REVIEW ARTICLE

Fixation of distal radius fractures in adults: A review

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KEYWORDS
Distal radius fractures; Osteosynthesis by reduction and internal fixation (ORIF)

Summary In patients for whom function is a priority, anatomic reduction and stable fixation are prerequisites for good outcomes. Several therapeutic options exist, including orthopedic treatment and internal fixation with pins (intra- and extrafocal), external fixation which may or may not bridge the wrist, and different internal fixation techniques with dorsal or palmar plates using or not, locking screws. Arthroscopy may be necessary in case of articular fracture. In the presence of significant metaphyseal bone defects, filling of the comminution with phosphocalcic cements provides better graft stability. The level of evidence is too low to allow recommending one type of fixation for one type of fracture; and different fixation options to achieve stable reduction exist, each with its own specific complications. With the new generations of palmar plate, secondary displacement is becoming a thing of the past.

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Introduction

Treatment has long been defined by the lack of correlation between anatomic reduction and function. This idea is only true in extremely elderly, dependent patients, with low functional needs. Thus, today anatomic reduction is the goal because it makes it possible to limit loss of function. The problem is not the type of fixation or the immobilization technique, but the quality and stability of reduction. A fracture with malunion is going to affect the radiocarpal joint (problems with underlying carpal alignment, loss of flexion–extension, loss of wrist strength) and the radioulnar joint (loss of pronosupination, ulnocarpal impingement syndrome). When the dorsal angle is greater than 20°, radial inclination is below 10°, and radial shortening is more than 6 mm, there are definite functional consequences. Thus the more a fracture is displaced and/or associated with an ulnar head fracture, the older the patient is (after the age of 60) and the more fragile the bone is (osteoporosis), the less immobilization (normally associated with reduction) will result in permanent reduction. A displaced fracture should therefore be reduced and stabilized. Although fragile bone can make fixation difficult to optimize a patient’s level of activity and autonomy, this aspect of treatment should never be neglected. Over time the limits of reduction and immobilization by cast including the elbow became evident (too much secondary displacement). Intra- and extrafocal

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Pinning techniques

Several techniques have been described in the literature and have evolved over time. This includes traction pins incorporated into the cast (which were first described by Bohler in 1929) and which require 8 weeks of immobilisation: they should be abandoned. Conventional styloid pinning with two pins seems to have been described for the first time by Willenegger and Guggenbühl in 1959: the first pin, introduced into the radial styloid on a nearly frontal plane and the second inserted into the radial tubercle (Lister’s tubercle) the sagittal plane [1]. The two pins are driven into the opposite cortex at a 45° angle. Friol et al. reported his experience with this technique in fractures with dorsal displacement [2]. The wrist is immobilized in a cast at the end of surgery and the pins should be removed after 6 weeks. Today this type of 2-pin extrafocal pinning is considered to be insufficient. Because of the frequency of a posteroi
ternal fragment, a third transverse distal radioulnar pin can be used, beginning at the ulna and crossing the distal radioulnar joint to stabilize the posteroi
ternal fragment in a reduced position. Mortier et al. described two disadvantages to this technique [3]: temporary bloqueag of pronosupination and the difficulty of reducing the posteroi
ternal fragment by an external manoeuvre. In fact, this technique can be implemented without performing temporary arthrodesis. Described by Py in 1969, elastic pinning of fractures of the distal radius can also be used to stabilize extraarticular fractures [4]. After reduction, a mini-incision is performed to recline the sensitive branches of the radial nerve and the long abductor tendon and the short extensor tendon of the thumb. An 18/10 pin, which has been blunted and curved along the last centimeters, penetrates the summit of the radial styloid. It slides against the medial cortex to the radial head. The second pin is inserted at the posterior edge of the articular surface of the radius, after incision of the dorsal annular ligament. It slides along the anterior cortex to the radial head. Theoretically postoperi
tive immobilization is unnecessary, so that early rehabilitation is possible. Never-
theless in the presence of significant posterior commination, immobilization is necessary. In a series of 100 fractures, Ebelin et al. reported three complex regional pain syndromes, three superficial infections, five irritations of the median nerve, two extensor tendon tears (II and III) and 21 secondary displacements [4].

