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ORIGINAL RESEARCH

MR Imaging Provides Practical Information for Preoperative Assessment of Radial Polydactyly with Bifurcation at the Metacarpophalangeal Joint Level

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Purpose: We aimed to evaluate the use of magnetic resonance imaging (MRI) to visualize unossified bone sites that are often not visible with radiography in pediatric radial polydactyly patients with bifurcation at the metacarpophalangeal (MP) joint level. The MRI validation could help in planning for surgical procedures.

Patients and Methods: A total of 141 thumbs in 139 pediatric patients with bifurcation at the MP joint on radiography were included in this study. All the patients had undergone MRI with proton density-weighted fat-suppressed fast spin-echo (FS PDWI) sequence and fast fat-suppressed 3D spoiled gradient-recalled echo (FS 3D SPGR) sequence. The MR images of the cartilaginous structure and joint characteristics at the MP joint were evaluated and categorized by two experienced radiologists.

Results: Our analysis demonstrated that MR imaging, especially the FS 3D SPGR sequence, yields better visibility of the cartilaginous structure and shows clearer joint characteristics that could not be detected by radiography. The abnormalities included a cartilaginous connection on the base of duplicated proximal phalanx, cartilaginous joint connection and the shape of articular cartilage on the head of metacarpal and soft tissue band. Radiologically encountered duplications at the MP joint level were successfully classified into six types based on the MRI-detected structural changes. The distribution of the six types was 17.7% (25/141) in type 1, 53.9% (76/141) in type 2, 2.8% (4/141) in type 3, 9.9% (14/141) in type 4, and 13.5% (19/141) in type 5.

Conclusion: This data showed that MR imaging provides practical information on the anatomic characteristics in radial polydactyly with bifurcation at the MP joint level that could aid surgical decision-making processes. Thus, the FS 3D SPGR sequence could be used as a MR imaging technique in radial polydactyly.

Keywords: polydactyly, congenital hand deformity, magnetic resonance imaging, classification, anatomy

Introduction

Radial polydactyly, also referred to as thumb duplication, is a common congenital malformation of the hand.[1,2] Wassel's classification system is a universally used classification system for Radial Polydactyly and is based on the bifurcation level of duplication in radiographs.[3] Wassel type IV corresponds to bifurcation at the metacarpophalangeal (MP) joint level while Wassel Type VII designates a triphalangeal.

Bifurcation at the MP joint level encompasses the Wassel type IV and parts of Wassel Type VII cases.[3,4] Data has shown that bifurcation at the MP joint level radial polydactyly is the most common type.[5,6] Surgical techniques and outcomes of bifurcation at the MP joint level radial polydactyly are diverse in the clinic and reflect diversity of articular abnormalities.[7,8] Presently, preoperative evaluation of radial polydactyly mainly depends on radiography. However, cartilaginous epiphyses and cartilage structures are not clearly displayed in radiographs at the time when operations are performed, thus leading to discrepancies with operative findings.[5,9]

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MR is an excellent imaging technique and widely used in the evaluation of the articular and physeal cartilage.[10,11] MR provides a new platform for more accurate assessment of the unossified bone abnormalities in pediatric patients with radial polydactyly. Here, we aimed to evaluate the use of MR imaging to visualize morphologic characteristics in pediatric patients with radial polydactyly bifurcation at MP joint level. This data would lay the basis for proper surgical planning and evaluation of patient prognosis.

Materials and Methods

A total of 274 thumbs diagnosed with radial polydactyly were referred to the department of radiology for X-ray and MR examination at the Second Hospital of Wenzhou Medical University from October 2016 to September 2019. The patients' x-ray films of the thumb were retrospectively reviewed and then patients with bifurcation at the MP joint level (Wassel Type IV and parts of Wassel Type VII cases) were enrolled in this study. The "floating" thumb in which the radial digit was attached to the side of ulnar thumb with thin, soft tissue pedicle was excluded from the study. Thumbs with poor quality of MRI images were also excluded. After the analyses, 141 thumbs (accounting for 51.5% of all the thumbs) in 139 pediatric patients were enrolled in the study. This study was approved by the institutional ethics committee, and informed consent was waivered.

