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HANDSURGERY

Malunion of the distal radius

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Abstract Fractures of the distal radius are extremely common injuries, which are steadily becoming a public health issue. One of the most common complications following distal radius fractures is still malunion of the distal radius. This review of the literature surrounding distal radius malunion covers the biomechanics of distal radial malunion, treatment options, indications for surgery, surgical techniques, and results.

Keywords Radius fracture · Malunion · Biomechanics · Treatment options · Surgical technique

Introduction

Fractures of the distal radius are extremely common injuries, which are steadily becoming a public health issue. Although it was once believed by many that all patients with distal radius fractures did relatively well, regardless of the treatment, it is now well recognized that distal radius fractures are associated with a high complication rate and frequent poor results. One of the most common complications following distal radius fractures is still malunion of the distal radius. Malunion of the distal radius usually occurs following conservative treatment. Now, that surgical fixation of distal radius fractures has become more commonplace, we are faced with an increasing number of malunion following operative treatment (Fig. 1a–i).

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Classification of distal radial malunion

Distal radial malunion may be extraarticular, intraarticular or both, intra- and extraarticular. The most common deformity following a malunited extraarticular fracture of the distal radius is the loss of the normal palmar tilt of the articular surface in the sagittal plane, loss of ulnar inclination in the frontal plane, and loss of length relative to the ulna. In addition, a certain rotational deformity of the distal fragment with respect to the diaphysis of the radius may exist. We found a rotational deformity in 23 out of 37 patients with a corrective osteotomy of a distal radial [1]. In both, dorsally and palmarly angulated malunion, pronation as well as supination deformities were identified. Although pronation deformity was relatively found more in patients with a palmar tilted malunion, there was no statistically significant difference between dorsal and palmar malunion with respect to the distribution of the direction of the rotational deformity. Losses of pronation–supination did not correlate with the amount of rotational deformity. Furthermore, the distal fragment may be translated in either the sagittal or the frontal plane [2]. Intraarticular malunion of the distal radius is characterized by a step-off or a gap at the radiocarpal and/or the distal radioulnar joint.

Complaints of patients with a radial malunion

It may be true that not all nonanatomically aligned fractures of the distal radius result in a poor functioning outcome. However, in our experience, many patients with a distal radius malunion complain of decreased range of wrist motion and forearm rotation, grip strength weakness, and pain, especially on the ulnar side of the wrist, where an ulna impaction as a result of the radius shortening often exists.

