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REVIEW ARTICLE

Modified dome osteotomy and anterior locking plate fixation for distal radius variant of Madelung deformity: a retrospective study

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ABSTRACT

Purpose: Dome osteotomy of the distal radius with Vickers ligament release is an established method of treatment for Madelung deformity. Many different surgical procedures have been proposed in literature but techniques, patient inclusion and efficacy evaluations are heterogeneous.

Materials and methods: A retrospective review of children affected by 'distal radius' Madelung deformity and treated with a standardized surgical procedure (modified reverse dome osteotomy of the distal radius and volar fixation with a small locking plate) between 2010 and 2018 at a single center was performed. The technique used in this study, reversing the shape of the classical dome osteotomy, allowed for an improved three-planar correction of the distal radial epiphysis and volar plate fixation allowed for an increased stability and reduced soft tissue morbidity. A structured follow-up including a prompt post-operative rehabilitation program (without wrist immobilization) was established. Pain relief, functional outcome and cosmetic appearance were assessed with a structured clinical assessment, DASH Score and radiographic assessment, accordingly.

Results: A total of 15 wrists in 13 children (12 females, mean age of 15.6 years, range 11–19) were included. The mean follow-up time was 3.8 years. Bone union and pain relief were obtained in all cases. Improvement in the range of motion was detected in extension, supination and flexion of the wrist. Radial inclination was increased by 15.3° and lunate subsidence by 4.1 mm.

Conclusions: The use of volar fixation with a small locking plate and immediate post-operative rehabilitation for reverse dome osteotomy of the distal radius in pediatric patients affected by 'distal radius' Madelung's deformity is stable and effective.

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Madelung's deformity; Vickers ligament; dome osteotomy

Introduction

Madelung deformity is a cluster of anatomical changes in the wrist and forearm attributed to premature epiphyseal fusion at the volar-medial portion of the radial growth plate, with preserved growth of the ulna, and the formation of an aberrant ligament tethering the radius and carpus, usually at the lunate level [1]. The anomalous radiocarpal Vickers ligament has been postulated to play a role in the primary development of the deformity, together with bone growth disorder [2]. However, it is also possible that deformity may be secondary to the mechanical effect on soft tissue of the asymmetrical growth of the radius [3–6].

Madelung deformity usually has a hereditary component and is associated with congenital disorders, such as Leri-Weill dyschondrosteosis, other SHOX disorders, and mucopolysaccharidosis [7]. It is more commonly associated with female sex and pathological features usually present bilaterally, with asymmetrical severity in children between the ages of 6 and 13 years [8]. During late childhood and early adolescence, features typically become more obvious; including evidence of wrist deformity, decreased wrist extension and ulnar deviation, decreased pronation and supination of the forearm, accompanied by wrist pain and difficulty associated with sporting and school activities. In Leri-Weill dyschondrosteosis and mupolysaccharidosis, paediatric carpal tunnel syndrome (CTS) has also been described [9]. Acquired deformity, such as those caused by hereditary multiple exostoses (post-traumatic or post-infection) are defined as 'pseudo-Madelung' because of the absence of the Vickers ligament [6]. This difference is important, as treatment requires the release of the volar ligament to realign the distal radius fragment during deformity correction.

Conventional X-ray findings are typical, showing lunate subsidence and increased concavity and irregularity of the lunate fossa, radial bowing with epiphyseal inclination, volar and ulnar tilt and radial length deformities, and reverse pyramid deformity of the proximal carpal row [10]. There is a spectrum of deformity (Figure 1) ranging from the most common 'distal radius' variant, the less common but more severe 'entire radius' variant and the rarest and most severe 'reverse radius' variant, characterized by the radius tilted dorsally and the ulnar head displaced volarly [11].

