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ORIGINAL ARTICLE

Surgical comfort and clinical outcomes of MIPO with an extra-short plate designed for distal radius fractures

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Abstract

Objectives Volar locking plates (VLPs) are increasingly used for distal radius fractures (DRFs) with minimally invasive plate osteosynthesis (MIPO), but surgery learning curves could be long. The purpose of this study was to assess a new extra-short plate with two locking diaphyseal divergent screws, specifically designed for MIPO, preserving the pronator quadratus muscle.

Materials and methods This retrospective study consisted of three phases: (i) the evaluation of surgical comfort with the incision size and the duration of 59 consecutive surgeries using the extra-short plate in DRFs; (ii) the verification of the implant ability to maintain radiographic indices compared immediately postoperatively and at consolidation. They included radial inclination (RI), volar tilt (VT) and ulnar variance (UV); (iii) the assessment of clinical outcomes at last follow-up through: pain measured on the visual analogue scale (VAS), QuickDASH score, patient-rated wrist evaluation (PRWE) score, grip strength, range of motion and complications.

Results In the first phase: mean incision size was 32 mm, and mean operative time was 28.5 min. In the second phase, there was no statistical difference between the two measures of the indices studied. In the third phase, mean follow-up time was 14.2 months, VAS score was 1.1, QuickDASH score was 11.4/100, and PRWE score was 9.5/100. Flexion was 91%, extension was 94%, and grip strength was 86% compared to the contralateral side.

Conclusion The surgical comfort may be related to short operative time and incision. The implant allowed maintaining the radiographic indices without secondary displacement. Functional clinical outcomes were satisfactory. This extra-short plate design belongs to a novel generation of VLPs.

Keywords Distal radius · Fracture · Mini-invasive approach · Extra-short locking plate · Pronator quadratus · Clinical outcomes

Introduction

Minimally invasive approaches with plating are a recent trend, especially in displaced distal radius fractures (DRFs). According to Obert et al. [1], although DRFs are frequent in adults, the level of evidence supporting a specific surgical technique is low. Nevertheless, arguments are emerging to support the use of the less invasive approaches. These arguments favour volar locking plates (VLPs) over percutaneous pinning in dorsally displaced DRFs [2, 3].

In the presence of a multitude of minimally invasive approaches for the distal radius, and the lack of a clear definition, we suggest defining these approaches based on three criteria: (i) a small skin incision from the aesthetic viewpoint; (ii) a minimal dissection of the soft tissues overlying the fracture fragments; and (iii) a muscle-sparing approach of the pronator quadratus (PQ) muscle. We therefore chose to develop a volar locking plate for the distal radius, inserted through a small skin incision while respecting the surrounding soft tissues. Our hypothesis is that in order to spare the PQ muscle, the plate must be extra-short with blunt edges and slid under the deep part of the muscle, without dividing it. An approach that is less invasive to the surrounding soft tissues preserves the rich vascular network of the distal

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radius and would therefore aid bone consolidation [4–6]. An implant especially designed for minimally invasive plate osteosynthesis (MIPO) preferably allows surgeons a rapid learning of the insertion technique without considerable lengthening of the surgery time, compared with the more conventional approaches. Ideally, a plate designed for MIPO is easy to use.

In this report, we describe our first objective which was to assess surgical comfort through incision size and operative time of consecutive surgeries performed by five hand surgeons, using the extra-short plate on DRFs. Our second objective was to assess the implant ability to maintain radiographic indices, with only two diaphyseal screws, based on radiological criteria of stability of both the hardware and the fracture. Our third objective was to assess, at the final follow-up, the clinical outcomes of patients operated for DRFs with the extra-short plate.

Patients and methods

Patients and study design

This single-centre, retrospective, observational study was approved by the Institutional Review Board. All patients gave their informed consent to participate in the study and to the anonymous use of their photographs. Patients enrolled in the survey underwent surgery for displaced DRFs requiring internal fixation. The study consisted of three phases for data collection: a first phase, with data collected on the day of the procedure; a second phase, from surgery until 6 weeks postoperatively; and a third phase at the last follow-up visit, at least 6 months postoperatively.