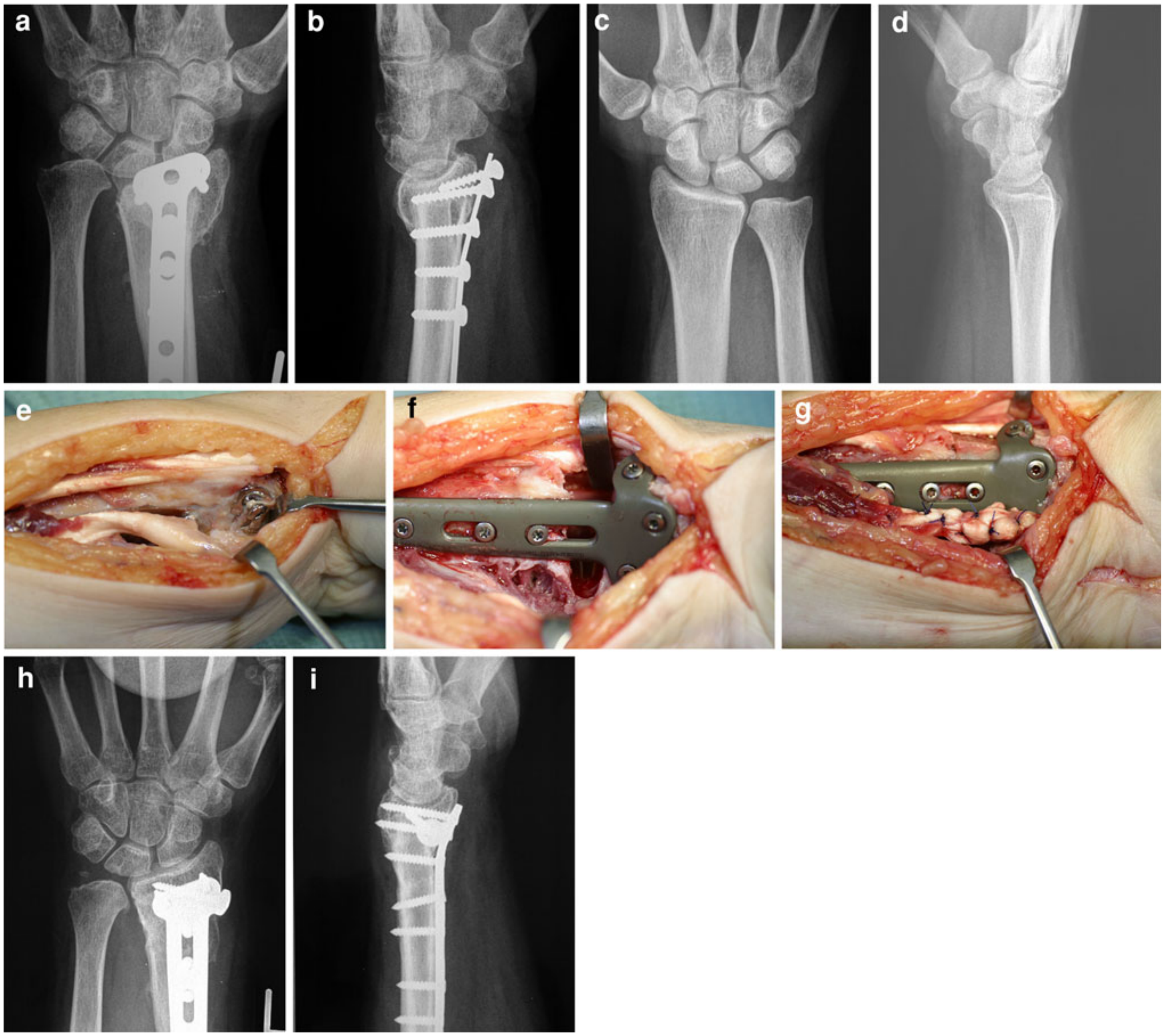

Fig. 1 **a** Malunited fracture of the left distal radius in a right-handed 40-year-old male following palmar plating using a non-locking plate. The pa-view shows a severe shortening of the radius relative to the distal ulna. **b** The lateral view shows a dorsal tilting of the articular surface of the radius of 40°. The distal screws are back out and the distal end of the palmar plate sticks out from the radius. **c** The pa-view of the uninjured opposite wrist shows an ulna neutral variance. **d** Lateral view of the uninjured opposite wrist. **e** Intraoperative a laceration of the tendon of the extensor pollicis longus is identified. **f** After corrective osteotomy of the distal radius there is a huge osteotomy gap. **g** The osteotomy gap is filled with a tailored corticocancellous bone graft from the iliac crest. The extensor pollicis longus tendon is repaired with use of the palmaris longus tendon. **h** 4 months after the corrective osteotomy the radius is healed. The pa-view shows an ulna neutral variance. There is a beginning osteoarthritis of the ulna head. **i** The lateral view shows a neutral position of the articular surface

Many patients, both women and men, are often unhappy with the unpleasant appearance of the wrist with a prominent ulna head typically for malunited Colles' type fractures and a bayonet deformity typically for a Smith's type fracture. Malunion of the distal radius can be associated with carpal tunnel syndrome [3–6]. All of these complaints are related to the disorders of the wrist joint caused by the deformity.

Biomechanics of distal radial malunion

Normal wrist biomechanics depend upon maintenance of the anatomical position of the distal end of the radius with respect to the carpus and the distal end of the ulna. Normal wrist motion consists of greater than 120° of wrist flexion and extension, 50° of wrist radial and ulnar deviation, and 150° of forearm rotation at the DRUJ [7]. The distal radius carries 80% of the axial load through the wrist, and the distal ulna carries 20% [8].

In clinical and laboratory studies, multidirectional deformity of the distal radius caused alterations of the radiocarpal joint, the midcarpal joint, and the distal radioulnar joint [9]. The osseous deformity affects the normal mechanics of the radiocarpal joint producing a limitation of the extension–flexion arc of motion. In addition, the malalignment affects the normal load transmission not only through the radiocarpal joint but also across the whole wrist joint. Dorsal tilting of radial surface shifts axial loading through the wrist dorsally and ulnarly and decreases the joint contact area. The pressure distribution on the radial articular surfaces becomes more concentrated [8, 10–13] and may represent a prearthritic condition of the wrist joint [14]. Furthermore, shortening of the radius and dorsal tilting of the articular surface increases the force borne by the ulna. The load through the ulna increases from 21 to 67% of the total load as the angulation of the distal radius fragment increases from 10° of palmar tilt to 45° of dorsal tilt [15]. Lengthening of the ulna by 2.5 mm increases the force borne by the ulna from 18.4 to 41.9% of the total axial load [8].

Malalignment of the surface of the distal radius in both the sagittal and coronal planes may result in a decreased mechanical advantage of the flexor tendons as they pass through the carpal tunnel [16], diminishing grip strength. In addition, median nerve compression neuropathy can also be encountered as a result of the deformity of the distal radius [3–6].

