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Original article

PROGNOSTIC VALUE OF POST-REDUCTION COMPUTED TOMOGRAPHY AFTER CLOSED REDUCTION FOR DEVELOPMENTAL DYSPLASIA OF THE HIP

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Abstract

Introduction: Assessment of hip position after closed reduction for developmental dysplasia of the hip (DDH) is challenging using plain radiography because of cartilaginous anatomy and cast-related artifacts. Post-reduction computed tomography (CT) performed in a narrow window may improve detection of inadequate reduction and guide early management. Aim: To evaluate the prognostic and decision-making value of post-reduction narrow window CT compared to plain radiography after closed reduction for DDH.

Material and methods: A prospective clinical study included 50 children treated with closed reduction for DDH. Twenty-five patients underwent native radiography and post-reduction CT in a narrow window protocol. CT parameters assessing quality of reduction were analyzed and compared to early need for re-intervention, persistent dysplasia and radiographic outcome at follow-up.

Results: CT identified persistent or inadequate reduction in 5 of 39 dislocated hips (12.8%), all of which required immediate change in treatment. In the native radiographs, persistent dislocation was reliably identified in only one case (2 hips), while three cases were initially missed because of poor visualization. None of the CT-derived parameters demonstrated a statistically significant correlation with later residual dysplasia defined by the center–edge angle. However, with another design of the study and a bigger sample, some parameters might show a statistically significant correlation.

Conclusion: Post-reduction narrow window CT provides superior detection of inadequate reduction compared to plain radiography and directly influences early clinical decision-making. However, CT parameters at the moment showed no certain prognostic value for predicting residual acetabular dysplasia.

Keywords: developmental dysplasia of the hip, closed reduction, computed tomography, prognosis, residual dysplasia

Introduction

Developmental dysplasia of the hip (DDH) after the emerging of the Graf technique for ultrasound screening in 1980's has become an easily manageable public health issue. It is a common musculoskeletal condition present at birth where the hip joint is dislocated or prone to dislocation, affecting approximately 1 to 7% of neonates in some populations. It represents a largely preventable cause of long-term childhood and adult disability. After developing triple prevention of DDH program in former Yugoslavia (clinical, ultrasound screening and wide diapering), the number of surgeries decreased triple from 1971 to 1985 (from 147 in 1971 to 43 in 1985)[1]. Besides the effective screening and prevention program, there are still around 20 patients yearly that require treatment[2,3]. The treatment algorithm for DDH is age-dependent and focused on achieving and maintaining concentric reduction of the femoral head in the acetabulum to promote normal hip development[3- 6]. Closed reduction is a procedure, typically designated for children aged 6-18 months, where the hip joint is, under anesthesia, manipulated back into place without an open incision. It might involve preoperative traction, an arthrogram (contrast dye injection) to confirm concentric placement of the head of the femur in the acetabulum, an adductor tenotomy, and placing the child in a spica cast for 6-12 weeks[7]. However, closed reduction, being relatively conservative in nature is preferred and attempted also in older children, encompassing a wider age range of treatment[3,8,9]. Achieving and maintaining concentric reduction of the femoral head in the acetabulum is the goal of the treatment. To confirm this, in addition to the clinical Ortolani signs and good intraoperative reduction and retention, imaging confirmation is necessary[10]. Traditionally, a native radiograph is the method of evaluation of closed reduction. But, the existence of artifacts (obtained by the abundant plaster cast material) makes the interpretation of the results almost impossible, especially for an unexperienced surgeon (Figure 1)[11].

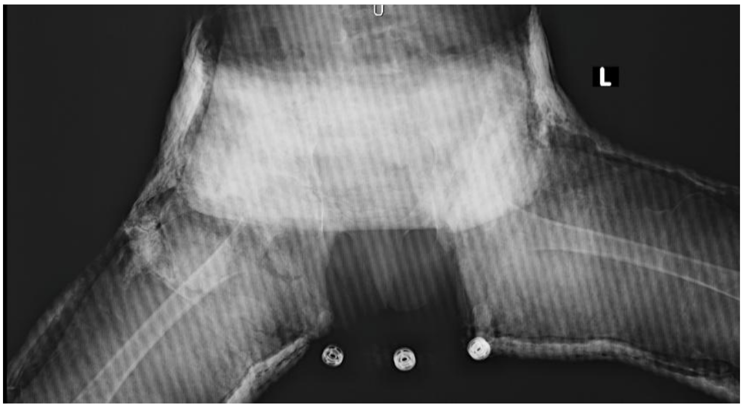

Fig. 1. Native radiograph after closed reduction in a patient with bilateral DDH

Having that in mind, computed tomography (CT) has emerged as a tool for precise evaluation of the success of the closed reduction (Figure 2)[12, 13].

