Was the ultrasound examination for developmental dysplasia of the hip performed correctly? Introduction of a rapid training tool for nonexpert practitioners

Manuele Lampasi[a], Giovanni Lucchesi[a], Camila Bettuzzi[b], Salvatore Bonforte[c] and Federico Canavese[d,e]

Pediatricians and general practitioners are involved in the newborn screening for developmental dysplasia of the hip. They often rely on the quality of the ultrasound (US) examination to make diagnostic and therapeutic decisions. Therefore, the professional must be able to assess its quality. The aim of our work is to present a new system to evaluate the quality of a neonatal hip US and to assess the effectiveness and reproducibility of this tool among professionals involved in the evaluation of the neonatal hip but not experts in the radiological examination of hip US. In a 15-min training session, 135 professionals involved in neonatal hip US screening with limited or no experience in evaluating the quality of hip US were taught to recognize the basic landmarks of hip US using evocative descriptions (Christmas ball) despite the technical terms. Before and after training, participants were given a test of 10 hip US images presented in random order and asked to identify incorrect images. One hundred thirty-five physicians participated in the study. In the first and second evaluation, participants answered 1.46 ± 2.49 and 8.64 ± 1.51 questions correctly on average ($P < 0.05$); analysis of the individual questions showed a significant improvement ($P < 0.05$) for all questions. A simple and relatively quick training tool can help professionals with little or no experience in interpreting neonatal hip US to understand when a hip US exam has been performed incorrectly and improve their diagnostic and therapeutic decisions. Level of evidence: III. *J Pediatr Orthop B* XXX: XXXX–XXXX

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[a]OrtoChildren Center, [b]OrtoPediatria, Bologna, [c]Family Pediatrician, Catania, [d]Orthopedic and Traumatology Department, IRCCS Istituto Giannina Gaslini and [e]DISC-Dipartimento di scienze chirurgiche e diagnostiche integrate, University of Genova, Genova, Italy

Correspondence to Giovanni Lucchesi, MD, OrtoChildren Center, Via Larga 8, 40023, Bologna, Italy
Tel: +393477684073; e-mail: lucchesigiovanni@gmail.com

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Introduction

Developmental dysplasia of the hip (DDH) encompasses a spectrum of disorders ranging from mild acetabular dysplasia to complete femoral head dislocation [1].

Early diagnosis is essential for effective treatment, improved prognosis, and reduction of invasive procedures [2–4] and has been made possible by the advent of neonatal hip ultrasound (US) over the past three decades [5–15]. However, it is not enough for newborns to undergo a hip US. It is essential that the US be performed correctly and according to specific criteria so that its interpretation can be reliable enough. In particular, the Graf technique requires that hip US be performed only by trained and certified examiners who must be periodically reassessed [5–14]. Although such a system is ideal, it is not universal. In many countries, no official certification or specific training is required to perform a hip US, regardless of whether the hip US is performed according to the Graf or Harcke principles [5–15]. This leads to a number of USs being performed incorrectly, resulting in pathological hips not being treated and reported as normal, or normal hips being overtreated and reported as pathological [16,17].

Screening for DDH is often performed by pediatricians and general practitioners who refer newborns at risk or with pathologic hips to an orthopedic surgeon based on medical history, clinical examination, and hip US [16,17]. When confronted with a hip US, the clinician must, therefore, be able to assess its quality and relevance to correlate the US findings with the clinical examination and make the correct therapeutic choice [18].

There are two possible solutions to improve diagnostic accuracy: (1) improve the training of professionals performing hip US or (2) provide pediatricians, general practitioners, and other specialists involved in neonatal hip evaluation with the tools they need to judge the quality of a hip US. For the latter reason, we have developed an original, fast, and simple system to help professionals quickly identify incorrectly performed hip US. Therefore, the aim of our work is to present a new system to evaluate the quality of a neonatal hip US and to assess the effectiveness and reproducibility of this tool among professionals involved in the evaluation of the neonatal hip but not experts in the radiological evaluation of hip US.

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Materials and methods

To evaluate the efficacy and quality of the method presented in this study to evaluate a neonatal hip US, we assembled a cohort of 135 general practitioners and pediatricians who were the participants of three consecutive training courses in the pediatric orthopedics held between February 2022 and March 2023 at our Institution.