At the midcarpal level, dorsal tilt of the distal radius may lead to a compensatory flexion deformity as an adaptive response to the dorsally rotated proximal carpal row [17], an extrinsic midcarpal dynamic instability [18], and a fixed carpal malalignment in dorsiflexion [19].

Angular and shortening deformity of the distal radius may cause incongruity of the distal radioulnar joint and reduction of radioulnar contact area [20]. Radial shortening in relation to the distal part of the ulna can increase the strain in the triangular fibrocartilage complex [21] and result in a disruption of the deep portion of the dorsal radioulnar ligament [22]. These factors may limit the arc of forearm rotation [23, 24].

Fellmann et al. [25] found that an anatomical reduction of acute distal radial fracture correlated with a significantly better range of motion, while McQueen and Caspers [26] found that motion was significantly worse in wrists with dorsal angulation of more than 12°. Jenkins and Mintowt-Czyz [27], and Cooney et al. [28] reported that decreased grip strength had a close relationship with the severity of residual fracture deformity. Aro and Koivunen [29] found that the functional end result was unsatisfactory in only 4% of patients with an acceptable anatomic result, compared with 25% of the patients with minor shortening and 31% of patients with gross shortening of the radius.

Treatment options

Treatment options for symptomatic malunion of the distal radius must take into account the patient's motivation, functional demands of the patient, and the anatomy of the deformity. Newer fixation devices allowing more stable fixation of osteoporotic bone have made the bone quality less important. Intervention to correct symptomatic malunions may be categorized into four broad areas: procedures aimed at restoring anatomic relationships, procedures aimed solely at gaining a functional improvement, procedures aimed at eliminating pain, and procedures that combined two or more of the above approaches.

Procedures aimed at eliminating pain are wrist denervation [30] and arthrodesis. Arthrodesis may involve the total wrist joint or only radius, scaphoid and lunate [31–33]. Proximal row carpectomy (PRC) is another option to preserve radiocarpal motion as long as the fossa lunata and the head of the capitate are free of degenerative changes. Langer [34] described a technique by replacing the lunate facet with use of the not destroyed medial articular surface of the scaphoid allowing a PRC as long as the capitate head is intact even if the radioscaphoid joint and the lunate fossa is destroyed. The use of pyrocarbon capitate head replacement may allow a PRC even if there is osteoarthritis of both, the radiocarpal and the midcarpal joint [35].

From the different procedures aimed solely at gaining a functional improvement on forearm rotation, we as others had very satisfactory results with Bowers hemiresection interpositional arthroplasty [36, 37]. Nowadays we prefer to use an ulnar head replacement to solve problems on the ulnar side of the wrist [38–41]. Procedures aimed at restoring anatomic relationships between the distal end of the radius and the carpus as well as the distal end of the ulna are primarily osteotomies of the distal radius and the ulna.

Indications and contraindications for radial corrective osteotomies

The indication for corrective osteotomy is symptomatic, rather than radiological, malunion. It depends on the limitation of function, the severity of pain, the presence of midcarpal instability, the associated problems of the distal radioulnar joint, and the displeasing appearance of the wrist.

From a radiological standpoint, there are no fixed parameters to determine the indication for corrective osteotomy. On the other hand, the shape and the length of the distal radius as base of an almost normal wrist and forearm function can only be restored by an open wedge osteotomy of the distal radius. Therefore, we recommend radial corrective osteotomy for all multidirectional deformities. Having in mind that any angular deformity in the sagittal plane affects the distal radioulnar joint ulna shortening is only indicated for dorsal malunion with dorsal tilting less than 10° and palmar malunion with less than 20° palmar angulation [41, 42]. For malunion with a radial shortening over 12 mm, a combined closed-wedge osteotomy of the radius and ulna shortening should be considered [43].

Poor general health and marked degenerative changes of the radiocarpal joint are contraindications for radial osteotomy. Additional contraindications include fixed carpal malalignment, because in this setting the carpus does not correct with the radius, and the patient will have ongoing pain. Evidence of an acute sympathetic reflex dystrophy may be a contraindication for radial corrective osteotomy. In those patients where the irritation of the median nerve caused by the dislocation of the distal fragment may cause the reflex dystrophy a corrective osteotomy should be considered. For patients with reduced finger function we recommend physiotherapy prior to the operative intervention. Nowadays, where locking plates allow a more rigid fixation of the distal radius, only a really severe osteoporosis is a contraindication for a radial corrective osteotomy.

A slight instability of the distal radioulnar joint is not a contraindication for radial osteotomy, because the corrective osteotomy reestablishes, in general, its stability. In several patients we observed a healing of a nonunited ulnar styloid following a radial corrective osteotomy without any procedure on the ulnar side of the wrist. Also, a marked instability of the distal radioulnar joint is no contraindication for radial osteotomy, but requires a simultaneous or a secondary procedure on the ulnar side of the wrist, such as an Adams' procedure [44]. As mentioned already, as others we have good results for malunited distal radial fractures associated with marked degenerative changes of the distal radioulnar joint with radial osteotomy combined with Bowers procedure [36, 37]. Due to persisting postoperative problems in some patients following Bowers' hemiresection arthroplasty, we recommend ulnar head replacement in combination with radial corrective osteotomy today [40, 41].

