Selective ultrasound screening for developmental hip dysplasia: effect on management and late detected cases. A prospective survey during 1991–2006

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Abstract

Background Early treatment is considered essential for developmental dysplasia of the hip (DDH), but the choice of screening strategy is debated.

Objective We evaluated the effect of a selective ultrasound (US) screening programme.

Materials and methods All infants born in a defined region during 1991–2006 with increased risk of developmental dysplasia of the hip, i.e. clinical hip instability, breech presentation, congenital foot deformities or a family history of DDH, underwent US screening at age 1–3 days. Severe sonographic dysplasia and dislocatable/dislocated hips were treated with abduction splints. Mild dysplasia and pathological instability, i.e. not dislocatable/dislocated hips were followed clinically and sonographically until spontaneous resolution, or until treatment became necessary. The minimum observation period was 5.5 years.

Results Of 81,564 newborns, 11,539 (14.1%) were identified as at-risk, of whom 11,190 (58% girls) were included for further analyses. Of the 81,564 infants, 2,433 (3.0%) received early treatment; 1,882 (2.3%) from birth and 551 (0.7%) after 6 weeks or more of clinical and sonographic surveillance. An additional 2,700 (3.3%) normalised spontaneously after watchful waiting from birth. Twenty-six infants (0.32 per 1,000, 92% girls, two from the risk group) presented with late subluxated/dislocated hips (after 1 month of age). An additional 126 (1.5 per 1,000, 83% girls, one from the risk group) were treated after isolated late residual dysplasia. Thirty-one children (0.38 per 1,000) had surgical treatment before age 5 years. Avascular necrosis was diagnosed in seven of all children treated (0.27%), four after early and three after late treatment.

Conclusion The first 16 years of a standardised selective US screening programme for developmental dysplasia of the hip resulted in acceptable rates of early treatment and US follow-ups and low rates of late subluxated/dislocated hips compared to similar studies.

Keywords Developmental dysplasia of the hip · Hip dysplasia · Hip ultrasound · Paediatric · Neonatal screening

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Introduction

Developmental dysplasia of the hip (DDH) is the most common musculoskeletal disorder in infants, and early

detection and treatment of at least severe DDH is considered essential to avoid later complicated treatment and possible disability [1]. Developmental dysplasia of the hip as a pathological entity encompasses features related to both morphology and instability. Acetabular dysplasia has been reported in about 0.5–4% of newborns, and neonatal hip instability in 1–2% [2–5]. Although hip instability can be assessed both clinically and sonographically, the morphological component (acetabular dysplasia) is detectable sonographically but not clinically in newborns. Although a close association between hip stability and morphology has been demonstrated, a normal acetabulum can coexist with a dislocatable femoral head and vice versa [2]. Late cases with subluxated or dislocated hips have been reported in 0.1–3.0 per 1,000 after clinical screening alone [5–7], and in 0.2–0.7 per 1,000 when selective ultrasonography is added to the clinical screening [7–12]. Different ultrasonography methods for diagnosing developmental dysplasia of the hip have been advocated, i.e. a static method (Graf's method) [13], followed by dynamic methods, and later by a combination of the two (Rosendahl's method) [14]. Treatment rates based on the different screening strategies vary from about 1% to 7.7% of all newborns [6, 15]. Avascular necrosis of the femoral head is a severe albeit rare complication reported in 1–4% of all treated infants [3, 16, 17].

Based on the experience of a large randomised controlled trial [7], selective US screening was established at our institution in 1990, in addition to the existing clinical screening. Here we report on rates and management of developmental dysplasia of the hip and rates of late-detected cases and surgical treatment from the first 16 years of this screening programme.

Materials and methods

DDH screening programme

All newborns had a routine clinical hip examination within the first 3 days after birth, before being discharged from the maternity unit. During the study period about 40 paediatricians with at least 2 years of experience were involved in the clinical assessment of the hips, including stability using the Barlow/Ortolani tests (Fig. 1). Limited hip abduction was also noted. Risk factors for developmental dysplasia of the hip from the medical history or clinical examination (Table 1) were recorded in a report form that also served as a referral for hip US (Appendix 1). The paediatric, orthopaedic and paediatric radiology departments managed the follow-up and treatment of developmental dysplasia

of the hip according to a predefined protocol that remained unchanged during the whole period (Appendix 2) [18]. Mild acetabular dysplasia was, however, often treated from birth rather than followed with US during the first years of the protocol.
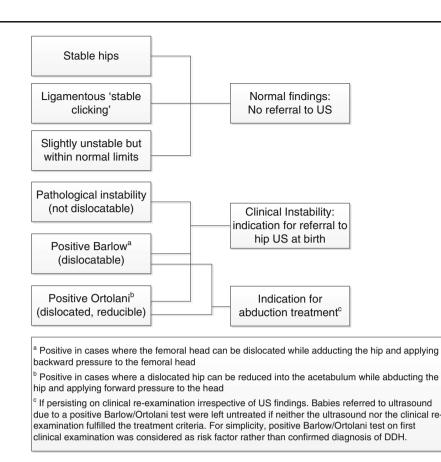
Population

We included all infants born at the maternity unit at Haukeland University Hospital from January 1991 through December 2006. The hospital provides the only delivery unit for the city and suburbs of Bergen, Norway and a large rural area within Hordaland County, Norway. It serves a population of approximately 400,000 inhabitants, predominantly ethnic Norwegians. The annual birth rates varied from 4,723 to 6,010. The annual migration rate of this area is low (1.6%) [19]. Minimum observation time was 5.5 years. We excluded children with developmental dysplasia of the hip caused by neuromuscular syndromes.