Intrafocal pinning was described by Kapandji in 1973, making postoperative immobilization which delays rehabi-
ilitation, unnecessary and preventing the secondary displacement which occurs with conventional pinning tech-
niques [5]. The pins are inserted directly into the fracture site, so that they can immediately act as a buttress to block dorsal displacement. Three 20/10-mm pins are necessary, inserted with a T-handle or a pneumatic motor. After reduction an external pin which controls external translation of the epiphysis is inserted first, by a mini-incision between the radius and the short and long extensors of the thumb. The second pin, which is posteroe
ternal, is slightly proximal and external to Lister’s tubercle, between the radial tendons and the long extensor of the thumb medially and the short extensor and long abductor of the thumb laterally. The third, posterointernal pin is to reduce and stabilize the third posterointernal fragment. An inci-
sion is made between the extensor tendons of the fourth and fifth fingers. Only the skin is cut. The subcutaneous layers are pulled back with a small clamp. The fracture site is identified by scraping the cortex from top to bot-
tom. The pins are inserted at a 40° angle until they touch the opposite cortex. The pins are always inserted from outside to inside. The pins should be cut so that their ends are under the skin to prevent tendon injury and secondary tears. The value of this method is that the posterointernal fragment is reduced. The theoretical disadvantage of this technique in the initial description without immobilization, was that it prevents healing of distal radioulnar articular lesions and other intracarpal ligament lesions which is a problem with all techniques without immobilization. Thus, in France especially, this simple, reproducible, transferrable technique, which was promoted by its inventor, has made internal fixation possible for many years with acceptable results in numerous fractures of the extraarticular distal radius [5–8]. Today it has been shown that ideally, pinning should be intra- and extrafocal, with at least four pins, with 18/10 or 20/10 mm pins inserted in an open-surgical procedure. In a randomized study, Strohm et al. compared a purely extrafocal technique with two pins and a modified Kapandji technique with a third styloid pin [9]. In that study although the rate of complications was similar (nervous complications in 17 and 13%, and pin migrations in 12 and 8% in the extrafocal and intrafocal groups, respectively) the functional and radiological results were better in the modi-
fied Kapandji group even though immobilization was twice as short (3/6 weeks) [9]. In a similar study, Gravier et al. obtained better results at 6 weeks by associating intra and extrafocal pins to control ulnar variance [10]. Pin related complications occur in 10–20% of cases involving especially the sensitive branches of the radial and neighboring nerves (Table 1). They can be avoided by using a mini-incision. A cadaver study by Hochwald et al. showed that there was an eight times greater chance of touching the sensitive branches of the radial nerves if pins were placed without an incision [18]. Migration, which is common in pinning, is a complication that varies depending upon the diameter of
### Table 1 Complications in the series with pins.

<table>
<thead>
<tr>
<th></th>
<th>Follow-up months</th>
<th>n fractures</th>
<th>Age</th>
<th>Tendon tear (%)</th>
<th>Tendonitis (%)</th>
<th>Infection (%)</th>
<th>Over correction (%)</th>
<th>Sensitive radial branch injury (%)</th>
<th>Complex regional pain syndrome (%)</th>
<th>Pin migration (%)</th>
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<td>7</td>
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<td>55</td>
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<td>7</td>
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<td>-</td>
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<td>57</td>
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<td>6–40</td>
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<td>2</td>
<td>3</td>
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<td>6.6</td>
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<td>3</td>
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<td>24</td>
<td>54</td>
<td>57.7</td>
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<td>-</td>
<td>5.5</td>
<td>11</td>
<td>15</td>
<td>15</td>
<td>-</td>
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<tr>
<td>Fornasieri et al. [16]</td>
<td>21</td>
<td>28</td>
<td>21</td>
<td>-</td>
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<td>-</td>
<td>25</td>
<td>21.4</td>
<td>7.5</td>
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<td>22</td>
<td>56</td>
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<td>4.5</td>
<td>4</td>
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</table>
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**Figure 1** AP view X-ray of a fracture after 4 months that had appeared to be reduced and stabilized with pins that were placed too vertically. However the patient had no more pronosupination and a CT scan showed malunion. The radial epiphysis was “projected” forward as shown on reconstructed CT scan images.

the pin, the threading, and bone quality. A certain number of complications also occurs during removal, prompting certain surgeons to let the pins protrude making removal easier, however this approach creates a risk of infection and painful morbidity. Although these technical modifications (intra- and extrafocal pinning, ascending pinning, threaded pins, protective end) have reduced iatrogenic complications in the tendons and the nerves, stable reduction varies. In case of posterior comminution, extrafocal pins in a vertical position can result in over-reduction [7] (Fig. 1). In the Soffcot symposium series, secondary displacement occurred in 30% despite 6–8 weeks of immobilization [19].

**External fixation**

Fractures of the distal radius (especially high energy) with epiphysial (articular) lesions or with associated dislocations can be considered composite osteoligamentous lesions rather than “fractures”. Thus after reconstruction of the articular surface, the stress exerted on this area should be neutralized. An external fixator can play this role and is the only tool to do this in high-energy fractures. Numerous models are available but very few manage to align the carpal bones with the wrist in a neutral position. The external fixator should be placed on a (strictly) frontal plane on the lateral side of the radius with insertion into the radius by open-surgery (lateral side of the distal third of the radial diaphysis) and the second metacarpal (proximal third). Reduction is only possible on this plane (Fig. 2a and b). However anatomic reduction in a closed fracture site is often impossible by external fixation and traction because in many cases ligamentotaxis depends upon finer dorsal radiocarpal ligaments and a transverse direction [20]. In polytraumatized patients, the main interest of external fixation is to achieve temporary reduction making it possible to perform a more in depth assessment of injuries by CT scan during traction. Additional surgery can then be performed for associated internal fixation with or without arthroscopy within 15 days after the first procedure (Figs. 3 and 4). Iatrogenic injury to the sensitive branches of the radial nerve is avoided by an open-surgical procedure following the rules for use of drill guides. Moreover an osteosynthesis before pin placement reduces postoperative pain. The main complication of the external fixator is pin site infections, which must receive daily care. After the fixator is placed supplementary wires are essential to stabilize the different fragments. Lin et al. compared two external fixation groups, one with and one without intramedullary wires and showed better stabilization of radial inclination on lateral view radiographs and better wrist strength in the group with pins [21]. Leung et al. showed the limits of external fixation by demonstrating
that this approach alone cannot prevent collapse of a comminuted fracture [22]. The randomized study by Werber comparing an external fixator with four or five pins to stabilize fragments, found better functional results and less pin migration in the group with five pins [23]. Distraction should be controlled at the end of the procedure: radiocarpal and mediocarpal joint spaces should not be increased by more than 50%, and fingers should be able to be rolled and unrolled completely. Several authors have compared a series of fixators with and without bridging the wrist. There was little or no difference and although the notion of “non-bridging” is interesting, it has not been shown to be beneficial for the patient. Mac Queen showed that in extraarticular metaphyseal fractures, like in articular fractures, the results of non-bridging joint fixation could be better than traditional fixation. In that comparative study, the complication rate was 42% [24].