Methods

Plate design

The plate is a locking volar anatomic titanium plate for the distal radius (Newclip Technics™; Haute Goulaine, France). It is extra-short, 30 mm long, and is designed to be slid and partially hidden under the pronator quadratus muscle. It is 19.5 mm wide distally where it follows the "watershed line". The plate has a single distal row of four holes for locking screws. The two central holes allow locked screws with fixed angles. The most radial and ulnar holes allow polyaxial locked screws of 20° for each. Diaphyseal fixation is insured by two slanting screws, positioned asymmetrically, with two different obliquities to enhance the construct rigidity. The more distal of these two screws can be a locking or a compression screw. The plate is 2.5 mm thick distally and 2.9 mm proximally, where the most proximal screw has a fixed ascending angle of 30° and is always locking. This screw orientation is designed to improve fixation to the cortical bone through a higher number of threads. All screws have a diameter of 2.8 mm.

Surgical Technique

Five hand surgeons performed the procedures. There were two experts (level V) and three specialists (level III) in hand surgery [7]. Surgery was carried out under brachial plexus block in the supine position with an arm tourniquet inflated at 250 mmHg.

The surgeon started by performing external manoeuvres to reduce the fracture. Part of the conventional Henry approach was then carried out on an average of 3 cm (Fig. 1a), starting distally at the proximal wrist crease. After longitudinal incision of the superficial flexor carpi radialis (FCR) tendon sheath, the FCR, median nerve and flexor tendons were retracted medially and the radial artery laterally. The PQ muscle was exposed (Fig. 1b). In a DRF, the distal edge of the PQ muscle is frequently divided by the fracture itself. If this was not the case, the surgeon incised it transversally and then raised it subperiosteally from the radius. A drilling guide was fixed to one of the distal holes of the plate and the diaphyseal part of the plate was then introduced underneath the muscle in a retrograde fashion (Fig. 2a). The "watershed line" was the landmark to place the distal part of the plate in optimal position proximal to it. The plate was held in place with two 1.2 mm Kirschner wires. After fluoroscopic control to verify satisfactory positioning of the plate, screws were placed in all four locking distal holes (Fig. 2b). The distal Kirschner wire was then removed and another fluoroscopic

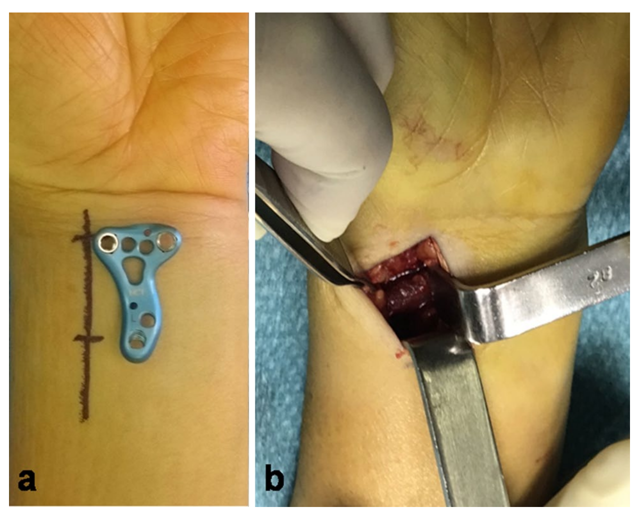

Fig. 1 **a** Design of the incision on part of the Henry approach on the left wrist; extra-short plate (Newclip Technics™) positioned next to the design. **b** After dissection, the pronator quadratus muscle, partially divided by the fracture, is exposed