Step 1: first rating by participants

Participants were first shown 10 US images of newborns with normal hips or varying degrees of DDH and asked to identify which US images were correctly performed and which were not. Participants had three possible options for each US image:

Option 1: The neonatal hip US is of sufficient quality and performed correctly; it does not need to be repeated;

Option 2: The neonatal hip US is not of sufficient quality and is not performed correctly; it needs to be repeated in a specialized center;

Option 3: I do not know, I do not have the expertise/knowledge to make a judgment.

Of the 10 US images, four were correctly performed on normal hips, while the remaining six were incorrect due to missing standard anatomical element ($n = 3$) or incorrect anatomical plane ($n = 3$).

Step 2: how to judge the quality of a neonatal hip ultrasound?

The explanation of the method for judging the quality of a correct or incorrect neonatal hip US image, called the 'Christmas ball' method, took an average of 15 min and was given to participants after completion of the initial evaluation (step 1).

The participant is first asked to focus on two aspects: the report and the images of the neonatal hip US.

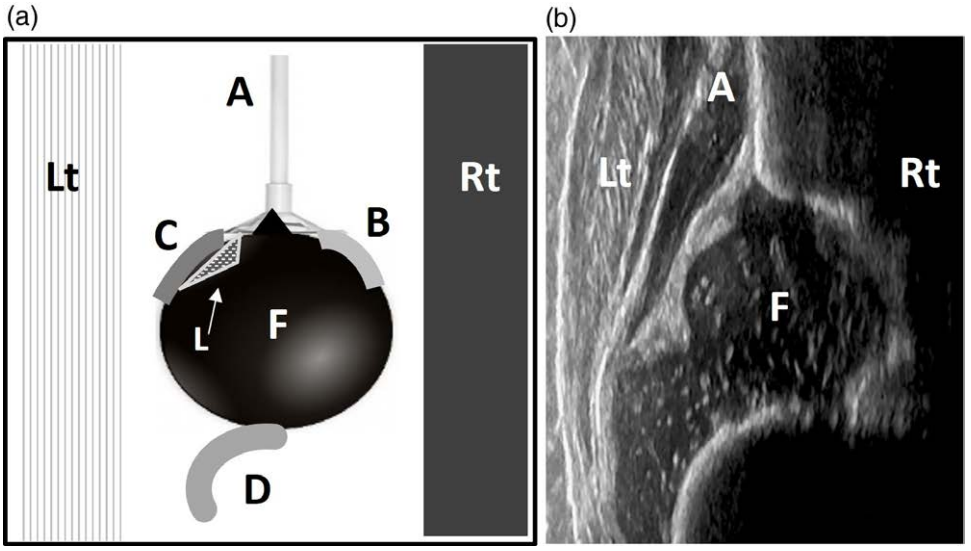
The report must be adequate, including at least a description of the Graf type with alpha and beta angle values and a morphologic description of the hip, and it must be consistent, that is, the Graf type must correspond to the alpha and beta angles given in the Graf table [5–14,17].

Two US images of each hip must be available, one with the angle measurements and one without. The following structures should be identified:

The US image must be rotated so that the brighter (more echogenic) superficial portion is on the left, the echogenic vertical line (line A, iliac bone) is at the top, and the darker (more anechogenic) deep portion is on the right (Fig. 1).

The femoral head (F) or 'Christmas ball' (Fig. 2) must be identified, consisting of an anechogenic rounded area bounded at the top by two echogenic arms: B on the right (acetabular roof, facing the anechogenic part of the image) and C on the left (facing the echogenic part of the image) and with a vertical support in the middle upper part (straight echogenic vertical line A); if it is difficult to identify such landmarks, the US image with the angle measurement lines can be used as an aid. These lines are actually drawn tangent to or in line with A, B, and C (Fig. 3). F may appear completely anechogenic

Fig. 1



Scheme of the 'Christmas ball' method (a) and the corresponding ultrasound image (b). The image is rotated with the echogenic (bright) part on the left (Lt), the anechogenic (dark) part on the right (Rt), and the vertical line (line A) at the top.

