.5%)	15 (2.7%)	
C			
C1	14 (5.5%)	29 (5.2%)	
C2	55 (21.7%)	156 (27.9%)	
C3	122 (48.0%)	248 (44.3%)	
Soong grade			0.075
0	71 (27.9%)	188 (33.6%)	
1	145 (57.1%)	315 (56.2%)	
2	38 (15.0%)	57 (10.2%)	

Complications after implant removal

During outpatient follow-up, none of the patients experienced major complications. Minor complications were reported for 26 (10%) patients (Table 6). Six patients complained of newly developed postoperative pain with subsidence during outpatient follow-up. Five patients complained of numbness or tingling sensations along the median nerve or around the operative scar. Five patients were rather dissatisfied with their operative scar after the implant removal. Prior to implant removal, 12 patients requested removal due to an unclear source of discomfort or pain, and 3 patients complained of persistent pain even after implant removal (1.2%).

Discussion

Among 806 patients who underwent VLP fixation for DRFs, 252 patients underwent plate removal during the 10-years study period. When comparing patient characteristics

Table 3 Implant removal rates depending on plate types

Group	Removal ($N=254$)	Retention ($N=560$)	Total	p value
Plate design				**0.006**
3.5 mm LCP T-plate	31 (33.0%)	63 (67.0%)	94	
2.4 mm VA-LCP Two Column Volar DRP	187 (30.7%)	422 (69.3%)	609	
2.4 mm LDRS, Extra-articular	16 (21.6%)	58 (78.4%)	74	
2.4 mm LDRS, Juxta-articular	18 (51.4%)	17 (48.6%)	35	
2.4 mm VA-LCP Volar Rim DRP	2 (100.0%)	0 (0.0%)	2	

LCP locking compression plate, *VA* variable angle, *DRP* distal radius plate, *LDRS* LCP distal radius system

Table 4 Insurance coverage for distal radius fracture treatment between implant removal (group 1) and retention (groups 2)

Group	Group 1 ($N=185$)	Group 2 ($N=332$)	p
Insurance			< 0.001
National health	62 (33.5%)	176 (53.0%)	
Private health	86 (46.5%)	103 (31.0%)	
Social welfare program	6 (3.2%)	16 (4.8%)	
Industrial accident	22 (11.9%)	8 (2.4%)	
Car	9 (4.9%)	29 (8.7%)	

between the removal and retention groups, the patients who underwent implant removal were younger and had lower rates of diabetes, hypertension, and cancer. Although there was no statistical difference, the patients who underwent implant removal tended to have higher rates of grade 2 plate prominence according to Soong classification. There were higher rates of private health insurance coverage in patients who underwent plate removal. In 186 (73.8%) patients, plate removal was performed in the absence of any clinical symptoms. Juxta-articular and volar rim plates were associated with higher removal rates. Overall, the patient satisfaction score improved from 4.1 to 4.4 after implant removal. In total, 93% of the patients in the removal group who participated in the follow-up interview answered that they would choose implant removal again if they were in the same situation. No major complications were reported, but several minor complications were reported in 10% of the patients who underwent plate removal.

Researchers have speculated on the characteristics of the patients who undergo implant removal compared to those who opt for retention. Our results show that the patients who underwent removal were younger, by 10 years, than the patients who did not. In addition, although not statistically significant, men showed a higher rate of removal. Moreover, lower rates of diabetes, hypertension, and cancer were reported among the patients who underwent removal. These results suggest that this may be a more active cohort. Therefore, we posit that the removal rate is higher among patients with higher activity levels, regardless of the clinical symptoms.

