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Original Article

Verification of hip reduction using anterior ultrasound scanning during Pavlik harness treatment of developmental dysplasia of the hip

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ABSTRACT

Aim: Ultrasound scanning (USS) is used for diagnosis and surveillance in developmental dysplasia of the hip (DDH). Lateral coronal scanning is performed with the hip flexed, in neutral adduction. In this position an unstable hip may dislocate, failing to demonstrate a reducible hip, leading to abandonment of harness treatment. Anterior ultrasound permits imaging of the flexed abducted hip in harness. This study evaluates the role of anterior & lateral USS in determining duration of treatment and reduction in DDH.

Method: Between 1997 & 2010, 233 patients requiring harness treatment received lateral USS, with dislocated & dysplastic hips re-imaged fortnightly. From 2005, anterior USS was used additionally to assess reduction in harness.

Results: One-hundred and eighteen patients (167 hips) received lateral USS, 115 (160 hips) received both. In the lateral cohort, 103 (140 hips) were treated successfully, mean duration 66.2 days (95% CI 60.2–72.1), with 15 (26 hips) failures (15.5%), mean 30 (CI 95% 19.3–40.6). In the anterior cohort, 107 (150 hips) were treated successfully, mean 53.3 (95% CI 49.8–56.7), with 8 (10 hips) failures (6.25%), mean 35.3 (CI 95% 25.5–44.9). Children receiving an anterior USS had a shorter duration of treatment ($p = 0.011$) and no difference in failures ($p = 0.21$).

Conclusions: A reduced duration of treatment for Graf 3 hips was observed. Anterior ultrasound allows earlier recognition of hips that fail to stabilize, via two observed modes of failure; failure of hip reduction and failure to stabilize after reduction.

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1. Introduction

Following on from our institutions previous work identifying the “ischial limb” as a reliable sonographic marker of the

central and deepest portion of the cartilaginous acetabulum during anterior ultrasound of the hip,¹ in addition to the regional anatomy originally described by Dahlström-et al,² we set out to review our own results with the technique.

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Anterior, dynamic and real-time ultrasound are terms used to describe techniques of scanning separate from that originally described by Graf³ in the coronal plane capturing static images of the hip. Clarke et al⁴ described a method of obtaining two-dimensional planar views of the hip using two lateral images to construct a three-dimensional representation of patho-anatomy termed real-time ultrasound. Dahlström et al² described a purely anterior dynamic technique, with the transducer centred over the femoral head & parallel to the femoral neck. Suzuki et al⁵ described imaging both hips simultaneously from the front (anterior) in extension and flexion-abduction.

The Graf US technique is performed with a laterally applied transducer on the neutrally adducted hip in 90 degrees of hip flexion and slight internal rotation. In this position an unstable hip will invariably dislocate and Graf standard plane imaging alone may not verify that concentric hip reduction is being achieved, leading to premature abandonment of harness treatment. Furthermore lateral USS gives poor quality imaging of the abducted hip in more rigid splints. This lead the senior author to adopt and develop a technique of dynamic anterior ultrasound, performed with the child supine in harness, hips flexed and abducted, transducer centred over the femoral head (Fig. 1), using the relationship of femoral head to ischial limb as a sonographic marker of reduction, as described in our previous paper.¹

The research questions during this study using anterior ultrasound imaging as an adjunct to standard lateral scanning were:

- 1) Can anterior ultrasound scanning aid identification of successful hip reduction in an abduction orthosis?
- 2) Can this technique demonstrate failure of hip reduction?
- 3) Does this imaging method improve Pavlik harness success rates and outcome?

Fig. 1 – Photograph of child undergoing anterior ultrasound scanning in Pavlik harness. Note the position of the transducer, placed anterior to the hip joint, centred on the femoral head. The transducer is held parallel to a plane drawn across the front of the pubic symphysis.

2. Method

Our regional surveillance protocol for infantile hip dysplasia since 1997 has been through a consistent selective US screening policy. Those with risk factors, positive family history and breech presentation during third trimester or at delivery are scanned at 6 weeks of age. Those children with an abnormal neonatal or six week examination are scanned as soon as practical after recognition. Hip instability according to clinical findings was assessed in every child by the primary examiner and subsequently the senior author at initial scanning clinic. The results were not recorded consistently in all cases, and therefore for the purposes of study we have not included this. Children with a completely normal scan (Graf 1) were discharged. Those with minor dysplasia and deemed to be stable (Graf 2a) were not treated in Pavlik and rescanned until confirmed normal (Graf 1). Those with instability, (Graf 2a unstable) abnormal scans (critical range dysplasia Graf 2c or decentered/dislocated Graf 3 and 4 hips) were treated accordingly, initially in a Pavlik harness and rescanned at weekly or fortnightly intervals in a dedicated hip treatment clinic.