Fig. 2

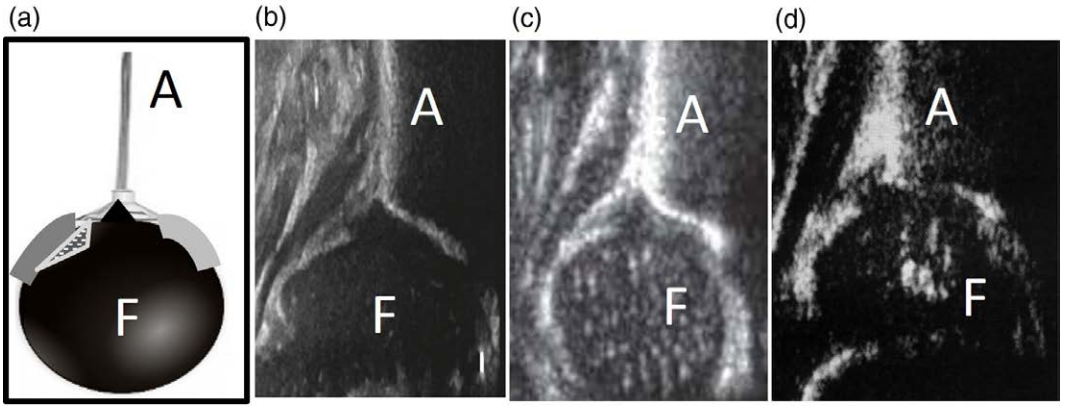


Diagram (a) of the 'Christmas ball' (F) with its vertical support A. Ultrasound examples of the Christmas ball, which can be anechogenic (dark; b), with white spots inside (c), or anechogenic with a whiter area in the center (dark; d).

with white echoes inside (sinusoids) or dark with an echogenic area in the center (ossific nucleus) (Fig. 2).

The line C must include a triangular structure (L, labrum) located in the lower part of C at the junction with F both in normal and dysplastic hips (Fig. 3).

At the level of the lower part of F, an echogenic hook (D) consisting of an echogenic arc, convex toward the top and left of the image, representing the chondro-osseous border of the femur, should be identified (Fig. 3).

At this point, to help examiners roughly understand the difference between images of normal and pathologic hips, they are told that in a normal hip, the femoral head (F) is bisected by a vertical line drawn along line A, and at least 50% of the femoral head is to the right of the line A, with the line B drawn appearing nearly horizontal; the alpha angle represents the angle between the line drawn along A and the line drawn along B [5–14,17,18].

In pathologic hips, the alpha angle decreases, the femoral head moves laterally, and less than 50% of the femoral head is bisected by the line drawn along A, with the line drawn along B becoming increasingly vertical and the line drawn along C becoming increasingly horizontal depending on the severity of the dysplasia [5–18] (Fig. 4).

With these concepts in mind, participants are instructed to evaluate items A, B, C, and D sequentially on US images; if only one of these requirements is not met, the image in question must be discarded and the neonatal hip US should be repeated at a specialized center (Fig. 5).

A: Is the line vertical? Is it well defined? Is the line tangent to it (available on the image with angle measurements) vertical? This assessment is important because a nonvertical A-line indicates an incorrect anatomical plane [5–14,17].

B: Is it well defined? B is usually absent or poorly defined in incorrectly performed neonatal hip US. We emphasize the importance of this element, which corresponds to the acetabular roof and becomes more horizontal in normal hips [5–14,17].

C: Does it include the labrum (L, triangular)? This structure is essential to show the standard anatomical plane;

D: Is the echogenic chondro-osseous border of the femur visible? D is usually poorly defined or not visible in incorrectly performed neonatal hip US, indicating an incorrect anatomical plane [5–14,17].

Step 3: second rating by participants

Finally, at the end of the course, participants were presented with the original images in a different order and asked again to judge whether the images were done correctly or whether they did not have the knowledge to make a judgment.