**Dorsal plates**

Internal fixation systems with dorsal plates were developed in response to the disadvantages of pins and external fixation, even when they are correctly used [25,26]. This type of internal fixation seems logical: there is general agreement that palmar displacement should be managed by palmar plates, thus why not apply the same reasoning to dorsal displacement since the posterior cortex of the distal radius is “thinner” and less resistant than the anterior cortex. The dorsal plate stabilizes reduction of posterior tilt. There are two main types of dorsal plates based on two philosophies, console-type plate fixation (which opposes or stabilizes) and column plates (which repair). Console-type plates were developed from T-plates with modifications in shape, material and size to adapt them to the posterior radius. The main goal of these plates is to oppose dorsal displacement with, in certain cases, the possibility of “on the plate” reduction. Column plates are based on the three column theory of Rikli: the radial and ulnar columns, the two cortical bone columns of the radius, injured by fractures, must be reconstructed with one or several plates which may be more or less anatomic, and must be adapted to each of these columns [27]. These two theories should be complementary, because preventing recurrent displacement and restoring the anatomy are two complementary goals. Three comparative biomechanical studies suggest that results can be extrapolated to patients. The study by Peine validated the column theory by showing that double plates were better than two distinct plates. This cadaveric study showed that biomechanical results were better with double column plates than with the IP plate (which should be considered a column plate) and the T-plate [28]. The study by Hahnloser et al. confirmed that double plates were more resistant than an IP plate in a clinical study [29]. The third biomechanical study of console plates compared the T-plate and the “rake-like” Gesensway et al.’s plate [30]. The latter is a precursor to locked systems, and was shown to be twice as rigid and presented a three times greater failure strength. Moreover, the importance of anterior cortical contact is crucial otherwise posterior loading is high [31]. These biomechanical validations should not make one forget the clinical reality of the potential difficulties of placement, the functional consequences of stiffness and especially complications. Most of the published series have evaluated and compared dorsal plate models. The fractures were not homogeneous among the groups, and included both extraarticular and comminutive fractures. Moreover, even if the fractures are not “too” complex, fragile bone makes the application of several plates difficult. Series such as Hahnloser et al.’s [29] which report few or no complications are rare — the rate is nearly 30% whatever the series (Table 2). The expected disadvantage of dorsal plates is their bulkiness in an anatomical zone with a risk of nerve and extensor tendon injury [26]. Lister’s tubercle cannot be left intact with “T-console-type” plates, which is a technical detail that authors tend to forget. However, in our experience, resection of Lister’s tubercle did not cause complications [39]. Complications of the tendon, tendinitis or tears especially of the extensor pollicis longus (EPL) are rare in practically all-dorsal plate series. There were none in the study by Carter et al. [26]. Tendonitis of the EPL was observed in 25% of first generation PI plates, because of an aggressive design, according to the authors. In these dorsal plate series the mean follow-up was 40.6 months in groups of approximately 20 patients (Table 2). For Letsch et al. [40], the posterior approach results in better reduction of the joint surface and clinical and functional scores were statistically better with dorsal plates than with palmar plates. However, Finsen et al. reported cases of over-reduction (increase in volar tilt) with the Forte plate [36]. Unlike Ring et al. [37], several authors — Fitoussi et al. [34],

**Figure 2** a and b: M2E3 fracture... articular displacement, treated by external fixation alone with no associated pins. Reduction was only successful on the frontal plane where fixators were placed.
Table 2: Functional results and complications in dorsal plate series in the literature.

<table>
<thead>
<tr>
<th>Author type of plate</th>
<th>n</th>
<th>Follow-up months</th>
<th>Age</th>
<th>Flex</th>
<th>Ext</th>
<th>PS</th>
<th>Grip strength (%)</th>
<th>Tendon tear (%)</th>
<th>Tendonitis (%)</th>
<th>Infection (%)</th>
<th>Over correction (%)</th>
<th>Nerve injury (%)</th>
<th>Regional pain (%)</th>
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<td>21</td>
<td>42</td>
<td>48°</td>
<td>69°</td>
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<td>94</td>
<td>7</td>
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<td>Axelrod and McMurtry T [33]</td>
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Figure 3  a and b: 46-year-old polytraumatized patient whose high-energy fracture of the distal radius (M4E4) was urgently treated by fixation alone resulting in temporary stabilization. Internal plate fixation was necessary during a single procedure at D15 because of insufficient reduction.

Vichard et al. [39] and Heim [41], suggest that dorsal plates should be systematically removed.