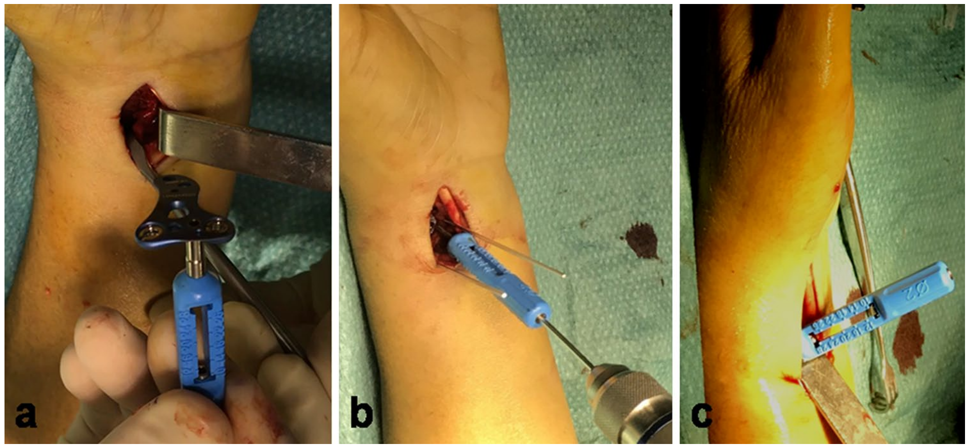

Fig. 2 **a** Drill guide fixed to a distal hole; the shaft part of the plate is introduced retrogradely under the pronator quadratus. **b** Plate fixed to the radius with two K-wires; drilling starts for the distal screws. **c** Proximal diaphyseal screw at 30° is the last to be fixed

control showed if a compression or a locking screw was needed in the distal hole for the diaphysis. The remaining temporary Kirschner wire was removed. The most proximal screw of the plate was positioned last (Fig. 2c). A final fluoroscopic control was performed and if the result was satisfactory, skin closure and drainage were carried out. Immobilisation was achieved with a simple wrist splint for 3 weeks and the patients were encouraged to move their fingers freely. Figure 3a shows a photograph before plate fixation through a conventional Henry approach (not MIPO) on a cadaver forearm, to allow a better exposure of the PQ muscle. Figure 3b shows the plate position relatively to the PQ muscle after fixation.

First-phase data

Preoperative epidemiological characteristics including: gender, age, profession, dominant side, operated side and trauma mechanism were recorded. Plain radiographs were assessed and the AO classification for distal forearm fractures was used. Patients with any AO subtype were enrolled, excluding: ulnar fractures (A1.1, A1.2

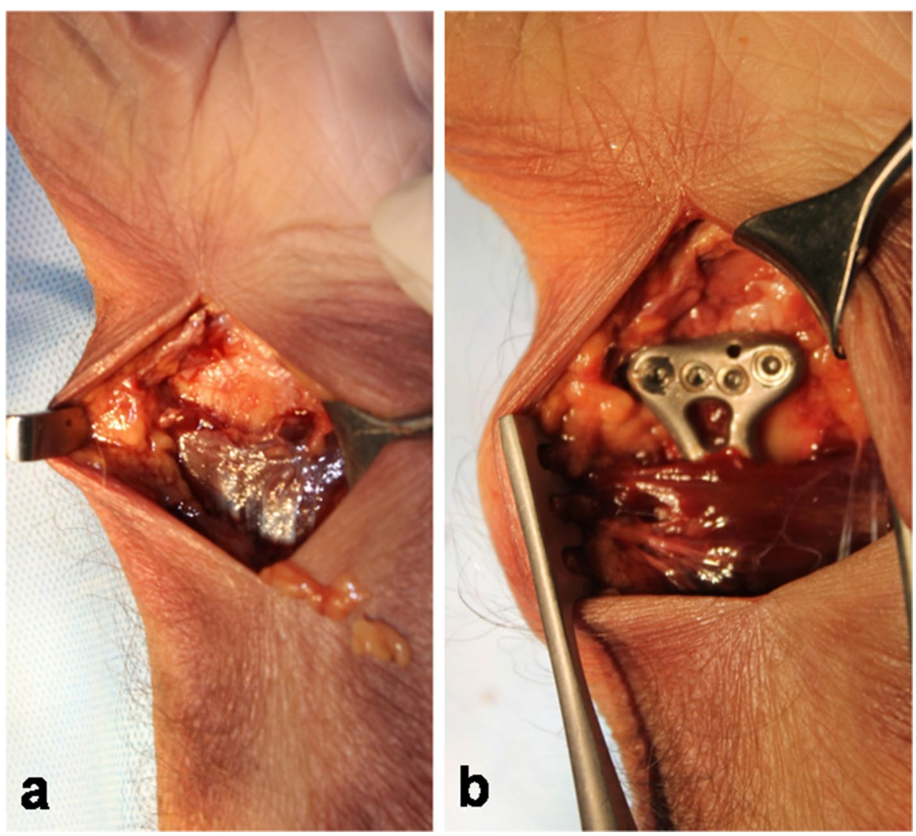

Fig. 3 **a** A photograph before plate fixation through a conventional Henry approach on a cadaver forearm. **b** Plate position relatively to the PQ muscle

