Circumferential rotational flap for centralization in radial longitudinal deficiency

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Background
The goals of surgical intervention for correction of radial longitudinal deficiency are to correct the radial deviation deformity of the wrist by centralizing the carpus on the distal end of the ulna, concomitant with balancing the soft tissue structures at the wrist, while preserving the growth potential of the distal ulna. Several skin incisions have been used; however, few of these procedures handled the problem of significant skin tension on the radial side with excessive skin available on the ulnar side, and the difficult full access to fully release the tethering structures on the radio-volar side.
Patients and methods
A total of 19 wrists in 13 patients with radial longitudinal deficiency of Bayne and Klug type IV were operated on by centralization using circumferential rotational flap between 2008 and 2016. The average age at the time of centralization was 18.5 months. Follow-up evaluation was done at 3-month intervals, and average follow-up was 42 months. Patients were evaluated at postoperative follow-up according to the clinical appearance of scar, wrist stability, and radiological parameters on preoperative and postoperative radiographs.
Results
There were no difficulties related to access, no part of any flap was lost, and there were no primary wound healing problems. Evaluation of the scar revealed no gross mismatch of the color, no proud or keloid contours, and no distortion, and good contour was restored. The subjective overall appearance was good, and the growth potential of the distal ulna was preserved.
Conclusion
A circumferential rotational flap was safely used for centralization procedure in this study. It provided additional skin on the radial aspect and took up the slack on the ulnar aspect and gave excellent access to the wrist and surrounding soft tissue structures without notable complications attributable to the flap.

Keywords:
centralization, flap, radial longitudinal deficiency

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Introduction

Radial longitudinal deficiency (RLD) is the most frequent pattern of congenital longitudinal deficiency, first described by Petit in 1733 [1], with an incidence ranging from 1 in 30 000 to 100 000 births [2,3] and characterized by hypoplasia of both the radius and soft tissue structures on the preaxial side of the forearm [4]. Although RLD is most commonly classified as described by Bayne and Klug [5], which classified the deficiency based on the radius and ulna, this traditional classification has been expanded distally to include the failures of the formation in the hand [6,7], and expanded proximally to include the failures of formation in the elbow and shoulder [8,9].

In spite of the advances over a quarter of millennium of investigation, the current surgical treatment of this condition is still insufficient in regaining 'normal' appearance and function within the wrist [4]. Centralization has been the most common wrist stabilization procedure used for managing severely deviated wrist in RLD [10,11]. Although many authors have worked to improve the wrist alignment and balance while preserving motion [11], and several skin incisions have been used for centralization, few of these procedures have handled the problem of significant skin tension on the radial side with excessive skin available on the ulnar side [9], and the difficult full access to fully release the tethering structures on the radio-volar side [12].

Approaches that have been used include a dorsal S-shaped incision with excision of the ulnar aspect

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redundant skin [13], several two-sided incisions with a radial z-plasty, and an ulnar-sided excision of excessive skin [14,15]. Manske *et al*. [16] described a transverse ulnar incision for excision of the redundant ulnar-sided skin, and Watson *et al*. [17] used a standard 60° z-plasty for the radial side, plus a similar z-plasty with a transverse central limb on the ulnar side to take up skin redundancy and transpose the skin to the deficient radial aspect. A bilobed flap has been described by Evans *et al*. [18], involving rotation of the ulnar-sided skin to the dorsum and the dorsal-sided skin to the radial side, but it has been complicated by problems with esthetics, leaving an ulnar-sided dog ear, and reports of distal tip necrosis because of the narrow nature of the flaps [19].

An ideal incision would provide additional skin on the radial aspect and take up the slack on the ulnar aspect, as well as give wide access to the wrist and surrounding structures [20]. The current study evaluated the results of circumferential rotational flap for centralization procedure in patients with RLD presented to Hand Surgery Unit, Mansoura University in Egypt, dealing with the issue of skin and soft tissue balancing on both wrist sides, and providing a full access radio-volarly for safe and gentle release of the distal ulna and tethering structures.

Patients and methods

After obtaining approval from the relevant Institutional Review Board (IRB) and the ethics committee, the study was initiated. The study was approved by the institutional ethics committee in the Orthopedic Department of Orthopaedic Surgery, Mansora University, Mansora, Egypt. The study population consisted of 19 wrists in 13 patients (nine males and four females) with RLD of Bayne and Klug type IV (complete absence of the radius), which were operated on between 2008 and 2016 at Mansoura University Hospital. Six patients were operated on bilaterally (one of them was female), whereas the other seven (four right and three left wrist) were operated on unilaterally. The average age at the time of centralization was 18.5±10.5 months (range, 5–38 months).

