Contemporary Advances in the Management of Madelung Deformity

From growth modulation to patient-specific three-dimensional correction

Running title: Advances in Madelung Deformity Management

Dr. Nishant

Assistant Professor in Orthopaedics, Netaji Subhash Medical College, Amhara, Bihta, India

Abstract: ***Madelung deformity is a three-dimensional growth disturbance of the distal radius characterized by volar-ulnar deficiency of the lunate facet, progressive radial bowing, carpal malalignment, and relative ulnar overgrowth. Management has shifted from procedure-based correction toward phenotype-, maturity-, and symptom-directed reconstruction. This narrative review summarizes contemporary advances in diagnosis, surveillance, surgical planning, and operative treatment, emphasizing developments reported during the past decade. Standardized radiographs remain the basis of assessment, while magnetic resonance imaging can identify the anomalous volar radiolunate or radiotriquetral tether and evaluate cartilage and triangular fibrocartilage complex pathology. Genetic evaluation for SHOX haploinsufficiency and associated dysplasias is increasingly relevant when deformity is bilateral or syndromic. In growing children with early disease, Vickers ligament release and physiolysis may reduce tethering and permit partial growth correction, although recurrence and progression remain possible. In established deformity, corrective radial osteotomy—dome, opening or closing wedge, or reverse wedge—remains the principal reconstructive procedure. Ulnar shortening, epiphysiodesis, or distal radioulnar joint salvage should be selected according to ulnar variance, maturity, articular congruity, and the dominant pain generator. Three-dimensional computed-tomography simulation, printed models, and patient-specific cutting or drilling guides allow multiplanar correction and may improve execution in severe or whole-bone deformity, but evidence is limited to small retrospective series and technical reports. The current literature supports durable pain relief after appropriately selected reconstruction but does not establish superiority of one osteotomy. Future multicenter prospective studies should use standardized radiographic measures, patient-reported outcomes, skeletal-maturity reporting, and long-term assessment of recurrence and arthritis.***

Keywords: Madelung deformity; distal radius; Vickers ligament; osteotomy; ulnar variance; three-dimensional planning; SHOX

Article Highlights

- Treatment is driven by symptoms, skeletal maturity, deformity location, ulnar variance, and distal radioulnar joint status—not radiographs alone.
- Early Vickers ligament release with physiolysis is a preventive strategy for carefully selected skeletally immature patients; it does not reliably reverse established three-dimensional deformity.
- Multiplanar distal radial osteotomy remains the reconstructive foundation for symptomatic established deformity, with ulnar procedures added selectively.
- Three-dimensional simulation, printed models, and patient-specific guides improve the surgeon's understanding of complex correction, but comparative evidence and cost-effectiveness data are not yet available.

1. Introduction

Madelung deformity is an uncommon disorder of distal radial growth in which asymmetric failure of the volar-ulnar physis produces a short, bowed radius; increased radial and palmar tilt; proximal and volar migration of the carpus; and a relatively long, dorsally prominent ulna. Symptoms usually emerge during the adolescent growth spurt and include ulnar-sided or central wrist pain, reduced forearm rotation, loss of wrist extension, fatigue with loading, and concern about appearance. The clinical phenotype ranges from a subtle radiographic abnormality to severe bilateral deformity associated with Léri-Weill dyschondrosteosis, Turner syndrome, or other skeletal dysplasias.

The central management problem is not simply how to normalize a radiograph. Madelung deformity combines physeal tethering, metaphyseal malorientation, carpal adaptation, ulnocarpal overload, and, in some patients, distal radioulnar joint (DRUJ) incongruity. Correction therefore must be matched to the patient's remaining growth, dominant symptoms, magnitude and distribution of deformity, and articular status. The literature remains dominated by small retrospective series. A 2019 systematic review found only level-IV evidence and substantial heterogeneity in indications and outcomes, preventing meaningful comparison of operations. Contemporary practice should consequently be framed as evidence-informed shared decision-making rather than a single prescriptive algorithm [1–5].