Anonymised details of children with abnormal scans were included in the DDH database comprising; gender, laterality, location of birth (hospital site), maternal age, delivery, birth weight, ethnicity, family history, congenital anomalies, abnormality of examination/reason for referral and risk factors for DDH. Crucially, the child's age at the time of presentation, initial scan, diagnosis, Graf classification, subsequent management, surveillance and duration of treatment were also recorded. Institutional approval was obtained, as was parental consent to scanning & treatment.

In 2005, the senior author introduced the technique of anterior USS in addition to standard lateral USS. Lateral ultrasound scanning necessitates removal of the limb from the abduction orthosis, risking loss of reduction in the unstable hip whereas anterior USS can be undertaken in-situ. Given these concerns, anterior USS was used additionally to monitor reduction & depth of hip location.

Between October 1997 and August 2010, two hundred and seventy six consecutive patients presented to our service and were found to have DDH on ultrasound scanning and underwent treatment in a Pavlik harness. In all patients, hip reduction in harness was monitored through ultrasound scanning.

2.1. Lateral scan cohort

Between 1997 and 2005 standard lateral US scanning was used as the sole method to monitor for hip reduction in 145 patients. Twenty seven patients from this cohort were excluded due to incomplete follow-up details.

2.2. Anterior scan cohort

Since 2005 anterior USS was used additionally to verify hip reduction in 131 patients. Within this cohort, 15 patients were excluded from study as their anterior USS was not performed

by the senior author and a further 1-patient was lost to follow-up.

Treatment was defined as application of a flexion-abduction orthosis (Pavlik harness) and subsequent monitoring with USS and clinical examination. Treatment in harness was continued until Graf 1 appearances were present. When a stable reduction could not be achieved in harness, verified through persistent ultrasound abnormalities, the harness was removed at the senior author's discretion in an attempt to avoid "Pavlik disease" which is defined as posterior, superior and lateral erosion of the acetabulum from an unreduced femoral head.⁶ Such children were subsequently scheduled for closed/open reduction depending on age and appearance of the ossific nucleus.

Subgroup analysis of the most clinically challenging hips, Graf 3's & 4's was also performed. For this analysis, bilateral cases proved problematic, as the majority of children with bilateral disease had different Graf grades in each hip. For this reason when performing subgroup analysis we examined each hip and its eventual outcome separately as a left or right hip.

Statistical analysis was performed by our institutions medical statistician using dedicated software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp). Distribution analysis using Shapiro–Wilk W test demonstrated that age at start and end of treatment, were not normally distributed. In addition, using the same method, duration of treatment was not normally distributed. Therefore non-parametric tests, Mann–Whitney U and Chi-squared were used to examine the data.

3. Results

3.1. Anterior ultrasound anatomy

Anterior USS allowed hip reduction to be monitored in the abducted position in harness in all children. Anterior scanning took approximately 1–2 min for each hip. In static mode the relative position of the femoral head to the cartilaginous acetabulum was readily visualized. The anterior scan plane employed allowed the demonstration of the anterior hip capsule, femoral neck chondro-osseous border, echo free articular cartilage and contour of the femoral head.¹ The femoral head fovea was recognized as an indentation in the anterior femoral head contour. The anterior acetabular cartilage rim could be delineated but was of variable appearance and echogenicity. The posterior acetabular cartilage rim was seen as an echo free zone. The posterior bony acetabular rim was readily identified as a hyper-echoic zone and this was contiguous with the ossification zone of the ischial contribution to the tri-radiate acetabular cartilage – the "ischial limb".¹ In dislocated hips the hypo-echoic acetabular cartilage rim proved difficult to visualize but in this situation the "ischial limb" was rapidly identified and identified the deepest part of the acetabulum (Fig. 2).

In the reduced hip the "ischial limb" lay on the same horizontal plane as the centre of the femoral head (Fig. 3) and in many hips the relative distance between femoral head articular surface and the "ischial limb" could be measured.

3.2. Cohort comparison

The lateral scan cohort consisted of 118 patients comprising 167 hips; 25 right, 44 left and 49 bilateral cases, with a female predominance; 104:14. The mean age at first presentation was 40 days. The anterior scan cohort, monitored with supplemental anterior USS, consisted of 115 patients comprising 160 hips; 22 right, 48 left and 45 bilateral cases, with a female predominance; 97:18. The mean age at first presentation was 30 days, with 49 children receiving an anterior USS on their first clinic visit, and 107 at the second. The Graf classification for hips in each cohort is given in Table 1.