Surgical technique

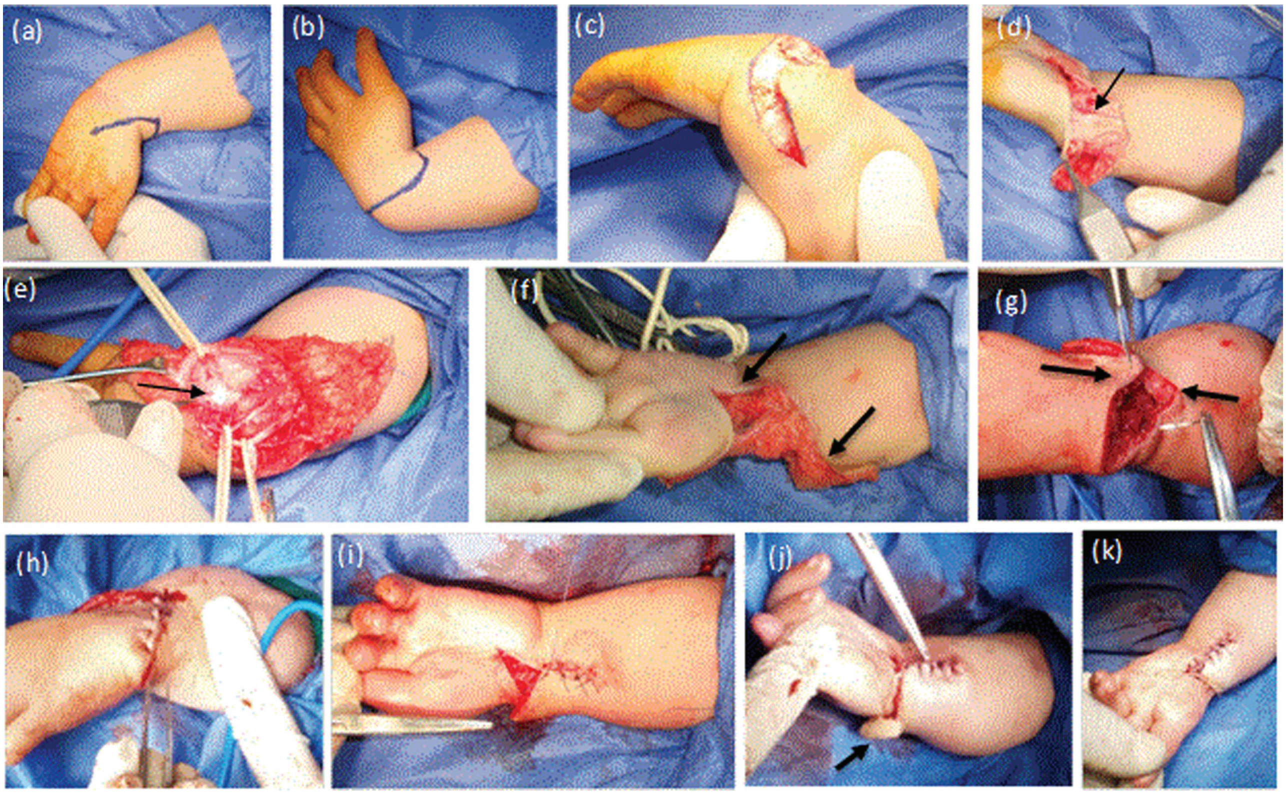
The incision required an ulnar longitudinal limb, dorsal transverse limb, and volar oblique limb sequentially (Fig. 1a, b). It was started as midlateral ulnar-sided incision along the ulnar border down to the wrist with the excessive dorsoulnar tissue included in the dorsal flap, then a transverse limb across Langer's lines (cleavage lines) at the supposed transverse access of the wrist, ended at the radial border of the wrist (Fig. 1c), and then a volar oblique limb directed volarly toward the little finger metacarpal head and ended just beyond the volar wrist crease (Fig. 1d), depending upon the necessary radio-volar-sided skin lengthening. The flap was elevated in a full-thickness manner, preserving the dorsal longitudinal veins (Fig. 1e).