Table 5 Reasons for implant removal

	Number		Rate (%)
Removal without clinical symptom	**186**		73.8
Nerve related	**13**		
Carpal tunnel syndrome		13	5.2
Carpal tunnel release combined		11	4.4
Tendon related	**4**		
EPL rupture		2	0.8
FPL tendon rupture		1	0.4
Flexor tendon adhesion		1	0.4
Implant related	**3**		
Broken screw		1	0.4
Screw joint penetration		2	0.8
Osteosynthesis problem	**2**		
Malunion		1	0.4
Nonunion		1	0.4
Part of another procedure	**18**		
Multiple implant removal		13	5.2
Other combined operation		5	2.0
Trigger finger		1	0.4
Medial epicondylitis		1	0.4
Forearm mass excision		1	0.4
Scar revision		2	0.8
Others	**26**		
Pain		12	4.8
Foreign body sensation		8	3.2
Plate palpation		1	0.4
Stiffness		3	1.2
Cold intolerance		2	0.8
Total	**252**		

There was no fracture pattern difference between the groups according to the AO/OTA classification. In a type C fracture, the distal screw must purchase the distal articular fragment and, therefore, it is usually necessary to place the plate very distally, which can irritate the flexor tendon [23]. Therefore, one would expect a higher rate of implant

Table 6 Complications with implant removal

	Number	Rate (%)
Major		
Plate removal failure	0	0
Refracture	0	0
Tendon rupture	0	0
Neurovascular injury	0	0
Wrist range of motion limitation	0	0
Deep infection	0	0
Minor		
Broken screw remains	2	0.8
Superficial infection	2	0.8
Wound dehiscence	1	0.4
Newly developed pain	6	2.4
Persistent preoperative pain	3	1.2
Tenosynovitis	2	0.8
Transient neuritis	5	2.0
Scar dissatisfaction	5	2.0
Overall 26 incidences in 252 patients (10.3%)		

removal for type C fractures. However, no difference was detected in the current study, which corroborates the results from a previous systematic review [13]. One possible explanation is that the difference could be diluted as so many implants were removed in asymptomatic patients, which may have developed tendon irritation, had the implant been left. Furthermore, the AO classification groups various fracture types together within the C-fractures. Not all these fractures require a very distal position of the plate.

Based on the Soong classification of plate position prominence, more grade 2 cases tended to end in removal. Sellas et al. reported a six times higher plate removal rate among patients with grade 2 prominence compared to that for grade 0 prominence [24].

Regarding the plate type, we found higher removal rates associated with the juxta-articular and volar Rim plates, which were designed to be placed distally to purchase the distal fragment, resulting in Soong classification grade 2 [22] and concern for flexor tendon irritation. If this position is required for fixation, some studies suggest that subsequent removal should be planned after bony union [25, 26]. Asadollash and Keith reported 21 cases of flexor tendon injuries within an average of 9 months from fracture surgery [27]. In the present study, these two types were removed within an average of 8 months. Rather than the patient's clinical symptoms, the surgeon's concern and discretion might have affected these outcomes. However, flexor tendon injuries were not reported in patients who retained the juxta-articular plates.

Although there is a small variation depending on the tier of the hospital, the operation costs associated with implant removal in the study setting averaged 179 USD. The cost for hospital stay during implant removal and recovery averaged 616.6 USD. In Korea, the patient is asked to pay 20% of the total cost under the national health insurance service plan. However, about 66.5% of the patients who underwent implant removal had additional health insurance compared with 47% of the patients who retained the implant. There was a significant difference regarding insurance coverage between the groups, especially regarding private health and industrial accident insurance coverage. These findings suggest that patients are more likely to have implant removal if they have no economical burden even in the absence of clinical symptoms. Those that would have had to pay themselves more often retained the implant. Insurance coverage seems to influence the rate of plate removal.

There are some conditions requiring the removal of the inserted volar plate including infection, tendon irritation, articular violation, non-union or malunion, and nerve irritation [8–10, 28]. However, some patients opt for plate removal without significant adverse symptoms, despite the lack of evidence regarding the advantages. Yamamoto et al. defined removal without clinical symptoms as routine removal [13, 18, 29]. In our study, 186 (73.8%) patients (73.8%) underwent implant removal without clinical symptoms after bony union.