Statistical analysis

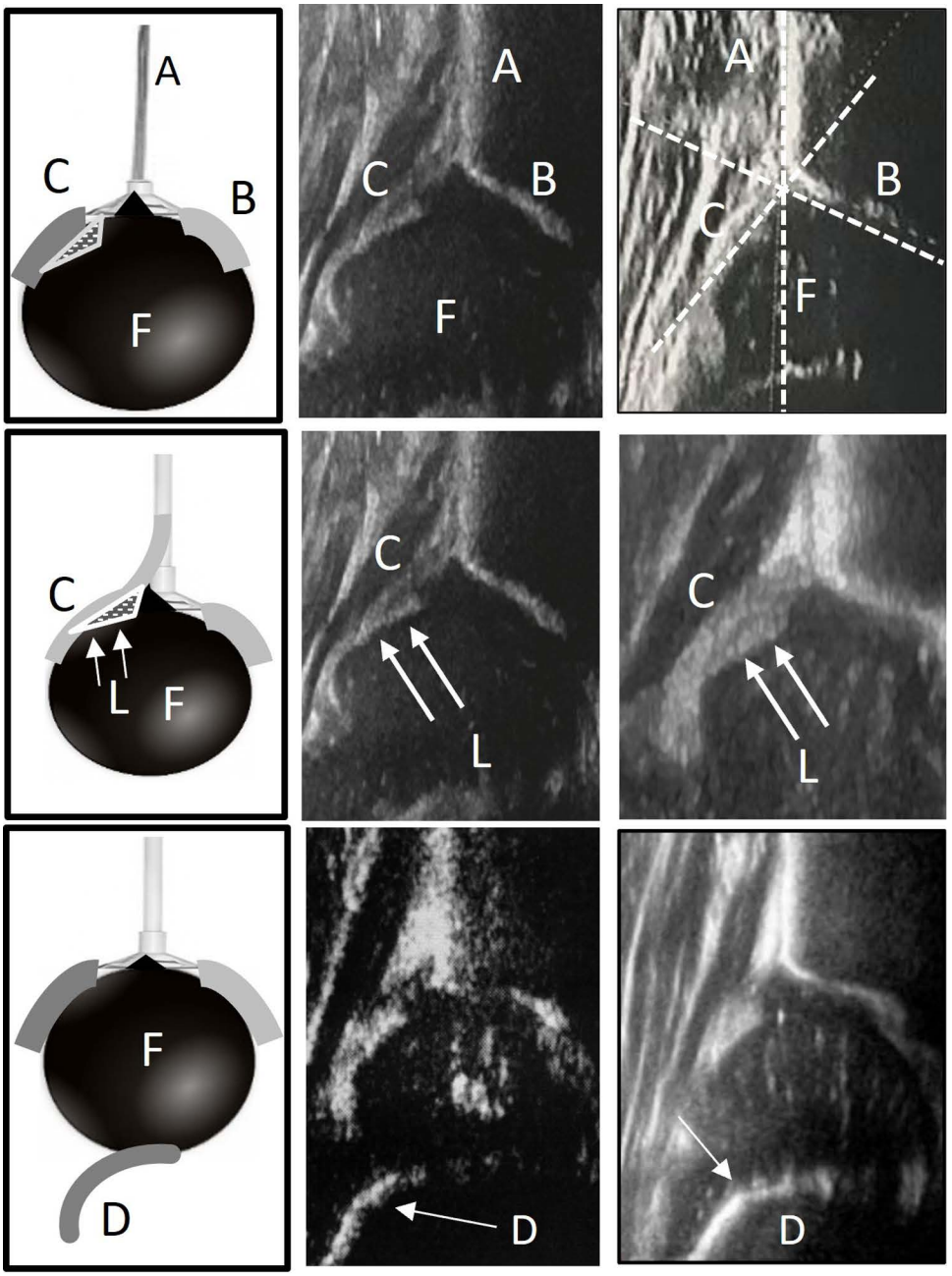
Results were collected, analyzed, and finally reported to the participants only after the completion of the two rating sessions. Statistical analysis was performed using SPSS software, version 19.0 (SPSS Inc., Chicago, Illinois, USA). Numerical variables are expressed as mean ± SD and frequency. The results of the two tests were compared statistically using the *t*-test. The threshold for statistical significance was set at $P < 0.05$.