MR Imaging Technique

The pediatric patients underwent retention enema with chloral hydrate before MR examination. The MR examination was performed on a 3.0-T scanner (Signa HDxt EXCITE, General Electric, Milwaukee) using a high-resolution 8-channel wrist coil. The patients were placed in supine position with the elbow flexion overhead, and the pronated hand positioned at the center of the wrist coil at the scanner's isocenter. The imaging protocol included proton density-weighted fat-suppressed fast spin-echo (FS PDWI) sequence in the transaxial/coronal/sagittal plane and fast fat-suppressed 3D spoiled gradient-recalled echo (FS 3D SPGR) sequence. Protocol parameters for the FS PDWI sequence were: TR range/TE range, 2500–3500/32–35; field of view, 14×14 cm; slice thickness, transaxial/coronal/sagittal plane 3mm/1.5mm/1.5mm with a slice gap of 0 mm. On the other hand, parameters for the 3D FS SPGR sequence were: TR/TE: 18/6 ms, flip angle: 15, field of view, 12×12 cm; slice thickness, 0.8mm; image matrix, 288×192. Multiplanar reconstruction of 3D FS SPGR sequence data was processed on the workstation.

MRI Analysis

Two experienced musculoskeletal radiologists analyzed MR images, of all patients retrospectively. Classification criteria were determined with regard to abnormalities of the morphologic characteristics at the MP joint. Next, the two observers were asked to classify each individual into different types independently base on the MRI findings. Finally, consensus was reached in case of disagreement. Inter-observer agreement was evaluated according to kappa coefficient.

Results

This study included a total of 141 thumbs in 139 pediatric patients (80 boys and 59 girls). The mean age at the time of performance of preoperative MRI was 13.3 months (range, 3–38 months). The MR imaging clearly demonstrated the cartilaginous structures at the MP joint and showed the exact joint characteristics, including epiphyses of the duplicated proximal phalanges, cartilaginous joint fusion, cartilaginous joint surface shape of the metacarpal and soft tissue band. Data from the FS 3D SPGR image allowed more accurate cartilage evaluation compared to that from FS PDWI image (Figure 1). Based on the MR findings of the cartilaginous structure and joint characteristics at the MP joints, radial polydactyly bifurcation at the MP joints was subdivided into six types (Figure 2). Inter-observer agreement was excellent (kappa value = 0.884, p = 0.001).

Type 1: There was convergency of the base of the two proximal phalanges, with a shared epiphysis. The shared epiphysis form of the MP joint with the broad distal metacarpal articular cartilage had a common joint cavity. This type included twenty-five thumbs (25/141, 17.7%). In twenty thumbs, there was equal size development in both duplicated proximal phalanges (or mild smaller radial digit), and diverged distally, with converged distal phalanges like a lobster's

Figure 1 Different imaging techniques of a case with radial polydactyly at the MP joint level. (**A**) Plain radiograph (PA view); (**B** and **C**) Coronal MR images of FS PDW imaging (**B**) and FS 3D SPGR imaging (**C**). Note better delineation of chondral morphology and joint characteristics in the duplicated digits when image obtained at FS 3D SPGR imaging.