Studies have reported functional improvement and decreased pain associated with implant removal in patients with DRFs [19, 30, 31]. In our study, the average preoperative DASH score (16.3) improved at the final follow-up (5.1). The majority of patients had implant removed without symptoms, therefore, the DASH improvement could be due to the removal itself. For the other patients who removed plate with specific reasons, another explanation may be that the patients with poor functional ability before implant removal experienced complications associated with VLP fixation, including tendon ruptures, screw joint penetration, malunion and non-union, and carpal tunnel syndrome. Proper management of complications and implant removal could have resulted in improved functional scores. Finally, among 165 respondents, the satisfaction score average was 4.1 ± 0.9 (range 1–5) immediately preceding the implant removal and 4.4 (range 1–5) at the time of the phone survey and 153 (93%) patients answered "yes'' when asked if they would undergo implant removal again under the same conditions.

It is possible to develop complications as a result of implant removal, and the use of the locking system in fracture management presents technical challenges during removal [8, 19, 32, 33]. One of the main reasons opposing removal in asymptomatic patients is that it could cause problems such as refracture, nerve damage, infection, tendon injury, and development of new pain [12, 18]. After defining the possible complications as major or minor, we did not find any major complications associated with implant removal,

and the VLPs were removed without incidence except for two cases where a broken screw remained. In total, only 10% of the patients reported minor complications which were all transient and resolved during the out-patient follow-up.

There are some limitations to the study that must be considered. All surgeries, VLP fixation, and removal were performed by a single hand surgeon. Therefore, implant removal outcomes were based on one surgeon's experience at a single-centre. In addition, we could not compare clinical outcomes with patients who did not undergo plate removal. The functional outcome measurements were self-reported in the medical chart, and additional data were collected by phone interview during the study. In addition, we encountered difficulties in attempting to assess information in elderly patients who could not participate in the telephone interview.

Our study showed that implant removal is more often performed in a young and healthy cohort. Although the implant removal was conducted without clinical symptoms in the majority of patients, overall patients presented improved functional outcomes with implant removal. The evidence is inconclusive regarding its necessity, however, implant removal after VLP fixation for DRF is not a challenging procedure and is not associated with major complications.

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Compliance with ethical standards

