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The assessment of the efficacy of radiography in diagnosing developmental dysplasia of the hip in infants younger than six months with reference to hips graded by Graf classification using ultrasonography

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Abstract. – OBJECTIVE: This study aims to evaluate the diagnostic effectiveness of radiography for developmental dysplasia of the hip (DDH) in infants being younger than six months by comparing the results with hips graded by Graf classification using ultrasonography (US). While US is standard for screening and diagnosing DDH in this age group, radiography may provide broader insights for screening programs and boost diagnostic precision.

PATIENTS AND METHODS: This retrospective research involved 994 hips from 497 newborns and infants under six months old who underwent hip US and radiography for DDH screening from August 2020 to September 2021. Radiographs were reassessed by an experienced pediatric orthopedic surgeon to identify DDH indications. Hips were graded using the Graf classification, and the primary outcome was the diagnostic accuracy of pelvic/hip radiography for DDH, using the US Graf classification as a reference.

RESULTS: Among the 994 hips assessed, 71 (14.3%) right and 51 (10.3%) left hips showed radiograph signs of DDH. Graf grades IIa to IV were found in the radiographs of 43 (8.7%) right and 47 (9.5%) left hips, which accurately diagnosed right- and left-sided DDH with a specificity of 87.0% and 92.4% respectively. Graf grades IIb to IV appeared in the radiographs of 7 (1.4%) right and 14 (2.8%) left hips, diagnosing right- and left-sided DDH with a specificity of 86.1% and 91.1%, respectively.

CONCLUSIONS: Our study results imply that radiographs may be limited in their diagnostic capacity for DDH in newborns and infants during the first six months of life.

Key Words:
Developmental dysplasia of the hip, Infant, Newborn, Screening, Ultrasonography, Radiography, Sensitivity and specificity.

Introduction

Developmental dysplasia of the hip (DDH) is an anatomical abnormality of the femoral head and the acetabulum of the hip joint[1]. Depending on the severity of these abnormalities, the hips may become dysplastic, subluxated, dislocated, or malformed. While the incidence of DDH with dislocated hips ranges from 1.5 to 5 in every 1,000 newborns, DDH with dysplastic hips can be seen in up to 100 newborns in 1,000. The variations in these rates are attributed to the differences in racial backgrounds, geographical regions, and availability of the clinical and imaging screening modalities[1-4].

Early detection and management of DDH are essential for implementing less invasive treatment methods and achieving better long-term outcomes[5-8]. DDH in newborns is primarily diagnosed based on clinical findings. However, the efficacy of clinical examinations, especially during the early or later periods of infancy, is controversial[2,9,10]. After Graf pointed out its use in diagnosing DDH in 1980[11], ultrasonography (US) has been regarded as the universal screening modality for all newborns or selective risky groups[5-6]. Nevertheless, there is still no consensus on its use for DDH screening during the first few months of life, nor is it sufficiently accessible[5,7,12]. There are a few countries that screen infants younger than six months for DDH based on a combination of universal clinical examinations and selective US, yet the absence of a national policy in this regard and the unavailability of the US remains a reality around the world[13,14]. As the ossification center of the femoral head becomes more prominent starting from the

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fourth month of life, the diagnostic power of the US reportedly reduces[9,15]. Additionally, the US is being questioned[15-17] due to being highly operator-dependent, requiring experienced physicians, and inter-observer inconsistencies.

Pelvic radiography is the most preferred diagnostic modality for DDH in children over six months. On the other hand, several authors[18,19] have recommended using radiographic screening instead of US to assess DDH in infants at four months of age. In addition, most orthopedic surgeons[2,12] favor using radiography in diagnosing DDH in infants over three months of age. The need for additional monitoring of infants with US during the first six months of life has been a matter of debate[10]. In this context, radiography of the hip may stand out as a beneficial imaging modality in selected situations.

In view of the foregoing, this study was carried out to evaluate the diagnostic efficacy of radiography of the hip in diagnosing DDH in newborns and infants younger than six months with reference to hips graded by Graf classification using the US.