Radial dome osteotomy correction is well established for the restoration of articular support to the lunate [5]. Many different surgical procedures have been proposed, but the heterogeneity of the techniques and efficacy evaluations do not enable a quantitative comparison of treatments [12–17]. Furthermore, variable outcomes reported may be due to the range of Madelung deformity severity included in patient cohorts.

This study aims to assess the advantages of the modified dome-shaped osteotomy of the distal radius with volar plate

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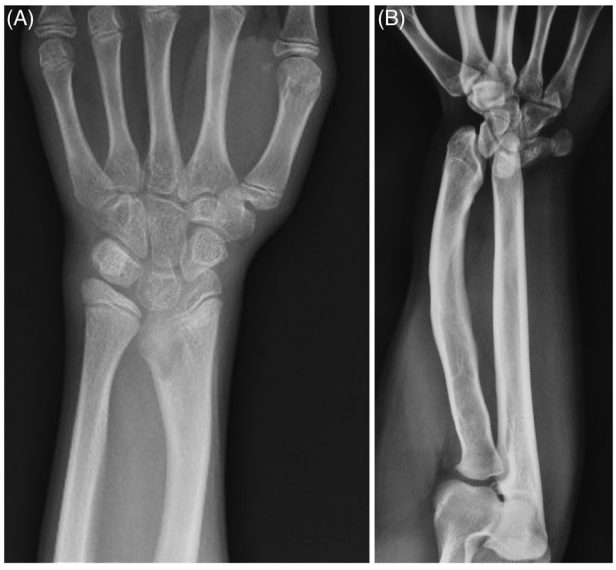

Figure 1. X-ray features of the 'distal radius' (A) and more severe 'entire radius' (B) variants of Madelung's deformity.

fixation in a homogeneous pediatric cohort affected by 'distal radius' Madelung's deformity with a standardized follow-up.

Materials and methods

Patient selection

All children with 'distal radius' Madelung deformity, treated with a standardized surgical procedure, including the modified reverse dome osteotomy of the distal radius and volar fixation with a small locking plate, at a single center between 2010 and 2018 were included. Exclusion criteria specified treatment with K-wires or external fixation (due to different post-operative immobilization and rehabilitation programs) or wide volar locking plates (due to the augmented invasivity of the hardware system and subsequent need for plate removal). Of the 24 children (28 wrists) with Madelung deformity treated at the single center during the study period, 13 patients (15 wrists) presented with the 'distal radius' variant, were treated with the modified technique and enrolled into the current study. Most patients were female ($n = 12/13$) and mean patient age at the time of surgery was 15.6 years (ranging from 11 to 19 years). Three patients were affected by Leri-Weill dyschondrosteosis; 2 were sisters who also presented with associated carpal tunnel syndrome and who underwent delayed carpal tunnel release. In 2 patients, bilateral surgery was necessary. All wrists were symptomatic, with constant pain or pain and functional impairment during daily activities.

Surgery was performed under general anesthesia in 8 cases, and brachial plexus block in 5 cases. The bone wedge was removed from the radial side in 5 cases and a block of hydroxyapatite was inserted in the defect in the opening ulnar side in 2 cases. In 8 cases, multiplanar correction and stabilization was achieved without adding bone graft or hydroxyapatite support to the ulnar side. Cancellous bone allograft was also added into the osteotomy line in 2 cases.

Surgical procedure

All surgical procedures included the release of the Vickers ligament and a modified dome-shaped osteotomy of the distal radius (Figure 2), reversing the traditional osteotomy commonly