Results

Demographics of the study participants

One hundred thirty-five physicians (32 males and 103 females) participated in the study (Table 1). There were 62 general practitioners (45.9%) and 73 pediatricians

Fig. 3



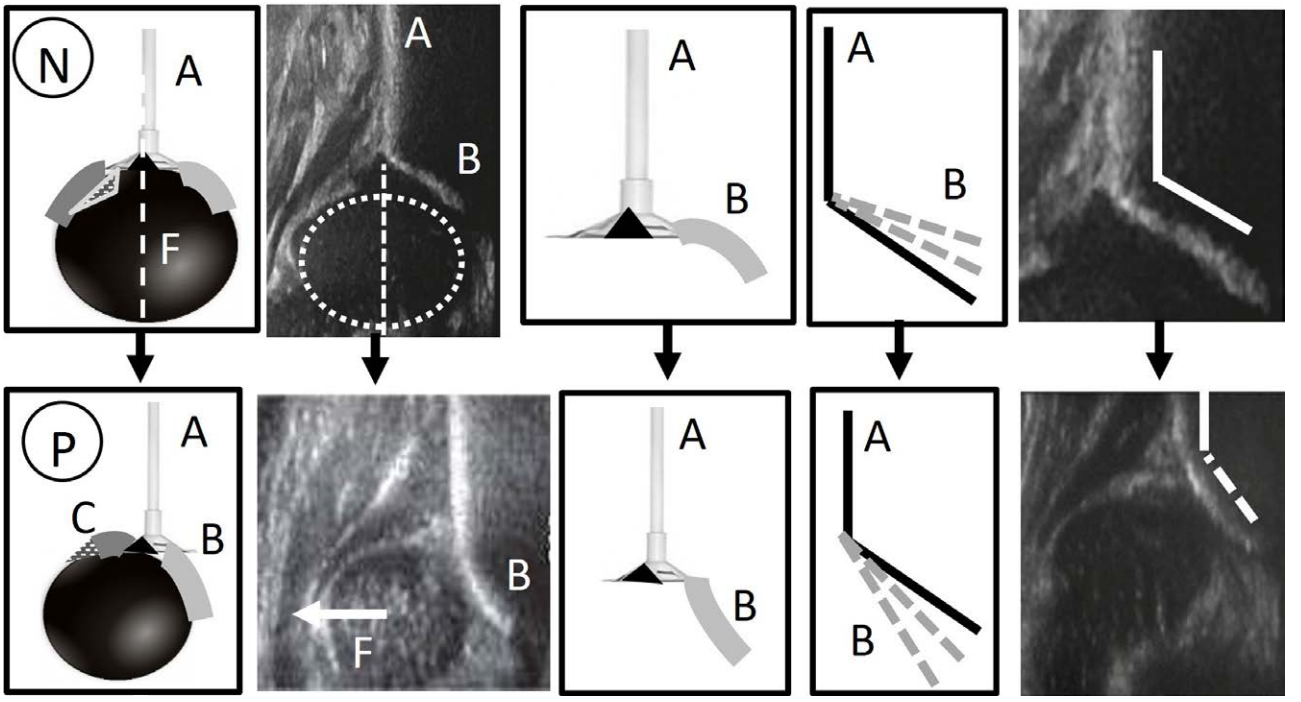
The femoral head (F) appears like a Christmas ball supported by a vertical cord A and two arms (B, deep and C, superficial). The lines used for angle measurements are tangent to (or in line with) A, B, and C. The arm C includes a triangular structure (L = Labrum), attached to the upper part of F. At the level of the lower part of F, there should be the hook (D) consisting of an echogenic arc, convex towards the top and left of the image.

(54.1%); 52.6% of the participants had been practicing for more than 10 years, 28.9% had between 0 and 4 years of experience, while the remaining 18.5% had been practicing for 5–10 years.

The mean age of the participating physicians was 42.6 ± 26.2 years; specifically, 38.5% of the participants were younger than 35 years, 38.5% were between 36 and 50 years, 18.5% were between 51 and 65 years, and the remaining 4.4% were older than 66 years.