Hip ultrasonography

The ultrasonography examination was performed 1–2 days after the clinical examination while the neonate was still in the maternity unit. During the whole time period of the study, the US examination was performed by one of six consultant paediatric radiologists with 2–20 years of experience in hip ultrasonography (AA, OE, SMA, JAB, KB, KR), using an RT200 machine until 1996 and thereafter an RT3600, both equipped with 5-MHz linear transducers (GE Healthcare, Munich, Germany). A modified Graf technique (Rosendahl's method) was used to assess hip morphology (Fig. 2) and stability (Fig. 3) [14]. Morphologically immature hips were considered within the normal range. In children with US findings suggestive of developmental dysplasia of the hip or when clinical instability had been demonstrated prior to the US examination, the children had a clinical re-examination by one of the paediatricians the following day. The results were recorded in the report form (Appendix 1), which also served as a referral to early abduction treatment or follow-up at the paediatric outpatient clinic.

Treatment and follow-up

Newborns with a persistent dislocated or dislocatable hip as assessed clinically or sonographically and those with severe sonographic dysplasia received immediate abduction treatment with a Frejka's splint (Appendix 2). Newborns with clinically or sonographically unstable but not dislocatable hips (i.e. pathological instability)

Fig. 1 Clinical assessment of hip stability at birth. The Barlow/ Ortolani tests are performed separately in the supine child with hips flexed to 90°, one hip at a time

Stable hips

Ligamentous 'stable clicking'

Slightly unstable but within normal limits

Normal findings: No referral to US

Pathological instability (not dislocatable)

Positive Barlow[a] (dislocatable)

Positive Ortolani[b] (dislocated, reducible)

Clinical Instability: indication for referral to hip US at birth

Indication for abduction treatment[c]

[a] Positive in cases where the femoral head can be dislocated while adducting the hip and applying backward pressure to the femoral head

[b] Positive in cases where a dislocated hip can be reduced into the acetabulum while abducting the hip and applying forward pressure to the head

[c] If persisting on clinical re-examination irrespective of US findings. Babies referred to ultrasound due to a positive Barlow/Ortolani test were left untreated if neither the ultrasound nor the clinical re-examination fulfilled the treatment criteria. For simplicity, positive Barlow/Ortolani test on first clinical examination was considered as risk factor rather than confirmed diagnosis of DDH.

or with mild sonographic dysplasia were subject to watchful waiting and were reviewed clinically and sonographically at 6 weeks of age. Treatment was then initiated if the clinical or sonographic examination showed deterioration or no improvement (Fig. 4). The rest were discharged at 6 weeks or had a repeat US exam at 12 weeks and/or a pelvic radiograph at 4 1/ 2 months as appropriate (Appendix 2). Newborns with stable (clinically and sonographically) and morphologically normal or immature hips at birth were discharged to routine follow-up within the public Healthy Child Programme, except that infants with a significant family history of late developmental dysplasia of the hip were referred for a pelvic radiograph at 4.5 months of age. Abduction treatment initiated at birth was typically continued for 3 months with clinical and US assessment at 6 weeks and at the end of treatment, but treatment was extended if necessary. In severe cases detected at birth and in cases where initial treatment was followed by deterioration or no improvement, the paediatric

Table 1 Indications for hip ultrasonography among newborns referred because of increased risk for developmental dysplasia of the hip. Figures are presented as total number and rates (%). More than one indication was possible for one infant

Risk factor	Total, $n=11,190$	Boys, $n=4,741$	Girls, $n=6,449$
Clinical hip instability on first newborn examination[a]	3,334 (29.8)	1,022 (21.6)	2,312 (35.9)
Positive family history[b]	4,739 (42.4)	2,253 (47.5)	2,486 (38.5)
Breech presentation at delivery	2,513 (22.5)	1,108 (23.4)	1,405 (21.8)
Congenital foot deformity	197 (1.8)	85 (1.8)	112 (1.7)
Other reason[c]	1,858 (16.6)	749 (15.8)	1,109 (17.2)

[a] Includes pathological instability, dislocatable and dislocated hips. Of 3,334 referred, 1,351 had dislocatable/dislocated hips and were treated

[b] ≥1 1st-degree (sibling, parent) or ≥2 2nd-degree (aunt, uncle, grandparent) relative

[c] Includes slightly unstable hips, clicks, torticollis, muscular hypo- or hyper-tonicity or unknown
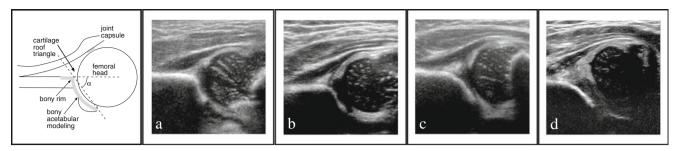
Fig. 2 Sonographic assessment of hip morphology in newborns using Graf's standard coronal view [13] and the alpha angle. Each hip was morphologically classified as (**a**) normal ($\alpha \geq 60°$), (**b**) immature ($50° \leq \alpha$ <60°), (**c**) mildly dysplastic ($43° \leq \alpha < 50°$) or (**d**) severely dysplastic ($\alpha < 43°$) [14]