This review focuses on newer developments that have altered evaluation or treatment: earlier recognition and etiologic classification; magnetic resonance identification of the pathologic volar tether; growth-preserving release and physiolysis; refined multiplanar osteotomy; selective management of the ulna and DRUJ; and virtual surgical planning with patient-specific instrumentation.

2. Methods

A targeted narrative review of MEDLINE/PubMed was performed through August 2026 using combinations of the terms 'Madelung deformity,' 'Vickers ligament,' 'physiolysis,' 'guided growth,' 'distal radius osteotomy,' 'ulnar shortening,' 'three-dimensional planning,' and 'patient-specific guide.' Reference lists of major reviews and key case series were screened for additional studies. Priority was given to systematic reviews, longitudinal clinical series, imaging studies, and reports describing contemporary planning or reconstructive techniques. Because clinical and radiographic outcomes were heterogeneous and most studies were uncontrolled case series, no quantitative synthesis was attempted. Emerging techniques are explicitly separated from established reconstructive principles.

Pathoanatomy and Classification

True Madelung deformity reflects focal growth disturbance of the volar-ulnar distal radial physis. The resulting deficiency of the lunate facet increases ulnar and palmar tilt of the distal radial articular surface. The lunate subsides proximally, the carpus assumes a triangular configuration, and the radius bows volarly and ulnarly. Relative ulnar overgrowth and dorsal subluxation of the ulnar head can create painful impaction, extensor tendon irritation, and DRUJ symptoms.

The anomalous volar radiolunate/radiotriquetral structure commonly termed the Vickers ligament originates from the volar-ulnar radius and inserts on the lunate or triquetrum. It may act both as a physeal tether and as a restraint that draws the carpus proximally and volarly. MRI studies have demonstrated this structure in true Madelung deformity, supporting its diagnostic and therapeutic relevance [6]. Its presence, however, should not be treated as the sole cause of every Madelung-like wrist.

A crucial contemporary distinction is between true Madelung deformity and Madelung-type deformity secondary to trauma, infection, tumor, multiple hereditary exostoses, or generalized dysplasia. The latter may lack a Vickers ligament and may have different growth potential, whole-bone geometry, and recurrence risk. The classification should record etiology, laterality, skeletal maturity, focal versus whole-bone involvement, ulnar variance, DRUJ congruity, and the presence of cartilage degeneration.

3. Modern Diagnostic Work-up

Clinical assessment

History should identify the dominant pain location, loading intolerance, cosmetic concern, rate of progression, functional limitations, and prior trauma. Examination documents wrist flexion-extension, radial-ulnar deviation, pronation-supination, grip strength, DRUJ stability, ulnocarpal impaction signs, tendon irritation, and the reducibility of carpal and DRUJ malalignment. Comparison with the contralateral limb is useful but may be misleading in bilateral disease. Surgical indications are primarily clinical: persistent pain, meaningful functional limitation, progressive deformity in a growing patient, or unacceptable appearance after informed discussion. Radiographic severity without symptoms is not, by itself, an indication for reconstruction.

Radiography

Standardized posteroanterior and true lateral wrist radiographs, ideally with bilateral forearm views, remain the essential study. Reproducible measurements include ulnar tilt, lunate subsidence, lunate fossa angle, palmar carpal displacement, and ulnar variance. McCarroll and colleagues proposed diagnostic thresholds that help distinguish Madelung deformity from normal variation [7]. Serial films in the same position are more useful than a single measurement for a child approaching the growth spurt. Full-length forearm radiographs are advisable when bowing extends beyond the distal metaphysis or when a corrective osteotomy is being planned.

MRI, CT, and three-dimensional characterization

MRI is most useful when the diagnosis is uncertain, when early tether release is contemplated, or when symptoms suggest chondral, triangular fibrocartilage complex (TFCC), or tendon disease. It can demonstrate the anomalous volar tether and define cartilage that is not visible on radiographs. Computed tomography is not routinely required in a young patient with a typical deformity. It becomes valuable for severe multiplanar deformity, DRUJ incongruity, revision surgery, and virtual surgical planning. Bilateral low-dose CT protocols can provide a patient-specific contralateral template, although the opposite wrist may also be affected.