Based on the overall good results after radial corrective osteotomy, nowadays there is no more an upper age limit for corrective osteotomy for malunited distal radius fractures, provided that there is adequate bone quality and impaired wrist function. As shown by Pillukat et al. [45], elderly people benefit significantly from a radial corrective osteotomy even they do not improve as much as younger patients do. Due to the enormous remodeling capacity of the distal radius, osteotomy is rarely necessary in children [46]. It is indicated if there is a growth arrest or if the time left for remodeling is too short for a complete spontaneous correction.

Timing for radial correction osteotomies

Radial corrective osteotomy should be performed as soon after the fracture as it is decided that the patient meets the criteria and the swelling is subsided. Jupiter and Ring [47] retrospectively evaluated the results for ten patients in whom a malaligned fracture of the distal end of the radius had been treated within a range of 6–14 weeks after the injury with an early reconstruction consisting of an osteotomy through the site of the fracture, autogenous cancellous iliac-crest bone-grafting, and internal fixation. They compared the results for these patients with those for ten patients in whom functional limitation after complete healing of a fracture of the distal end of the radius in a malreduced position had been treated at 30–48 weeks after the injury with late reconstruction consisting of an osteotomy, corticocancellous bone-grafting, and internal fixation. The average duration of follow-up was 48 months after the early reconstructions and 34 months after the late reconstructions. After the early reconstructions, flexion of the wrist averaged 45°, extension of the wrist 52°, pronation of the forearm 79°, and supination of the forearm 77°, compared with 42°, 45°, 77°, and 68°, respectively, after the late reconstructions. Grip strength averaged 42 kg after the early reconstructions, compared with 25 kg after the late ones. One patient from each cohort had mild pain in the radiocarpal joint. According to the scale of Fernandez, there were seven excellent and three good results after the early reconstructions, and one excellent, seven good, and two fair results after the late reconstructions. Complications included a rupture of the extensor pollicis longus tendon 12 weeks after one of the early reconstructions, persistent pain at the donor site of the iliac-crest bone graft after a late reconstruction, and a delayed union that necessitated a second procedure after another late reconstruction. Based on these data, Jupiter and Ring recommended early reconstruction for patients who have radiographic characteristics that are predictive of persistent functional limitation, because early reconstruction is often technically easier and reduces the overall period of disability.

Preoperative work-up

Preoperative work-up includes an exact evaluation of the clinical situation and the radiological findings. The indication for corrective osteotomy is usually based on plain radiographs of the injured wrist. Comparison of the opposite side is helpful to determine ulnar variance and the inclination in the frontal and sagittal plane. A CT may be helpful to detect degenerative changes and malalignment of the distal radioulnar joint as well as rotational deformity of the distal radius. An arthroscopy of the wrist may be indicated to assess the articular cartilage and the ligaments, especially in intraarticular malunion.

Preoperative drawing of the planned surgical intervention showing the level of osteotomy, the angle of correction, and the ulnar plus is important. Nowadays the preoperative planning of the surgical intervention is often done on a computer [48–50]. Athwal et al. [48] described a technique which has the additional benefit of reducing radiation exposure to the patient and surgical team because fluoroscopy is not used during the procedure. Other benefits of the computer-assisted technique include the ability to perform multiple surgical simulations to optimize the alignment plan.

Operative technique

Most surgeons feel that the approach to expose the distal part of the radius depends on the direction of the deformity using a classic palmar Henry approach for palmarly tilted malunions [51, 52] and a dorsal incision between the third and fourth dorsal compartments for dorsally angulated malunions [53]. In 1937, Campbell [54] published a technique in which the radius is osteotomized through a radial approach. Now that newer plates designed specifically for the palmar fixation of dorsally unstable distal radius fractures by incorporating buttress pins and screws that lock to the plate are available, the idea to correct dorsally tilted malunion through a palmar approach has become more popular [55–60]. As far as we know, the technique was first described in the 1970s by Lanz [61].

However, there are many facts which may influence the approach to the distal radius for corrective osteotomy. For dorsal malunion of the distal radius following palmar plate fixation the radius can easily be approached using the prior incision. If the distal fragment of the radius following dorsal plating is displaced in the direction opposite to the plate or if the fracture is overcorrected a second approach on the palmar aspect of the radius may be needed. In the rare situation where an additional procedure on the carpal ligaments or on the ulnar side of the wrist simultaneous with the corrective osteotomy of the radius is required, the radius should be approached dorsally.