Ulnar aspect dissection was then carried down exposing the ulna, proximal border of the ulnar carpus, and base of the metacarpals (Fig. 1e), followed by radial-side dissection, including volar, radial, and rest of dorsal aspects for identification and release for radial-sided structures (Fig. 1d). After elevation of the dorsal flap, the dorsal compartment of the extensor carpi ulnaris was opened and the extensor carpi ulnaris is mobilized and protected with a loop. After reflecting the extensor retinaculum, the extensor digitorum communis tendons, and the extensor indicis proprius were mobilized and protected. Then arthrotomy of the ulnar-carpal joint was done with gentle capsular release of the capsule off the distal end of the ulna radially. Exposure on the radio-volar side included identification and protection of the abnormally located median nerve, and radial-sided muscles such as brachioradialis or radial wrist extensors, which can be released if rudimentary and without excursion (Fig. 1d).

Under control of image intensifier, using a single sharp end k-wire, a track of one cm in the distal ulna was done (Fig. 2a), and then the wire was passed with the sharp end distally into the carpus, and the middle finger metacarpal, or between ring and middle metacarpals (Fig. 2b), withdrawing the k-wire distally out of its exit leaving a few millimeters of its blunt side exposed out of the carpus (Fig. 2c). The carpus is then reduced over the end of the ulna, and then the blunt end was driven to the track in the distal ulna, and the k-wire was passed intramedullary into the ulna (Fig. 4b).

As the wrist was brought into a new straightened position (Figs 1f, 2d), the hand was rotated ulnarly, and the flap was rotated in a radio-volar direction, filling the gap in the radial and volar aspect. At first, skin closure of the dorsal aspect was done having the radial angle of the distal skin fitted to the created angle at the start of the ulnar limb of the approach (Fig. 1g, h), then closure of the radio-volar aspect was done between the ulnar skin edge of the volar incision and the radial side of the rotated flap (Fig. 1i), leaving a variable extra skin of the distal flap that had been removed in line with the distal radio-volar skin edge (Fig. 1j, k). The patient was placed in a well-padded, noncircumferential long-arm splint to allow for postoperative swelling.

Figure 1



Technique of the flap: (a, b) oblique volar and dorsal incisions planning. (c) Dorsal flap. (d) Exposure of the radio-volar aspect, identification and protection of the aberrant median nerve (black arrow), radial-sided muscles, and radial wrist extensors, that can be released if rudimentary and without excursion. (e) Elevated of the flap in a full-thickness manner. Extensor carpi ulnaris and fingers extensors were mobilized and protected. Dissection was then carried down exposing the ulna, and proximal border of the carpus (black arrow). (f) The wrist was brought into a new straightened position; the black arrows illustrate the radial skin edge of the flap and the ulnar side of the volar incision. (g, h) The hand was rotated ulnarly, and skin closure of the dorsal aspect was done having the radial angle of the distal skin fitted to the created angle at the start of the ulnar limb of the approach (black arrows). (i) Closure of the radio-volar aspect between the ulnar skin edge of the volar incision and the radial side of the rotated flap. (j, k) Extra skin of the distal flap had been removed in line with the distal radio-volar skin edge (black arrow).

