Evaluation of three ultrasound techniques used for the diagnosis of developmental dysplasia of the hip (DDH)

Poster No.: C-2049
Congress: ECR 2012
Type: Scientific Exhibit
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Keywords: Dysplasias, Diagnostic procedure, Ultrasound, Pediatric, Musculoskeletal system, Musculoskeletal joint
DOI: 10.1594/ecr2012/C-2049

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Purpose

Developmental dysplasia of the hip (DDH) represents a wide spectrum of abnormalities affecting the proximal femur and acetabulum that range from instability, dysplasia, variable degrees of subluxation to an established dislocation. The normal development of the hip joint depends on congruent stability of the femoral head within the acetabulum. Early diagnosis of DDH is essential because it is generally accepted that the early detection can enable less invasive and potentially more effective corrective procedures (1, 2).

Ultrasound is the preferred method for diagnostic imaging of the immature hip and there are a number of techniques available for early detection of DDH. The purpose of this 3-year prospective study was:

- To determine the sensitivity, specificity, and accuracy of Graf’s, Harcke’s and Morin's techniques separately in the diagnosis of DDH.

Methods and Materials

Over a 3-year period, all infants presenting to the Division of Pediatric Orthopaedics of The Clinical Hospital of the State University of Campinas (Brazil), who were clinically suspected of having DDH, underwent the informed consent process and were invited to participate in this study.

225 infants clinically suspected of DDH were examined, comprising a total of 450 single hip studies. The assessment included a clinical questionnaire, physical examination, conventional radiography and ultrasound of both hips. Infants were excluded if they had neurological or muscular disorders detected on physical examination. The mean age and gender of the 225 study participants were as follows: age, 7.79±6.44 weeks; male/female, 36.4%/63.8%.

Clinical questionnaire and physical examination

The questionnaire included information on gender, age, rank of birth, kind of delivery, position of the baby in the uterus, family history of DDH, heritage of the participating child and family and associations with other orthopaedic problems such as torticollis and congenital foot deformity.

The Ortolani and Barlow manoeuvres were used to assess the hips of newborns for DDH by both neonatologist and a senior orthopaedic surgeon.
**Conventional radiographs of both hips**

The initial radiographs were performed on the same day as the physical examinations conducted by an orthopaedic surgeon, and the ultrasound examinations performed by the radiologist. The radiologist and the orthopaedic surgeon were blinded to any medical history or any exam results among study participants. The follow-up radiographs of the subjects were obtained between 6 and 18 months of age, when the ossific nucleus of the femoral head was already present.

The radiographic projections used include anteroposterior (AP) and frog-lateral views of both hips. The latter view is useful for demonstrating the relationship of the femoral head to the acetabulum (Figure 1). The references lines used in the interpretation of AP radiographs for DDH were (Figure 2):

- Hilgenreiner's line
- Perkin's line. The intersection of the Hilgenreiner's line with Perkin's line divides the hip area into four quadrants. The medial metaphyseal beak of the proximal femur should lie within the inner quadrant on normal hips.
- Shenton's line. Discontinuity of Shenton's line represents hip subluxation or dislocation.
- Acetabular index. The acetabular angles were classified as normal or abnormal according to the Atlas of Roentgenographic Measurements (3).

The radiographs were classified as:

- normal when all radiological criteria described above were normal;
- abnormal if one of the criteria was abnormal and;
- inconclusive if the infant hip was in an inappropriate position. Abnormal pelvic positioning adversely affects the diagnosis value of the references lines.

**Classification of the infant hips**

The hips of the infants were classified on the bases of clinical, physical and radiological findings into 3 groups: normal, dysplasic and/or subluxated and dislocated and further divided in confirmed, safety and probable diagnosis, except for the last group. This classification was considered final and served as the gold standard of the study. By comparing this final classification with the three different sonographic methods, the sensitivity, specificity, false positive ratio and accuracy were calculated for the various cutting points.

**Diagnostic Criteria**

1. **Group 1: Normal hip**
1.1. Confirmed Diagnosis

- Follow-up radiographs normal (the femoral head ossific nucleus was visible); adequate assessment of both the position of the femoral head and the appearance of the acetabulum. None of these infants underwent any treatment for DDH.

1.2. Safety Diagnosis

- The initial radiographs normal; normal physical examination by both neonatologist and orthopaedic surgeon; no follow-up radiographs.

1.3. Probable Diagnosis

- The initial radiographs normal; abnormal physical examination by only one examiner (neonatologist or orthopaedic surgeon); no follow-up radiographs.
- The initial radiograph inconclusive; normal physical examination by both neonatologist and orthopaedic surgeon; no follow-up radiographs.

2. Group 2: Dysplasic and/or subluxated Hip

2.1. Confirmed Diagnosis

- The initial radiographs with high acetabular index; abnormal physical examination by both neonatologist and orthopaedic surgeon.

2.2. Safety Diagnosis

- The initial radiographs with high value of acetabular index; abnormal physical examination by only one examiner (neonatologist or orthopaedic surgeon).
- Discontinuity of Shenton's line on the initial radiograph (subluxation); normal value of acetabular index; abnormal physical examination by both neonatologist and orthopaedic surgeon.