orthopaedic surgeons were involved. The Frejka's pillow was either replaced with an age-adapted abduction orthosis, or sometimes traction and closed or open reduction followed by cast abduction treatment was initiated. All US examinations after the initial newborn examination were performed at the paediatric radiology department by one of the six consultant paediatric radiologists using a high-resolution US machine (Acuson 128 XP until 1996, and later an ATL HDI 5000, both with a linear 5–10/12 MHz transducer; Siemens, Erlangen, Germany), and the same modified Graf's technique. The results were archived manually until 2001 and thereafter in the RIS/PACS system (Agfa IMPAX Web1000, v.5.0; Agfa Gaevert, Mortsel, Belgium). Pelvic radiographs replaced US examinations from 4.5 months of age and were performed by one of six paediatric radiographers according to a standardised protocol and read by one of the six paediatric radiologists. On radiographs, hips were classified morphologically based on the acetabular index (AI) according to Tönnis and Brunken [18] (Appendix 2), with or without a subluxated or dislocated femoral head (Fig. 5) [20]. A flattened femoral head or a thinned femoral neck suggestive of avascular necrosis of the femoral head was also noted [16]. Children with radiographic abnormality of the hip(s) or who had been treated surgically were regularly seen by a paediatric orthopaedic surgeon until skeletal maturity or normalisation. Su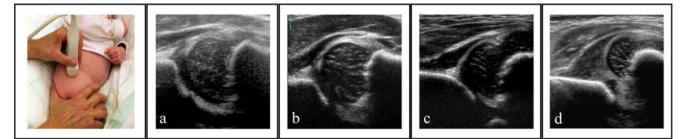rgical treatment included closed reduction (including traction, cast treatment and adductor tenotomy), open reduction and osteotomies.

The Healthy Child Programme and recognition of late DDH

In this national programme, hips are examined at 6 weeks, 6 months and 1 year of age to detect late-presenting developmental dysplasia of the hip (i.e. after 1 month of age). When there is clinical suspicion of late developmental dysplasia of the hip, usually limited abduction of flexed hips, the child is referred for hip imaging or a clinical expert hip-assessment at the paediatric outpatient clinic until 3 months of age, and thereafter to the paediatric orthopaedic clinic. During the study period, an associate orthopaedic hospital, Kysthospitalet in Hagevik, received some referrals querying late developmental dysplasia of the hip. The corresponding radiographs were re-analysed in consensus (KR, KI) to standardise the diagnosis of late developmental dysplasia of the hip.

Data collection and analysis

All data on risk factors, on results of clinical, US and radiographic examinations and on treatment were collected prospectively and registered in the DDH-screening report form (Appendix 1). Data on late referrals were also collected prospectively. All data were

Fig. 3 Sonographic assessment of hip stability in newborns (Rosendahl's method) [14]. By using a modified Barlow maneuver with the baby in the same lateral position, hips were classified as (**a**) stable, (**b**) unstable (significant movement of the femoral head, but not dislocatable), (**c**) dislocatable or (**d**) dislocated
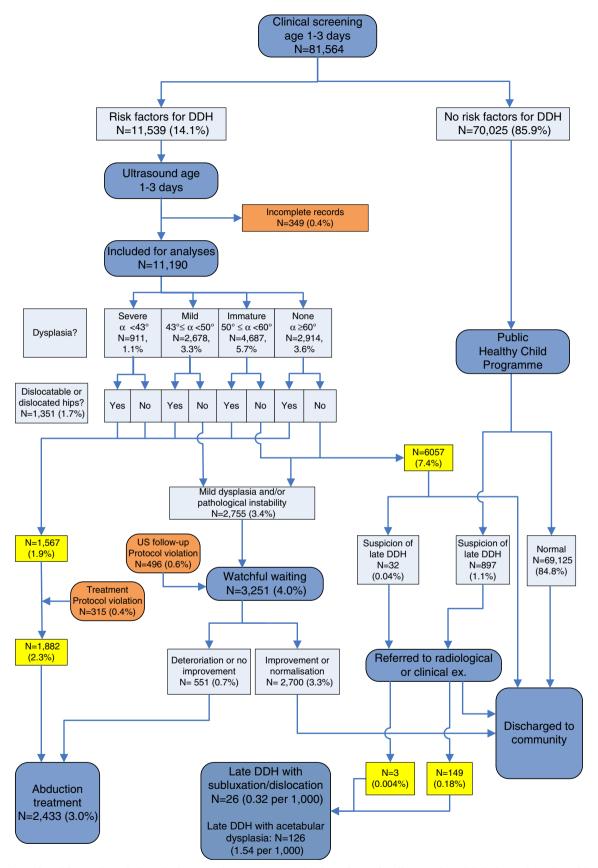
Fig. 4 Flow of participants through the selective screening programme. The denominator for all proportions (%) is the total number of live births (81,564) from January 1991 through December 2006
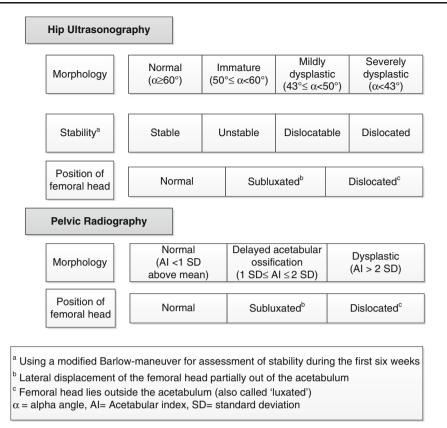
Hip Ultrasonography

Morphology	Normal (α≥60°)	Immature (50°≤ α<60°)	Mildly dysplastic (43°≤ α<50°)	Severely dysplastic (α<43°)

Stability[a]	Stable	Unstable	Dislocatable	Dislocated

Position of femoral head	Normal	Subluxated[b]	Dislocated[c]

Pelvic Radiography

Morphology	Normal (AI <1 SD above mean)	Delayed acetabular ossification (1 SD≤ AI ≤2 SD)	Dysplastic (AI > 2 SD)

Position of femoral head	Normal	Subluxated[b]	Dislocated[c]

[a] Using a modified Barlow-maneuver for assessment of stability during the first six weeks
[b] Lateral displacement of the femoral head partially out of the acetabulum
[c] Femoral head lies outside the acetabulum (also called 'luxated')
α = alpha angle, AI= Acetabular index, SD= standard deviation