Postoperative care

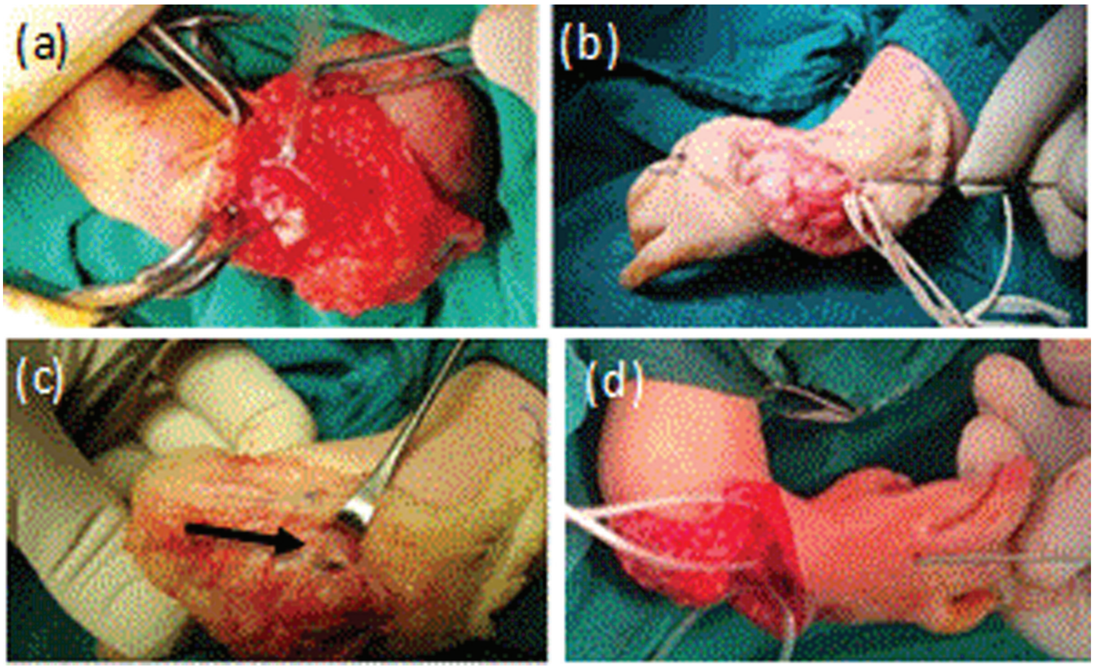
The limb was elevated, and assisted finger movement was encouraged by the parents for the first 48 h. Sutures were removed at 10–12 days postoperatively, and a long-arm cast was applied. K-wire is kept in place for 12 weeks. Then, a below-elbow custom wrist splint was applied and continued for another 6 months (Fig. 3b). During this period, the parents were advised to passively mobilize all the finger joints and elbow, and the child was encouraged to use the hand in day-to-day activities so as to develop prehension in the new wrist position.

Follow-up evaluation was done at 3-month intervals. The average follow-up was 42 months (14–68 months). Patients were evaluated at postoperative follow-up according to the clinical appearance, wrist stability, and radiological parameters on preoperative and postoperative radiographs. Clinically, scar assessment was based on the color (perfect, slight, or gross mismatch) and the contour (flat, proud, or keloid), which were combined to make an overall appearance assessment [12], documenting any distortion (none, mild, moderate, or severe). Wrist range of motion and radial deviation were recorded. Radiologically (Fig. 4c, d), the hand forearm angle (HFA), measured as the acute angle between longitudinal axis of the third metacarpal and longitudinal axis of the distal ulna; hand forearm position (HFP), measured as the shortest distance between a line drawn through the longitudinal axis of the distal ulna and the base of the ulnar-most metacarpal [16] (negative measurements (mm) refer to radial transposition of the carpus, whereas positive measurements indicate ulnar transposition) [22]; and ulna length (UL) were measured [21] in anteroposterior radiographs and recorded. Final radiological measurements were compared with the preoperative data.

Results

A total of 19 wrists of 13 RLD cases were subjected to wrist centralization using a circumferential rotational

Figure 2



Intramedullary k-wire application. (a) A track of one cm in the distal ulna was done. (b) k-wire was passed with the sharp end distally into the carpus, and the middle finger metacarpal, or between ring and middle metacarpals. (c) Withdrawing the k-wire distally out of its exit leaving a few millimeters of its blunt side exposed out of the carpus (black arrow). (d) The blunt end was driven to the created track in the distal ulna and the k-wire was driven intramedullary.

flap. There were no primary wound healing problems. Evaluation of the scar revealed no gross mismatch of the color, no proud or keloid contours, and no distortion. The subjective overall appearance was good (Fig. 3e, f). The parents reported an improvement in the appearance as well as the function of the hand, which would be attributed to the improved stability of the carpo-ulnar pseudo-articulation.

There was no neurovascular complication in the present study. Complications recorded were one immediate postoperative slowed capillary refill, which resolved after a dressing change in the immediate postoperative period; two cases of pin-tract infection, which required oral antibiotics and frequent dressing, and both patients had removed the k-wires at 3 months postoperatively; one case had superficial infection at the ulnar-side stitches, which required removal of few stitches and daily dressing; and in two wrists, accidental extrusion of the k-wire occurred after a couple months postoperatively, where one had pulled out on changing the cast while removing the old cast, whereas the other by the patient himself while playing (the hooked end of the k-wire hanged with his clothes). No complications were attributed to the surgical approach.