Patients and Methods

Study Design

The material of this retrospective study consisted of the 994 hips of 497 newborns and infants who were six months old or younger and underwent hip US and radiography for DDH screening in the Konya City Hospital between August 2020 and September 2021. The study protocol was approved by the local Ethics Committee (Necmettin Erbakan University Ethics Committee, Decision No. 2023/4123). The study was performed in accordance with the ethical principles set forth in the Declaration of Helsinki. Written consent forms could not be obtained from the parents of the children due to the study's retrospective design and the anonymity of data.

Population and Sample

The population of this study consisted of 1,010 newborns and one to six-month-old infants screened for DDH with both hip US and pelvic radiography in the Konya City Hospital. Pursuant to the institutional DDH screening policy, the newborns and infants underwent a clinical examination by an experienced pediatric orthopedic surgeon and US of the hip. Pelvic radiographs and hip US of the newborns and infants included in the study were obtained from the hospital information system. The newborns and infants whose radiographs had poor image quality or did not meet the Tönnis criterion for unrotated positioning during radiography (n=433) and who had US of the hip and pelvic radiography more than ten days apart (n=80) were excluded from the study[20,21]. In the end, 994 hips of 497 newborns and infants, 270 females and 227 males, were included in the study sample (Figure 1).

Interventions

Hip US was performed by experienced radiologists per the standard lateral and coronal ap-

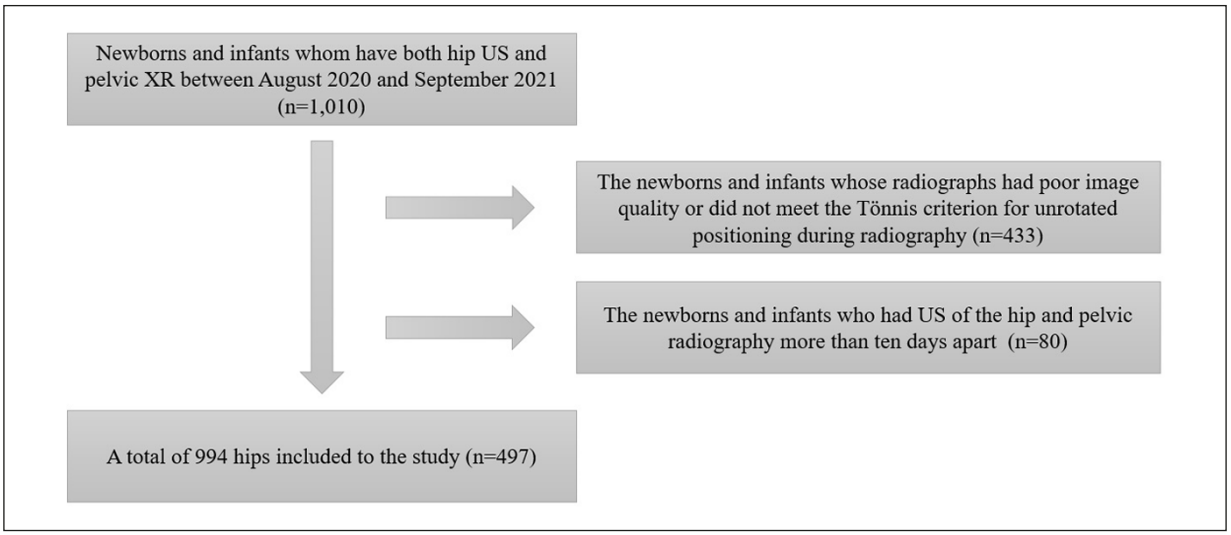

Figure 1. The flow chart of the study population.

proach using a Sonoline G60S ultrasound system (SIEMENS, Erlangen, Germany) with a 7.5 MHz linear probe. Hips were graded based on Graf classification. Accordingly, mature, normal, and healthy hips were categorized as grade 1 hips, and immature and pathological hips and hips with DDH were categorized as grade IIa to IV hips[15,22,23].