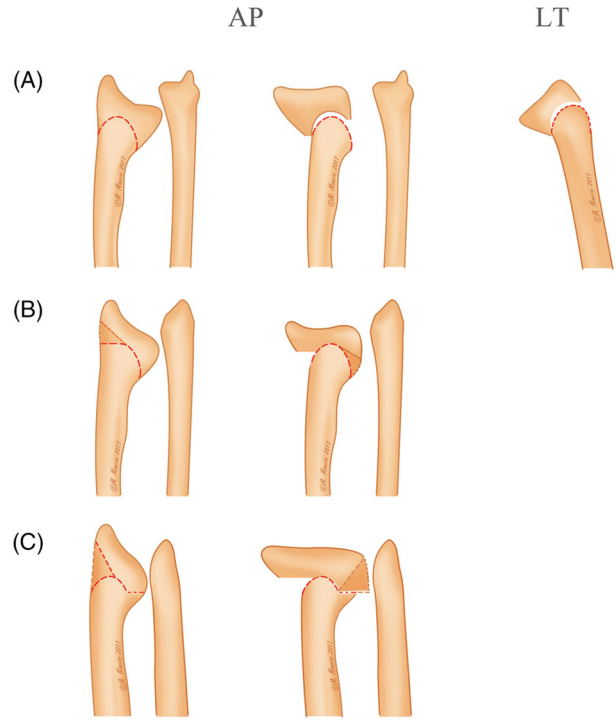

Figure 2. Multiplanar osteotomy with the possibility to perform reverse wedge osteotomy (A) inserting the bone wedge harvested from the radial side into the opening ulnar side (B) of the distal radius, to facilitate the correction. This can be used to achieve an improved correction in the more severe 'entire radius' variant of the deformity (C).

proposed in literature [6,16–19]. Surgery was performed either under general anesthesia or in cases of compliant children, a brachial plexus block was performed and the children were entertained with a movie in the operating room [9]. The surgical access was on the radial side of the flexor carpi radialis tendon and the pronator quadratus muscle was incised radially, leaving a cuff for reattachment. During the dissection, the distal radioulnar joint (DRUJ) was preserved and the Vickers ligament was isolated and accurately released from the volar aspect of the distal radius to expose the radial metaphysis and shape the line of the osteotomy. The osteotomy was performed with the convexity distally on the proximal stump of the radius, and the concavity proximally on the distal stump. The line of the osteotomy was drawn proximal to the epiphysis and DRUJ to allow for accurate positioning of the plate without affecting the growth plate. The planned osteotomy line was marked and fenestrated with a K-wire, then the osteotomy was performed using the ultrasonic micro-vibration of a piezoelectric surgical saw, that allowed preservation of the dorsal periosteum and protection of the soft tissues (Figure 3). The reversed shape of the dome osteotomy was used to achieve a multiplanar correction of the distal radial fragment in extension and radial deviation. The proximally concave osteotomy of the distal fragment allows for an adequate dorsal translation of the radius and reduction of the DRUJ (Figure 3(A)). This technique also allows a simultaneous reverse wedge osteotomy, with the bone wedge harvested from the radial side of the distal radius then inserted into the ulnar side, augmenting the angular radial correction (Figure 3(B,C)). When required, the bone wedge was removed from the radial side [13,15,17] in order to avoid impingement with the radial diaphysis during translation-rotation of the distal radius, placed into the opening ulnar side or a block of hydroxyapatite was inserted in the defect in the opening ulnar side. Multiplanar correction and stabilization was mainly achieved