Etiologic and genetic evaluation

Bilateral deformity, short stature, mesomelia, family history, or dysmorphic features should prompt consideration of SHOX haploinsufficiency and related conditions. Identifying a systemic diagnosis improves counseling about progression, recurrence, limb-length issues, and family screening. Endocrine or genetic referral is appropriate when the phenotype extends beyond an isolated wrist. This etiologic step is an advance in management because it prevents technically successful local correction from being interpreted without the patient’s broader growth disorder.

Nonoperative Management and Surveillance

Observation is appropriate for asymptomatic or minimally symptomatic deformity. Activity modification, intermittent splinting, nonsteroidal anti-inflammatory medication when appropriate, and hand therapy can reduce symptom flares but do not alter the physeal disturbance. Therapy should maintain forearm rotation and optimize strength without forceful attempts to remodel a structural deformity. In a growing child, follow-up every 6 to 12 months during rapid growth—with clinical examination and standardized radiographs when progression is suspected—is reasonable. Counseling should explain that symptoms, not appearance alone, often determine treatment and that surgery may improve pain and alignment without restoring normal anatomy.

4. Growth-preserving and Preventive Surgery

Vickers ligament release and radial physiolysis

The principal preventive operation combines release or excision of the Vickers ligament with physiolysis of the abnormal volar-ulnar physeal bridge. Its objective is to remove the tether before deformity becomes fixed and allow the remaining physis to resume more symmetric growth. This strategy is most rational in a skeletally immature patient with documented progression, a demonstrable tether or physeal bar, and sufficient growth remaining. It is less predictable near maturity or when severe metaphyseal and carpal deformity has already developed.

Otte and colleagues reported early results supporting the safety of ligament release with radial physiolysis, with

Paper ID: SR26829094913 DOI: https://dx.doi.org/10.21275/SR26829094913

preservation of motion and improvement in some supination deficits [8]. The major limitations are small cohorts, variable maturity assessment, and short follow-up. Families should understand that physiolysis is not a corrective osteotomy: it may slow progression or permit partial remodeling, but it may not normalize existing tilt, lunate subsidence, or ulnar variance. Repeat surgery or later osteotomy may still be required.

The term 'guided growth' is sometimes used broadly in this setting, but current evidence most directly supports tether release/physiolysis rather than a standardized implant-based hemiepiphysiodesis equivalent to that used around the knee. Distal radial and ulnar epiphysiodesis can be useful adjuncts in selected near-mature patients, particularly to control anticipated ulnar overgrowth, but requires careful growth prediction and is not a substitute for correcting established multiplanar malalignment.

Corrective Reconstruction of the Radius

For established symptomatic deformity, the distal radius remains the reconstructive foundation. The goals are to reorient the articular surface, restore carpal support, improve forearm rotation and wrist extension, reduce ulnocarpal overload, and improve appearance. Exact normalization is neither always possible nor necessary. Overcorrection, excessive lengthening, and failure to respect adapted soft tissues may create stiffness, nonunion, nerve irritation, or DRUJ incongruity.

Dome osteotomy

A distal radial dome osteotomy permits correction in multiple planes while maintaining broad cancellous contact. Combined with volar tether release, it has produced durable improvement in pain, appearance, supination, and extension. Mid- to long-term follow-up demonstrates maintained radiographic correction and generally good function, although severe and whole-bone deformity is associated with more arthritis and worse outcome scores [9,10]. More recent pediatric series also report favorable aesthetic and functional outcomes, while documenting some early loss of radiographic correction during remodeling [11,12]. The dome remains versatile but technically demanding: the center and orientation of the arc determine whether correction addresses tilt, translation, and rotation without unwanted shortening.

Wedge and very distal osteotomies

Opening-wedge, closing-wedge, reverse-wedge, and very distal intra-articular-adjacent osteotomies are alternatives chosen according to the deformity apex and the required balance of angulation, translation, and length. A reverse-wedge technique can improve palmar carpal displacement and DRUJ alignment by transferring a metaphyseal wedge rather than simply closing or opening one side [13]. Very distal osteotomy offers independent control close to the articular deformity but has limited bone stock and demands secure fixation [14]. Opening correction can restore length but may require graft and increases soft-tissue tension; closing correction is inherently stable but shortens the radius and can worsen positive ulnar variance if the ulna is not addressed.