3.3. Comparison of treatment duration

In the lateral scan cohort, 103 children comprising 140 hips (83.8%) were successfully treated in harness (23 right, 43 left, 37 bilateral). The mean age at the start of treatment was 40.1 days (95% CI 33.3–46.8), end of treatment 106.4 (95% CI 98.1–114.7), with a mean duration of 66.2 days (95% CI 60.2–72.1).

In the anterior scan cohort, 107 children comprising 150 hips (93.75%) were successfully treated in harness (19 right, 45 left, 43 bilateral). The mean age at the start of treatment was 29.5 days (CI 95% 23.4–35.5), end of treatment 82.9 (CI 95% 75.7–90.1) with a mean duration of 53.3 days (95% CI 49.8–56.7). Children receiving supplemental anterior US scanning were found to have a statistically significant shorter duration of harness treatment (53.3 days versus 66.2 days) ($p = 0.011$, Mann–Whitney U).

3.4. Failures of hip reduction in harness

Of the 167 hips in the lateral scan cohort, 26 hips (2 right, 2 left, 11 bilateral) were unsuccessfully treated, a failure rate of

Fig. 2 – Anterior ultrasound scan of a dislocated hip.

Fig. 3 – Anterior ultrasound scan of a located hip (FH: femoral head, A: acetabular labrum, Li: ischial limb).

15.5%. These failures consisted of 18 Graf 4 hips, 7 Graf 3's and 1 Graf 2c. The mean age at the start of treatment was 30.6 days (CI 95% 16.9–44.2), end of treatment 60.6 (CI 95% 45.9–75.2) with a mean duration of 30 days (CI 95% 19.3–40.6). Of the 160 hips in the anterior scan cohort, 10 hips (3 right, 3 left, 2 bilateral) were unsuccessfully treated in Pavlik, a failure rate of 6.25%. These failures consisted of 7 Graf 4 hips and 3 Graf 3's. The mean age at the start of treatment was 37.8 days (CI 95% 21.9–53.7), end of treatment 73.1 (CI 95% 61.4–84.8) with a mean duration of 35.3 (CI 95% 25.5–44.9). Though the proportion of observed failures in this anterior scan cohort was smaller, this was not found to be statistically significant ($p = 0.21$, Chi-squared).

3.5. Subgroup analysis – Graf 3 and Graf 4 hips

Of the 160 hips in the anterior USS cohort, 15 hips were classified as Graf 4 (7 right, 8 left). Of these 7 were unsuccessfully treated (failure rate 46.6%). Including failures and successes, patients with a Graf 4 hip in this cohort had a mean age at start of treatment of 31.2 days (CI 95% 18.5–43.8), end of treatment

77.5 (CI 95% 64.3–90.6) with a mean duration of 46.2 (CI 95% 36.0–56.3). Of the 167 hips in the non anterior USS cohort, 27 hips were classified as Graf 4 (12 right, 15 left). Of these 18 were unsuccessfully treated (failure rate 66.6%). Including failures and successes, patients with a Graf 4 hip in this cohort had a mean age at start of treatment of 25.6 days (CI 95% 16.9–34.2), end of treatment 75.6 (95% CI 60.9–90.3) with a mean duration of 49.9 (CI 95% 36.4–63.4). There was no statistically significant difference found in failure rate ($p = 0.645$) nor duration of treatment ($p = 0.794$).

One hundred and thirteen hips were classified as Graf 3 (46 right, 67 left) in the anterior USS cohort, of which 3 were treated unsuccessfully (failure rate 2.65%). Again, including all patients, the mean age at start of treatment was 21.02 days (CI 95% 17.5–24.5), end of treatment 76.6 (CI 95% 71.8–81.3) with a mean duration of 55.6 (CI 95% 52.9–58.9). Ninety hips were classified as Graf 3 (41 right, 49 left) in the non anterior USS cohort, of which 7 were unsuccessfully treated (failure rate 7.77%). Mean age at start of treatment was 26.7 days (CI 95% 22.37–31.0), end of treatment 93 (CI 95% 85.1–110.8) with a mean duration of 66.3 days (CI 95% 56.6–72.9). Despite the difference in percentage failure rates, no statistically significant difference was found in failure rate ($p = 0.300$), perhaps explained by the relatively high success rates in both cohorts (97.3% versus 92.2%). Duration was not normally distributed and therefore non-parametric tests were used. There was a statistically significant shorter duration of treatment found for Graf 3 hips in the anterior USS cohort ($p = 0.01$, Mann–Whitney).