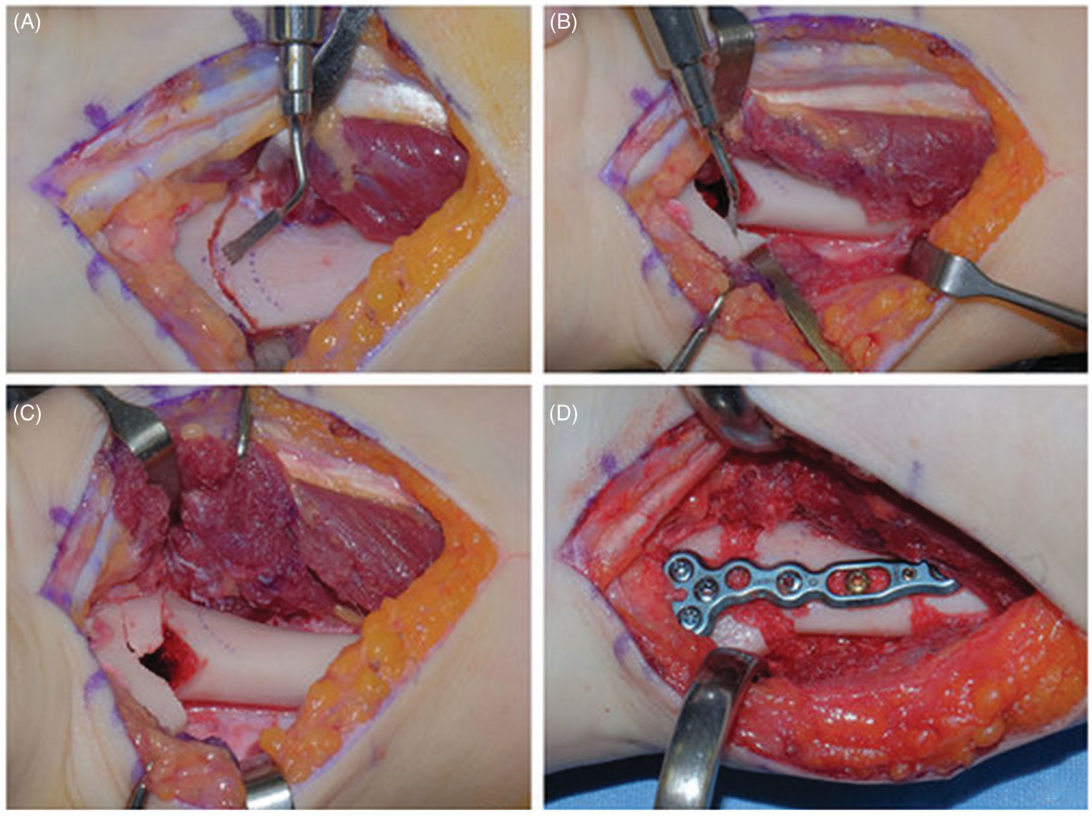

Figure 3. The line of osteotomy is marked and fenestrated with a K-wire (A), and osteotomy is performed with the ultrasonic micro-vibration of a piezoelectric surgical saw (B). The bone wedge is removed from the radial side and placed into the opening ulnar side (C). The correction is maintained with a small locking volar plate; in this case additional cancellous bone graft was inserted (D).

without the addition of bone graft or hydroxyapatite support. At the beginning of the experience, cancellous bone allograft was also added into the osteotomy line to further enhance bone healing. The multiplanar correction of the distal radial fragment was secured with small volar locking plates and screws with angular stability (Figures 3(D) and 4). Depending on the size of the radial epiphysis, locking plates originally designed for metacarpal or dorsal wrist fractures fixation (smaller than the traditional volar plates) were used. Plates were also contoured according to the required radius correction and shape. The pronator quadratus was reattached onto the radius. According to the less severe deformity of the distal radius variant, no concomitant ulnar surgery was performed; ulnar epiphysiodesis in children with uncompleted growth or ulnar shorthening in almost completed bone growth should be considered at initial surgery with ulnar variance >5 mm or painful ulna within the carpal canal [14,15,20–23].

Post-operatively, the wrist was not immobilized with a plaster cast and rehabilitation was initiated 72 h post-surgery. The rehabilitation program included both physical therapy (PT) and constraint-induced movement therapy (CIMT), to improve the overall functional recovery of the entire upper limb for daily, playing and school activities [20]. In younger children ($<$ around 10 years), an elbow gutter splint was applied during playing activities to avoid accidental direct traumas.

Patient follow-up

All patients were assessed with a radiographic post-operative examinations at 2 weeks and 4 weeks. All patients were then called for a further follow-up assessment for the purposes of this study. Assessment included clinical, DASH and radiographic assessments.