Fixation and minimally invasive refinements

Fixation has evolved from Kirschner wires and casting toward low-profile plates when bone size and correction permit. Plates allow earlier controlled motion and may improve stability in large or rotational corrections, but hardware prominence in a small distal fragment remains a concern. Percutaneous drilling and limited approaches can reduce soft-tissue disruption, yet direct visualization is useful when releasing the volar tether or protecting neurovascular structures. No fixation method has demonstrated superiority in comparative trials; selection depends on age, bone quality, osteotomy geometry, and surgeon experience.

Selective Management of the Ulna and DRUJ

A modern plan does not automatically add an ulnar procedure. Relative ulnar overgrowth may be the major pain generator, a secondary manifestation corrected indirectly by radial reorientation, or a persistent mechanical problem requiring separate treatment. The decision is guided by ulnar variance, ulnocarpal impaction, DRUJ congruity and stability, maturity, and the effect of simulated radial correction.

Ulnar shortening osteotomy is effective when symptoms are predominantly ulnar-sided and the deformity of the radius is modest or when positive ulnar variance persists after radial planning. Adult series report symptom improvement and union, and combined radial and ulnar osteotomy can restore more balanced anatomy in severe deformity [15,16]. Shortening alone does not correct lunate facet deficiency, palmar carpal translation, or substantial radial malorientation; it should therefore not be used as a radiographic shortcut when the radius is the principal deformity.

Ulnar epiphysiodesis may control progression in a child nearing maturity when predicted residual growth would otherwise recreate positive variance. DRUJ salvage- Darrach resection, Sauvé-Kapandji arthrodesis, or other procedures- is reserved for selected skeletally mature patients with painful, irreducible incongruity or arthritis. These operations sacrifice or alternative joint mechanics and should not be first-line treatment in adolescents. TFCC debridement or repair may be considered when arthroscopy identifies a discrete symptomatic lesion, but arthroscopy cannot correct the underlying osseous malalignment.

Three-dimensional Planning and Patient-specific Execution

The most visible recent advance is the application of three-dimensional (3D) technology. Thin-slice CT can be segmented to create a virtual model of the radius, ulna, carpus, and DRUJ. The deformity can then be compared with a mirrored contralateral template or a normative model. Surgeons can simulate osteotomy level and orientation, quantify rotation and translation, test fixation, and anticipate the effect on ulnar variance and joint congruity before entering the operating room.

Printed models improve spatial understanding and permit rehearsal or plate contouring. Patient-specific cutting, drilling, or reduction guides can translate the virtual plan to the bone. Reports using 3D models and simulation for severe Madelung deformity describe accurate multiplanar correction and clinical improvement [17,18]. The technology is particularly attractive for whole-bone deformity, revision surgery, combined radius-ulna correction, and anatomy in which conventional two-dimensional templating cannot separate angulation from rotation.

The enthusiasm must be calibrated to the evidence. Current publications are small series or case reports without controls. CT adds radiation, segmentation and engineering add time and cost, and a guide can reproduce an imperfect plan with great precision. Cartilage, ligament tension, and the adapted carpus are incompletely represented in a rigid bone model. Accordingly, 3D planning should be viewed as a decision and execution aid—not an independent indication for surgery or proof that maximal anatomic correction is desirable. Low-dose protocols, transparent reporting of planned-versus-achieved correction, and comparative studies are priorities.

A Practical Contemporary Algorithm

Recent retrospective outcome and decision-making studies reinforce that procedure selection should be phenotype-specific and that radiographic correction does not uniformly predict patient-reported benefit [19,20]. The following framework is therefore a decision aid rather than a hierarchy of operations.