Fig. 5 Radiologic assessment of developmental dysplasia of the hip. Ultrasonography is used until the age of 4.5 months, with separate assessment of morphology and stability (Rosendahl's method) [14] during the first 6 weeks of age. Thereafter when the hips are considered stable the position of the femoral head is assessed rather than stability [20]. Pelvic radiographs are used from 4.5 months of age onwards

entered into a Microsoft Access 2010 database by one of four people during 2005–2011. To ensure that all babies (including low-risk babies) born at our hospital who had received abduction treatment or surgery were included in the dataset, additional searches based on all the DDH-related diagnoses and procedures (abduction treatment, traction, plaster cast, open and closed reductions, and osteotomies) and on diagnosis of avascular necrosis of the femoral head were performed retrospectively within the database of the university hospital (including Kysthospitalet in Hagevik) during August–October 2012. Additional information was retrieved from the clinical patient records when needed. The Access database was exported into IBM® SPSS® Statistics, version 20.0 (Armonk, NY). Data were summarised as rates per 100 and per 1,000 with corresponding 95% confidence intervals (CI) as appropriate [21].

Ethics approval

The research protocol was approved by the Regional Ethics Committee for Medical and Health Research (003.07) and performed in accordance with the 1964 Declaration of Helsinki. This study was exempted from the requirement of parental written informed consent.

Results

Of 81,564 live births (49.1% girls), 11,539 (14.1%, 95% CI 13.9–14.3) babies were identified as being at risk for developmental dysplasia of the hip and had a hip US examinations. Of these, 349 newborns with incomplete report forms from the newborn examination (unidentifiable subjects with substantial lack of clinical or sonographic information) and without further treatment or follow-up were excluded from further analyses related to early treatment and follow-up. For the 11,190 infants (57.6% girls) with adequate information, indications for hip US are presented in Table 1. Of these, 67.9% had normal acetabular morphology but 5.2% of those with normal morphology had dislocated or dislocatable hips (Table 2). The remaining 70,025 (85.9%) newborns were classified as low-risk (Fig. 4).

Table 2 Sonographic hip morphology at birth by gender among 11,190 babies at risk for developmental dysplasia of the hip based on the worst affected hip, and number (%) with clinically or sonographically dislocatable or dislocated hips according to morphology

	Hip morphology, n (%)			Number (%) with additional dislocatable/dislocated hips		
	Total	Boys	Girls	Total	Boys	Girls
Normal	2,914 (26.0)	1,685 (35.5)	1,229 (19.1)	12 (0.4)	4 (0.24)	8 (0.65)
Immature	4,687 (41.9)	2,059 (43.5)	2,628 (40.8)	224 (4.8)	65 (3.2)	159 (6.1)
Mild dysplasia	2,678 (24.0)	829 (17.5)	1,849 (28.7)	420 (15.7)	83 (9.9)	337 (18.2)
Severe dysplasia	911 (8.1)	168 (3.5)	743 (11.5)	695 (76)	125 (74.4)	570 (76.7)
Total	11,190 (100)	4,741 (100)	6,449 (100)	1,351 (12)	277 (5.8)	1,074 (16.7)

Treatment and follow-up of early detected cases

In all, 2,433 infants received abduction treatment after early detected developmental dysplasia of the hip (3.0% of the whole cohort, 21.7% of those at risk); 1,882 (2.3%) were treated from birth and 551 (0.7%) were treated after clinical and sonographic surveillance (414 after a mean of 6 [range 4–9] weeks, 105 after a mean of 12 [range 10–18] weeks and 32 after 20 weeks). Of the 1,882 infants treated from birth, 315 (0.4% of whole cohort) received early treatment without a valid indication according to the protocol (Table 3), of whom 231 (73.3%) were treated based on mild dysplasia alone. An additional 2,700 (3.3% of the whole cohort,

24.1% of those at risk) were followed clinically and sonographically from birth until significant improvement or normalisation (Table 4), with a mean follow-up time of 11 weeks (range 4–64 weeks). The yearly rates of both abduction treatment and of US follow-up declined slightly throughout the study period (Fig. 6). Of the 1,882 infants who were treated from birth, 1,351

Table 3 Rates of early abduction treatment according to clinical and sonographic findings at birth. Rates (% with 95% confidence interval [CI]) are presented with the total number of live births (81,564) as the denominator

Early abduction treatment	Total	Boys	Girls	% of whole cohort (95% CI)
Treatment from birth: total	1,882	412	1,470	2.3% (2.2–2.4)
Dislocatable or dislocated hip (clinically or sonographically) *and* severe dysplasia	695	125	570	
Dislocatable or dislocated hip (clinically or sonographically) *without* severe dysplasia	656	152	504	
Sonographically severe dysplasia, *without* dislocatable/dislocated hip	216	43	173	
Other reasons[a]	315	92	223	
Treatment from ≥6 weeks (after watchful waiting and repeat ultrasonography)	551	116	435	0.7% (0.6–0.8)
Total early treatment	2,433	528	1,905	3.0% (2.9–3.1)

[a] Mildly dysplastic but stable hips, or pathologically or slightly unstable hips on clinical examination