Conflict of interest The author(s) declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Ruch DS, McQeen MM (2015) Distal radius and ulna fractures. In: Bucholz RW, Beaty JH, Rockwood CA, Jr; Green DP (eds) Rockwood and Green's fractures in adults, vol 1, 7th edn. Wolter Kluwer Health/Lippincott, Wiliams & Wilkins, Philadelphia.
2. Singh RP, Carter LM, Whitfield PH (2013) Antimicrobial prophylaxis in open reduction and internal fixation of compound mandibular fractures: a collaborative regional audit of outcome. Br J Oral Maxillofacial Surg 51(5):444–447. https://doi.org/10.1016/j.bjoms.2012.08.019
3. Wilcke MK, Hammarberg H, Adolphson PY (2013) Epidemiology and changed surgical treatment methods for fractures of the distal radius: a registry analysis of 42,583 patients in Stockholm County, Sweden, 2004–2010. Acta Orthop 84(3):292–296. https://doi.org/10.3109/17453674.2013.792035
4. Hevonkorpi TP, Launonen AP, Huttunen TT, Kannus P, Niemi S, Mattila VM (2018) Incidence of distal radius fracture surgery in Finns aged 50 years or more between 1998 and 2016 - too many patients are yet operated on? BMC Musculoskelet Disord 19(1):70. https://doi.org/10.1186/s12891-018-1983-0
5. Lee DY, Park YJ, Park JS (2019) A meta-analysis of studies of volar locking plate fixation of distal radius fractures: conventional versus minimally invasive plate osteosynthesis. Clin Orthopedic Surg 11(2):208–219. https://doi.org/10.4055/cios.2019.11.2.208
6. Jeudy J, Steiger V, Boyer P, Cronier P, Bizot P, Massin P (2012) Treatment of complex fractures of the distal radius: a prospective randomised comparison of external fixation 'versus' locked volar plating. Injury 43(2):174–179. https://doi.org/10.1016/j.injury.2011.05.021
7. McFadyen I, Field J, McCann P, Ward J, Nicol S, Curwen C (2011) Should unstable extra-articular distal radial fractures be treated with fixed-angle volar-locked plates or percutaneous Kirschner wires? A prospective randomised controlled trial. Injury 42(2):162–166. https://doi.org/10.1016/j.injury.2010.07.236
8. Gyuricza C, Carlson MG, Weiland AJ, Wolfe SW, Hotchkiss RN, Daluiski A (2011) Removal of locked volar plates after distal radius fractures. J Hand Surg Am 36(6):982–985. https://doi.org/10.1016/j.jhsa.2011.03.032
9. Musgrave DS, Idler RS (2005) Volar fixation of dorsally displaced distal radius fractures using the 2.4-mm locking compression plates. J Hand Surg Am 30(4):743–749. https://doi.org/10.1016/j.jhsa.2005.03.006
10. Alter TH, Sandrowski K, Gallant G, Kwok M, Ilyas AM (2019) Complications of volar plating of distal radius fractures: a systematic review. J Wrist Surg 8(3):255–262. https://doi.org/10.1055/s-0038-1667304
11. Dennison DG (2010) Distal radius fractures and titanium volar plates: should we take the plates out? J Hand Surg Am 35(1):141–143. https://doi.org/10.1016/j.jhsa.2009.10.029
12. Busam ML, Esther RJ, Obremskey WT (2006) Hardware removal: indications and expectations. J Am Acad Orthop Surg 14(2):113–120. https://doi.org/10.5435/00124635-200602000-00006
13. Yamamoto M, Fujihara Y, Fujihara N, Hirata H (2017) A systematic review of volar locking plate removal after distal radius fracture. Injury 48(12):2650–2656. https://doi.org/10.1016/j.injury.2017.10.010
14. Arora R, Lutz M, Hennerbichler A, Krappinger D, Espen D, Gabl M (2007) Complications following internal fixation of unstable distal radius fracture with a palmar locking-plate. J Orthop Trauma 21(5):316–322. https://doi.org/10.1097/BOT.0b013e318059b993
15. Rozental TD, Blazar PE (2006) Functional outcome and complications after volar plating for dorsally displaced, unstable fractures of the distal radius. J Hand Surg Am 31(3):359–365. https://doi.org/10.1016/j.jhsa.2005.10.010
16. Tarallo L, Adani R, Mugnai R, Catani F (2011) The treatment of distal radius articular fractures of C1–C2 type with DVR plate: analysis of 40 cases. Musculoskelet Surg 95(3):225–230. https://doi.org/10.1007/s12306-011-0140-9
17. Jakubietz MG, Gruenert JG, Jakubietz RG (2012) Palmar and dorsal fixed-angle plates in AO C-type fractures of the distal radius: is there an advantage of palmar plates in the long term? J Orthop Surg Res 7(1):8. https://doi.org/10.1186/1749-799X-7-8