Corrective osteotomy should include correction of malrotation of the radius along with correction of angular deformities and radial shortening. Correct rotational alignment of the distal radius with respect to the radial diaphysis can easily be achieved by application of a buttress plate on the palmar aspect of the radius. In patients with a soft tissue problem associated with distal radius malunion, such as FPL laceration, the soft tissue problem may influence the choice of the approach to the radius.

The osteotomy can be performed either at the prior fracture site or at a different site. In many cases it is technically easier to perform the osteotomy proximal to the original fracture site. However, this can result in a severe humpback deformity of the distal radius and/or a dislocation of the distal radio-ulnar joint. The humpback deformity with the long axis of the carpus palmar to the long axis of the radius may disturb force transmission and can lead to a re-fracture after hardware removal.

Such problems can be avoided by locating the osteotomy as close to the original fracture site as possible and by exact preoperative planning of the center of rotation. The center of rotation can lie in, on, or outside the margins of the radial cortex [62]. When a limited lengthening is needed, the center of rotation lies on the bone margins and an incomplete opening-wedge osteotomy is enough. To our experience this situation is encountered in many palmar malunion. When the radius needs to be largely lengthened, the center of rotation is away from the bone and a complete osteotomy is required. This situation is rarely given in palmarly angulated malunion but in most dorsal malunion.

It is important to restore the anatomic relationship between the distal radius and the distal ulna. Radial shortening up to 12 mm can be corrected with a radial osteotomy alone. If radial lengthening is complicated by soft tissue contracture, complete tenotomy or z-lengthening of the brachioradialis tendon may be helpful [63]. While callotaxis is an useful technique to achieve satisfactory length for young patients with growth arrest, combined radius–ulna osteotomy can be recommended for elderly people [43, 64].

Mostly, the defect created by the open wedge osteotomy is filled with corticocancellous or with cancellous bone graft from the iliac crest. Ring et al. [65] compared retrospectively two cohorts of ten patients who had a corrective osteotomy for a malunited fracture of the distal radius to see whether the outcome was affected using a non-structional cancelleous bone graft compared with a trapezoidal corticocancellous bone graft. They found that at follow-up radiographic and functional results were comparable between groups.

Some investigators have reported about the use of bone substitute [66, 67]. Hemicallotaxis is also described for correction of the radial deformity [68]. If the osteotomy gap is small and the radius is fixed using a locking plate it may be okay to leave the gap alone, but there is a certain risk for a secondary loss of reduction. Hence, the patient should have a high compliance. In most palmarly angulated malunion in the sagittal plane, the graft will form a triangular shape with its apex placed dorsally. For dorsally tilted malunion a double trapezoidal-shaped graft is needed to fill the gap.

Most surgeons harvest the bone graft from the iliac crest. In 1988, Watson [69] picked by a technique described by Durman [70] cutting the graft longitudinally from the distal end of the proximal fragment of the radius. Campbell harvested the graft from the distal ulna. Whatever is used to fill the osteotomy gap, the large cancellous bone surface of the osteotomy of the distal radius guarantees a fast integration of the bone graft, respectively—the bone substitute and a fast consolidation.

How to fix the radius in corrective osteotomies? Every technique used for fixation of the distal radius in acute fractures, such as pinning and plating, can also be used to stabilize the distal radius in corrective osteotomy. However, decision making on how to fix the radius should take into account the quality of the bone stock, the quality of the bone graft, and the interval between the injury and the corrective osteotomy. To avoid implant failure, the used plate should be strong, especially in a longstanding malunion and if the bone graft is very tiny [71]. Another option for stabilizing the site of the corrective osteotomy is an external fixator with pins placed in the distal fragment [68]. This allows postoperative adjustment if the restoration of length or alignment proves to be inadequate.

Author's preferred technique of corrective osteotomy for dorsal malunion of the distal radius

A Y-shaped incision with the long leg of the Y overlying the radial artery is carried out over the distal radiopalmar aspect of the wrist. The oblique leg of the Y on the palmar side extends to the middle crease of the wrist where it crosses the flexor carpi radialis. The dorsal leg of the Y ends at the radial border of both radial wrist extensors (Fig. 2a). Throughout the whole procedure care is taken to protect the superficial branch of the radial nerve, which remains attached to the subcutaneous flap (Fig. 2b). The first extensor compartment and any additional subcompartment are released (Fig. 2c, d). The third dorsal compartment is opened and the extensor pollicis longus tendon is transposed subcutaneously (Fig. 2e). The tendon of the brachioradialis muscle is partially or if necessary totally detached from the radius. The pronator quadratus together with the flexor pollicis longus muscle and the radial artery is retracted from the radius to the ulnar side (Fig. 2f).