and A1.3), simple extra-articular fractures without a tilt (A2.1), articular fractures of the dorsal rim (B2.1, B2.2 and B2.3) and a highly comminuted metaphysis (A3.3, C2.3, C3.2 and C3.3). CT scans were also analysed when available to aid classification. Associated lesions such as skin injury, ulnar styloid fracture and median nerve compression were investigated. Incision length and mean operative time knife-to-skin were recorded during surgery.

Second-phase data

Radiological data for the second phase were noted at two follow-up visits: (i) early postoperative period, within 3 weeks of surgery; and (ii) 6 weeks postoperatively. Radiological indices were compared statistically at both follow-up visits. They included radial inclination (RI), volar tilt (VT) and ulnar variance (UV). Other stability criteria recorded were: displacement of the hardware or the fracture. The need for physiotherapy sessions after splint removal and any complications were also assessed.

Third-phase data

Data were collected at the last follow-up visit, at a minimum of 6 months after surgery. They included: range of motion (ROM), and grip strength measured as kilogram-force (kgf) with a Jamar® hydraulic dynamometer (Performance Health, Reims, France). ROM and grip strength were investigated for both the surgical and the contralateral sides for statistical comparison. At the final follow-up, the simplified "Disabilities of the Arm, Shoulder and Hand Questionnaire" (QuickDASH) score was computed for each patient, as well as the "Patient-Rated Wrist Evaluation" (PRWE) score. Evaluation also included pain assessed according to the visual analogue scale (VAS), patients' satisfaction with the scar size, and complications such as complex regional pain syndrome (CRPS) or tendon problems. Final radiographs were also assessed.

Data for the second and third phases of the study were collected by an evaluator (G.A.) who was different from the operators.

Data analysis

Data were analysed using Microsoft Excel 365 (Microsoft®, Redmond, Washington, US). For statistical comparisons of the parameters examined in both phases, the paired Student's *t* test was used. A two-sided confidence interval of 95% was chosen. P-values < 0.05 were considered statistically significant. Photographs were obtained for comparison using a digital camera preoperatively, during surgery and at the postoperative follow-up visits.

Results

First-phase outcomes

Fifty-nine patients (42 women and 17 men) underwent surgery for DRFs with the extra-short plate. Mean age at surgery was 58.2 years (range 16–88). Twenty-five patients (42%) were retired. Fifty-two patients (88%) were right-handed and seven (12%) left-handed. The left wrist was operated on in 42 patients (71%) and the right wrist in 17 patients (29%). The dominant side was involved in 19 patients (32%).

The trauma mechanism was a simple fall from standing in 35/59 patients (59%). The other patients (41%) injured their wrist following high-impact trauma (sports or fall from height). A detailed distribution of fracture subtypes according to AO classification is shown in Table 1. Twenty-nine patients (49%) had an associated ulnar styloid fracture and two (3%) presented with symptoms of median nerve compression leading to carpal tunnel (CTR) release during the same procedure. One patient had a volarly open fracture of type IO 1 according to AO classification prompting internal fixation on the same day as the injury. Mean incision length was 32.3 mm (range 24–50). Mean operative time was 28.5 min (range 20–50).

Second-phase outcomes

Fifty-two patients (37 women and 15 men) completed the second phase of the study. Postoperatively, no local complications (infection, haematoma) were detected. A comparison of radiological indices (RI, VT and UV) at the

Table 1 Distribution of distal forearm fracture subtypes according to AO classification

	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3
A	–	–	–	–	15	3	1	10	–
B	0	0	0	–	–	–	0	1	1
C	4	8	0	9	0	–	7	–	–

–: Patients with these fracture subtypes were not candidates for surgery with the extra-short plate and were not enrolled in the study

Table 2 Radiological indices at the early postoperative period and at consolidation