Table 4 Rates of watchful waiting for babies at risk for developmental dysplasia of the hip who had unstable (not dislocated/dislocatable hips) and/or mild dysplasia as newborns
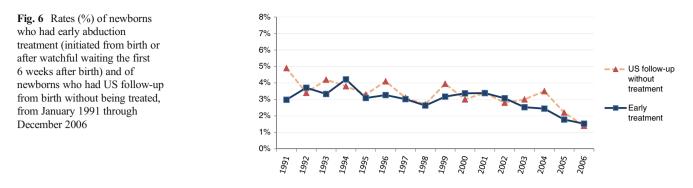
Watchful waiting from birth	Total	Boys	Girls	% of whole cohort, (95% CI)
Only ultrasonography follow-up, no treatment				
Clinical or sonographic pathological instability alone	774	316	458	
Mild sonographic dysplasia alone	260	108	152	
Both pathological instability and mild dysplasia	1,212	442	770	
Other reasons[a]	454	210	244	
Total[b]	2,700	1,076	1,624	3.3%, (3.2–3.4)
Treatment after 6 weeks or longer of watchful waiting[c]				
Clinical or sonographic pathological instability alone	106	22	84	
Mild sonographic dysplasia alone	86	19	67	
Both pathological instability and mild dysplasia	317	63	254	
Other reasons[a]	42	12	30	
Total	551	116	435	0.7%, (0.6–0.8)

Rates (% with 95% confidence interval (CI)) are presented with the total number of live births (81,564) as the denominator

[a] Immature hips on ultrasonography and slightly unstable hips on clinical newborn examination

[b] 1,539 (57%) were followed until 6 weeks, 876 (32%) until 3–4 months, and the remaining 285 (11%) longer than 4 months before initiation of treatment

[c] These children are included in the early treatment rate (Table 3)

Fig. 6 Rates (%) of newborns who had early abduction treatment (initiated from birth or after watchful waiting the first 6 weeks after birth) and of newborns who had US follow-up from birth without being treated, from January 1991 through December 2006

(1.7% of the total cohort, 71.8% of those treated from birth) had clinically or sonographically dislocatable or dislocated hips; 695 of them also had severe sonographic dysplasia (Table 4).

Late-detected cases

Of the 81,564 infants, 26 (0.32 per 1,000, 92% girls) were treated for severe late developmental dysplasia of the hip with a subluxated or dislocated hip (Table 5). Of these 26 children, two were from the risk group. These two girls were reported to have normal hip US examinations at birth, but evaluated in retrospect one of them had a mildly dysplastic hip. One hundred twenty-six other infants (1.54 per 1,000, 83% girls) were treated after a late diagnosis of isolated residual dysplasia (Table 5); one girl was from the at-risk group. Median age at diagnosis was 16 weeks (range 6–156 weeks) for

the 26 late cases with subluxation/dislocation, and 11 weeks (range 5–208 weeks) for the 126 late cases with residual dysplasia. Five other children presented with residual dysplasia later than 5 years of age; two girls at ages 16 and 18 years were from the at-risk group and had received routine abduction treatment from birth, and three at ages 8, 17 and 19 years (one girl) were from the low-risk group. Additional details are summarized in Appendix Table 7.

Surgical treatment

Thirty-one children underwent a first surgical treatment before 5 years of age (0.38 per 1,000) (Table 6). From the at-risk group, nine children had initial surgical treatment (two open and seven closed reductions), and seven underwent surgical treatment after failure of initial abduction treatment. Fifteen low-risk infants underwent surgical treatment due to late-detected developmental dysplasia of the hip. Further details are provided in Appendix Table 7.

Avascular necrosis

Avascular necrosis of the femoral head was diagnosed in 7 of the 2,585 treated children (0.27%, 95% CI 0.07–0.47%). In four children (one boy, three girls) the avascular necrosis occurred after treatment from birth, and in three (all girls) it occurred after treatment of late-detected developmental dysplasia of the hip (Appendix Table 7).

Discussion

To summarise the salient points of this population-based prospective study, 14.1% of all newborns were identified as being at risk for developmental dysplasia of the

Table 5 Children with late-detected developmental dysplasia of the hip diagnosed before 5 years of age according to low-risk or at-risk criteria for developmental dysplasia of the hip. Rates (% with 95% confidence interval [CI]) are presented with the total number of live births (81,564) as the denominator

	Low-risk group[a] (boys + girls)	At-risk group[b] (boys + girls)
Late subluxation	16 (2+14)	2 (0+2)
Late dislocation	8 (0+8)	0
Total (late subluxation + dislocation)	26 (2+24)	
Rate per 1,000 (95% CI)	0.32 (0.20–0.44)	
Late residual dysplasia	125 (21+104)	1 (0+1)
Total (residual dysplasia)	126 (21+105)	
Rate per 1,000 (95% CI)	1.54 (1.27–1.81)	

[a] No risk factors and not examined by early ultrasonography
[b] Examined by ultrasonography as newborns because of risk due to heredity, breech presentation, foot deformities or pathological instability on clinical examination

Table 6 Children undergoing a first surgical treatment performed before 5 years of age according to low-risk or at-risk categories for developmental dysplasia of the hip

	Low-risk group[a] (boys + girls)	At-risk group[b] (boys + girls)
Surgical treatment[c]		
Osteotomy	3 (0+3)	3(0+3)
Open reduction	3 (0+3)	4 (3+1)
Closed reduction	9 (0+9)	9 (2+7)
Total (0 weeks-5 years)	31 (5+26)	
Rate per 1,000, (95% CI)	0.38 (0.25–0.51)	

Rates (% with 95% confidence interval [CI]) are presented with the total number of live births (81,564) as the denominator

[a] No risk factors and not examined by early ultrasonography

[b] Examined by ultrasonography as newborns because of risk from heredity, breech presentation, foot deformities or pathological instability on clinical examination

[c] All in need of surgery from the low-risk group were late-detected cases. All from the at-risk group were detected from birth (nine had initial surgical treatment and seven were treated surgically after failure of abduction treatment)

hip and had a hip US examination at birth. Of the whole cohort, 3.0% received treatment based on early screening, 2.3% from birth and 0.7% after 6 weeks or more of clinical and sonographic surveillance. An additional 3.3% normalised spontaneously after watchful waiting from birth. A total of 0.32 per 1,000 children were treated for late-detected subluxation or dislocation, all but two from the group that did not have early ultrasonography. A total of 0.38 per 1,000 had surgical treatment before age 5 years. AVN was diagnosed in seven of all children treated (0.27%), four after early and three after late treatment.