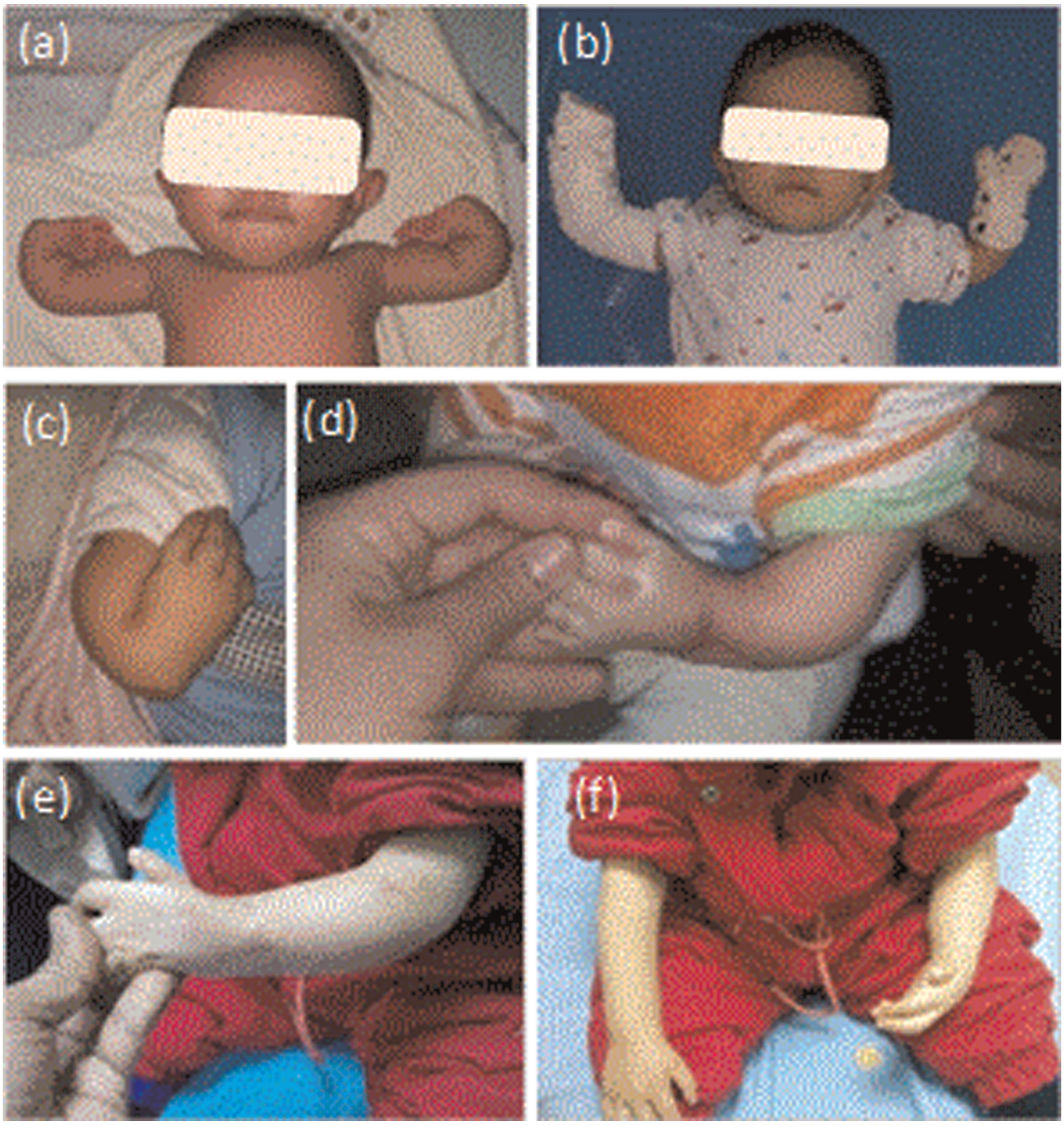
The final resting radial deviation of the wrist averaged 20.5±18.4°. The total range of motion in flexion extension arc averaged 68.7±35.8° (range, 30–140°) in latest follow-up visit, whereas the average range of motion in radial ulnar deviation arc was 60±38.7° (range, 10–150°) in the last follow-up.