2.3. Probable Diagnosis

- The initial radiographs with high value of acetabular index; normal physical examination by both neonatologist and orthopaedic surgeon.
- Discontinuity of Shenton’s line on the initial radiograph (subluxation); normal value of acetabular index; abnormal physical examination by only one examiner (neonatologist or orthopaedic surgeon).
- The initial radiograph inconclusive; abnormal physical examination by both neonatologist and orthopaedic surgeon.

3. Group 3: Dislocated Hip
• On the initial radiograph: discontinuity of Shenton's line and the medial metaphyseal beak of the proximal femur or the femoral ossific nucleus lies into the outer quadrants formed by the intersection of the Hilgenreiner’s and Perkin’s lines.

**Ultrasound examination of the hips**

All ultrasound scans were performed by the senior author (EMBP) who is a skeletal radiologist with special interest in neonatal hips. Detailed descriptions of the three ultrasound techniques used would be beyond the scope of this presentation, but can be found in the cited references. The ultrasound methods used in this study reflect two different philosophies - one based on the morphologic criteria (Graf's and Morin's techniques) and the other on dynamic examination (Harcke’s technique).

1) Graf’s technique

Graf classifies the hip into 4 main types, ranging from normal to dislocated hip (Figures 3-7). The criteria on each the classification is based are child's age, alpha and beta angles, configuration of the promontory and the characteristics of the hyaline cartilage of the acetabular roof (Table 1).

<table>
<thead>
<tr>
<th>Type</th>
<th>Bony Promontory</th>
<th>Cartilage roof</th>
<th>Alpha angle</th>
<th>Beta angle</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mature hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ia</td>
<td>Angular</td>
<td>Covers the femoral head</td>
<td># 60°</td>
<td>&lt; 55°</td>
<td>Any age</td>
</tr>
<tr>
<td>Ib</td>
<td>Slightly rounded</td>
<td>Covers the femoral head</td>
<td># 60°</td>
<td>&gt; 55°</td>
<td>Any age</td>
</tr>
<tr>
<td>Type II</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ila</td>
<td>Rounded (physiological immature,)</td>
<td>Covers the femoral head</td>
<td>50-59°</td>
<td>&gt; 55°</td>
<td>&lt; 6 weeks</td>
</tr>
<tr>
<td>Type</td>
<td>Description</td>
<td>Covers the femoral head</td>
<td>Degree</td>
<td>Duration</td>
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<tr>
<td>Ila(+)</td>
<td>Rounded</td>
<td>55-59°</td>
<td>&gt; 55°</td>
<td>6-12 weeks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(physiological immature, appropriate for age)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ila(-)</td>
<td>Rounded</td>
<td>50-54°</td>
<td>&gt; 55°</td>
<td>6-12 weeks</td>
<td></td>
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<tr>
<td></td>
<td>(maturational deficit)</td>
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<td></td>
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<tr>
<td>Ilib</td>
<td>Rounded</td>
<td>50-59°</td>
<td>&gt; 55°</td>
<td>&gt; 12 weeks</td>
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<td></td>
<td>(delay ossification)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Ilc</td>
<td>Rounded or flattened</td>
<td>43-49°</td>
<td>&lt; 77°</td>
<td>Any age</td>
<td></td>
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<tr>
<td></td>
<td>(critical hip)</td>
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<td>Decentering Hip</td>
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</tr>
<tr>
<td>D</td>
<td>Rounded or flattened</td>
<td>Displaced</td>
<td>43-49°</td>
<td>&gt; 77°</td>
<td>Any age</td>
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<tr>
<td>Eccentric hip</td>
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</tr>
<tr>
<td>Illa</td>
<td>Flattened</td>
<td>Pressed upwards</td>
<td>&lt; 43°</td>
<td>&gt; 77°</td>
<td>Any age</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without structural</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>alteration</td>
<td></td>
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</tr>
<tr>
<td>IIIb</td>
<td>Flattened</td>
<td>Pressed upwards</td>
<td>&lt; 43°</td>
<td>&gt; 77°</td>
<td>Any age</td>
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<td></td>
<td></td>
<td>with structural</td>
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<td></td>
<td>alteration (echogenic)</td>
<td></td>
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<tr>
<td>IV</td>
<td>Flattened</td>
<td>Pressed downwards</td>
<td>&lt; 43°</td>
<td>&gt; 77°</td>
<td>Any age</td>
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<td></td>
<td></td>
<td>interposed between the</td>
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<td></td>
<td></td>
<td>femoral head</td>
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</table>
2) Harcke's technique

Harcke's technique is subjective and emphasis the positional relationship between the femoral head and the acetabulum, as well as hip stability. The diagnostic exam should include a coronal view in the standard plane at rest and a transverse view of the flexed hip with and without stress. The hips are classified as normal, subluxated and dislocated (Figures 8-11).

3) Morin's technique

Morin et al (1985), consider that a percentage of femoral head coverage by the bone acetabular roof below 33% indicates abnormal hip and above 58% indicates normal hip, hips with coverage percentages between 33 and 58% remains without a definite diagnosis (Figure 12).