We acknowledge several limitations of our study. Children with late-detected developmental dysplasia of the hip may have moved out of our catchment area. However, the migration rate is low [19], and children with subluxated or dislocated hips would most likely have been referred back unless the family had moved to another major region of the country because our hospital has a regional service. We also performed detailed searches within hospital records to avoid missed cases. The strengths of this study include standardised and unchanged protocols for clinical and US screening and management throughout the study time period, and a prospective collection of data. Well-trained physicians performed the clinical screening. As few as six experienced paediatric radiologists performed all the US examinations using a validated, combined US technique,

as well as all the radiographic interpretations. We therefore acknowledge that good clinical education and well-organised clinical screening at birth performed by experienced investigators is essential for success with this selective US strategy.

The proportion identified as at-risk of developmental dysplasia of the hip compared well to the 7–18% reported in similar surveys [7, 8, 10–12]. Identification of groups at risk for developmental dysplasia of the hip has been addressed in several studies [3]. In our study, family history of developmental dysplasia of the hip was the most frequent risk factor, in agreement with a recent review [22]. However, there is no consensus on the best way to measure the different risk components, and calibration of risk scoring methods in different populations is frequently poor. Future identification of susceptibility genes for developmental dysplasia of the hip might help improve the validity of methods and their effectiveness in guiding management decisions. The rates of immediate treatment (2.3%), treatment after watchful waiting (0.7%), and monitoring until spontaneous improvement (3.3%) compare well with the results of a previous randomised controlled trial performed at our institution [7]. In some regions selective US screening has resulted in treatment rates of 1–4% [23, 24], while universal US screening has resulted in treatment rates of up to 7.7% [15, 24, 25]. The observed decrease in annual, early treatment rates was partly a result of watchful waiting rather than treatment of mild developmental dysplasia of the hip, reflecting better adherence to the implemented screening programme. This gradual change was encouraged by an ongoing randomised controlled trial that showed that there were no differences in radiographic outcome at 6 years of age between children who did and did not receive abduction splinting for mild developmental dysplasia of the hip from birth [26].

The major objective of the selective US screening programme was in fact met, in that the rate of late subluxated or dislocated hips was lower than those based on a previous randomised controlled trial and on historical data (0.32 vs. 1.3 and 2.6 per 1,000 births, respectively) [7]. The rate of 0.32 per 1,000 compares well to other studies using selective US (0.2–0.7 per 1,000) [7–11] or universal US screening (0.13–0.3 per 1,000) [7, 10]. However no screening strategy has succeeded in eliminating all late cases, suggesting that US examination is less than 100% sensitive or that dysplastic but stable hips at birth can progress to dislocation. The development of a clinically and sonographically normal newborn hip into later

dislocation appears less likely because all but three of the late-presenting cases in our survey were low-risk babies, i.e. had no US screening. The relatively low rate of late-detected subluxations and dislocations in our study suggests that a universal US screening programme might not be cost-effective because it would require considerable resources both for initial screening and for follow-up [27]. However, 16 of 18 late-detected subluxations and all eight late dislocations were from the low-risk group, and all but two of the subluxations were on girls. This finding might support an argument for offering US screening for at least all girls in regions with higher rates of late-detected subluxations and dislocations. Most children with late-detected developmental dysplasia of the hip were treated for residual dysplasia without subluxation or dislocation. These children were mainly referred for asymmetry on hip abduction, which in absence of subluxation might be positional and related to preferred sleeping position, for example, secondary to torticollis. The natural course of acetabular dysplasia remains unknown, but radiographic residual dysplasia has been shown to occur in 2–3% of healthy 5-month-old children without any risk factors [28]. This suggests that at least the majority of these infants would have recovered without treatment. The rate of a first surgical treatment of 0.38 per 1,000 compares well with a rate of 0.40 per 1,000 reported for another selectively screened population [8].

The concept of "watchful waiting" in cases of mild dysplasia for at least 6 weeks proved helpful, because hips in four out of five infants normalised spontaneously within the first 6 months. One might argue that postponing the US screening programme until 6 weeks of age would allow for spontaneous recovery, facilitating the identification of those in need of treatment. We suggest four arguments against delayed US screening. First, treatment may be unduly delayed in newborns with clinically undetected but severe pathology on ultrasonography. This was true for one in ten of those treated from birth in this study. This figure is conservative because some of the dislocatable or dislocated hips were first acknowledged at the clinical re-examination after first being identified on ultrasonography. Second, knowledge of the baseline appearance of the newborn hip helps interpretation of clinical and sonographic development during the first 6 weeks of age and thus allows for personalised management decisions. Third, postponing hip ultrasonography to 6 weeks or later would increase costs because all babies would have to be scheduled for outpatient ultrasonography and paediatric visits. Finally, some babies might not show up at 6 weeks of age because of lack of parental compliance.

Preferred screening policy for developmental dysplasia of the hip in newborns is debated, and international guidelines are lacking. Extensive literature reviews emphasise the need to reach an agreement [3, 17, 29]. Only two large randomised controlled trials evaluating different screening strategies have been performed [7, 10], both advocating a selective strategy with ultrasonography offered to those at increased risk. The European Society of Paediatric Radiology (ESPR) task force on developmental dysplasia of the hip in 2011 endorsed selective US screening in areas with a high prevalence of late DDH and suggested that universal US screening be considered if selective screening has no effect on the rate of late cases [30].