Index	Early period Mean ± SD	Consolidation Mean ± SD	*P*-value
*Radial inclination	21.5 ± 2.7	21.6 ± 2.8	0.510
*Volar tilt	7.4 ± 4.0	7.3 ± 4.0	0.279
**Ulnar variance	− 0.84 ± 1.0	− 0.82 ± 1.0	0.568

SD Standard Deviation

*Radial inclination and volar tilt are in degrees

**Ulnar variance is measured in millimetres. The minus sign indicates that the ulna projects more proximally than the radius

Table 3 Wrist range of motion (ROM) and grip strength of operated and contralateral sides

Variable	Operated Mean ± SD	Contralateral Mean ± SD	*P*-value
*Flexion	51.2 ± 9.8	55.8 ± 9.5	<0.0001
*Extension	60.5 ± 8.5	64.0 ± 8.6	<0.0001
*Pronation	89.9 ± 0.8	90.0 ± 0.0	0.323
*Supination	88.3 ± 4.8	87.7 ± 6.4	0.462
**Grip strength	20.7 ± 13.6	24.1 ± 14.0	<0.0001

SD Standard Deviation

*ROM is in degrees

**Grip strength is in kilogram-force (kgf)

early postoperative period and at consolidation 6 weeks after surgery is shown in Table 2. There was no significant difference between the two measures. Neither fracture nor hardware displacement was detected and all patients showed fracture consolidation on radiographs at 6 weeks postoperatively. Forty patients (68%) underwent physiotherapy and 12 patients (32%) chose self-rehabilitation after splint removal.

Third-phase outcomes

Forty-three patients from the second phase were assessed at final follow-up at 6 months postoperatively as a minimum. Nine patients (17%) were lost to the final follow-up visit. Mean follow-up time was 14.2 months (range 6–26.5). A comparison of ROM and grip strength of both the operated and contralateral sides is shown in Table 3. There was no statistical difference regarding pronation (P-value = 0.323) or supination (P-value = 0.462) between the two wrists. Flexion was 91%, extension was 94% and grip strength was 86% compared with the contralateral side. There was a statistically significant decrease in these measures (P-value < 0.0001). Mean QuickDASH was 11.4/100 (range 0–45) and mean total PRWE was 9.5/100 (range 0–52). Pain measured on the VAS was 1.1 (range 0–4). All patients expressed full satisfaction with the scar size. Three patients (6.9%) experienced CRPS type 1 that resolved within the usual timeframe with medication and physiotherapy. No changes regarding the hardware or fracture site were observed on the last radiographs compared with those taken at the 6-week follow-up visit. No neurological problems occurred. The radiological and clinical outcomes of the case of a 53-year-old woman with a left DRF and median nerve compression are illustrated in Fig. 4. Internal fixation with the extra-short plate and CTR were carried out. X-rays of a case of a 60-year-old woman with left A2.2 DRF are illustrated in Fig. 5. Figure 6 shows the case of a right extra-articular volarly displaced DRF in a 60-year-old woman. Figure 7 shows a right DRF with volar opening of type IO 1 according to AO classification in an 88-year-old woman.

Discussion

Some epidemiological features of our patients are similar to those of other studies. In our series, mean follow-up time was 14.2 months and in the meta-analysis of Franceschi et al. [8], it was 11.6 months. They had predominantly women (75%) and a mean patients' age of 60.1 years. In our study, 71% were women and the mean patients' age was 58.2 years. We had 44 patients (74%) over 50 years of age at the time of surgery. Some studies have reported that 85% of older women with a Colles' fracture have low bone density [9], leading to an increased fragility. Like in other surveys [10], a simple fall from standing was the main cause of injury in our patients. Regarding the fracture types according to AO, there were 29 type A (49%), two type B (4%) and 28 type C (47%). Thus, we had a similar distribution to Franceschi et al. [8] who had 49% type A and 47% types B and C. The extra-short plate is suitable for most AO subtypes of displaced distal radius fractures, excluding: partial articular dorsal rim (volar plates are not indicated for these fractures)—a highly comminuted metaphysis because this short plate is not indicated to bridge complex metaphyseal comminution—fractures extending very proximally on the diaphysis (where evidently the 30 mm plate is not long enough). The five hand surgeons who performed the procedures followed the instructions of the insertion technique of the extra-short plate and found it to be simple and reproducible, as can be deduced from the mean operative time in our series. It was 28.5 min and thus was shorter than that reported in other papers (34–61 min) [5, 10, 11]. On account of the straightforward technique and the reduced operative time, it may be inferred that the learning time of mini-invasive surgery with this extra-short plate for the DRFs is also reduced. Our incisions were longer than in other studies [5, 11]. The scar size was not our main concern although all patients were fully satisfied with it. We prefer a slightly longer incision allowing