Of the study participants, 87.4% ($n = 118$) had not attended previous courses/webinars on the subject and had no experience interpreting a neonatal hip US, 11.1% ($n = 15$) had attended courses/webinars on the subject but had limited experience interpreting a neonatal hip US, and 1.5% ($n = 2$) had attended specific training

Fig. 4



Normal (N, first row) and pathological (P, second row) hips. First and second columns: the Christmas ball F is in the center of the vertical line drawn along line A in normal hips, while it is displaced to the left in pathological hips. A and B (third to fifth columns) are essential to support the Christmas ball, and B must be sufficiently horizontal. In pathological hips, arm B is more oblique.

courses and were comfortable interpreting a neonatal hip US.

Results of the test

In the first evaluation, participants answered an average of 1.46 ± 2.49 questions correctly. In the second evaluation, performed after the theoretical training, the average number of correct answers was 8.64 ± 1.51 ($P < 0.05$). The analysis of the individual questions showed a significant improvement ($P < 0.05$) for all questions (Table 2).

Regarding the identification of the incorrect images between the first and second evaluation, the percentages changed as follows:

Images with incorrect anatomical planes ($n = 3$) were identified in 11.9–17.8% and in 86.3–93.5% of the cases in the first and the second evaluation, respectively.

The images with missing standard anatomical element:

Absence of femoral head ($n = 2$) was recognized in 20–25.9% and in 96.8–98.4% of the cases in the first and the second evaluation, respectively;

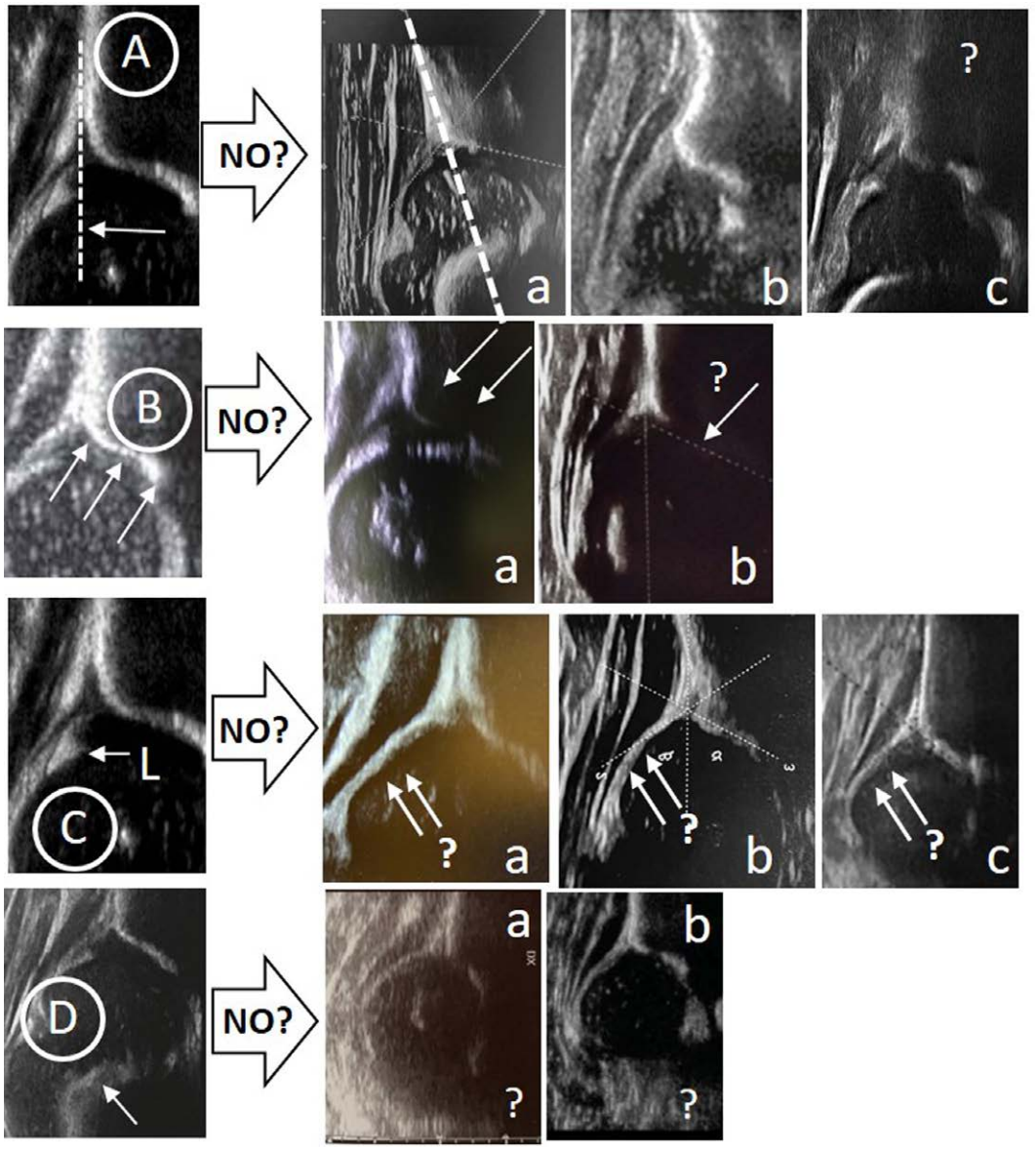
Absence of D hook ($n = 1$) was recognized in 19.3% and in 74.2% of the cases in the first and the second evaluation, respectively.

