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Independent External Medical Audit for Children's Health Ireland and National Orthopaedic Hospital Cappagh on Indications for Pelvic Osteotomy in Children with Developmental Hip Dysplasia

1. AUTHOR DETAILS AND DISCLOSURE

1.1. I am not aware of any actual or potential conflicts of interest in conducting this audit. All surgeon and patient identifiable data have been removed from the records and X rays.

1.2. I have been a fellow of the Royal College of Surgeons since 1998. I was appointed as a Consultant Orthopaedic Surgeon in 2007 at Bristol Royal Hospital for Children. I have been in continuous, active clinical practice since that time and my qualifications include MA (Cantab), MRCS (Eng), FRCS (Orth).

1.3. I have experience in the diagnosis, management and operative treatment of paediatric orthopaedic conditions including developmental hip dysplasia (DDH). I work in a major paediatric trauma and tertiary referral centre for children's orthopaedics. I run the Bristol paediatric hip dysplasia clinic. I have published research and review articles on the long term outcomes after treatment of developmental hip dysplasia. I was a clinical Fellow with Dr Robert Salter in Toronto in 2005/6. I am a member of the International Hip Dysplasia Institute.

1.4. I have been asked by Children's Health Ireland (CHI) and National Orthopaedic Hospital Cappagh to audit decision making for pelvic osteotomy, in young children with DDH, against published consensus principles. The audited period was from January 2021 to December 2023. Children were included over the age of one year but less than 7 years.

2. METHODOLOGY AND BACKGROUND DATA

2.1. Redacted orthopaedic clinic records and X rays for children with DDH undergoing pelvic osteotomy at Temple Street Hospital (TSH), Crumlin Hospital (CRH) and National Orthopaedic Hospital Cappagh (NOHC) were made available to me in batches for each of the surgeons performing the procedure. Surgeons were anonymised "A-N". A random selection of 10 cases from each surgeon's series at each institution was made. This audit is based on reviews of those records and radiographs as provided to me by the institution where the index procedure was performed. It is not a complete review of practice but rather an audit specifically to look at the indications for pelvic osteotomy that have been advised and performed for children aged 1-7 years between January 2021 and December 2023. Additional information has been recorded in some cases to assist with understanding the decision making.

2.2. At the outset the expectation was that most of the children undergoing treatment by pelvic osteotomy would have had persistent hip dysplasia after failure of bracing, or delayed diagnosis of hip instability, requiring closed hip reduction, with muscle releases and prolonged spica casting, or open hip reduction and spica casting. There are good quality data on radiological indices that predict risks for persisting dysplasia in these settings, based in the main on age at time of reduction and acetabular index (AI). Persisting dysplasia, after successful hip reduction, would warrant pelvic osteotomy in those children with a reduced likelihood of spontaneous improvement after a period of observation (1). An audit form set out the planned methodology based on these assumptions.

2.3. In many of the TSH and NOHC cases sampled, there was no record of closed or open hip reduction after delayed diagnosis, no record of either hip ever having been dislocated and often no history of treatment soon after birth by splint or brace for hip instability. Pelvic X rays have often been

arranged because of a family history of hip dysplasia, report of a “clicky” hip or asymmetric thigh creases identified in the community. Some children have been treated in an abduction brace around the age of one year following referral with pelvic X rays showing acetabular immaturity. Cases with no prior history of a diagnosis of DDH have sometimes been termed “stable acetabular dysplasia” by the treating surgeons (2). Hip instability, subluxation or dislocation were not described in these cases.

2.3.1. It would be unusual for corrective pelvic osteotomy in childhood to be indicated in large numbers of essentially untreated hips. There are no reliable data, in the audit age range, predicting which of these, if any, might be at particular risk of idiopathic adolescent dysplasia (3,4) and/or adult hip osteoarthritis (2).

2.3.2. The peer reviewed literature examining the relationship between acetabular dysplasia and future risk of arthritis, for hips with silent or stable dysplasia identified serendipitously on pelvic X rays, does not reach consistent conclusions. It is generally accepted, however, that a centre edge angle (CEA) below 20-25 degrees at skeletal maturity probably predicts a significant future risk of hip arthritis. CEA is not a reliable measure under the age of 5 years, which is the age group studied in this audit. An AI during this period that is within a reasonable range of normal, typically within the 90th centile from the mean, based on contemporary normative population data (5), would generally be considered reassuring with no imminent requirement for pelvic osteotomy.