Palmar plates

Anterior comminution sometimes (often?) associated with dorsal displacement motivated Nonnenmacher to use a palmar plate (bowl osteosynthesis) confirming that posterior pinning could not “always” solve “everything” [42]. In our experience this technique, which associates different approaches, results in significant stiffness, even if it is difficult to know whether this is due to the technique or the fracture (with enough displacement or fragmentation for the surgeon to consider the use of a “bowl”). With palmar plate fixation the injured zone is avoided while intact areas and the most resistant cortex are approached. Fernandez has long supported the solution of the “palmar plate” for “dorsal displacements” [43–45]. The anterior approach (Henry’s approach) is known and taught, and supported by surgeons. The quadrator pronatus is scraped or detached with an electric scalpel on the side of the radius and can be reinserted. The radial epiphysis can be exposed to the articular capsule. In dorsally displaced radial fractures, reduction is obtained with the wrist in hyperflexion with a periosteal elevator placed in the fracture line. The brachioradialis can be detached if necessary making reduction easier and allowing control of the dorsal epiphysis [44,45]. The plate is first attached to the diaphysis with a screw in an oval hole, which is present on most plates, then controlled by C-arm fluoroscopy to confirm correct plate size and position on the radius. The plate is then screwed to the epiphysis with hyperflexion maintained by the surgical assistant. Reduction may also be performed on the plate after fixation on the epiphysis. A perioperative oblique lateral view radiograph is systematically performed to visualize
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Figure 4  Functional results at 6 months.

any intraarticular screws (the wrist is X-rayed laterally with the elbow slightly flexed so that the joint space is visible). The interest of palmar plates in fractures with dorsal displacement is mainly and perhaps only the possibility of visualizing reduction of the anterior cortex, which should normally be anatomic, which is essential for stability of distal fractures of the radius even in the case of articular fractures (Figs. 5 and 6). Several rules must be followed to avoid an iatrogenic event with palmar plate fixation: avoid using bicortical screws more than 18–20 mm long in the Lister’s tubercle (Figs. 7 and 8), make sure that the diaphyseal screws do not protrude from the cortex (10 or 12 mm screws normally). These problems with screw size have developed since the diameter was reduced (from 3.5–2.4 mm) [46]. These simple precautions preserve the extensor tendons, which can develop tendinitis, synovites or even tears. Sügün

Figure 5  M3 E3 fracture with reduction and anatomical fixation with third generation plate fixation which provides contact with the anterior cortex.
et al. showed that in 46 fractures treated with internal fixation by 230 locked screws, 59 protruded from the posterior cortex causing symptomatic tenosynovites in 14 cases. They also showed that the tenosynovial compartments that were the most frequently affected were the second (22/59) and the fourth (21/59) [47].

Plate development

First generation

First generation plates validated the notion of anterior fixation. These were standard T-plates or non-specific epiphyseal plates which were limited by their shape and the number of epiphyseal screws.

Second generation

In second-generation plates, screws could be locked into the plate. The possibility of stabilizing the screws in the plate created new possibilities for anterior fixation (internal fixation of fractures with dorsal displacement without posterior intrafocal pinning, neglecting posterior comminution). Three epiphyseal locked screws and three diaphyseal screws are enough for good stability. Several studies have confirmed the mechanical value of a locked plate system in porous bone in which minimal axial stress can cause the screw to move in the plate. The resistance to stress with a locked plate system is increased by more than four times. If the screw and plate remain stable, stress to the “fragile” or fragmented bone can be transferred to subchondral bone [48].

Figure 6  Postoperative AP and lateral view at 6 months shows stable reduction.

Figure 7  Internal fixation with third generation plate. The cortical screw is slightly long, but the length of the epiphyseal screws seems correct.
In a cadaver model with a circumferential bone defect mimicking comminution and with three distal screws, Levin showed that two locked plate systems (DRP – Synthes, DVRA – Hand innovation) were more resistant than an unlocked system (volar T-plate) [49]. The increase in rigidity and the stable alignment between the metaphysis and the diaphysis with the locked palmar plate allowed immediate mobilization, which is difficult to imagine, according to Levin et al., with similar types of bone and with an unlocked palmar plate, a dorsal plate or external fixation [49]. However in two other studies Trease et al. [50] and Koh et al. [51] did not find any significant difference between locked and unlocked plates for rigidity and failure strength. Screw position is also important. In an extraarticular model Drobetz et al. showed that as soon as the screws (2.4 mm) were in the subchondral zone (area 4 mm above the joint surface), the resistance of the system was better than with a row of more proximal screws (more than 4 mm with fracture site collapse and radial shortening that was four times greater [1.38 mm for 0.36 mm]) [52]. Although a plate with solid epiphyseal screws rarely "comes apart", it has not been shown that a screw that "holds" in a plate is better than a screw that "holds" in the bone! Finally, there are no clinical studies showing that locked screw systems are better than unlocked screw systems in patients. The study by Koshimune et al., like our unpublished comparative study, did not show any difference between locked and unlocked palmar plates [53]. However "T-plates" do not fit tightly onto a small epiphysis and sometimes prevent console-type fixation. On the sagittal plane, the upper radial epiphysis has interindividual differences in height and inclination complicating the placement of extremely distal plates to reach chondral bone.