Fig. 2. Single slice of a CT scan after closed reduction in a patient with left DDH

The complications related to failed closed reduction are residual dysplasia of the acetabulum, subluxation of the hip and avascular necrosis. All of them are connected to prolonged morbidity and need for additional surgeries. Several authors have proposed certain measurements in the postoperative CT that could imply an existence or appearance of immediate and delayed complications[12,14-15].

Materials and methods

Study Design

This clinical study was conducted at the Clinic for Orthopedic Diseases in the period from 2016 to 2025, involving patients selected according to defined inclusion and exclusion criteria. All participants underwent a surgical intervention - closed reduction of the hip, at the Clinic for Orthopedic Diseases. The follow-up examination - native radiography and computed tomography - were performed on the same or the next day at the Institute of Radiology. The parents/guardians of the patients voluntarily consented to their children's participation in the study by signing a prior informed consent form. The study protocol adhered to the principles of the Declaration of Helsinki and local ethical standards and was approved by the Ethics Committee of the Faculty of Medicine in Skopje.

Patient selection

This cross-sectional segment of the study included a total of 25 patients in whom closed reduction was performed. The inclusion criteria were as follows: children from the neonatal period up to four years of age; clinically, sonographically, and/or radiographically confirmed DDH (developmental dysplasia of the hip), i.e., hip dislocation or subluxation; according to sonographic inclusion criteria, patients with type 3 and type 4 hips according to Graf classification were included in the study; patients in whom closed reduction was performed as the primary treatment modality; patients whose parents agreed to the procedure and completed the informed consent in accordance with ethical standards for obtaining information and its use for scientific purposes.

The exclusion criteria were as follows: patients with associated conditions such as neuromuscular disorders; teratologic dislocation (due to genetic disorders, arthrogryposis); patients who had previously undergone surgical intervention of the hip; patients with incomplete documentation.

Previous treatment with an orthosis (Pavlik, Hilgenreiner, Tübingen) was not an exclusion criterion.

In all patents, radiograph and CT scan were performed after the intervention using a narrow window according to a specific protocol aligned with the ALARA principle (as low as reasonably achievable) to evaluate the success of the reduction, with instructions for lead shielding of the genital region of the subject[16]. The selection of patients in whom this method was performed was operator-dependent.

Material and methods

Closed reduction is a procedure in which the femoral head is repositioned into the acetabulum using a specific maneuver, without the use of a surgical incision. The intervention is performed in the operating room as follows:

- the patient is under general anesthesia and positioned on a special table on which the reduction is carried out;
- the reduction is performed with careful abduction, elevation, and flexion of the femur;
- after achieving the Ortolani reduction phenomenon, the stability of the reduction is assessed, and the angles of hip adduction and extension at which redislocation would occur are evaluated;

- the range within which the reduction remains stable is referred to as the "Ramsey safe zone"[17].

Excessive abduction and flexion are avoided because of the possible occurrence of avascular necrosis of the femoral head (AVN). In addition to clinical assessment, the position is also evaluated intraoperatively using plain radiography. In some patients, tenotomy of the hip adductors is required; this is performed percutaneously, using a tenotome or a No. 15 scalpel. If the position is satisfactory in terms of retention (maintenance of the position), application of a bulky plaster cast immobilization is continued. This extends from the umbilicus to the ankles of both legs, regardless of whether the dislocation is unilateral or bilateral. After the patient awakens from anesthesia and the plaster material has stabilized, a post-reduction evaluation of the hip is performed using computed tomography in the first group, or plain radiography in the control group. In some patients, preoperative traction of the extremities is also applied.

Computed tomography with a narrow window is performed in patients with plaster cast immobilization. Immobilization and the short duration of the examination eliminate the need for anesthesia in these patients.

In cooperation with radiologic technologists, the imaging itself is performed according to the following protocol:

- the patient is placed in the supine position, in a craniocaudal direction, with the head up;
- since the legs are in abduction, they must be positioned at the level of the widest part of the gantry;
- lead shielding is placed over the genital region;
- in order to minimize radiation exposure, only the region at the level of the triradiate cartilage is marked on the tomogram;
- the scan width extends bilaterally to the level of the subtrochanteric line.