Discussion

One of the key roles of pediatricians and general practitioners is to ensure that newborns receive all necessary health screenings, including the diagnosis of DDH. Hip US is an essential tool for the early diagnosis of DDH in both selective and universal screening programs. In many countries, no official certification or specific training is required to perform a hip US, regardless of whether the hip US is performed according to the Graf or Harcke principles [5–15]. Regardless of the technique used, this leads to a number of US being performed incorrectly, resulting in pathological hips not being treated and reported as normal, or normal hips being overtreated and reported as pathological [18].

Ideally, pediatricians and general practitioners should perform hip US or rely on certified sonographers, but in most countries, hip US is performed by general sonographers in daily clinical practice. Physicians receive the US images and the report of the examination and often make decisions based on the report received (normal or abnormal). However, it is common that many hip USs are performed incorrectly or do not meet the required criteria; in particular, Walter *et al.* [18] reported that only 51.9% of US images showed correct sonographic images according to Graf's criteria.

Fig. 5



Items to analyze in the left column. Examples of possible errors in the other columns: (A) Line A is oblique (a), curved (b), and poorly defined (c). (B) B is not well defined (a and b); the angle measurement line should be tangent to B, but seems to be drawn without a precise landmark (c). (C) The triangular structure L is missing (a, b, and c). (D) The hook D is missing (a and b).

Early detection by hip screening and early splinting are recommended to prevent surgery and future comorbidities. Notably, the incidence of DDH detection and nonoperative management in newborns who underwent universal US screening was higher than in those who underwent selective or clinical screening, as reported by Kuitunen *et al.* [19]. Therefore, it is important that pediatricians and general practitioners are able to understand the quality of the US examination and correlate it with clinical findings, regardless of the US method used to evaluate the newborn hip [4,18,19].

In addition, many pediatricians and general practitioners consider neonatal hip US to be an ultraspecialized imaging exam or do not feel knowledgeable enough to judge its validity. The participants in the study had an interest in pediatric orthopedics and, in most cases, more than 10 years of experience. However, they had little or no knowledge of how to interpret a neonatal hip US. It is also possible that in the future, artificial intelligence (AI) will assist in detecting poorly performed US examinations or interpreting correctly performed US examinations. However, local differences should be considered as there may be different approaches

Table 1 Demographics of the study participants

Sex	Male	Female		
	32 (23.7%)	103 (76.3%)		
Age	<35 years	36–50 years	51–65 years	>66 years
	52 (38.5%)	52 (38.5%)	25 (18.5%)	6 (4.4%)
Specialization	Pediatricians	Other practitioners		
	73 (54.1%)	62 (45.9%)		
Years of practicing	<4 years	5–10 years	>10 years	
	39 (28.9%)	25 (18.5%)	71 (52.6%)	
Experience in neonatal hip US	No experience	Limited experience	Moderate experience	
	118 (87.4%)	15 (11.1%)	2 (1.5%)	
Total number of physicians	135			

US, ultrasound.