**Third generation**

Third generation plates were developed with a polyaxial locked screw technology in which the surgeon (not the plate) decides the direction of the screw. The polyaxial property of the screws (limited from 10° – 20°) was a challenge for the manufacturer: the screw must remain imbedded and the plate should not be more than 2 mm thick otherwise complications will develop on the flexor apparatus. The main advantage of this polyaxial technology is to be able to place a screw in the radial styloid.

**Fourth generation**

Finally, both industrials and plate designers have imagined a fourth generation plate in which a real effort in implant design provides optimal application on the exposed radial surface: the ulnar column is further forward than the radial column (Fig. 9).

Published series have reported regular, good functional results for epiphyseal fixation with many different palmar plates (Table 3). The specific complications of palmar plates (Table 4).

Figure 9   Bird’s eye view showing the palmar side and the area of application of a plate that is more ulnar than radial. Plate design should be based on this principle, and should not be too radial.

involve the flexor tendons (plates that are too distal [66]) or the extensor tendons (screws that are too long). However, the rate of complications with palmar plates is lower in published studies than with dorsal plates or pins. The main
<table>
<thead>
<tr>
<th>Table 3</th>
<th>Functional results of different series of palmar plates.</th>
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<tr>
<td></td>
<td>Follow-up</td>
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<tr>
<td>Constantine et al., 2002 [55]</td>
<td>12</td>
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<tr>
<td>Kamano et al., 2002 locked plates [56]</td>
<td>14</td>
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<td>Sakhaii et al., 2003 locked plates [57]</td>
<td>10</td>
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<tr>
<td>Dumont et al., 2003 [58]</td>
<td>&gt;18</td>
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<td>Schutz et al. 2003 locked plates [59]</td>
<td>6</td>
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<td>Orbay and Fernandez 2004 locked plates [45]</td>
<td>16</td>
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<tr>
<td>Krimmer et al., 2004 locked plate [60]</td>
<td>62</td>
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<td>Prokop et al., 2004 locked plates [61]</td>
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<tr>
<td>Margalit et al., 2005 Meta-analysis ant &amp; post [62]</td>
<td>23</td>
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<tr>
<td>Kreder et al., 2005 [63]</td>
<td>6 months</td>
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<td>24 months</td>
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<td>Koshimune et al., 2005 unlocked plates [53]</td>
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<td>Ruch and Papadonikolakis, 2006 [64]</td>
<td>22</td>
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<td>Rozental et al., 2006 [65]</td>
<td>17</td>
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</table>
### Table 4  Complications reported in the different series of (ANTERIOR) plates.

<table>
<thead>
<tr>
<th>Study</th>
<th>Follow-up months</th>
<th>n patients/age (C of the AO)</th>
<th>Pain syndrome (%)</th>
<th>Compression median nerve</th>
<th>Tendon complications</th>
<th>Intraarticular screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbay and Fernandez, 2002 locked plate [66]</td>
<td>12.5</td>
<td>7/54</td>
<td></td>
<td></td>
<td>4.5% irritation of extensor</td>
<td></td>
</tr>
<tr>
<td>Drobetz and Kutscha Lissberg, 2003 locked plates [54]</td>
<td>26</td>
<td>50/62</td>
<td>6</td>
<td>2%</td>
<td>14%</td>
<td>–</td>
</tr>
<tr>
<td>Constantine et al. 2002 [55]</td>
<td>12</td>
<td>20/41</td>
<td></td>
<td></td>
<td>5%</td>
<td>10% (irritations) 1 screw</td>
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<tr>
<td>Kamano et al., 2002 locked plates [56]</td>
<td>14</td>
<td>?/54</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Sakhaii et al., 2003 locked plate [57]</td>
<td>10</td>
<td>100/63</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1 screw</td>
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<tr>
<td>Dumont et al., 2003 [58]</td>
<td>&gt; 18</td>
<td>166/59</td>
<td>0.6</td>
<td>12%</td>
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<tr>
<td>Schutz et al., 2003 locked plates [59]</td>
<td>6</td>
<td>24</td>
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<td>–</td>
<td>1 screw</td>
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<tr>
<td>Orbay and Fernandez, 2004 locked plates [45]</td>
<td>16</td>
<td>24/75</td>
<td>4.3</td>
<td>–</td>
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<tr>
<td>Krimmer et al., 2004 locked plates [60]</td>
<td>62</td>
<td>55/62</td>
<td>1.6%</td>
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<td>–</td>
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<tr>
<td>Prokop et al., 2004 locked plates [61]</td>
<td>12</td>
<td>40/49</td>
<td>2.5</td>
<td>4%</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Margaliot et al., 2005 Meta-analysis ant &amp; post [62]</td>
<td>23</td>
<td>603/51</td>
<td>2.5</td>
<td>5.6%</td>
<td>2.6% (tears)/5.2% (irritations)</td>
<td>–</td>
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<tr>
<td>Kreder et al., 2005 [63]</td>
<td>6 months</td>
<td>84/39</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td></td>
<td>12 months</td>
<td>73/39</td>
<td>–</td>
<td>–</td>
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<tr>
<td></td>
<td>24 months</td>
<td>62/39</td>
<td>3</td>
<td>2%</td>
<td>–</td>
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<tr>
<td>Koshimune et al., 2005 locked plates [53]</td>
<td>12</td>
<td>22/68</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Koshimune et al., 2005 unlocked plates [53]</td>
<td>12</td>
<td>31 (19)/74</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>–</td>
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<tr>
<td>Ruch and Papadonikolakis, 2006 [64]</td>
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<td>14 (14)/46</td>
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<td>1 (irritation)</td>
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<tr>
<td>Rozental and Blazar, 2006 [65]</td>
<td>17</td>
<td>41 (19)/53</td>
<td>–</td>
<td>–</td>
<td>3 (irritation)</td>
<td>–</td>
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<tr>
<td>Rampoldi and Marsico, 2007 [67]</td>
<td>70</td>
<td>–</td>
<td>1</td>
<td>3 extensors</td>
<td>2 flexors</td>
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</table>
advantage of palmar plates is to solve the problem of secondary displacement and to allow immediate mobilization in patients. Published studies on palmar plates, like those on dorsal plates have looked at one type of plate to treat all fractures of the distal radius with dorsal displacement. We discover that most sagittal tilt is reduced with anteversion of $6^\circ$ or less. In published cases palmar plates usually play a role of internal fixation [57,59–61]. This type of plate is indicated in the presence of significant posterior comminution or associated with anterior comminution (Laualan M4) and prevents the need for grafts in comminuted fractures in patients with osteoporosis or in younger patients with high-energy traumas. In the studies by G. Leclerc et al. [17] and S. Huard et al. [68] the comminution was not filled with a bone substitute or a graft in association with palmar plates, and these were M3 or M4 comminuted fractures in 60% of the cases. There was no loss of sagittal tilt. For Constantine et al., satisfactory visualization of the radiocarpal joint is not possible with the anterior approach [55], which is always possible by arthroscopy (anterior approach) or with open surgery. Reduction of articular surfaces is performed indirectly. Any graft is performed with a short dorsal incision, which increases the morbidity of the procedure. Gouzou et al. [69] studied the indications for systematic release of the median nerve of the carpal tunnel by measuring intratunnel pressure in patients with a wrist fracture. One of the accepted theories is that intracarpal tunnel pressure of more than 40–50 mmHg results in perfusion deficits of the median nerve-causing parenthesis. In the series by Fuller et al. [70] only one case of pressure above 40 mmHg was found and the patient had no symptoms. These symptoms seem to be associated with a difference between articular pressure and intracarpal tunnel pressure. Gouzou et al. [69] showed that reduction and stabilization of the fracture relieved any preoperative dysesthesia and that there was no indication for emergency neurolysis.