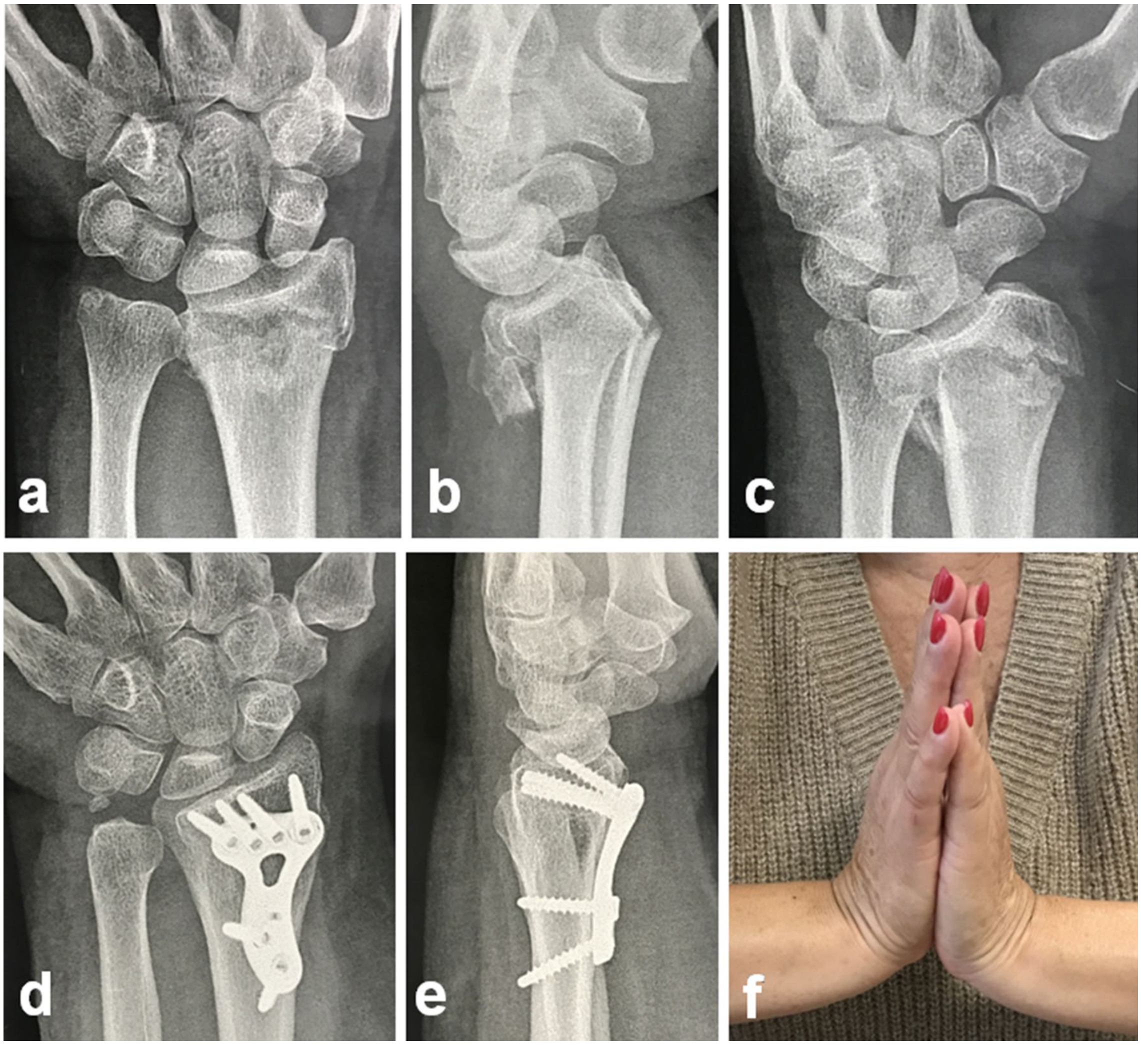

Fig. 4 **a** Coronal, **b** sagittal and **c** oblique X-ray views of a left A3.2 fracture with ulnar styloid fracture. **d** Coronal and **e** sagittal X-rays at 7 months follow-up. **f** Clinical outcomes at 7 months after fixation with the extra-short plate