Here as well, unlike the standard hip scanning protocol, slices with a thickness of 10 mm (1 cm) are obtained only in the axial (transverse) plane. In this way, the lowest possible number of CT slices are acquired and used for analysis.

Variables

The variables are divided in two categories: the first one correlating to the reduction success-immediate term complications requiring prompt change of treatment, and the other one correlating to predicting the long-term complications requiring delayed operative interventions.

The first category consists of these parameters (Figure 3):

- Femoral head-acetabulum contact
- Morphology of the acetabula
- Widened joint space
- Modified Shenton-Menard's line
- Posterior line of the femoral neck that does not enter the acetabulum.

Positive findings were no contact between the head and the acetabulum, blunting or notching of the acetabulum in the anterior or posterior rim, widening of the joint space as a sign of insufficient reduction. Disrupted Shenton-Menard line indices persistent hip dislocation, as well as deviation of the posterior neck line other than in the acetabulum.

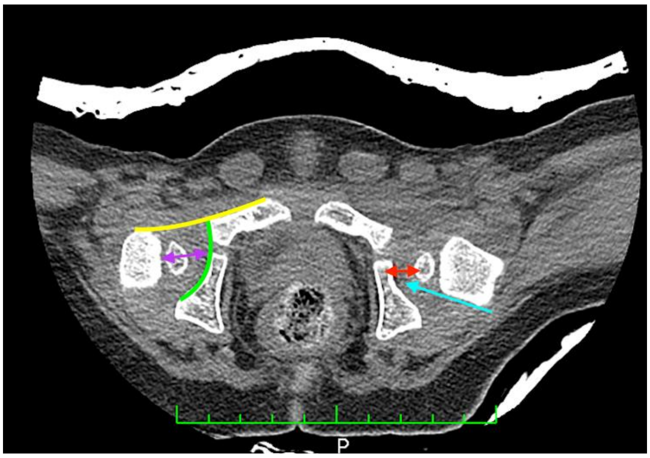

Fig. 3. Reduction success parameters: femoral head-acetabulum contact (red double head arrow), morphology of the acetabula (green line), widened joint space (purple double headed arrow), disrupted modified Shenton's line (yellow line), posterior line of the femoral neck that does not enter the acetabulum (turquoise arrow). This is a CT slice of successful reduction

The second group of parameters to be recorded are those that would provide predictive value for the presence, as well as the extent, of residual dysplasia, and thereby an assessment of the future need for reconstructive procedures of the acetabulum or the proximal femur. This group includes the following parameters (Figure 4):

- Anterior acetabular index
- Posterior acetabular index
- Axial acetabular index
- Acetabular version

All measurements originated from a trans-triradiate baseline drawn at the anterior margin of the posterior portion of the triradiate cartilage. Four angles defining acetabular structure were measured, as described by Buckley *et al.* [18] These angles include the anterior and posterior acetabular indices. The third angle, the axial acetabular index, is the sum of angles 1 and 2. Acetabular version, the fourth measurement, is defined as the difference between the triradiate baseline and the line bisecting the third angle.

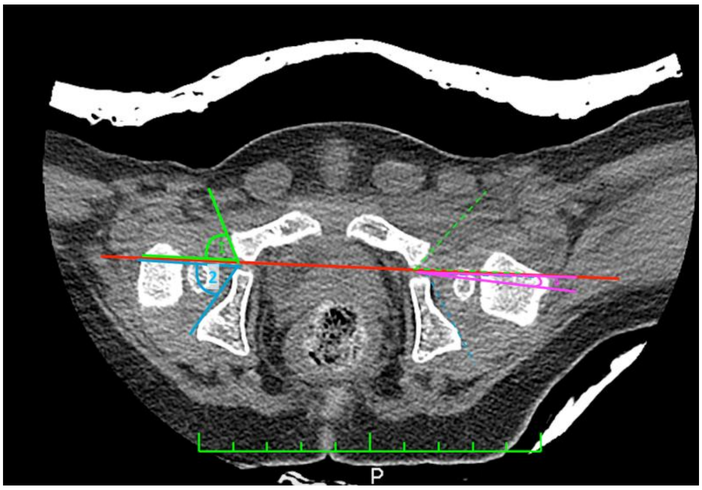

Fig. 4. Complication prediction parameters: anterior acetabular index (green angle-1), posterior acetabular index (blue angle-2), axial acetabular index (sum of both angles 1+2), acetabular version (between the trans-triradiate line and the line that intersects the axial acetabular index-pink angle, 4), trans-triradiate line is the red line that connects the centers of both triradiate cartilages

Outcome measurement

Follow-up clinical and radiographic examinations were performed in all patients at the time of intervention and at six-month intervals. The shortest follow-up period was one year. Clinically, the immediate outcome was intraoperative assessment of retention and reduction and follow-up outcome was assessed according to the McKay criteria (Table 1)[19].