Study outcomes

Study outcomes included pain relief, wrist motion, overall functional capacity and radiographic measurements for radial inclination and lunate subsidence [18,19,24]. Improvements in outcome quality measure adopted were those proposed by Peymani et al. [24]; including range of motion (ROM), radial inclination and lunate subsidence were measured. The DASH score was also used to measure pain and functional outcomes. The visual analogue scale (VAS) was recorded because of the children older than 9 years could adequately understand the concept of the VAS. On the other hand, due to the young age of the patient cohort, measurements of grasping and pinching were not regarded as reliable indicators, especially with regard to pre-operative assessment reliability, and were therefore not included. Personal experience in cosmetic evaluation and improvement feeled by the patient was individually recorded.

Results

Mean follow-up was 3.8 years (ranging from 11 months to 9 years to). No pain or motion or skin impairment were registered from internal fixation in this series. During the early, programmed post-operative rehabilitation, no relapse of the correction was observed (Figure 4). Bone union was obtained in all cases. No changes of the lunate shape were observed at radiological follow-up and no post-operative complications were recorded. During the follow-up

Figure 4. Pre-operative X-ray of the 'distal radius' variant of Madelung's deformity (A) and X-ray at medium term follow-up (B).

there was no requirement for the removal of the volar plates or screws.

Mean post-operative DASH value was 16/100 (only one patient reported 35 points) during follow-up. Pain relief was achieved in all cases; mean post-operative VAS at rest was 0 and during activities was 1.6 (from 1.1 to 1.9). Two patients referred the appearance of recurrent shoulder pain, caused by the postural adaptations due to the wrist pain and reduced motion. Improvements in range of motion (ROM) were detected in extension, supination and flexion of the wrist, with mean improvements of 21° (from 16°to 31°), 14° (from 12° to 18°) and 10° (from 7° to 12°), respectively. The mean radial inclination of the distal radius was improved by 15.3° (from 15.1 to 15.6°) and the lunate subsidence by 4.1 mm (from 4 to 4.3) on radiographic assessment (Table 1).

No children had pain or growing affection by the plates at the longer follow up. No removal of the plates or screws was required and no post-operative complications were recorded.

Discussion

Relief of symptoms, increased range of motion of the wrist, improved articular support for the lunate, and improvement in cosmetic appearance are the primary aims of surgery in Madelung deformity. Corrective dome osteotomy of the distal radius is widely used, proven to enable both carpal traction resolution and distal radius alignment correction [18,19,24]. Adequate correction of the distal radial fragment alignment can be achieved only after the complete release of the Vickers ligament; due to the counter traction exerted by the ligament during radial translation and extension of the radial epiphysis. Therefore, the volar approach for distal radial osteotomy in patients with Madelung deformity is the approach of choice. Surgical treatment of the 'pseudo-Madelung' deformity could also be performed *via* a dorsal approach due to the absence of the Vickers ligament [10,24–26]. However, the restoration of normal wrist anatomy cannot be predicted, and further procedures, also in adult age, may be necessary at the ulna level [18,21].

According to the clinical and radiological characteristics [10,11], the severity of the variants, despite various degree of deformities, vary widely. Reports in literature to date often present results of mixed variants. The current study was designed to limit potential bias caused by heterogeneity, enrolling only patients with the more common and less severe 'distal radius' variant. Further, as stabilization with a locking plate and early post-operative rehabilitation have recently proven to be more effective in correction and healing [6,11–17], patients treated with K-wires or external fixation were excluded from study inclusion. The modified reverse dome osteotomy technique described in this study achieves a multiplanar correction of the distal radius with an increased dorsal and radial translation potential. The usual proximally concave osteotomy easily allows the sliding of the distal fragment alongside the border, but reversed shape avoided interposition of the dorsal cortex of the distal radial fragment in the medullary canal of the radial shaft when greater angular corrections are required. On the other hand, in the distal concave technique hinging at the lateral bony edge occurred. In the currently described technique the conflicting bone edge removal enables the performance of an additional reverse wedge osteotomy, which may be even more useful in more severe variants of Madelung deformity, especially for the correction of lunate subsidence.