Images for this section:
**Fig. 1:** Diagram in the frog-leg position showing dislocation of the left hip. DDQ, developmental dysplasia of the hip.
**Fig. 2:** Diagram showing the lines and the acetabular index used to assess the developing hip. â, acetabular index; FM, femoral metaphysis; HL, Hilgenreiner’s line; PL, Perkin’s line; SL, Shenton’s line; DDQ, developmental dysplasia of the hip.
Fig. 3: Normal mature hip. Type Ib according to Graf (#= 65°, #= 74°); angular bony promontory (arrow); IL, ilium; TC, hypoechoic triradiate cartilage; 1, Baseline; 2, acetabular roof line; 3, Labral line; (*), hyaline cartilage of the acetabular roof; (+), labrum.
**Fig. 4:** Figure 4. A, B. Same hip. Physiological immature hip, appropriate for age. Type IIa(+) according to Graf (β= 55°, α= 77°); rounded bony promontory (arrow); FH, femoral head; GT, great trochanters; IL, ilium; TC, hypoechoic triradiate cartilage; 1, Baseline; 2, acetabular roof line; 3, Labral line; (*), hyaline cartilage of the acetabular roof; (+), labrum.

**Fig. 5:** Critical hip. Type IIc according to Graf (β= 44°, α= 74°); Rounded or flattened bony promontory; FH, femoral head; GT, great trochanters; TC, hypoechoic triradiate cartilage.
Fig. 6: Graf type IIb (θ = 34°, ψ = 123°)
Fig. 7: Graf type IV
Fig. 8: A: Transverse neutral sonogram of normal hip shows the femoral head (CF) centered over the triradiate cartilage with pubis (P) anteriorly and ischium (IS) posteriorly; B, Sonogram of a dislocated femoral head.

Fig. 9: A: Transverse flexion sonogram of a normal hip; B: Transverse flexion sonogram of an abnormal hip.
Fig. 10: A1, A2: Normal posterior lip of the acetabulum shows triradiate cartilage (T) between ilium and ischium. Femoral head is not normally seen on this view; B1, B2: Instable hip, the femoral head is seen on this view after stress maneuvers.
Fig. 11: Posterior lip sonogram of a dislocated hip shows abnormally positioned femoral head (FH).
Fig. 12: Morin’s technique
Results

Of the 450 hips classified on the bases of clinical, physical and radiological findings, 407 (90.4%) were classified as normal, 30 (6.7%) as dysplasic and/or subluxated and 13 (2.9%) as dislocated.

The sensitivity, specificity, false-positive ratio and accuracy were analysed for the various cutting points in the ultrasonographic exam, according to the Graf’s, Harcke's and Morin's techniques, separately.

Comparing the results, it was proven that the most adequate ultrasound technique for the diagnosis of DDH was Graf’s technique, being the alpha angle (acetabular inclination angle) the most reliable criteria for treatment indication. Considering the cutting point at the level of type IIa(+), the Graf’s technique reached 100% of sensitivity and 96.6% of specificity for the confirmed (definitive) diagnosis; 87.5% and 96.4% for the confirmed and safety diagnosis and 87.5% and 93.8% for the confirmed, safety and probable diagnosis together.

Through Graf’s technique, it was not possible to establish definitive criteria in order to distinguish the physiologic immaturity of the hip from minor dysplasia of the hip, which needs treatment.

Using Harcke's technique, the best cutting point was achieved when classifying the hips with isolated instability as normal. The sensitivity value was 100% and the specificity value was 95.8% for the confirmed (definitive) diagnosis; 80.0% and 96.4% for the confirmed and safety diagnosis and 80.0% and 96.6% for the confirmed, safety and probable diagnosis together.

Using Morin's technique, considering as normal the hips with the percentage of coverage of the femoral head by the bony acetabulum greater or equal to 44%, the sensitive value was 93.3%, and the specificity value was 76.2% for the confirmed (definitive) diagnosis; 79.2% and 77.9% for the confirmed and safety diagnosis and 79.2% and 78.4% for the confirmed, safety and probable diagnosis together.

Images for this section:
Fig. 13: ROC curves comparing Graf’s (curve 1), Harcke’s (curve 2) and Morin’s techniques (curve 3). We only included the hips with a confirmed clinical and radiological diagnosis.
**Fig. 14:** ROC curves comparing Graf's (curve 1), Harcke's (curve 2) and Morin's techniques (curve 3). We included the hips with a confirmed and a safety clinical and radiological diagnosis.

**Fig. 15:** ROC curves comparing Graf's (curve 1), Harcke's (curve 2) and Morin's techniques (curve 3). We included all the hips.
Conclusion

• Comparing the results, the most adequate ultrasonographic technique for the diagnosis of DDH was the Graf’s technique.
• The sensitivity and specificity for diagnosis DDH of Morin’s technique were lower than the other two techniques.
• Dynamic examination (Harcke’s technique) may be used as a complement of the Graf’s technique.

References


Personal Information