Table 1. MacKay criteria for clinical evaluation of DDH

Grade	Rating	Description
I	Excellent	Stable, painless hip: negative Trendelenburg sign; full range of motion
II	Good	Stable, painless hip; slight limp; slight decrease in range of motion
III	Fair	Stable, painless hip; limp, positive Trendelenburg sign and limited range of motion, or a combination of these
IV	Poor	Unstable or painful hip, or both; positive Trendelenburg sign

Radiographically, two parameters were analyzed on plain radiographs - all parameters were alignment of the superior line of the femoral neck with the acetabular cavity/triradiate cartilage and the integrity of Shenton-Menard's line (if visible). All of the abovementioned parameters were analyzed on CT scans. Follow up radiographs included assessment of the acetabular index and the center-edge angle according to Wiberg.

Results

Twenty-five patients were included in the study. Majority of them were 23 (92%) female and two (8%) were male. Thirty-nine of the hips were dislocated, bilateral in 14 patients, right-sided in 3, left-sided in 8. All analyses were performed on a per-hip basis unless otherwise stated.

Five of 39 (12.8%) hips were found intraoperatively to have suboptimal hip stability despite apparently satisfactory reduction. Only one case (two hips) of persistent dislocation was detected on postoperative native radiography by the most experienced surgeon, while in three cases (three hips), artifacts and poor visualization masked persistent dislocation, which was subsequently confirmed on the postoperative CT. All the reduction success parameters were positive in the dislocated hips (no contact femoral head-acetabulum, blunt morphology of the acetabula, widened joint space, disrupted modified Shenton-Menard's line, posterior line of the femoral neck did not enter the acetabulum). In two patients, repeat reduction with adductor tenotomy was performed, and post-procedural CT demonstrated successful hip retention. In one patient, an open reduction was performed, while in the fourth patient an open reduction combined with femoral osteotomy was carried out. Computed tomography demonstrated complete diagnostic accuracy in evaluating closed reduction outcomes in developmental dysplasia of the hip (DDH). All successfully reduced and unreduced hips were correctly classified, yielding a sensitivity, specificity, and accuracy of 100%. In contrast, native radiography displayed significantly lower sensitivity (28.6%), while specificity and overall accuracy remained moderately high (86.0% and 77.6%, respectively) (Table 2).

Table 2. Diagnostic validity of CT and native radiography in evaluating closed reduction outcomes in developmental dysplasia of the hip (per-hip analysis)

Parameter	CT (%)	Radiography (%)	Fisher's Exact Test (*p*-value)	Odds Ratio (95% CI)
Sensitivity	100.0	28.6	<0.001	∞ (4.5–∞)*
Specificity	100.0	86.0	0.0134	∞ (2.8–∞)*
Accuracy	100.0	77.6	<0.001	∞ (5.0–∞)*

Fisher's exact test confirmed statistically significant differences between CT and native radiography for all diagnostic parameters ($p<0.05$). The odds ratios approached infinity, reflecting the absence of false positive or false negative findings in the CT group. These results highlight the superior diagnostic reliability of CT in verifying the adequacy of closed reduction compared to conventional native radiography.