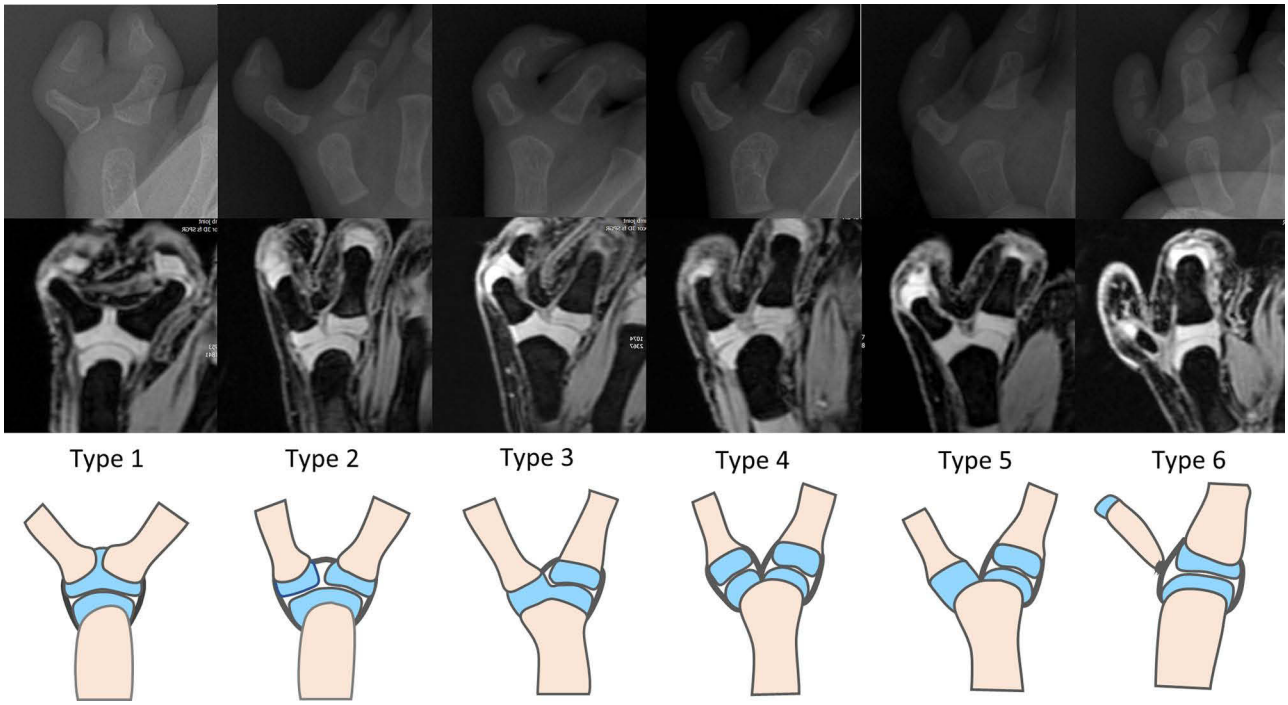

Figure 2 Subclassification of bifurcation forms at the MP joint in radial polydactyly. The upper row shows the plain radiographs, the middle row shows MR images and the lower row shows the diagram in Type 1–6.

claws (Figure 3A). The remaining five thumbs had raised proximal phalanx of the radial from the radial base of the ulnar digit (Figure 3B and C). The radial digit was very small and accompanied morphological abnormality of phalanges.

Type 2: There were two separate phalanges, including the epiphyses, supported by a single wide metacarpal head, and formed a common joint. This type included seventy-six thumbs (76/141, 53.9%). The interphalangeal (IP) joints revealed a deviated ulnar, divergent, or convergent. Forty-seven thumbs had smooth shape of the distal metacarpal cartilage (Figure 4A). On the other hand, twenty-nine thumbs had irregular shape of the distal metacarpal, with a ridge in the middle of the joint surface, or concave in one side and convex in the other side (Figure 4B and C).

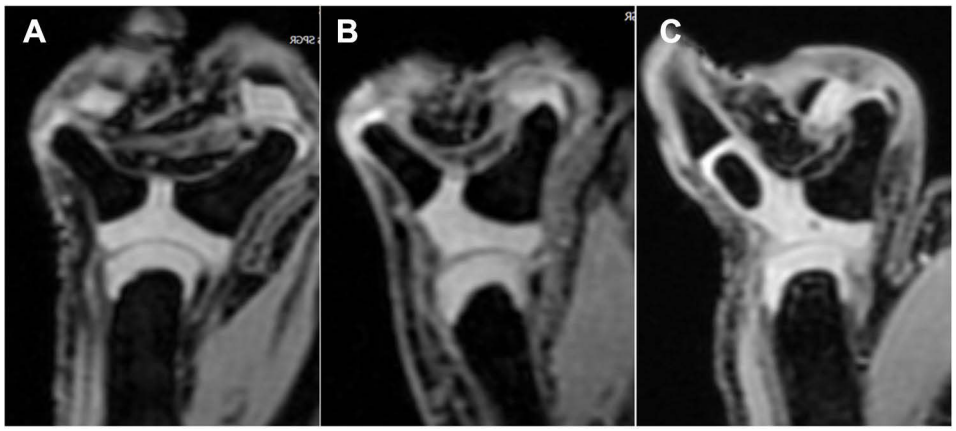

Figure 3 Type I radial polydactyly with bifurcation at MP joint level.

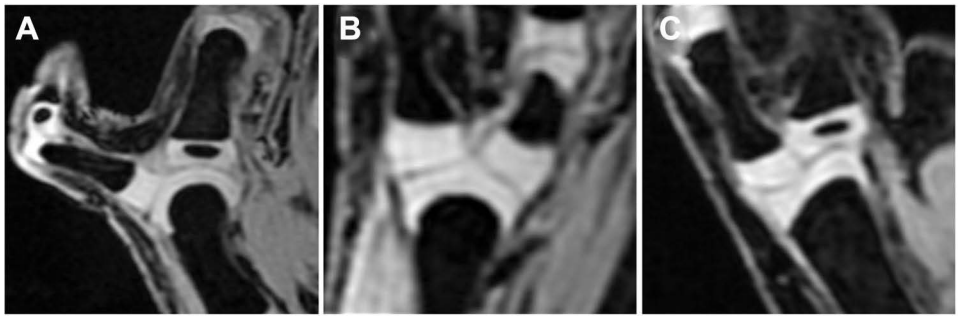

Figure 4 MR images show different cartilaginous joint surface shape of the metacarpal in Type 2. (**A**) The broad distal metacarpal articular cartilage with smooth surface. (**B**) The distal metacarpal head had two articular surfaces separated by elevated cartilaginous ridge. (**C**) The surface of the distal metacarpal articular demonstrate concave in one side and convex in the other side.