Table 2 Features of the ultrasound images in the questions (assigned in random order) and number of correct answers per participant

Questions	Features of the ultrasound in the question	Pre	Post	*P*-value
1	Correctly performed	10.4%	85.5%	<0.05
2	Correctly performed	8.1%	78.2%	<0.05
3	Correctly performed	9.6%	89.5%	<0.05
4	Correctly performed	5.9%	73.4%	<0.05
5	Missing standard anatomical element (femoral head; A)	20.0%	96.8%	<0.05
6	Missing standard anatomical element (femoral head; A, B, and C)	25.9%	98.4%	<0.05
7	Missing standard anatomical element (D hook)	19.3%	74.2%	<0.05
8	Incorrect anatomical plane (line A curved)	11.9%	87.9%	<0.05
9	Incorrect anatomical plane (line A oblique)	17%	93.5%	<0.05
10	Incorrect anatomical plane (line A oblique; L not visible)	17.8%	86.3%	<0.05
Correct answers per participant		1.46 ± 2.49	8.64 ± 1.51	<0.05

and management options. Luo *et al.* [20] have highlighted the promise of AI in pediatric orthopaedic care, particularly in assisting with the preliminary assessment of DDH and guiding treatment strategies for specialist care. However, highlighting the importance of a nuanced approach to health technology adaptation, effective integration of AI into clinical practice will require adaptation to specific regional health care contexts.

The strength of the reported method is that we chose not to start with overly technical US descriptions, but with images that are easily recognizable to a relatively inexperienced eye, such as the 'Christmas ball', which the study participants actually learned to recognize quickly, as evidenced by the significant improvement in the second round of ratings.

In fact, since neonatal US images of normal hips are comparable, the study participants were not asked to recognize individual anatomical structures, but rather to recognize whether the particular US image roughly corresponds to the standard image of a normal hip US. The focus of the method is not to teach participants to recognize a pathological hip but rather to teach them to recognize whether the US of a hip diagnosed as normal has been performed correctly.

Our results show that the reported training tool is a quick (15 min), inexpensive, and effective method to provide pediatricians and primary care physicians with little knowledge of interpretation of neonatal hip US with some tools to understand if the examination they are dealing with was performed correctly, thus limiting errors in diagnosis and treatment. To the best of our knowledge, there are no other simple and quick methods in the literature to train professionals in this area. For example, to clarify potential sources of confusion and to highlight the most common errors and mistakes made either during the US examination or during the reporting process, Chlapoutakis *et al.* [16] described the most important aspects of Graf's US technique. However, their report is meant for trainees attending formal courses on this technique and not as a quick tool for nonexpert practitioners.

This method represents only a first step for those wishing to approach the study of hip US and should not be considered a substitute for the information contained in detailed textbooks, and professionals should continue their training with formal 'hands-on' courses, even though this would require a considerable amount of additional time [10,21,22]. Furthermore, it would be desirable for every pediatrician and general practitioner to have direct contact with a trained and experienced sonographer to quickly resolve any doubts.

We acknowledge some limitations of the reported method. Some items (such as the identification of the labrum, L) are essential but require a greater learning curve for adequate recognition. In addition, we deliberately did not include all the elements of the two Graf checklists as they are too complex for an inexperienced user. However, we have included the most important items and those more commonly missing in erroneous US images as observed in our clinical practice. In addition, we considered an increase in the percentage of correct answers as a proxy for understanding of the method, and participants were not assessed on this. Finally, it is possible that this evaluation may not be applicable to all settings where different approaches to the management of hip dysplasia exist.

Conclusion

The 'Christmas ball method' is a simple and relatively quick training tool to help professionals with little or no experience in interpreting neonatal hip US and to help them understand when a US examination has been performed incorrectly. The reported method represents a small additional step in improving the care of patients with DDH. The tool may also provide an incentive for sonographers to improve their training and adhere to the correct criteria or, alternatively, not to perform this type of US.

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Conflicts of interest

There are no conflicts of interest.

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