Today at least 30 firms propose palmar locked plates. Normally the rigid support allows immediate mobilization for the patient. One of the results is that secondary displacement no longer occurs in purely metaphyseal or metaphyseal-epiphyseal type Mx E2 fractures. However, the extracost of autostable screws must be justified (10 times more than standard screws).

### Hybrid fixation systems

The Trimed® system combines the advantages of palmar and dorsal plates and pins and validates the column theory. Theoretically, it should be more beneficial. It combines low-profile plating systems associating mini-plates and clips, which, in particular, stabilize pins in the plates. This system is still extremely difficult to implement but allows fixation of different fragments. On the other hand, the combined surgical approaches increase the well-known risk of neurological complications with the external approach, and of tendon impingement with the posterior approach. In our experience these combined approaches are associated with increased stiffness. Compared to external fixation, this system has been shown to be more rigid in a cadaver model of articular fracture [71]. However, in a type C2 articular fracture model, Taylor et al. did not find any difference in rigidity between a palmar locked plate (DVRA — Hand innovation) and the Trimed® system which is adapted to the columns and fracture fragments [72]. The Trimed® system only seems to provide better control of the ulnar column. Immediate mobilization is easy to imagine with this system. Konrath et al. published a series of 27 patients who were treated with this technique and followed up for 29 months. Acceptable anatomic results were found in 25/27 patients and a mean flexion-extension arc of 115° [73]. The main innovation of this system is to have added the notion of mini-fragments to the list of therapeutic options and to offer numerous solutions to the surgeon.

Another dorsal nail/plate system is also available (Hand Innovation). This includes a “nail”, which is inserted into the proximal diaphysis of the radius above the fracture and a “plate”, which is attached by a curved junction, which is applied to the dorsal distal radius. A prospective series of 27 patients was reported by Kaba et al. with good overall results (functional, objective, subjective, social and radiographic) in 90% of patients at 6.5 months of follow-up in patients whose mean age was 71.7 years old with 86% of non-filled comminutions [74]. The disadvantage of this system is the dorsal overhang, and the risk of injury to the extensors.

Recently an intramedullary nail has become available (Micronail® - Wright medical). The external approach is used to insert 2.4 mm screws into the radial styloid in a divergent fashion in the epiphysis and 2.7 mm screws proximally, which are locked using a drill guide. A series of 23 patients were reported including 13 purely metaphyseal fractures, (extraarticular) [75]. At 6 months the flexion-extension arc was 131°, the pronosupination arc was 165° and the DASH score was 8. Radiographic assessment showed the following parameters: radial inclination was 4° on lateral X-ray, radial inclination was 22° on AP view, and positive ulnar variance was 0.2 mm. No complications were reported. The inconvenience of this system is the lateral insertion and the risk of injury to the sensitive radial nerve branches.