The used special radius correction plate is positioned as far distally as possible and fixed by a locking screw through the middle of the three distal holes (Fig. 2g). The plate must be positioned according to the angle of correction of the ulnar inclination. Therefore, the plate is pivoted around the middle of the three distal holes until the angle between the radial border of the radius and the radial border of the proximal part of the plate corresponds to the angle of correction of the ulnar inclination. After positioning of the plate the radial and ulnar distal screw holes are drilled and locking screws are inserted. After distal fixation of the plate the stem of the plate sticks out from the radius. The angle between the shaft of the radius and the stem of the plate corresponds to the necessary correction of the radius in the sagittal plane.

With the plate in place the site of the osteotomy is marked with an osteotome. It should be as close to the original fracture site as possible and lie just proximal to the distal three screws. The osteotomy is carried out with use of an oscillating saw (Fig. 2h). The angle of osteotomy in both planes in relation to the long axis of the radial shaft should be half of the planned angle of correction. This has proved to be advantageous; while opening up the osteotomy a double trapezoid gap is created which eases the fitting and wedging in of the bone graft. If a smaller angle is chosen, the distal fragment needs to be tilted more with the result that the long axis of the carpus lies palmar to the axis of the forearm. Therefore, the load transmission through the radiocarpal joint is still affected. If one chooses a greater angle for the osteotomy, the distal fragment becomes longer. This, in turn, results in a posterior humpback when the fragments are spread.

The osteotomy gap is opened up with a spreader inserted between the posterior cortices of the fragments (Fig. 2i). This brings the stem of the plate in contact with the shaft of the radius as soon as the distal fragment has reached its proper position of correction. With two plate-holding forceps the plate is fixed temporarily to the radial shaft (Fig. 2i). A double trapezoid, bicortical bone graft harvested from the iliac crest is now inserted into the widened gap (Fig. 2j). However, the use of cancellous bone graft will be enough. The plate is then fixed definitively to the radius. A lag screw is inserted through the plate into the bone graft. The extensor retinaculum will not be sutured and the tendon of the extensor pollicis longus remains subcutaneously. The pronator quadratus muscle is loosely sutured to the tendon of the brachioradialis muscle. After a careful hemostasis the wound is closed. The wrist is immobilized in a palmar plaster splint until the wound has healed properly.

The patient begins active exercises of the fingers immediately after surgery. The day after surgery, elbow motion and forearm rotation start. The suction drain is removed on the second day after operation and the sutures after 2 weeks. Usually this coincides with the removal of the plaster splint. Physiotherapy includes wrist motion as well as forearm rotation. The plate is only removed if it caused