Type 3: The thumbs were like those in type 2, with two separate phalanges. However, there was a cartilaginous connection between the proximal phalanx and metacarpal of the radial digit. The joint space was only formed at the ulnar segment, and there was absence of any radial joint space. This group contained four thumbs (4/141, 2.8%).

Type 4: The distal metacarpal bifurcated with two cartilaginous head and formed two independent MP joints with duplicated digits. There was a total of fourteen thumbs (14/141, 9.9%) in this group. The distal phalanges of the duplicated digits were mostly both ulnar deviation. The MR image showed abnormal delta configuration of the metacarpal with the epiphysis extending distally on the radial aspect in one case of this group (Figure 5A).

Type 5: They were similar to type 4 but the radial digit MP joint was replaced by cartilaginous connection. This group included three thumbs (3/141, 2.1%).

Type 6: It had a dysplastic radial digit attachment to the MP joint capsule of well-developed ulnar digit with a fibrous structure. There were nineteen thumbs (19/141, 13.5%) in this group. In eighteen cases, the radial digit was apparently hypoplastic, while the remaining one thumb showed intra-axial soft-tissue syndactyly of the duplicated digits. Besides, MR images of two cases showed abnormal delta bone in the interphalangeal joint which caused joint deviation (Figure 5B).

Discussion

Bifurcation at the metacarpophalangeal joint level is relatively common, and accounts for more than half of all the radial polydactyly phenotypes in this study. An ideal orthopedic surgical procedure for any radial polydactyly deformity must consider both postoperative appearance and functional reconstruction. Pathologic anatomy of the MP joint level radial polydactyly determines the selection of various surgical techniques.

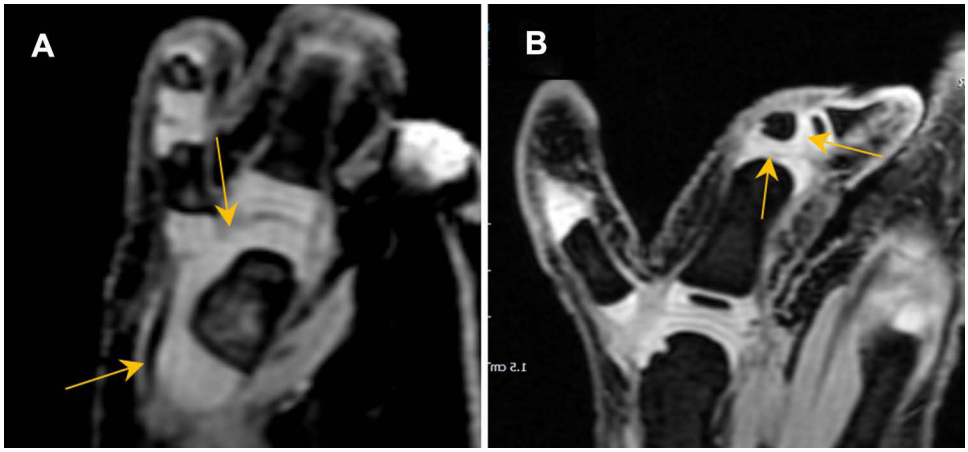

Figure 5 MR images show abnormal delta bone in two cases. (**A**) Abnormal delta configuration of the metacarpal (arrow). (**B**) Abnormal delta bone in the interphalangeal joint which caused joint deviation (arrow).

Several studies on the pathologic anatomy of Wassel type IV radial polydactyly have often aimed at guiding and evaluating surgical management and treatment. In 1992, Islam et al classified Wassel type IV radial polydactyly into five groups depending on the structural findings at surgery.[5] In1997, Horii et al subclassified Wassel Type IV duplications into four types based on the pathologic connection (cartilage, joint, or fibrous tissue of the radial digit to the ulnar components at surgery).[7] These studies focused on the anatomical joint relationship at the level of duplication and the key point was cartilaginous structure. Subsequent studies modified the Wassel's classification by considering cartilaginous structure and triphalangeal component on the hypothesis that certain characteristics might influence surgical treatment.[6,8,12]

Physical exam and radiologic assessments are not precise in the assessment of articular abnormalities in the MP joint in skeletally immature patients. Thus, other previous studies carried out arthrography in patients with duplication at the MP joints demonstrated by radiography.[13–15] A total of 38 thumbs underwent arthrography before or at the start of surgery after general anesthesia. Although arthrography could provide detailed information of the cartilaginous structure, it is invasive and should be performed under anesthesia. Therefore, it failed to provide sufficient time for proper planning of surgical procedures. In 2014, Johnson et al approximated the most proximal bones involved in the duplication on PA radiographs of the thumb to distinguish between a separate and shared epiphysis.[16] But that measurement method was complicated and time consuming. In addition, it could not provide information on other cartilaginous structures apart from demonstration of the existence of a shared epiphysis.