optimal surgical exposure and potentially less X-rays to position the plate: the main aim of using volar plates is to reduce the anterior cortex anatomically under direct visual control and favour the intact areas where the cortical bone is stronger, avoiding the damaged dorsal side [12]. A recent study showed that persistent posterior comminution in DRFs treated with VLPs did not seem to impact outcomes [13].

The second phase of our study demonstrated the implant ability to maintain radiographic indices with divergent shaft locking screws. Anatomical reduction allowed all fractures in our series to consolidate around 6 weeks postoperatively. There was no secondary displacement of the hardware or the fracture. This is compatible with papers stating that secondary fracture displacements are exceptional with volar radius plates [14]. A variable angle fixation for two distal screws adds to the fragments stability: radial styloid or dorso-ulnar fragments can be easily reached with polyaxial screws. Stabilization of the dorso-ulnar fragment with at least one screw of the VLP is necessary to prevent postoperative fracture dislocation [15]. Moreover, the diaphyseal screws seem to enhance the osteosynthesis strength. Firstly, these two screws are divergent medially and laterally, and consequently seize bone in a three-dimensional fashion. Secondly, the most proximal screw, slanting at 30°, is usually 14–16 mm long in our series. Thus, it is fixed in the radius with more threads than perpendicular screws of other volar plates, where the maximum advised length is 12 mm to avoid any protrusion from the dorsal cortex [1].

The clinical outcomes of the third phase were satisfactory. Flexion, extension and grip strength were significantly decreased, but no further than in other studies, and did not affect the patients' quality of life as can be deduced from the PRWE or QuickDASH scores [5]. The latter was similar to other surveys [11]. We observed no flexor tendon ruptures

Fig. 5 **a** Coronal, **b** sagittal and **c** oblique X-ray views of a left A2.2 DRF with ulnar styloid fracture. **d** Coronal and **e** sagittal X-rays at 6 weeks follow-up

at the last follow-up visit at 6 months, perhaps on account of the protection provided by the PQ muscle that partially hides the plate [11]. Moreover, all the plates in our series were Grade 0 or Grade 1 according to Soong et al. radiographic grading of the implant prominence and none was Grade 2 [16]. Like other authors, we highlight the importance of protecting the flexor tendons from rupture, because they can be damaged by volar plates [17]. We did not observe any problems with the extensor tendons. A small proportion of patients (6.9%) exhibited symptoms of CRPS type 1 of variable severity but these resolved favourably. This finding was similar to another study [5], and within the wide range of other surveys, taking into consideration that these studies did not always have the same diagnostic criteria for CRPS type 1 [18]. No changes regarding the radiographic indices were observed on the last radiographs compared with those taken at the 6-week follow-up visit.

Some authors have questioned why there is such an enthusiasm for volar plates over percutaneous pinning in DRFs [19]. One answer might be the trend effect, since the younger hand surgeons are more likely to use volar plates due to their surgical education. Another more relevant reason is biomechanical. In a cadaveric study, volar plating proved to be more stable than pinning in an artificially created intra-articular fracture with a dorsal comminution [2]. This finding is particularly relevant in patients with poor bone quality and might further motivate plating in elderly patients [2, 19], although a literature review found that in patients over 65 years of age, there is no difference in outcomes between functional and surgical treatments [20]. Restoring radial anatomic parameters, particularly ulnar variance and volar tilt, is essential for a good functional outcome [21]. A recent paper comparing pinning and volar plating in a randomized controlled trial showed no evidence of a difference in outcomes in patients treated for dorsally displaced DRFs [22]. Meta-analyses comparing the outcomes of volar distal radius plating with percutaneous pinning are not always conclusive, even if the plating group scored better on the DASH questionnaire [8]. They had a better function in the early postoperative period, and better flexion and supination with volar plates, but did not seem to prefer plating over pinning [23]. Other surveys were more conclusive regarding the benefits in terms of pain relief and functional outcomes in the early postoperative period after using fourth-generation VLPs in displaced DRFs [3].