The pelvic radiographic images were reviewed by one pediatric orthopedic surgeon (A.S.S.) with at least ten years of experience in DDH. For each hip, the acetabular index (AI) and the acetabular depth ratio (ADR) were measured as recommended by Tönnis[21].

The femoral head's positioning in the outer quadrant formed by the Hilgenreiner and Perkins lines and the disruption of the Shenton's line in radiographs, and AI values higher than the previously defined age- and gender-based reference values were deemed to indicate DDH pathology[7,20,21,24]. Accordingly, each hip was categorized as compatible or not compatible with DDH. The DDH grades of the hips, including dysplastic, subluxated, and dislocated hips, were deemed radiographic evidence for DDH. The ossific nucleus within the femoral head was also noted in cases where it was evident.

Variables

Data on the demographic and clinical variables, including AI and ADR data, ossification of the head of the femur, and Graf grades of the hips, were obtained from the hospital information system and patients' medical files.

Statistical Analysis

The study's primary outcome was the diagnostic accuracy of pelvic/hip radiographs for DDH with reference to hips graded by Graf classification using the US. Accordingly, hips were categorized into two groups based on Graf classification in order to identify pathological hips: (i) hips graded IIa through IV, and (ii) hips graded IIb through IV.

The descriptive statistics obtained from the collected data were expressed as mean ± standard deviation values in case of continuous variables determined to conform to the normal distribution, as median with minimum-maximum values in case of continuous variables determined not to conform to the normal distribution, and as numbers and percentages in case of categorical variables. The Shapiro-Wilk, Kolmogorov-Smirnov, and Anderson-Darling tests were used to analyze the normal distribution characteristics of the numerical variables.

Diagnostic accuracies of radiographs for DDH were calculated based on Graf classification, specificity and sensitivity values, negative predictive values (NPV), and positive predictive values (PPV). Jamovi project 2.3.24.0 (Jamovi, version 2.3.24.0, 2023, available at: https://www.jamovi.org) and JASP 0.17.1 (Jeffreys' Amazing Statistics Program, version 0.17.1, 2023, available at: https://jasp-stats.org) software packages were used in the statistical analyses.

Results

497 newborns and infants with a median age of 66 days (range: 1-181 days), 270 (54.5%) males and 227 (45.5%) females, were included in the study sample.

The details of the radiographic imaging findings are given in Table I. The median AI was 24.8° and 25.8° for the right and left hips, respectively. There were 69 (13.9%) right and 48 (9.7%) left hips with increased AI values. Broken Shenton's line was detected in 14 (2.8%) right and 16 (3.2%) left hips. Accordingly, 71 (14.3%) right-sided and 51 (10.3%) left-sided hips were found to be compatible with DDH (Table I).

Table I. Radiographic imaging findings of the right and left hips of children.

	Right hip (n = 497)	Left hip (n = 497)
Acetabular index (°)†	24.8 [16.2-43.6]	25.8 [15.8-46.9]
Children with increased acetabular index‡	69 (13.9)	48 (9.7)
Acetabular depth ratio†	0.204 [0.089-0.356]	0.205 [0.069-5.373]
Femoral head ossification‡	54 (10.9)	50 (10.1)
Broken Shenton's line‡	14 (2.8)	16 (3.2)
DDH, according to radiographic findings‡	71 (14.3)	51 (10.3)

†Median [min-max], ‡n (%). DDH: Developmental dysplasia of the hip.

Table II. Sonographic classification according to the Graf method.

	Right hip (n = 497)	Left hip (n = 497)
Sonographic hip types‡		
Type I	454 (91.3)	450 (90.5)
Type IIa	36 (7.2)	33 (6.6)
Type IIb	6 (1.2)	10 (2.0)
Type IIc	1 (0.2)	2 (0.4)
Type D	0 (0)	0 (0)
Type III	0 (0)	2 (0.4)
Type IV	0 (0)	0 (0)
Pathological hips based on Graf types‡		
From IIa to IV	43 (8.7)	47 (9.5)
From IIb to IV	7 (1.4)	14 (2.8)

‡N (%).