18. Tan A, Chong A (2016) Reasons for implant removal after distal radius fractures. J Hand Surg Asian-Pacific 21(3):321–325. https://doi.org/10.1142/s2424835516500284
19. Vos DI, Verhofstad MH (2013) Indications for implant removal after fracture healing: a review of the literature. Eur J Trauma Emerg Surg 39(4):327–337. https://doi.org/10.1007/s00068-013-0283-5
20. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP (2007) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. The Lancet 370(9596):1453–1457. https://doi.org/10.1016/s0140-6736(07)61602-x
21. Tang JB (2009) Re: Levels of experience of surgeons in clinical studies. J Hand Surg Eur 34(1):137–138. https://doi.org/10.1177/17531934097321
22. Soong M, Earp BE, Bishop G, Leung A, Blazar P (2011) Volar locking plate implant prominence and flexor tendon rupture. J Bone Joint Surg Am 93(4):328–335. https://doi.org/10.2106/jbjs.J.00193
23. Rubensson CC, Ydreborg K, Boren L, Karlander LE (2015) Flexor tendon repair after rupture caused by volar plate fixation of the distal radius. J Plast Surg Hand Surg 49(2):112–115. https://doi.org/10.3109/2000656X.2014.951050
24. Selles CA, Reerds STH, Roukema G, van der Vlies KH, Cleffken BI, Schep NWL (2018) Relationship between plate removal and Soong grading following surgery for fractured distal radius. J Hand Surg Eur 43(2):137–141. https://doi.org/10.1177/1753193417726636
25. Cross AW, Schmidt CC (2008) Flexor tendon injuries following locked volar plating of distal radius fractures. J Hand Surg Am 33(2):164–167. https://doi.org/10.1016/j.jhsa.2007.11.011
26. Kitay A, Swanstrom M, Schreiber JJ, Carlson MG, Nguyen JT, Weiland AJ, Daluiski A (2013) Volar plate position and flexor tendon rupture following distal radius fracture fixation. J Hand Surg Am 38(6):1091–1096. https://doi.org/10.1016/j.jhsa.2013.03.011
27. Asadollahi S, Keith PP (2013) Flexor tendon injuries following plate fixation of distal radius fractures: a systematic review of the literature. J Orthop Traumatol 14(4):227–234. https://doi.org/10.1007/s10195-013-0245-z
28. Jung HS, Jung HS, Baek SH, Lee JS (2020) How many screws are needed for reliable stability of extra-articular nonosteoporotic distal radius fractures fixed with volar locking plates? Clin Orthop Surg 12(1):22–28. https://doi.org/10.4055/cios.2020.12.1.22
29. Hanson B, van der Werken C, Stengel D (2008) Surgeons' beliefs and perceptions about removal of orthopaedic implants. BMC Musculoskelet Disord 9:73. https://doi.org/10.1186/1471-2474-9-73
30. Snoddy MC, An TJ, Hooe BS, Kay HF, Lee DH, Pappas ND (2015) Incidence and reasons for hardware removal following operative fixation of distal radius fractures. J Hand Surg Am 40(3):505–507. https://doi.org/10.1016/j.jhsa.2014.11.022
31. Marlow WJ, Singhal R, Dheerendra S, Ralte P, Fischer J, Waseem M (2012) Distal radius volar locking plates: does a variable angle locking system confer a clinical advantage? Acta Orthop Belg 78(3):309–316
32. Ehlinger M, Adam P, Simon P, Bonnomet F (2009) Technical difficulties in hardware removal in titanium compression plates with locking screws. Orthop Traumatol Surg Res 95(5):373–376. https://doi.org/10.1016/j.otsr.2009.03.020
33. Bae JH, Oh JK, Oh CW, Hur CR (2009) Technical difficulties of removal of locking screw after locking compression plating. Arch Orthop Trauma Surg 129(1):91–95. https://doi.org/10.1007/s00402-008-0769-5

Affiliations

Jun-Ku Lee[1] · Younghun Lee[2] · Choongki Kim[1] · Minwook Kim[2] · Soo-Hong Han[2]

Jun-Ku Lee
jg197@naver.com

Younghun Lee
leeyh027@naver.com

Choongki Kim
coilzone@hanmail.net

Minwook Kim
kmu3102@naver.com

[1] Department of Orthopaedic Surgery, Seoul Paik Hospital, Inje University College of Medicine, Seoul, Republic of Korea

[2] Department of Orthopaedic Surgery, CHA Bundang Medical Center, CHA University School of Medicine, 351 Yatap-dong, Bundang-gu, Seongnam-si, Gyeonggi-do, Republic of Korea