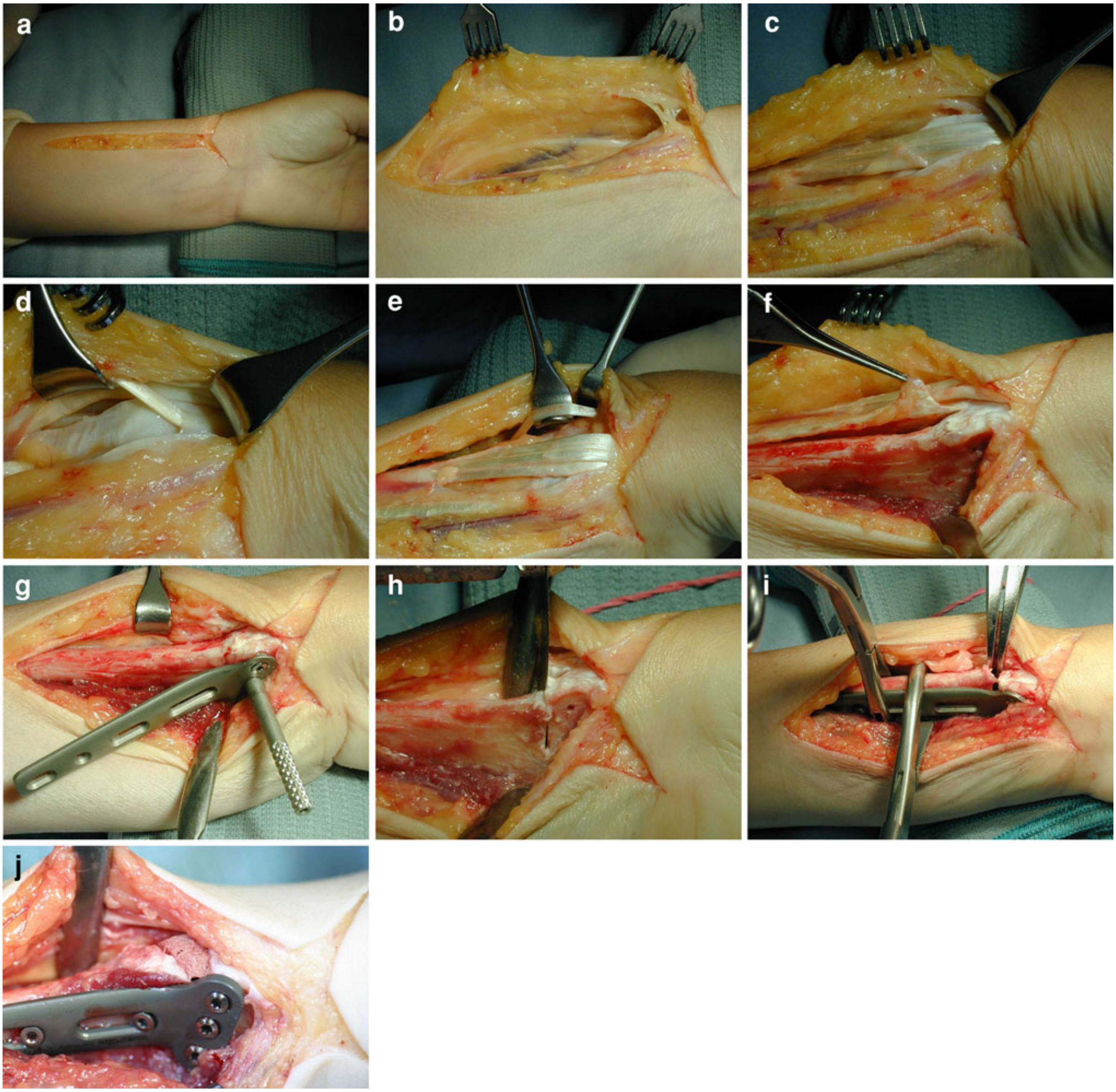

Fig. 2 **a** Author's technique for corrective osteotomy of a dorsal tilted distal radius malunion: the radius is approached from radio-palmar by a Y-shaped incision with the long leg of the Y overlying the radial artery. **b** Throughout the whole procedure care is taken to protect the superficial branch of the radial nerve, which remains attached to the subcutaneous flap. **c** The first extensor compartment **d** and any additional subcompartment are released. **e** The third dorsal compartment is opened and the extensor pollicis longus tendon is transposed subcutaneously. **f** The tendon of the brachioradialis muscle is partially or if necessary totally detached from the radius. The pronator quadratus together with the flexor pollicis longus muscle and the radial artery is retracted from the radius to the ulnar side. **g** The used special radius correction plate is positioned as far distally as possible and fixed by a locking screws. After distal fixation of the plate the stem of the plate sticks out from the radius. The angle between the shaft of the radius and the stem of the plate corresponds to the necessary correction of the radius in the sagittal plane. **h** The osteotomy is carried out with use of an oscillating saw. The angle of osteotomy in both planes in relation to the long axis of the radial shaft should be half of the planned angle of correction. **i** The osteotomy gap is opened up with a spreader. This brings the stem of the plate in contact with the shaft of the radius as soon as the distal fragment has reached its proper position of correction. With two plate-holding forceps the plate is fixed temporarily to the radial shaft. **j** A double trapezoid, bicortical bone graft harvested work-up from the iliac crest is now inserted into the widened gap. A lag screw is inserted through the plate into the bone graft. **k** Preoperative pa-view showing the extreme shorting of the distal radius. **l** The preoperative lateral view shows a dorsal tilting of the distal radius surface of more than 50°. The lunate followed the articular surface in the dorsal tilting while the capitate is flexed to compensate the tilting of the radius and the proximal carpal row. **m** 6 months after the corrective osteotomy the osteotomy is healed and the length of the radius is restored. **n** The lateral view shows a neutral tilting of the articular surface, a good result with respect to the preoperative situation

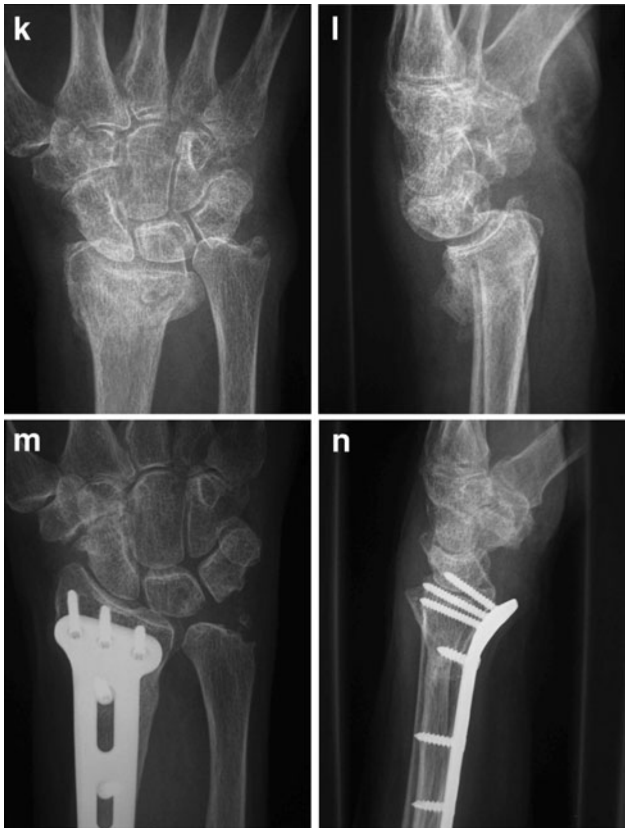

Fig. 2 continued

problems [58, 59, 72]. Pre-and postoperative results are demonstrated (Fig. 2k–n).