Based on the sonographic Graf grades, 91.3% of the right hips and 90.5% of the left hips were categorized as grade I (normal/mature), and 43 (8.7%) right and 47 (9.5%) left hips were categorized as grade IIa through IV (immature/pathological). Of the hips identified as immature and pathological, 36 (7.2%) right and 33 (6.6%) left hips were categorized as grade IIa. The remaining seven (1.4%) right and 14 (2.8%) left hips were determined to be compatible with DDH. The distribution of the hips by Graf grades is shown in Table II.

The distribution of the diagnostic parameters, including sensitivity, specificity, NPV, PPV, and accuracy, by the hips categorized according to the Graf grades are shown in Tables III and IV. The pelvic/hip radiographs diagnosed right and left-sided DDH with specificities of 87.0% and 92.4%, respectively, with reference to the hips graded as IIa through IV, thus identified as pathologic in terms of US-based Graf classification (Table III). The overall diagnostic accuracies were 81.9% for the right hip and 87.1% for the left hip.

Hips graded IIb through IV, excluding grade IIa hips, diagnosed right and left-sided DDH with 86.1% and 91.1% specificities, respectively. The diagnostic accuracies for the right and left hips were 85.5% and 90.1%, respectively (Table IV).

The relationship between the Graft grades of the hips and the radiographic status of the acetabulum is given in Table V. Although the ultrasonographic and radiographic diagnoses were compatible in all cases with grade IIc and III hips, there were considerable differences between the ultrasonographic and radiological diagnoses in cases with grade IIa and IIb hips.

Discussion

The findings of this study revealed that the pelvic/hip radiographs diagnosed DDH with ac-

Table III. Association of radiological diagnosis of DDH with pathological imaging findings using the Graf method (types from IIa to IV).

	Diagnosis based on the Graf method						
	Normal	Pathological (types from IIa to IV)	Sensitivity (%)	Specificity (%)	NPV (%)	PPV (%)	Accuracy (%)
Right hip							
Radiologically normal	395	31	27.9	87	92.7	16.9	81.9
Radiologically DDH	59	12					
Left hip							
Radiologically normal	416	30	36.2	92.4	93.3	33.3	87.1
Radiologically DDH	34	17					

DDH: Developmental dysplasia of the hip, NPV: negative predictive value, PPV: positive predictive value.

Table IV. Association of radiological diagnosis of DDH with pathological imaging findings using the Graf method (types from IIb to IV).

	Diagnosis based on the Graf method		Sensitivity (%)	Specificity (%)	NPV (%)	PPV (%)	Accuracy (%)
	Normal	Pathological (types from IIb to IV)					
Right hip							
Radiologically normal	422	4	42.9	86.1	99.1	4.2	85.5
Radiologically DDH	68	3					
Left hip							
Radiologically normal	440	6	57.1	91.1	98.7	15.7	90.1
Radiologically DDH	43	8					

DDH: Developmental dysplasia of the hip, NPV: negative predictive value, PPV: positive predictive value.

curacy rates ranging from 81.9% to 90.1%, depending on the side and the Graf grade of the hip in newborns and infants up to six months. The diagnoses made based on the radiographs were consistent with those made based on the US for hips graded as IIc and III, according to the Graf classification system. Nevertheless, there were considerable variations between the diagnoses made based on radiographs and the US for hips graded as IIa and IIb.

Digital X-ray imaging, a fast technique with low radiation, may potentially become the preferred auxiliary technique for diagnosing and monitoring DDH in infants aged 3-6 months[16]. Given the absence of ossific hip joints, pelvic radiography is not recommended for infants aged 3-4 months[2,7,19]. Nevertheless, the diagnostic efficacy of pelvic/hip radiography depends on the positioning of children during imaging, successfully visualizing the secondary ossification centers within the femoral heads and osseous acetabular morphology, and the reproducibility of DDH anteroposterior pelvic radiographs[1,18,25,26]. Improper patient positioning might lead to false-positive and false-negative diagnoses. Furthermore, the ossification usually does not start in newborns and infants under three months of age. This study featured the re-evaluation of the radiographs in terms of DDH diagnosis. Due to insufficient imaging quality and indecent exposure to the pelvic anatomic landmarks, almost half of the images had to be excluded. Hence, the technical issues might limit the reliability of the results.