### Addition of injectable cements in fractures of the distal radius

In cases of metaphyseal comminution, the defect must be filled (autograft, injectable phosphocalcic cement) or compensated for (locked plates). In these cases the primary properties of microporous injectable cement are to provide structural filling and stability. Initial studies compared orthopedic treatment and injection of phosphocalcic cement, or reported the results of replacing fixation with this injectable substitute, especially Norian®. Good functional and radiological results were reported by Kopylov et al. [76] and Jupiter et al. [77] in the first cases (6 and 5 cases respectively) treated by reduction alone, injection with Norian® and a dorsal splint. In a prospective randomized study comparing orthopedic treatment and Norian® alone, Sanchez Sotelo et al. [78] found that functional recovery was faster and radiographic improvement better (less
collapse) in the Norian® group. Kopylov et al. [79] compared the functional and radiological results in two groups of fractures presenting with secondary displacement and treated with either repeat reduction + fixation or Norian®. Wrist strength and the speed of functional recovery were better with Norian®. However, the authors agreed that the use of Norian® alone was not enough to stabilize the fracture. In a cadaver fracture model with various types of fixation, Higgins et al. showed that Norian® could not prevent secondary collapse when used alone and emphasized the necessity of associating this product with internal fixation [80]. In a comparative study of two groups of nine patients, one treated by Kapandji pinning, the other by reduction and Norian®, Jeyam et al. showed that the pin group had better functional and radiological results [81]. Nevertheless, in the different studies Norian® has been shown to effectively fill a metaphyseal defect. More recently, in a prospective randomized study comparing two groups of fractures (with internal fixation or not) with or without Norian®, Cassidy et al. showed that functional recovery in the first year was better in the Norian® group [82]. The most recent experimental or clinical studies in the distal radius are encouraging (increased resistance to mechanical failure) even if it is difficult to extrapolate these results for clinical use when phosphocalcic cement is used in addition to a locked plate system [83]. In a meta-analysis on the use of injectable phosphocalcic cement in comminuted fractures, Bajammal et al. found that these cements had a one major benefit: a lower rate of secondary displacement than with an autograft [84]. Moreover, there was less pain in the group of fractures that were filled with cement, and certain studies showed better functional results. Moreover, several studies have shown that these cements help prevent loosening of pedicular screws: which could be similar to trauma in the upper limbs [85]. We used Norian® and Arexbone® to fill M3 or M4 comminuted fractures of the distal radius treated by pinning [46,86]. The goal was to avoid the collapse, which can occur even after 8 weeks. Functional results were good and control of radial shortening was satisfactory in 39 cases published with Norian®. Similar results were obtained in 24 cases using Arexbone®. In our experience with an increasing number of cases with very porous osteoporotic bone, we use injectable cement as a “screw stabilizer” to increase screw strength, by injecting cement around the screw (Fig. 10).

**Principles of use**

There are certain principles that should be followed whatever the indication or type of phosphocalcic cement:

- cement can only replace a graft, not internal fixation;
- the cement does not have osteoinductive properties, and its function is structural: to fill in a defect and obtain mechanical resistance to loading forces… it is therefore not indicated in cases of delayed union or pseudarthrosis;
- the main property of the cement is to resist loading forces and it has been tested in a dry environment. The differences among existing cements are based on these two parameters: resistance to loading force and testing in a humid environment;
- cement should be prepared according to the manufacturer’s instructions (this often involves mixing a powder with a liquid until a smooth paste is obtained);
- depending on the cement used, the temperature T° in the operating room, in the room where the cement is found or both, can affect the time the cement takes to harden: the higher the temperature, the faster the cement hardens;
- the cement is injected after the fracture has been stabilized, in the area of comminution, under double visual and fluoroscopic C-arm control;
- the cement should be injected once it has become paste-like to avoid leaking into the soft tissues; if a leak occurs, it is logical to remove the cement;
- there is always a radiolucency around the injected cement on postoperative radiographs: this is the bone/cement interface, where blood is present;
- the speed of resorption of this family of cements is slow (several years) and dose-proportional, because replacement is centripetal in apposition with the bone.
Recommendations, level of evidence and practical approach

Although this fracture is very frequent, the level of evidence is too low to clearly support the use of one particular technique. Despite the knowledge and up to date analysis of these fractures, it is difficult to compare “fractures of the distal radius” because of the many different specific types of lesions. It is probably more appropriate and realistic to compare similar lesions (purely metaphyseal, high energy metaphyseal-epiphyseal) in groups of patients (similar bone quality, age and/or level of activity). Thus, for the moment, the problem is not only to compare the techniques, but also to understand the limits and iatrogenic risks of each technique. Helen Randoll and Raj Madhok have been publishing reviews of the literature edited by the Cochrane Library for many years, which include randomized or comparative studies that respect high quality methodological criteria. Their aim is to determine the existing level of evidence on the subject of distal radius fractures. Based on a certain number of studies, several points can be recommended depending upon the type of fracture or the type of treatment. Fractures requiring reduction and with a risk of secondary displacement (metaphyseal comminution, significant displacement) cannot be treated by cast immobilization alone in patients with high functional expectations (autonomy): level III/B [87].