To date, data on the use of MRI for preoperative assessment in radial polydactyly remain scant. Operation of radial polydactyly is usually before 3 years old. The children do not usually cooperate with thumb placement, coupled with the existence of deformities with small thumb, thus making it difficult to obtain an ideal plane. 3D SPGR sequence involves thin-layer high-resolution scanning, and any plane images could be obtained through post-processing. 3D SPGR provides T1-weighted images with better inter-cartilage contrast (hyperintense), and intra-articular fluid (hypointense) is considered the standard in quantitative morphological evaluation of cartilage.[11,17] In this study, we demonstrated that 3D SPGR imaging was useful and could identify the cartilaginous structure in duplicated digits at the MP joint. MRI delineates a cartilaginous connection on the base of duplicated proximal phalanx, cartilaginous joint connection, the shape of articular cartilage on the head of metacarpal and soft tissue band. Besides, other abnormal patterns of bone involvement such as longitudinally bracketed epiphysis (delta bone) can be clearly demonstrated by MRI. Lack of early identification of these deformities could warranty an extra operation[18].

Based on the previous reports,[5,7,14,15] the anomalistic form of the MP joints was subdivided into five types; a cartilaginous connection at the base of the two proximal phalanges, phalanges separation by a common joint, disappearance of the MP joint of the radial digit and replacement by cartilaginous connection, distal metacarpal bifurcated with two cartilaginous head to form two separate joints and attachment of radial digit with soft tissues. Their findings at surgery or arthrography are in sync with our MRI findings. In addition, we report a new appearance of

the distal metacarpal bifurcated with two cartilaginous head accompanied by cartilaginous joint fusion in radial digit. The previous reports might have been limited by sample size or lack of distinction between type 3 and type 5.

In types 1 and 4, MRI showed cartilaginous connection on the base of duplicated proximal phalanx and two cartilaginous head of the distal metacarpal. This demonstrated the exact bifurcation level which is of proximal phalanx and metacarpal and reconstruction techniques should be planned based on the type. In type 2, MRI demonstrated the articular surface shape of the metacarpal articular surface, which is usually broad and might be smooth or irregular (a ridge or in the middle, or concave-convex appearance). To obtain favorable joint congruency and smooth movement, it is imperative to shave the cartilaginous joint surface based on the MRI findings. Moreover, MRI could show the thickness of the articular surface, a feature that cannot be identified on arthrography. In type 3 and type 5, there is cartilaginous connection between the metacarpal and radial digit. In type 6, also known as dysplasia type,[8,19] the radial digit is attached to the joint capsule by fibrous band. If there are tight connections with joint capsule or attachment of abductor pollicis brevis muscle to the base of the vestigial thumb, there could be need for soft tissue reconstruction. At times, prominence of the metacarpal head might require reduction.[19] In addition, a surgeon could use MR examination at any time for preoperative assessment. Our study showed a high success rate of MR examination in pediatric patients under sedation. Overall, MRI proved to be an effective and feasible imaging method.

However, our study did not compare the MR findings with intraoperative findings and did not report surgical procedures related to different groups. Besides, we did not analyze the association between the soft tissue abnormalities in bifurcation at MP joint level radial polydactyly and the selection of surgical treatment. Thus, there is need for further studies to determine if MRI could identify soft tissue abnormalities such as ligamentous deficiencies or aberrant tendon insertions.

In conclusion, this study successfully characterized cartilaginous structure abnormalities in radial polydactyly with bifurcation at the MP joint level using MR imaging. 3D SPGR imaging is recommended in the evaluation of radial polydactyly. The MRI findings would allow surgeons to obtain detailed information that is not usually provided by radiography; that will assist in making precise surgical plans and help prevent secondary deformities.

Data Sharing Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics Approval

This study was conducted in accordance with the declaration of Helsinki. The studies involving human participants were reviewed and approved by the Ethics Committee of the Second Hospital of Wenzhou Medical University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

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Author Contributions

All authors contributed to data analysis, drafting or revising the article, have agreed on the journal to which the article will be submitted, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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