Clinical phenotype	Preferred strategy	Key caveat
Minimal symptoms; any maturity	Education, observation, activity modification; therapy for motion/strength	Operate only for meaningful symptoms, progression, or informed cosmetic concern
Early progressive deformity; substantial growth remaining	MRI when tether/physeal bar status will alter treatment; consider Vickers release + physiolysis	Prevent progression; counsel that later osteotomy may still be needed
Established deformity; symptomatic; growing or near maturity	Multiplanar radial osteotomy ± tether release; assess predicted ulnar growth	Correct the principal radial deformity without chasing every radiographic abnormality
Predominant ulnar impaction with modest radial deformity	Ulnar shortening ± epiphysiodesis depending on growth	Confirm that radial malorientation is not the dominant pain generator
Severe radial deformity with positive variance or DRUJ incongruity	Planned radial correction; add ulnar shortening/osteotomy only if residual mechanics require it	Consider 3D planning for whole-bone, rotational, or revision cases
Mature wrist with painful irreducible DRUJ arthritis	Joint-preserving correction when feasible; selected salvage procedure	Reserve resection/arthrodesis salvage for nonreconstructable painful disease

Perioperative Planning and Outcome Assessment

Preoperative documentation should include pain location, range of motion, grip strength, a validated upper-extremity patient-reported outcome measure, cosmetic priorities, and standardized radiographic parameters. The Pediatric Outcomes Data Collection Instrument, QuickDASH/DASH, Patient-Reported Outcomes Measurement Information System instruments, and patient-specific functional goals are all reasonable, but consistency is more important than instrument proliferation. For bilateral surgery, staged correction usually simplifies rehabilitation and allows the first side to inform the second.

Postoperative rehabilitation is dictated by fixation and concomitant soft-tissue procedures. Early finger and elbow motion is encouraged; forearm and wrist motion begins when osteotomy stability permits. Follow-up must extend beyond union to document recurrence during remaining growth, DRUJ symptoms, hardware irritation, tendon problems, and late degeneration. Radiographic improvement should be reported alongside- not in place of- pain, function, satisfaction, and reoperation.

Complications and Failure Modes

- Under-correction or recurrence because the operation was performed before a growth spurt without addressing the tether or ulnar growth.
- Overcorrection, unintended translation or rotation, and DRUJ incongruity after a poorly centered osteotomy.
- Delayed union, nonunion, loss of fixation, or symptomatic hardware, particularly with large opening corrections or small distal fragments.
- Median or ulnar nerve irritation, tendon irritation, stiffness, and complex regional pain syndrome.
- Persistent pain because the dominant generator- ulnocarpal impaction, TFCC pathology, cartilage degeneration, or DRUJ disease- was not identified.
- Technically accurate correction with limited clinical benefit because adapted carpal anatomy and patient priorities were not incorporated into the plan.

Evidence Gaps and Research Priorities

The rarity and phenotypic heterogeneity of Madelung deformity make single-center comparative trials difficult, but they do not justify continued inconsistent reporting. A prospective multicenter registry should capture etiology, SHOX status when tested, skeletal age, growth remaining, whole-bone involvement, preoperative imaging, operative details, planned-versus-achieved correction, complications, and reoperations. Core outcomes should include pain, forearm rotation, wrist extension, grip strength, a validated patient-reported score, appearance/satisfaction, radiographic measures, and follow-up through maturity. Comparative questions of highest value are: physiolysis versus observation in early disease; radial osteotomy alone versus combined ulnar correction for defined phenotypes; conventional versus 3D-assisted planning; and long-term joint preservation after correction. Health-economic and radiation analyses should accompany technology studies.

5. Conclusion

Contemporary management of Madelung deformity is increasingly individualized. Earlier recognition, etiologic evaluation, MRI demonstration of the volar tether, and growth-preserving release have expanded options before deformity is fixed. For established symptomatic deformity, a carefully planned multiplanar radial osteotomy remains the principal reconstructive operation; ulnar and DRUJ procedures should be added according to residual mechanics rather than habit. Three-dimensional simulation and patient-specific guides are valuable for complex anatomy, but their clinical superiority remains unproven. The best current practice combines precise phenotyping, restrained correction, explicit counseling, and standardized long-term outcome assessment.

Declarations

Conflict of interest: [The authors declare no conflicts of interest / insert disclosures].

Funding: [No external funding / insert funding source].

Ethical approval: Not applicable to this narrative review.

Informed consent: Not applicable.

Author contributions: [Insert CRediT roles].

Acknowledgments: [Insert if applicable].