Tönnis[21] was one of the pioneer physicians who reported on the relationship between radiographic parameters and DDH. In 1976, he published a database, including the age- and gender-specific cut-off values of AI and dysplasia grades, i.e., light or severe, which can be used as a reference in the radiography of hip joint AI varies depending on the age and gender of the newborns and infants[1,21]. AI values of 30° or less have been regarded as normal for newborns, whereas AI values of 22° or less have been regarded as normal for children older than one year[1]. Age- and gender-specific AI cut-off values reported by

Table V. Radiographic classification of Graf type pathologic hips.

Pathologic type on ultrasonography (Graf type)	Overall		Right hip		Left hip	
	Normal according to radiography	DDH according to radiography	Normal according to radiography	DDH according to radiography	Normal according to radiography	DDH according to radiography
Type IIa (n = 69)	51	18	27	9	24	9
Type IIb (n = 16)	10	6	4	2	6	4
Type IIc (n = 3)	0	3	0	1	0	2
Type III (n = 2)	0	2	0	0	0	2

DDH: Developmental dysplasia of the hip.

Tönnis[21] were used to determine the cases with increased AI values in this study.

An ossification center is required if the Tönnis[21] classification system is to be used as a reference. Therefore, due to the absence of ossification in infants younger than three months of age, the Tönnis system cannot be applied to all cases[2]. Hence, the upgraded International Hip Dysplasia Institute classification categorized the newborns' and infants' images to evaluate the acetabulum's state as normal or dysplastic[2,28]. In this context, the upgraded International Hip Dysplasia Institute classification was used concurrently with the cut-off values reported by Tönnis et al[21] in this study.

Doski et al[2] and Li et al[7] addressed the efficacy of radiographs in diagnosing DDH in different age groups in their studies. In one of these studies, Doski et al[2] studied the efficacy of the upgraded International Hip Dysplasia Institute Classification system in diagnosing DDH in children aged 3-22 months. However, they did not group the patients according to their ages. In another study, Li et al[7] investigated the efficacies of various imaging techniques in diagnosing DDH in children with suspected DDH, including children with acetabular dysplasia, subluxation of the femoral head, and complete dislocation of the femoral head. They grouped the patients in three different age groups: 0-6 months, 7-12 months, and older than 12 months. Consequentially, they determined that X-ray radiography diagnosed DDH with 78.9% accuracy overall. In comparison, the diagnostic accuracies of radiography in diagnosing pathological DDH, that is, hips graded IIb through IV based on Graf classification, were 85.5% and 90.1% for the right and left hips, respectively. They also found comparable diagnostic accuracies of radiography in diagnosing DDH, even though, unlike this study, they applied universal screening to all children with suspected DDH.

Price et al[10] investigated the use of X-rays in 5-month-old children to detect the defects associated with the learning curve of the US. Yet, they did not find any patient with late DDH in their patient group and concluded that using X-rays in 5-month-old children discharged from the clinic is neither cost-effective nor indicated. Others[24] showed that the US is an effective and alternative modality to X-ray in the follow-up of 6-month-old children who previously received DDH treatment.

A limited number of studies[20,23,27-30] compared the diagnostic efficacies of radiography with that of the US. Despite the significant methodological differences between these studies, radiography provided results comparable to those of the US overall. In parallel with the results of this study, Atalar et al[20] reported that plain radiography diagnosed DDH with a sensitivity of 61% and a specificity of 87% in children aged 4-50 weeks compared to the US. Taken together with the literature data, this study's findings suggest using plain radiography in infants with IIa and IIb grade hips, which might produce even better results when combined with clinical findings and follow-up data in selected situations.