Conclusion

The first 16 years of a standardised selective US screening programme for detecting developmental hip dysplasia resulted in an early treatment rate of 3.0%, 2.3% from birth and 0.7% after initial clinical and sonographic follow-up. An additional 3.3% of children were followed sonographically until spontaneous improvement. Rates of late subluxation or dislocation, surgical treatment and avascular necrosis were low compared to other screening programmes. We suggest that the applied screening programme is a reasonable approach, supporting the ESPR task force recommendations [30].

Appendix 1 Report form for babies at risk for developmental dysplasia of the hip referred to hip US at birth

Report form Referral Hip Ultrasound Referring clinician: _____

_____ _____ ☐ Girl ☐ Boy
Surname Birth date

_____ _____
Birth date mother Date of examination

Reason for referral (please indicate all reason(s)):
☐ Positive clinical findings
☐ Equivocal clinical findings
☐ Breech position at birth ☐ extended legs ☐ not extended legs
☐ Family history of DDH (siblings/parents): who _____
☐ Family history of DDH in at least two second grade relatives (grandparents, aunts, uncles):
   who: _____
☐ Foot deformities (pes equinovarus) or other particular reason, as indicated: _____

Tonicity:
☐ Hypo-tonicity- both legs fall easily until 90° of abduction
☐ Normal tonicity-both legs can easily be brought until 80-90° of abduction
☐ Hyper-tonicity- Abnormally high tonicity; 75° or less of abduction

Other clinical findings:

	Right		Left	
	yes	no	yes	no
Stable clicking (1)	☐	☐	☐	☐
Stable hips (2)	☐	☐	☐	☐
Slightly unstable, but within normal (3)	☐	☐	☐	☐
Pathological instability, not dislocatable (4)	☐	☐	☐	☐
Positive Barlow test (dislocatable) (5)	☐	☐	☐	☐
Positive Ortolani test (dislocated, reducible) (6)	☐	☐	☐	☐

Ultrasound findings: Date: _____

	Right	Left
Graf type (morphology) (Normal; Immature; Mild; Severe)	_____	_____
Stability (1-stable, 2-unstable not dislocatable, 3-dislocatable. 4-dislocated)	_____	_____

Re-evaluation: Date: _____ Clinician: _____

	Right	Left
Clinical findings (numeration as above):	_____	_____
Ultrasound:	_____	_____

Appendix 2 Protocol for management of developmental dysplasia of the hip at Haukeland University Hospital

Routines for management of developmental dysplasia of the hip (DDH).

Departments of Paediatric Radiology, Paediatrics and Paediatric Orthopaedic Surgery, Haukeland University Hospital

1. Screening of newborns:

    Premature babies (gestational age <33 weeks) are not referred to hip US after breech presentation at birth, but on all other indications as for full-term born babies. US is performed before departure from the hospital, unless the clinical circumstances require earlier examination.

2. Indication for treatment and further follow-up at 6 weeks in children who are not already under treatment:

    a. Persisting mild dysplasia (<50°): Initiate treatment with Frejka's splint. Clinical re-exam within 2–3 weeks, clinical and sonographic re-exam at 12–14 weeks.
    b. 50–55°: No treatment. New clinical re-exam at 12 weeks.
    c. ≥55°: No re-exam, unless siblings with late-presenting DDH. If that is the case, a re-exam should be performed at 12 weeks, unless the alpha angle is ≥60° at 6 weeks.

3. Indication for treatment and further follow-up at 3 months in children who are not already under treatment:

    a. No improvement from 6 weeks of age (50–55°): Orthosis
    b. 55–58°: Radiograph at 5 months
    c. ≥58°: No re-exam.

4. Indication for continuation of treatment at 3 months in children with abduction treatment:

    a. <55°: Continuation of treatment for 1–2 months, followed by radiograph
    b. 55–58°: Continuation of Frejka's splint treatment for 1 month. Parents stop treatment alone at home. New re-exam and radiographs at 6 months.
    c. ≥58°: Stop treatment. Re-exam with radiograph at 6 months of age.

5. Indication for later follow-up and treatment (after 3 months of age)*:

    a. Dysplasia: Acetabular index (AI) >2 standard deviations (SD) above mean: Orthosis

Appendix

Table 7 First surgical treatment, including osteotomies, open and closed reductions, for children considered to be at risk and at low risk for developmental dysplasia of the hip at birth, respectively. Cases of avascular necrosis of the femoral head (AVN) are also presented for both risk groups. All cases marked with a, b and c are included in the rate of a first surgical treatment performed before 5 years of age

Patient	Age at diagnosis, months (m), years (y)	Diagnosis	Initial treatment, start-end in weeks (w)	First surgical treatment, start-end in months (m)	Age at first surgical treatment, months (m), years (y)	AVN, side, age in years (y)
At-risk group						
Girl[a]	0 m	Left subluxation severe bilateral dysplasia	Frejka 0–16 w, Orthosis 32–40 w	Salter osteotomy	24 m	
Girl[a]	0 m	Bilateral subluxation	Frejka 0–12 w	Salter osteotomy	36 m	
Girl[a]	0 m	Right subluxation	Frejka 0–16 w	Salter osteotomy	36 m	
Girl	0 m	Mild dysplasia and bilateral instability	Frejka 0–18 w, Orthosis 18–24 w	Salter osteotomy	6 y	Left, 4 y
Girl[e]	0 m	Mild dysplasia at birth, residual dysplasia at 16 years	Frejka 0–12 w	PAO	16 y	
Girl[e]	0 m	Mild dysplasia at birth, residual dysplasia at 18 years	Frejka 0–12 w	PAO	18 y	
Girl[a]	0 m	Right dislocation	Frejka, 0–12 w	Open reduction, cast	3 m	