The preoperative HFA average was 63±21° radial angulation (range, 22–91°), whereas at k-wire removal (3 months postoperatively) averaged 7±13° radial angulation (range, 25° ulnar to 21° radial). At the final follow-up, HFA averaged 25±18° radial angulation (range, 3.5° radial to 64° radial), with an average final correction obtained of 37±26°. There was a statistically significant difference between preoperative and final angles (P=0.001).

Regarding HFP, preoperatively, the hand was positioned to the radial side of the longitudinal axis of the distal ulna, averaging −11±3 mm displacement (range, −15 to −3.6 mm), whereas at k-wire removal (3 months postoperatively) averaged 6±4.7 mm, and at the latest follow-up, HFP averaged 4.8±8 mm (range, −7 to 14 mm). There was a statistically significant improvement (P=0.001) in the position achieved, which in an ulnar direction averaged 16±8.5 mm.

Preoperative UL averaged 54.3±7.1 mm, and averaged 70.2±22.5 mm at the midterm follow-up radiograph for each patient in the study (Table 1), whereas at the latest radiographs averaged 82.9±31.7 mm. The final

Figure 3



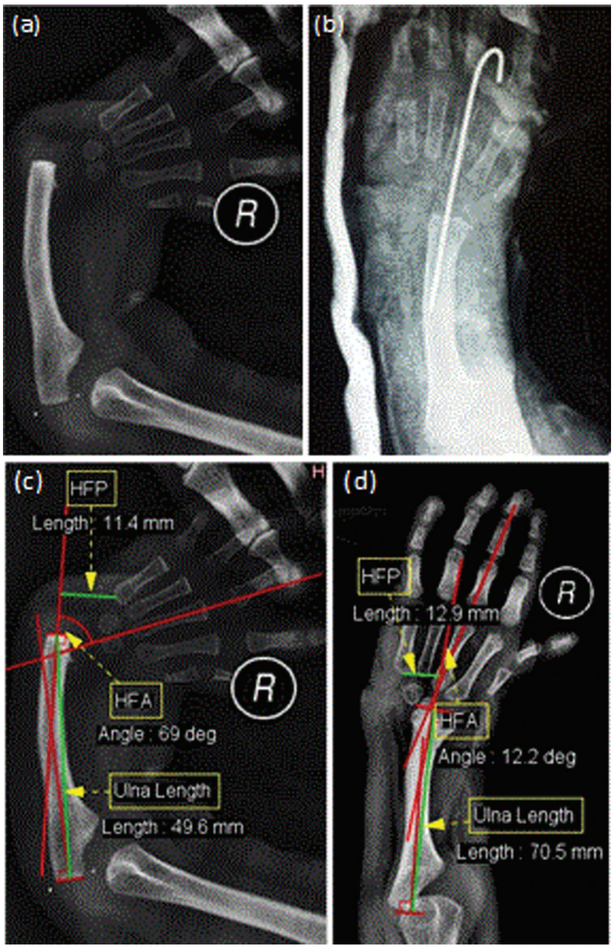
Clinical assessment: (a) Bilaterally affected patient. (b) Right side postoperative well-padded, noncircumferential long-arm splint, and left side below elbow custom wrist splint after k-wire removal. (c) Right side affected patient. (d) At k-wire removal, 12 weeks postoperatively. (e, f) Clinical follow-up; a smooth satisfactory contoured wrist and good overall appearance.

UL obtained during the follow-up period averaged 28.6±27.3 mm (P=0.003). No distal ulnar physeal arrest or ulnocarpal spontaneous fusion was recorded on any follow-up radiograph.

Discussion

Repositioning the hand and carpus upon the forearm longitudinal axis is a central goal of treatment in RLD [13], considering that a stable wrist motion and sufficient forearm length are important prerequisites for achieving a functional and cosmetically acceptable upper limb [23]. Wrist realignment procedures have focused on soft tissue balancing and stabilization of the ulnocarpal relationship to fulfill collinearity of the ulna with the long metacarpal (centralization) [13]. Although several skin incisions have been used for centralization procedure in treatment of RLD, few of these procedures address the problem of substantial skin tension on the radial aspect with excessive skin available on the ulnar side [12]. In RLD, the carpus articulates with the radial side along the ulna, and the ulnar-carpal articulation may be difficult to identify and follow circumferentially [9].