Results

More than 200 papers on radial corrective osteotomy were published. Those who include data show that corrective osteotomy improves wrist and forearm motion as well as grip strength, and diminishes pain. The changes from pre- to postoperative are statistically significant. Between 1975 and 1999, we performed 195 corrective osteotomies for dorsal malunion of the distal radius; 181 were carried out using the above-described technique. Preoperative radiographs revealed an average dorsal tilt of the articular surface of 24°, an average ulnar inclination of 13°, and an average ulnar variance of plus 6 mm. Preoperatively, extension of the wrist averaged 44° (range 30°–50°), flexion of the wrist averaged 34° (range 25°–50°), supination of the forearm was on average 66° with a range from 55° to 90°, and forearm pronation ranging from 60° to 90° averaged 64°. The average grip strength was 29 kg compared with 69 kg in the contralateral hand. At an average of 54 months after the osteotomy, extension and flexion of the wrist had improved on average to 49° with extension of the wrist ranging from 45° to 55° and flexion ranging from 40° to 60°. Supination of the forearm had improved on average to 78° (range 70° to 90°) and pronation on average to 77° (range 65° to 90°). The average grip strength had increased to 40 kg. Postoperative measurements of the radiographs showed on average a palmar tilt of the articular surface of 7°, an radial inclination of 22°, and an ulnar plus variance of less than 1 mm [59].

In a study published in 2002 we were able to show that patients with no or only a minor residual deformity after corrective osteotomy had significantly better results than those with a gross residual deformity as shown for wrist extension and forearm supination [73].

For corrective osteotomy of intraarticular malunion of the distal part of the radius we found that intraarticular osteotomy can be performed with acceptable safety and efficacy [74, 75]. The results of intraarticular corrective osteotomy are comparable with those of osteotomy for the treatment of extraarticular malunion. However, the indication is limited by both chronology and the type of injury. It is preferable to reserve such a procedure for those malunited fractures that have a relative simple intraarticular component.

Many are written in the literature regarding the technique and results of corrective osteotomies for extraarticular malunions. Also, there is good information on intraarticular corrective osteotomies, but there is a paucity of literature on the most complex types, the combined intra- and extraarticular distal radius malunions. Therefore, we evaluated the radiographic and functional outcome of a series of patients with combined intra- and extraarticular malunion of the distal radius treated by corrective osteotomy at four institutions [76]. Eighteen skeletally mature patients were evaluated at an average of 78 months after corrective osteotomy for a combined intra- and extraarticular malunion of the distal part of the radius. The indication for osteotomy in all patients was the combination of an extraarticular deformity (≥15° palmar or ≥10° dorsal angulation or ≥3 mm radial shortening) and intraarticular incongruity of ≥2 mm (maximum step-off or gap) as measured on lateral and posteroanterior radiographs. The average interval from the injury to the osteotomy was 9 months. The average maximum step-off or gap of the articular surface prior to surgery was 4.1 mm. All 18 patients healed uneventfully and the final articular incongruity averaged 0.4 mm. Final range of motion and grip strength significantly improved ($P < 0.05$), averaging 89 and 84% of the uninjured side, and 185 and 241% of the preoperative measures, respectively. The rate of excellent or good results was 72% according to the validated rating system Mayo Modified Wrist Score, and 89% according to the unvalidated system of Gartland and Werley. The mean DASH score was 11, which corresponds to mild perceived disability.

Eleven of the 18 cases normalized their upper limb function. Four patients had complications that were successfully treated. According to the rating system of Knirk and Jupiter, four had a Grade 1 and one had a Grade 2 osteoarthritis of the radiocarpal joint on radiographs. Only two of these patients reported occasional mild pain. Osteoarthritis did not correlate with strength, motion and wrist scores. In summary, outcomes of corrective osteotomy for combined intra- and extraarticular malunions are comparable to those of osteotomy for isolated intra- and extraarticular malunions.

Complications

The complications following a corrective osteotomy of the distal radius are the same as seen following operative treatment of acute fractures of the distal radius. One major complication following corrective osteotomy is nonunion. We found 4 nonunion out of 400 osteotomies [77].

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