A certain number of randomized studies have shown that the differences among techniques for simple (E2 or less) or complex (higher than E2) articular fractures are mainly based on the complications (Fig. 11a–c). Thus the meta-analysis by Margaliot comparing the results of plate fixation (18 studies, 603 patients) to external fixation (28 studies, 917 patients) did not show any difference between the two techniques for recovery of wrist strength, mobility, radiographic anatomy, pain or functional assessment scales [62]. The external fixation group had the most infections, material failures with secondary displacement and neurological complications, and the plate group had the most tendon complications and removal of material. The results of this study did not make it possible to recommend one technique rather than another. In a randomized study, Kreder et al. showed that the radiographic and functional results of external fixation (88 patients) were not better than those of internal fixation (91 patients) although recovery was faster [63]. On the other hand, in another similar randomized study comparing external fixation and a dorsal plate, Grewal et al. found a longer tourniquet times, poorer functional results and more complications in the dorsal plate group [88]. Joint incongruence of more than 1–2 mm will result in osteoarthritis that is visible on radiograph, but without functional consequences: the benefits of aggressive preventive treatment have not been clearly shown: level III/B [87].

There are 13 series evaluating pin fixation including 940 fairly elderly patients presenting with unstable fractures [89]. However, in five of the six series comparing pinning and orthopedic treatment, pinning was extrafocal and anatomical results (and functional results in 3 series) were better. In the other series intrafocal pinning was used and was associated with more tendon and nerve complications than with extrafocal pinning. Moreover, the two studies

Figure 11 a–c: 43-year-old patient, high-energy fracture with radiocarpal and radioulnar dislocation M4 E4, U3. Open internal fixation for “anatomic” reduction and fixation. But this approach cannot prevent the development of arthritis due to osteochondral lesions from impaction, which do not respond to existing treatment.
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comparing resorbable and metal pins showed that there were more complications with the resorbable material. Finally, one of the two series comparing the duration of immobilization after extrafocal pinning did not find any difference in functional results between 1 and 6 weeks. On the other hand, there were more complications with early mobilization after intrafocal pinning. Finally in case of pinning, intra- and extrafocal pins should be associated with at least three pins, which should be inserted by mini-incision: level 1b/A, III/B [87].

Nine randomized series including 510 patients with unstable fractures have evaluated external fixation techniques [90]. The series were very different making global analysis of the results difficult: comparison of different external fixation designs (bridging or non-bridging the wrist), or different types of the same design. Two of the three trials comparing bridging or non-bridging systems had better results in the radio-radius fixation group for recovery of grip strength, flexion and anatomic outcome. Results were better in one trial when external fixation was associated with pins to stabilize bone fragments. Functional results were not better with pins covered in hydroxyapatite (one trial), using multiplanar fixation (one trial) or dynamic fixation (one trial). With external fixation, one or two specific techniques must be associated for stabilization of fragments (not just external fixation alone): level 1b/A [87].

Ten very different trials studying the use of grafts and bone substitutes and including 874 patients were analyzed [91]. Association of an autograft (1 trial), polymethylacrylate (PMMA) (1 trial), or Norian (2 trials) showed better anatomical and functional results (in 2 of them) compared to cast immobilization alone. Bone filling was only shown to improve anatomic outcome but not functional results compared to external fixation. The association of an autograft with external fixation did not improve results (1 trial). Complications from cement (leaking into soft tissues) or graft integration were rare and mild. There are no meta-analyses of palmar plate fixation. Reduction is better with locked palmar plates than with external fixation: level III/B [87]. It is probably not necessary to fill metaphyseal bone defects when palmar plates are used: level III/B [87]. A comparison of palmar and dorsal plates shows that results were better in the palmar plate group, but the series were short with different types of fractures. This type of fixation seems to make it possible to ignore the articular elements of the fracture with identical functional results as in Mx fractures (purely extraarticular) and Mx E2 fractures. Internal fixation with a locked palmar plate allows early mobilization, good functional and radiological results with a low rate of complications and no loss of fracture reduction: level III/B [17]. Palmar plates, like low-profile column type dorsal plates, are less bulky than dorsal plates: level 1b/A [87].

Conclusion

The therapeutic method chosen depends upon each fracture, the metaphyseal (M) and epiphyseal involvement as well as the reducibility of the articular fragments (E). Intra- and extrafocal pinning can be used in grade M2 or less metaphyseal fractures associated or not with grade E2 or less epiphyseal lesions (external cunean tendon, fracture with a sagittal articular... or isolated posteriointernal fragment).

If bone is found to be fragile perioperatively or in patients greater than 70 years old, locked palmar plate fixation seem to be the logical choice.

In case of an isolated metaphyseal fracture greater than grade M2, with circumferential comminution, locked palmar plate fixation is necessary. External fixation with additional pinning is often necessary in epiphyseal lesions greater than grade E2, (these are usually grade M3 of M4 lesions). In these cases, an additional approach or an arthroscopic approach is necessary to obtain reduction and stabilization of displaced articular fragments that is as anatomic as possible. Metaphyseal-epiphyseal bone defects require filling by bone graft or an injectable bone substitute. In case of significant displacement of the styloid and the head or neck of the ulna, fixation can be discussed, but is not necessary in most cases.

Disclosure of interest

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L. Obert is a consultant for several firms that commercialize plates for the distal radius.

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