3.6. Modes of failure

Two principle modes of failure were observed during harness treatment, failure to reduce and failure to stabilize. This was only demonstrated by adjunctive anterior scanning in harness. With harness treatment the majority of decentered and dislocated Graf 3 hips reduced promptly and hip reduction was verified immediately on harness application. Anterior ultrasound scanning allowed the distance between femoral head articular surface and the “ischial limb” to be measured following hip reduction. In children with unilateral hip dislocation this limb-articular surface distance was slightly greater on the dislocated side, implying a partial or eccentric reduction had been achieved. In most instances “deep” concentric reduction was obtained within a fortnight with equal limb-articular surface distances. In Graf 4 hips an eccentric initial reduction was more common and anterior scanning clearly demonstrated those as hips that remained dislocated during the first 2–3 weeks of harness treatment. In these children Pavlik harness treatment was discontinued early and invariably a closed/open reduction was required at a later stage. Once hip reduction was achieved, stability was assessed by gentle dynamic posterior stressing under ultrasound guidance. This was performed in both the abducted position (monitored by anterior scanning) and in neutral adduction flexed position (monitored by lateral scanning). A subgroup of children were identified with persistent hip instability, despite a concentric reduction being achieved in abduction. In these children whose hips failed to stabilize, early closed reduction under general anaesthesia proved

Table 1 – Graf classification for hips in each cohort.

Grade	Ant US cohort	No Ant US cohort
1	0	0
2a unstable	10	23
2b	3	2
2c	10	19
2c unstable	9	6
3	113	90
4	15	27

effective. This was verified with hip arthrography, followed by a 3–4 week period of hip spica and subsequent removable splinting (Pavlik in small children, abduction orthosis in larger).

4. Discussion

This study has demonstrated that children receiving an anterior USS, in addition to standard lateral scanning, have a shorter duration of treatment in Pavlik harness compared with children receiving lateral scanning only. This was most clearly seen in subgroup analysis of children with Graf 3 hips. Though the observed failure rate of the two overall cohorts was lower in those receiving an anterior USS (6.25% versus 15.5%), this was not found to be statistically significant, nor was failure rate found to be significantly different in either of the subgroups. As expected Graf 4 hips were the most challenging, with a higher failure rate in both cohorts and no statistically significant difference in outcome or treatment duration.

This study has a number of limitations. Firstly the cohorts are not randomized, but form a consecutive series of patients from one surgeons' practice over thirteen years. Anterior ultrasound scanning was introduced after eight years of experience gained with standard lateral scanning & managing children with DDH, introducing an element of "improved experience" bias for more recently treated children, irrespective of scan method. Subgroup analysis of Graf 4 hips is limited by overall number of Graf 4 hips and the disparity in proportion of Graf 4 hips between cohorts. A much larger proportion of Graf 4 hips were observed in the lateral scan cohort. A significant limitation when considering duration of treatment was brought about by the lack of service provision in providing a weekly DDH scanning clinic. As such, our scanning clinic was fortnightly and this may be reflected by marginally longer durations of treatment overall in both cohorts compared with other studies.^{7,8} We have not included data on clinical stability though children were examined for this, as it was not recorded consistently enough to be used for study. We believe given the level of USS evaluation that was performed, clinical findings would add little, though recognize many surgeons find this of great interest and our view may not be shared.

The strengths of this study include the large study size of 327 hips in 233 consecutive patients. Both cohorts had similar numbers of patients and demographics. Given the number of patients included in the study, we were able to perform subgroup analysis of those with Graf 3 and Graf 4 hips in isolation. The senior author reviewed all patients personally and was responsible for subsequent decisions regarding management making this a single surgeon series. As the senior author was the only surgeon in the unit with an interest in Paediatric orthopaedics, all patients presented to his clinics, ensuring an accurate and comprehensive data record.