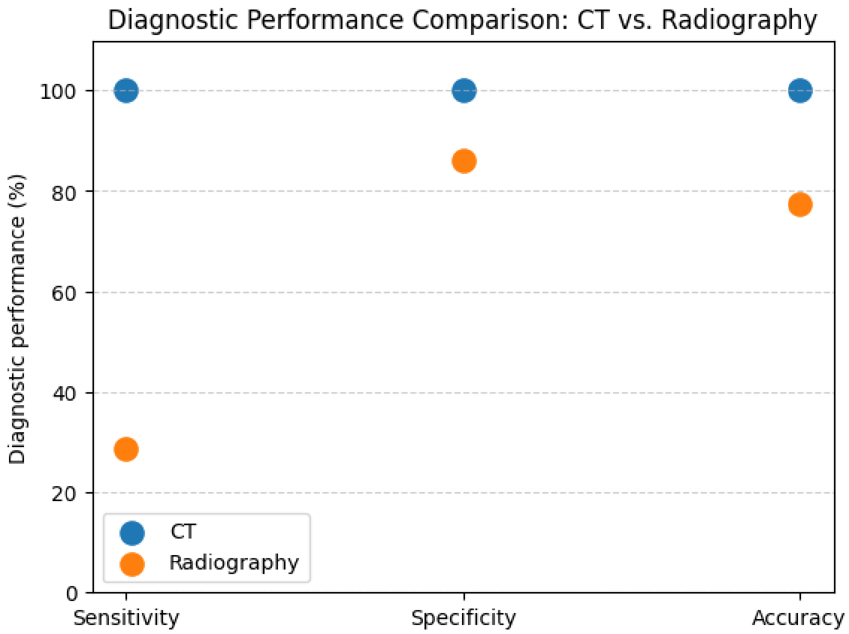

Fig. 5. Dot plot comparing diagnostic performance parameters of computed tomography (CT) and plain radiography in the evaluation of closed reduction in developmental dysplasia of the hip. CT demonstrates maximal sensitivity, specificity, and accuracy (100% across all parameters), whereas radiography shows markedly reduced sensitivity (28.6%) with relatively preserved specificity (86.0%) and overall accuracy (77.6%).

The radiographic outcome and the need for further surgical intervention were based on analysis of the center–edge (CE) angle according to Wiberg and the acetabular index. The outcome was assessed using the most recent radiograph. A center–edge angle value >10° was considered indicative of a good outcome, whereas a center–edge angle <10° was regarded as an unsatisfactory outcome; acetabular angle >30° was associated with residual dysplasia. Most hips (33) had satisfactory results, while in 17 hips the outcome was unsatisfactory. Accordingly, the mean CE angle in the 17 hips that required further treatment or demonstrated residual dysplasia was 2°, whereas in those that did not require additional surgical intervention or show residual dysplasia it was 21°. None of the CT parameters showed a statistically significant correlation with the radiographic outcome as defined by the center–edge angle and the acetabular index. All measured values, including acetabular angle measurements, the modified Shenton–Menard line, and the posterior femoral neck line, demonstrated no statistically significant predictive value for the outcome of residual dysplasia when compared with the CE angle. Likewise, the two parameters used to assess the success of reduction on plain radiographs showed no association with the CE angle or the acetabular index.

Clinically, according to the McKay criteria, one patient had a fair outcome (grade III), five had a good outcome (grade II), while the majority, 19 patients, had an excellent outcome (grade I) (Figure 6).

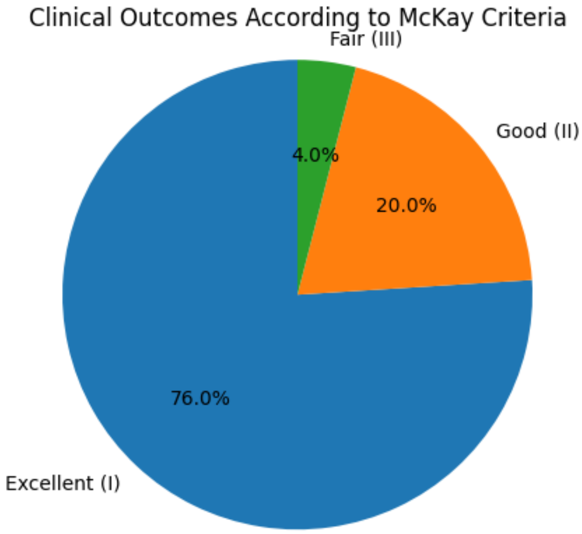

Fig. 6. Pie chart showing the distribution of clinical outcomes according to the McKay criteria

Discussion

The advantage of narrow-window CT over plain radiography as a post-procedural method for assessing the success of hip reduction in developmental (congenital) hip dislocation is unquestionable and has been confirmed in multiple studies[3,6,14-15, 20-24].

In our study, the superiority of the method was confirmed by the fact that post-procedural CT demonstrated an unsatisfactory hip reduction in four patients, while the radiograph was nonconclusive in three of them. The experience in interpreting post-procedural plain radiographs in our series is noteworthy; however, this cannot be regarded as a general rule[25].