Minimally invasive surgery is a trend in orthopaedics, particularly in DRFs. It is justified by a strong aesthetic demand from the patients. Many authors believe that less violation of the fracture environment aids bone consolidation and leads to fewer adhesions [5, 6, 17]. The latter

Fig. 6 **a** Coronal, **b** sagittal and **c** oblique X-ray views of a right A2.3 (Goyrand-Smith) DRF with ulnar styloid fracture. **d** Coronal and **e** sagittal X-rays at 7 months follow-up

finding would enable patients to regain normal ROM and daily activities earlier than more invasive approaches. Nevertheless, we agree with Rey et al. [11] that minimally invasive internal fixation is a means and not an end, especially in a very common injury such as DRF [19]. We also believe that the treatment of DRFs should always be personalised [14]. MIPO is one of the techniques offering the smallest incisions, avoiding a massive exposure [24]. It employs part of the conventional Henry approach but the PQ muscle is not divided. The volar plate, anatomically pre-shaped, is easily slid in MIPO in a retrograde manner underneath the PQ muscle without detaching it, as demonstrated by a recent anatomic investigation [25]. The arguments for sparing the PQ muscle are supported by theoretical aspects related to its function as a stabiliser of the distal radio-ulnar joint [26]. It also has role in vascularising the distal radius volar surface [4]. Moreover, there are practical aspects for sparing or repairing the PQ muscle which include optimal coverage of the hardware and therefore protection of the overlying flexor tendons [27]. Sparing the PQ muscle also seems to reduce pain in the early postoperative period [28] although some studies have failed to prove the merits of PQ muscle repair at 1-year follow-up [29]. We think that sparing the PQ muscle is better achieved with a short plate slid and screwed under the muscle belly, rather than a standard-length plate fixed through the muscle belly and requiring more dissection to enable the insertion of the proximal screws. Some authors advocate that tendons and ligaments surrounding the fracture serve as a mould to its reduction [30], and fracture alignment by traction force facilitates its reduction by a ligamentotaxis effect [5, 6, 17]. Finally, another practical aspect of using MIPO is patients' higher satisfaction according to a recent meta-analysis [31], although the clinical scores, grip strength and ROM were the same with MIPO and conventional approaches as noted previously in another paper [10].

Our study has some limitations. It is retrospective with a small number of patients and was not randomised to compare the extra-short plate with another design or the MIPO with a more conventional approach. Other limitations include the number of patients (17%) lost to last follow-up, at 6 months postoperatively as a minimum. Thus, some potential delayed complications like tendon ruptures

Fig. 7 **a** Coronal, **b** sagittal and **c** oblique X-ray views of a right A3.2 volarly open DRF. **d** Coronal and **e** sagittal X-rays at 3 months follow-up

could not be assessed. According to some authors, up to 82% of their patients were lost to follow-up at 1 year, but this did not necessarily mean they were doing poorly [9].

Conclusion

The extra-short plate design, with shaft divergent locking screws, and its insertion technique are reliable for internal fixation in distal radius fractures. Our approach provides surgical comfort and using this implant resulted in good functional outcomes with no complications such as osteosynthesis displacement or tendon rupture. The insertion technique with this plate is simple, reproducible and less time-consuming than with other plates and has all the advantages of mini-invasive surgery. This extra-short plate can be considered as the first in a line of a fifth-generation volar locking plates.

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Authors contributions GA involved in material preparation, data collection and analysis and manuscript drafting. JB involved in data collection and manuscript correction. M-OF involved in conception of the study, data collection and manuscript revision.

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Compliance with ethical standards

Conflict of interest Marc-Olivier Falcone has a financial relationship with Newclip Technics™. The other authors declare that they have no competing interest.

Ethical approval The study received the Institutional Review Board approval number: COS-RGDS-2019-04-002-FALCONE-MO.

Informed consent All patients provided their informed consent to participate in the study and to the anonymous use of their data and photographs for publication.

Availability of data and material The data are available on request from the authors.

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