Table 7 (continued)

Patient	Age at diagnosis, months (m), years (y)	Diagnosis	Initial treatment, start-end in weeks (w)	First surgical treatment, start-end in months (m)	Age at first surgical treatment, months (m), years (y)	AVN, side, age in years (y)
Girl[b]	0 m	Bilateral immature and pathologically unstable hips. At 8 weeks mild dysplasia and subluxated left hip	Ultrasound surveillance 0–8 w	Closed reduction, cast	2 m	
Girl[a]	0/3 m	Bilateral dysplasia at birth. Left dislocation at 3 weeks	Frejka 0–3 w	Closed reduction, cast 1–3 m	1 m	Right, 3 y
Girl[b]	0 m	Dislocated and severely dysplastic hips	–	Closed reduction, cast	0 m	
Girl[b]	0 m	Dislocated and severely dysplastic hips	–	Closed reduction, cast 0–1 m, orthosis 1–8 m	0 m	
Girl[b]	0 m	Right dislocation	–	Closed reduction, cast	0 m	
Girl[b]	0 m	Left dysplasia	–	Closed reduction, cast, orthosis	0 m	
Girl[b]	0 m	Right dysplasia	–	Closed reduction, cast	0 m	
Girl[d]	0 m	Left dislocation and severe bilateral dysplasia at birth (32nd gestational week)	Frejka 0–12 w	None	–	Left, 4 y
Boy	0 m	Left dislocation, right subluxation	Frejka 0–16 w	Salter osteotomy	10 y	
Boy[b]	0 m	Bilateral subluxation	–	Open reduction and cast (birth), orthosis 0–12 m, Salter osteotomy 36 m	0 m	Right, 4 y
Boy[b]	0 m	Left dislocation	–	Open reduction, cast (birth), Salter osteotomy at 10 years	0 m	
Boy[a]	0 m	Left dislocation	Frejka 0–12 w	Open reduction, cast	48 m	
Boy[a]	0 m	Left dislocation	Frejka 0–12 w	Closed reduction, cast	3 m	
Boy[b]	0 m	Right dislocation	–	Closed reduction, cast 0–3 m	0 m	
Low-risk group						
Girl[c]	36 m	Late right subluxation	–	Salter osteotomy	48 m	
Girl[c]	15 m	Late right subluxation	–	Salter osteotomy	60 m	
Girl[c]	10 m	Late restricted abduction right	–	Salter osteotomy	36 m	
Girl[e]	17 y	Residual dysplasia at 17 years	–	PAO	17 y	
Girl[c]	7 m	Late left dislocation	–	Traction, open reduction, adductor tenotomy	7 m	Left, 3 y
Girl[c]	18 m	Late right dislocation	–	Open reduction	18 m	
Girl[c]	2 m	Late right subluxation	–	Open reduction, adductor tenotomy, cast, orthosis 2–21 m	2 m	Right, 3.5 y
Girl[c]	5 m	Late left dislocation	–	Traction, closed reduction, cast, orthosis 6–12 m	5 m	Left, 3 y

Table 7 (continued)

Patient	Age at diagnosis, months (m), years (y)	Diagnosis	Initial treatment, start-end in weeks (w)	First surgical treatment, start-end in months (m)	Age at first surgical treatment, months (m), years (y)	AVN, side, age in years (y)
Girl[c]	8 m	Late left dislocation	—	Closed reduction, cast	8 m	
Girl[c]	7 m	Late left irreducible dislocation	—	Closed reduction, cast	7 m	
Girl[c]	2 m	Late left subluxation	Orthosis 8–76 w	Traction, closed reduction, cast	18 m	
Girl[c]	12 m	Late left subluxation	—	Traction, closed reduction, cast	12 m	
Girl[c]	3 m	Late left subluxation	—	Traction, closed reduction, cast	3 m	
Girl[c]	1.5 m	Late right dislocation	—	Traction, closed reduction, cast	1.5 m	
Girl[c]	6 m	Late right dislocation	—	Closed reduction, cast	6 m	
Girl[c]	6 m	Late left subluxation	—	Traction, closed reduction	6 m	
Boy	48 m	Late bilateral dysplasia	—	Salter osteotomy	7+8 y	
Boy[e]	8 y	Residual dysplasia at 8 years	—	Salter osteotomy	8 y	
Boy[e]	19 y	Residual dysplasia at 19 years	—	PAO	19 y	

PAO periacetabular osteotomy

[a] Surgical treatment after failure of initial abduction treatment

[b] Initial surgical treatment the first weeks of life

[c] Surgical treatment due to late detected developmental dysplasia of the hip

[d] Included due to AVN, did not have any surgical treatment

[e] The five additional cases of late developmental dysplasia of the hip detected after 5 years of age

b. Delayed acetabular ossification (1 SD≤AI≤2 SD): new radiograph within 2–4 months

c. Normal (AI <1 SD above mean)

d. Children who are followed until 10–11 months of age due to unsatisfactory AI: Last radiograph at 18–24 months of age.

6. Late presenting DDH in need of treatment:

a. All cases where traction is considered: Referral to orthopaedic surgeon.

b. Older than 6 months of age and newly detected: Referral to a paediatric orthopaedic surgeon.

c. Younger than 6 months of age, and in some cases older than 6 months but already followed for some time at the paediatric radiology department: Continuation of treatment managed by the paediatric radiology department.

*Age-adapted mean values of the acetabular index (AI) with one and two standard deviations (SD) indicated. (Tönnis, Brunken 1968 [18])

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