Alternative methods for evaluating the success of closed reduction include ultrasound, tomography, and magnetic resonance imaging. However, the use of CT offers several advantages in patients with plaster cast immobilization for the following reasons: compared to CT, ultrasound is operator-dependent, does not allow visualization of the posterior aspect of the acetabulum, and requires modification of the plaster cast immobilization, which may compromise the stability of the reduction. Radiation exposure can be reduced to 0.1 rad, meaning that CT involves lower radiation than conventional tomography[26]. Magnetic resonance imaging is less accessible and more expensive than CT; the examination itself takes longer and requires anesthesia.

Over the past 20 years, a number of anatomical hip measurements on CT scans have been described. Weiner described various stages of normal acetabular development using CT[27]. Toby recommended contact of the medial portion of the femoral head as the principal parameter for successful hip reduction; however, in most patients at 6 months of age in our series, the femoral head was still unossified[24]. Of particular interest is the observation by Cooper, who introduced the posterior femoral neck line directed toward the triradiate cartilage as a parameter, offering high negative predictive value-an important feature for avoiding undetected persistent dislocations and their deteriorating consequences[15].

In this study, 33 of 50 hips had a center-edge angle greater than 10°, which is consistent with a satisfactory outcome. None of the measured variables demonstrated statistical significance in predicting the outcome of hip dysplasia as defined by the CE angle. Although statistically non-significant, these findings suggest a potential prognostic value of CT scans in assessing the anterior, posterior, axial acetabular index, as well as the acetabular version angle.

In a larger and differently designed study, there may be an opportunity to statistically verify the relationship between positioning of the femur, acetabular morphology and persistent dysplasia following closed reduction of the hip.

This study highlights the clear clinical value of computed tomography (CT) as a post-procedural imaging modality for the immediate evaluation of closed reduction in developmental dysplasia of the hip (DDH). Our findings support and reinforce existing evidence that narrow-window CT offers superior diagnostic accuracy compared to plain radiography in confirming concentric hip reduction, particularly in patients immobilized in a hip spica cast. The ability of CT to reliably visualize the relationship between the femoral head, acetabulum, and triradiate cartilage, independent of ossification status, makes it uniquely suited for early post-reduction assessment, when timely and accurate decision-making is crucial.

In our cohort, CT demonstrated unequivocal superiority by identifying persistent dislocation in cases where plain radiography suggested acceptable reduction. This finding underscores a key limitation of post-procedural radiography, which remains highly dependent on image quality, patient positioning, and interpreter experience. While experienced centers may achieve acceptable radiographic interpretation, this cannot be generalized, particularly in less specialized settings. In contrast, CT provides consistent, reproducible, and operator-independent assessment, significantly reducing the risk of missed or delayed diagnosis of persistent or incomplete reduction - events known to adversely affect long-term outcomes.

Beyond its role in immediate verification of reduction, CT also shows promise as a tool for prognostication. Although none of the CT-derived parameters in this study demonstrated statistically significant predictive value for residual dysplasia as defined by the center–edge angle, several trends merit attention. The relative positioning of the femoral metaphysis with respect to the modified Shenton–Menard line, as well as the orientation of the posterior femoral neck line toward the triradiate cartilage, may reflect biomechanical relationships relevant to acetabular development. The lack of statistical significance in the present study is likely attributable to sample size and study design rather than an absence of biological relevance.

Importantly, CT offers these diagnostic and potentially prognostic advantages while maintaining acceptable radiation exposure, which can be reduced to levels lower than those of conventional tomography. When compared to alternative modalities, ultrasound is limited by operator dependence and inadequate visualization of posterior acetabular structures, while magnetic resonance imaging is less accessible, more costly, time-consuming, and frequently requires anesthesia in young patients.

Conclusion

In conclusion, narrow-window CT should be regarded as the preferred method for immediate post-reduction evaluation following closed reduction in DDH. Its ability to accurately confirm hip retention, detect persistent dislocation, and potentially provide early indicators of long-term complications positions CT as a pivotal tool in optimizing patient outcomes. Larger, prospective studies with extended follow-up are warranted to further clarify the predictive value of CT-based parameters for residual dysplasia and to refine imaging-based risk stratification in DDH management.

Conflict of interest statement. None declared.

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