References

[1] Peymani A, Johnson AR, Dowlatshahi AS, et al. Surgical management of Madelung deformity: a systematic review. Hand (N Y). 2019;14(6):725-734. doi:10.1177/1558944718793179.
[2] Dubey A, Fajardo M, Green S, Lee SK. Madelung's deformity: a review. J Hand Surg Eur Vol. 2010;35(3):174-181. doi:10.1177/1753193409346070.
[3] Kozin SH, Zlotolow DA. Madelung deformity. J Hand Surg Am. 2015;40(10):2090-2098.
[4] Ali S, Kaplan S, Kaufman T, et al. Madelung deformity and Madelung-type deformities: a review of the clinical and radiological characteristics. Pediatr Radiol. 2015;45(12):1856-1863. doi:10.1007/s00247-015-3390-0.
[5] Farr S, et al. The pathogenesis and management of Madelung deformity. J Hand Surg Eur Vol. 2023. PMID:37572317.
[6] Hanson TJ, Murthy NS, Shin AY, Kakar S, Collins MS. MRI appearance of the anomalous volar radiotriquetral ligament in true Madelung deformity. Skeletal Radiol. 2019;48(6):915-918.
[7] McCarroll HR Jr, James MA, Newmeyer WL, Molitor F, Manske PR. Madelung's deformity: diagnostic thresholds of radiographic measurements. J Hand Surg Am. 2010;35(5):807-812.
[8] Otte JE, Popp JE, Samora JB, et al. Treatment of Madelung deformity with Vickers ligament release and radial physiolysis: a case series. J Hand Surg Am. 2019. PMID:29934079.
[9] Harley BJ, Brown C, Cummings K, Carter PR, Ezaki M. Volar ligament release and distal radius dome osteotomy for correction of Madelung's deformity. J Hand Surg Am. 2006;31(9):1499-1506. doi:10.1016/j.jhsa.2006.07.012.
[10] Steinman S, Oishi S, Mills J, Bush P, Wheeler L, Ezaki M. Volar ligament release and distal radial dome osteotomy for the correction of Madelung deformity: long-term follow-up. J Bone Joint Surg Am. 2013;95(13):1198-1204.
[11] Carvalho M, Sá Cardoso P, Alves C, et al. Madelung deformity: esthetic and functional outcomes from surgical treatment with distal radial dome osteotomy and Vickers ligament section. Rev Bras Ortop. 2022;57(1):113-119. doi:10.1055/s-0041-1731362.
[12] Rus R, et al. Early distal radius remodeling after radius dome osteotomy in Madelung deformity. J Hand Surg Am. 2024. PMID:38808178.
[13] Mallard F, Jeudy J, Rabarin F, et al. Reverse wedge osteotomy of the distal radius in Madelung's deformity. Orthop Traumatol Surg Res. 2013. PMID:23622863.
[14] McCarroll HR Jr. Very distal radial osteotomy for Madelung's deformity. Tech Hand Up Extrem Surg. 2010. PMID:20526161.
[15] Bruno RJ, Blank JE, Ruby LK, Cassidy C, Cohen G, Bergfield TG. Treatment of Madelung's deformity in adults by ulna reduction osteotomy. J Hand Surg Am. 2003;28(3):421-426. PMID:12772098.
[16] Laffosse JM, Abid A, Accadbled F, et al. Surgical correction of Madelung's deformity by combined closing wedge osteotomy of the radius and ulnar shortening osteotomy. Int Orthop. 2009;33(6):1601-1607. doi:10.1007/s00264-008-0711-z.
[17] Catena N, et al. Use of a 3D model for correction of a Madelung deformity. J Hand Surg Asian Pac Vol. 2022. PMID:36099456.
[18] Kodama A, et al. Dual corrective osteotomy of the radius and ulna for Madelung deformity using three-dimensional simulation. Case report. 2023. PMID:36606355.
[19] Reck A, et al. Results of primary radial corrective osteotomy in Madelung's deformity. J Hand Surg Eur Vol. 2023. PMID:36564532.
[20] Martínez-Álvarez S, et al. Treatment decision-making in Madelung deformity. 2026. PMID:41133434.