Figure 4



Radiological assessment. (a) RLD patient's preoperative anteroposterior radiograh. (b) Postoperative radiograph showing the intramedullary k-wire. (c, d) Preoperative and 9-month postoperative follow-up radiographic parameter measurments on anteroposterior radiographs for a sample case: the hand forearm angle (HFA), as the acute angle between longitudinal axis of the third metacarpal and longitudinal axis of the distal ulna; hand forearm position (HFP), as the shortest distance between a line drawn through the longitudinal axis of the distal ulna and the base of the ulnar-most metacarpal [16]; and the ulna length [21] (UL) in the anteroposterior radiographs. RLD, radial longitudinal deficiency.

Moreover, the surgery around the distal ulnar physis has the potential to cause injury and growth disturbance, resulting in additional forearm shortening [11], considering that exposure through the radial side is usually necessary to mobilize the carpus sufficiently to be brought distally enough to articulate with the distal end of the ulna [9].

As the ideal incision would provide additional skin on the radial side and take up the slack on the ulnar side [20], and allow open access to the radial aspect of the joint for soft tissue release [12], the use of a circumferential rotational flap enabled to take advantage of the extra skin on the dorsoulnar side, which can be rotated to help deal with the deficiency of skin on the radio-volar side, as the redundant skin flap of the dorsoulnar side is transposed to the radio-volar defect created by straightening the wrist, whereas the distal dorsal skin of the hand would match the proximal dorsal skin defect left after rotating the flap radio-volarly. Esthetically, it leaves a smooth satisfactory contoured wrist.

Table 1 Ulna length

	Mean±SD (mm)	*P* value
Preoperative	54.3±7.1	
Midterm follow-up	70.2±22.5	0.003*
Final follow-up	82.9±31.7	0.003*
Final length obtained	28.6±27.3	

Ulna length measured on midterm follow-up period of each patient in the series. *P less than or equal to 0.05, significant.

The wide exposure provided by the flap permits wider access to all aspects of the joint than any other incision, particularly the radio-volar aspect of the wrist, to fully release the tethering structures on the radio-volar side, offering the capability for gentle manipulation of the distal ulnar physis preserving its potential growth, the carpus radially to be mobilized enough distally to override the distal ulna, and provide safe identification and protection of neurovascular structures particularly the aberrant median nerve that may innervate in a radial sensory nerve distribution. There were no neurovascular complications in the present study, except one immediate postoperative slowed capillary refill, which resolved after change the dressing in the immediate postoperative period.

Although the ulna in RLD is known to be hypoplastic, further growth arrest can occur with injury or pressure on the ulnar physis during centralization surgery [9], and in most reported series, the final length of the ulna was 50% of normal [23]. In our series, at the latest follow-up radiographs, the average growth gained in length postoperatively was 28.6±27.3 mm (P=0.003), representing about 53.3% of the preoperative average UL of 54.3±7.1 mm, signifying that a significant ulna growth continued postoperatively and no injury occurred to the distal ulnar physis during the centralization procedure using the circumferential rotational flap. Comparison of the final UL with that of the contralateral ulna or the ipsilateral humerus was not possible, as six patients were bilaterally affected, and not all the patients had preoperative radiographs for the full length of humerus, so we compared it with the preoperative UL.

Although our results showed significant improvement (P=0.001) from a preoperative average HFA of 63±21° radial angulation to 25±18° at the latest follow-up examination, it was much better following k-wire removal at 12 weeks postoperatively and averaged 7±13°. However, HFP showed improvement from a preoperative average of −11±3 mm radial displacement to 4.8±8 mm at the latest follow-up, with minimal loss of improvement compared with the average after k-wire removal (6±4.7 mm). Options exist for the optimum time to remove the intramedullary k-wire. Lamb recommended several months to decrease the risk of recurrence [24]. The longer the pin is left in place, the more the corrected position is held, but the risk of pin complications is high [9]. We removed k-wire 12 weeks after surgery, which is more than previous studies [13,23], except a couple case of accidental k-wire removal after 8 weeks postoperatively. Pin-tract infection was recorded in two wrists, resolved by oral antibiotics and frequent dressing, and the k-wires were removed at 12 weeks postoperatively.

Conclusion

The circumferential rotational flap allows excellent access to the radio-volar aspect of the wrist, with rotation of the redundant skin in a radio-volar direction, while the distal hand and carpus are rotated in an ulnar-sided direction. It was safely used for centralization procedure in this study, preserving the growth potential of the distal ulna without notable complications attributable to the flap.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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