The technique of anterior (dynamic) ultrasound has been described previously. Suzuki et al⁵ highlighted its diagnostic use with a large linear transducer that allowed simultaneous comparison of both hips. Emphasis was made on using an anterior reference measurement plane drawn across the pubic symphysis – this would imply a caudally directed

scanning plane to transect the centre of the hip calling into question the term anterior scan. Clarke et al⁴ introduced the concept of real-time ultrasound using two views to precisely evaluate the anatomical relationships when deciding upon reduction and commented on the potential of dynamic scanning to assess stability. Though anterior ultrasonography in DDH screening is well documented, few studies have examined its clinical effectiveness and results in comparison to standard lateral scanning.⁹ Of the limited studies available, it would appear that lateral ultrasonography as described by Graf¹⁰ when compared with anterior scanning, tends to overestimate the number of unstable hips and leads to a greater number of indeterminate results requiring follow-up.¹¹ This may be explained by the position of the limb during lateral scanning. Anterior ultrasound scans have been used to assess and monitor hip reduction after closed reduction and hip spica application¹² but its role during early harness management has not been described.

In our experience, we found the ability to determine the 'mode of failure' over time as one of the major benefits of anterior scanning. Of the 10 hips that failed Pavlik, on initial anterior scanning four were noted to be irreducible, of which three remained irreducible and one locatable but unstable; three partially locatable hips, of which two subsequently reduced but remained unstable and one failed to reduce; two reducible hips in a bilateral case, one of which went on to deep location but remained unstable with the contralateral hip becoming irreducible; and one located hip that initially remained located, that subsequently became unstable in a patient with an irreducible contralateral hip. Conversely, the ability to monitor an initially unstable hip in harness as it progressively locates and gains stability is a hugely reassuring demonstration of the efficacy of treatment, allowing the surgeon to avoid unnecessarily prolonged harness treatment. We feel this accounts for the shorter duration of treatment observed in the anterior USS cohort and Graf 3 subgroup.

Interestingly, no difference in treatment duration was found in the Graf 4 subgroup, as one might have expected anterior USS would be better at visualizing reduction in harness as proposed. Possible explanations include the high failure rates observed in both cohorts producing similar mean treatment durations and relatively small, poorly matched cohort sizes, with a predominance of Graf 4 failures in the no anterior USS arm (18 of 27 hips). Combining both study cohorts, our observed failure rate of 59.5% is comparable with the published literature on the outcome of Graf 4 hips managed in Pavlik.¹³ It would appear the natural history for a Graf 4 hip managed in Pavlik is skewed towards failure; it is therefore not unsurprising no statistically significant difference in outcome was observed between cohorts.

Though the observed failure rate in the anterior USS cohort was two and a half times lower (6.25% versus 15.66%), it did not reach statistical significance. This may be explained by the relatively high success rates in each cohort overall (93.7% anterior USS, 83.8% no anterior USS). This is perhaps not surprising, given that all patients received standard lateral scanning out of harness, with the anterior USS cohort receiving an additional anterior scan in harness. Therefore, both cohorts received the same treatment, but different (or

additional) diagnostic/surveillance imaging that was used to determine subsequent treatment duration. Given this, we can conclude that the addition of an anterior scan did not affect outcome, but did effect duration for the reasons stated previously, namely visualizing deep concentric reduction, avoiding prolonged harness treatment. It could be argued there are a number of potential influencing factors including modification to the treatment pathway such as more clinics and improved expertise/experience of the senior author in treating DDH and physiotherapists in applying/monitoring the harness. In reality, our clinic frequency has remained the same and has not been able to change given institutional constraints. Anterior USS gives immediate evidence hips are reducible and therefore experience gained with lateral scanning is less relevant and our physiotherapy technique has not changed, with information given to families remaining consistent throughout.

Several authors have highlighted the beneficial role of adjunct ultrasound to monitor treatment in harness. In a series of 31 patients treated in Pavlik harness and monitored using ultrasound, Bell et al¹⁴ commented on the ability to identify those failing to achieve concentric reduction, in which harness treatment was abandoned early. This has also been observed in studies examining the management of dislocated hips treated with Pavlik from the outset,¹⁵ with a mean treatment duration of only 21 days. In a small study of fifty patients by Carmichael et al¹⁶ evaluating the timing of discontinued harness treatment, ultrasound surveillance was found to be clinically justified and cost effective. Despite the abundance of published papers in the orthopaedic and radiological literature surrounding ultrasound techniques in DDH, there are no studies that have examined the role of anterior USS compared with standard USS techniques in terms of treatment duration and outcomes using a sizeable cohort. Many authors have observed and commented on the beneficial aspects of anterior/dynamic techniques, but few detailed precise treatment durations and subgroup analysis. We therefore hope our observations with the technique add to the evidence base.

In conclusion, we believe anterior ultrasound scanning is a useful adjunct to standard scanning as it permits visualization of the hip in harness and dynamic testing. Our study suggests a shorter duration of treatment, based on the ability to observe mode of failure or confirmation reduction.

Conflicts of interest

All authors have none to declare.

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