Pain relief and correction of the alignment of the articular surface of the intermediate column of the radius is the surgical aim. Surgery provides a more biomechanically advantageous and stable surface for load transfer across the radiocarpal joint. Bony or bone substitute grafts inserted in a metaphyseal gap may further improve stability during osteotomy fixation. In this patient cohort, cancellous bone grafting was utilized in the first two cases, however following evidence available in adult patients, suggesting that bone grafting in corrective osteotomy does not enhance bone healing or structural support in the presence of a stable locking plate fixation, cancellous bone grafting was abandoned [27]. Results from the current study suggest that a locking plate fixation without bone grafting enables adequate stability also in pediatric patients.

Following osteotomy, small volar locking plate fixation enabled a relatively straightforward intra-operative correction of the radial epiphysis. Dissection is minimized by the smaller size of the plates, causing less trauma to the patient. The first plate fixation onto the epiphysis allows the utilization of the hardware itself in the maneuvers needed for distal radius mobilization. Further,

Table 1. Mean values of the clinical and radiological outcomes at mean follow-up of 3.8 years.

	Mean VAS pain scale			Mean range of motion					
	At rest	During activities	Mean DASH scale	Wrist extension	Wrist flexion	Supination	Pronation	Mean radial inclination	Mean lunate subsidence
Baseline	3	6.8	58	0–54°	0–81°	0–73°	0–71°	39.7°	4.85 mm
Follow-up	0	1.6	16	0–75°	0–85°	0–87°	0–81°	24.4°	0.75 mm

stable fixation allowed for immediate post-operative rehabilitation without the application of a plaster cast. PT and CIMT were both performed due to their proven effectiveness in distal movement recovery, shoulder movement improvement and control strategies compensation [20]. Traditional volar plates have previously been utilized by other authors, however we chose the smaller locking plates originally designed for metacarpal or segmental dorsal wrist fracture fixation based on the size and shape of the epiphysis in pediatric patients [16]. In the current cohort, no hardware removal was needed because of the smaller plate and no prominence of the plate over the line of the metaphysis [13,14,24]. In order to eliminate such complications in children, hardware removal is a common practice. However, the risk of complications associated with hardware removal in pediatric patient's upper extremity are still not fully understood in case of an asymptomatic implant [23]. Complications described in K-wires fixation [28] are minimized such as pin loosening, loss of correction, pin migration, infections, skin irritation and pain, immobilization in plaster cast and the possible growth effects of drilling across the physis [29–32].

This study is limited by a mid-term follow-up. Despite the homogeneity of the current retrospective study, in front to relevant heterogeneity of the literature, evidences in outcomes are comparative with those described in literature. The results following the personal technique in Madelung deformity do not show significant differences with the outcomes mainly reported in the Peymani et al. systematic review [24].

Conclusion

The use of volar fixation with a small locking plate and immediate post-operative rehabilitation for reverse dome osteotomy of the distal radius in pediatric patients affected by 'distal radius' Madelung's deformity is stable and effective. The technique was enable to add reverse wedge osteotomy if needed and achieved a stable and effective correction and stabilization of the osteotomy. The first locking plate fixation at the distal radius epiphysis facilitated the maneuvers needed for its mobilization. The high stability of the final fixation allowed early and safe rehabilitation program and major compliance of the children with no plaster cast utilization.

Statement of informed consent and human and animal rights

The retrospective archive studies did not need ethics approval. It was conducted in accordance with the Helsinki Declaration and in all cases the specific informed consent forms for the surgical treatment and plate fixation were signed. No studies regarding human or animal rights were conducted in the study or used for teaching or new intervention research.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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