Geertsema et al[23] compared the use of radiography in 5-month-olds with the standard 12-week ultrasound in newborns at risk for DDH to prove the efficacy of delayed ultrasound between three and five months in clinically stable hips. However, they did not find any significant difference between the two methods in diagnosing persistent DDH after 18 months of age. Tudor et al[22] analyzed the efficacies of the US and X-ray in diagnosing DDH in infants aged 4-6 months with immature hips and found a significant difference between the two methods in DDH incidence. In a study[22] conducted between 2003 and 2005, the use of anteroposterior radiographs in identifying the hips requiring treatment resulted in a decrease in the number of hips requiring treatment from 51.75 per 1,000 hips to 30.77 per 1,000 hips. Therefore, they recommended radiography be performed on each child over three months old diagnosed with DDH by the US. The studies that compare these two imaging modalities should provide more conclusive data, considering that the US is a widely accepted screening tool for DDH.

Atalar et al[16] investigated the use of pelvis anteroposterior radiographs in infants (age range, 4 to 6 months) with risk factors for DDH and normal hip findings in the US. They concluded that the US might not be sufficient in diagnosing DDH in their patient group and suggested that radiography might help diagnose DDH in infants less than six months of age and at risk for DDH, even if the US indicated a normal hip. The efficacy of these two modalities could not be compared in this study since the efficacy of radiography in diagnosing DDH in infants younger than six months was assessed with reference to hips graded by Graf classification using the US.

Weinstein et al[31] categorized DDH into different groups depending on the radiographic findings. Accordingly, they categorized DDH into dysplasia, subluxation, and dislocation groups, with varying imaging findings. They defined sub-

luxation based on the presence of a broken Shenton's line together with a subluxated ossification center and dysplasia based on the presence of the inclination of the acetabulum with a centralized ossification center, regardless of unbroken Shenton's line. In comparison, in this study, broken Shenton's line and increased AI were regarded as the radiographic indicators of DDH. In addition, the hips diagnosed with DDH were categorized into dysplastic, subluxated, or dislocated. The fact that there were only a few newborns and infants with subluxated or dislocated hips prevented making significant comparisons between different groups of hips created based on radiography. Therefore, large-scale studies are needed to shed more light on the effect of subluxation and dislocation of the hips on the imaging-based diagnosis of DDH.

This is the first study to reveal the accuracy of radiography on the Graf type IIa-III and IIb-III hips in the same study group. The remarkable difference in the accuracy of radiography between Graf type IIa-III and IIb-III hip might be a result of the age difference of the study groups. Taking into account that the only difference between the Graf type IIa and IIb hips is the age of the infants[8,9], the better accuracy of the radiography on the Graf type IIb-III hips might be explained by this age difference.

Limitations of the Study

Apart from its strengths, such as its large sample size, there were also some limitations to this study. The first limitation was its retrospective design. The second limitation was the lack of follow-up data. As a reason, follow-up data could reveal cases with late-onset DDH. Thirdly, we did not assess the intra- and interobserver variations for radiographic and ultrasonographic assessment of the hips.

Conclusions

This study's findings suggest that stand-alone radiography may not be sufficient in diagnosing DDH in newborns and infants younger than six months. Immature or early presenting dysplastic hips might be overlooked in children screened only by radiography. Further studies to be conducted with infants who benefited from radiography in diagnosing DDH are needed to further elaborate on the efficacy of radiography in diagnosing DDH.

Conflict of Interest

The authors declare that they have no conflict of interests.

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Ethics Approval

The study protocol was approved by the local Ethics Committee (Necmettin Erbakan University Ethics Committee, Decision No. 2023/4123). The study was performed in accordance with the ethical principles set forth in the Declaration of Helsinki.

Informed Consent

Written consent forms could not be obtained from the parents of the children due to the study's retrospective design and the anonymity of data.

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Authors' Contribution

Both authors contributed equally to the design, preparation and final version of the work.

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Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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