2.3.2.1. Children with a stable hip and an AI between one and two standard deviations from the mean, which bridges the 90th centile (Z score of 1.28), would reasonably be considered to have borderline or critical dysplasia. This requires ongoing surveillance and intervention if there is no improvement over time. A high rate of spontaneous

resolution, to an AI within one standard deviation of the mean, would be anticipated in this young age group.

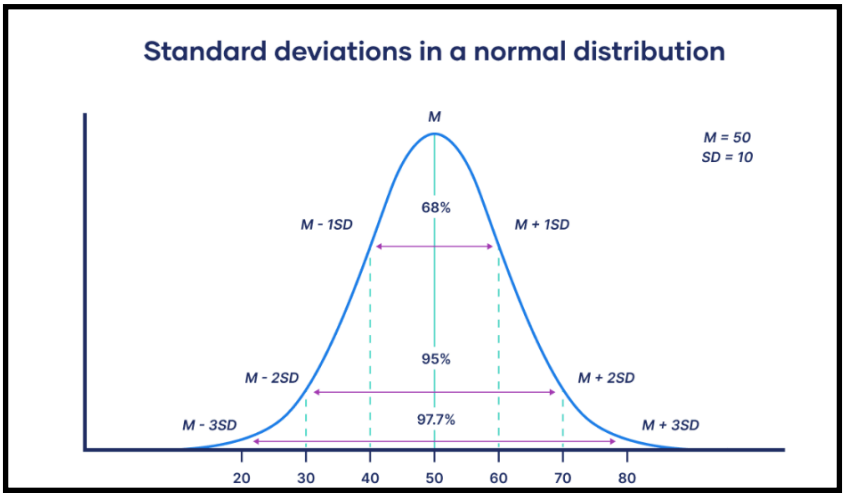
2.3.2.2. Those children with a stable hip and an AI above 2 standard deviations from the mean should be considered for pelvic osteotomy if that extent of dysplasia persists.

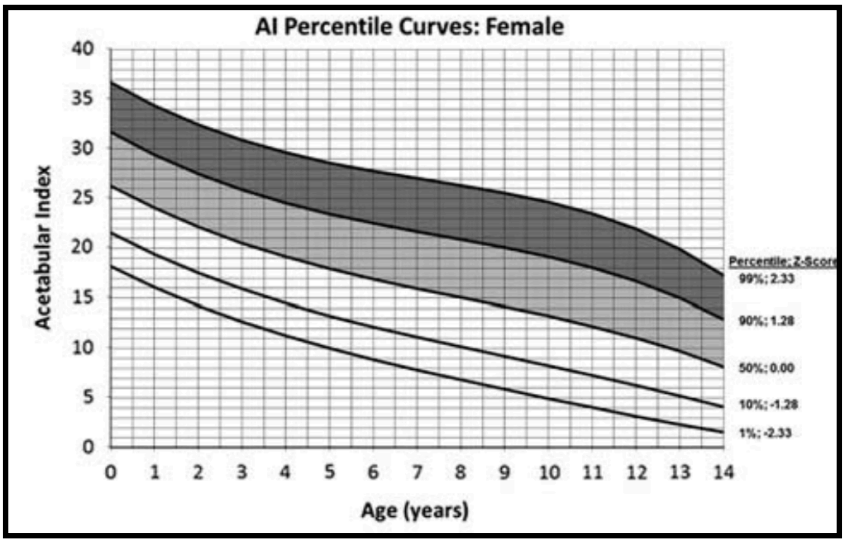
2.3.2.3. Those with a stable, concentrically located hip and an AI below the 90th centile should not routinely be recommended pelvic osteotomy.

2.3.2.4. It is accepted that there is variation on the thresholds at which different surgeons will recommend pelvic osteotomy.

2.3.3. Intervention, by pelvic osteotomy in childhood, for persistent elevation of AI above the 90th centile in previously untreated hips would be considered reasonable with the goal of preventing persistent acetabular dysplasia at skeletal maturity. However this is neither actively screened for, in any country to my knowledge, nor often required for children with no prior personal history of treated DDH.

2.3.4. The normative data for AI used in this audit are presented below with percentiles and Z scores (5). The latter are the number of standard deviations of a value above or below the mean. With a normal distribution of data about the age-specific mean, 68% and 95% of the values would fall within one and two standard deviations of the mean respectively. At the upper range of the reference AI data used in this audit, the 84th and 98th percentiles are equivalent to one and two standard deviations, or Z scores, from the mean. In the graphs of the reference data for AI that is used for this audit, the 90th and 99th percentiles are provided and progressively darker shaded above the 50th percentile. They equate to Z scores of 1.28 and 2.33 respectively.





2.4. For children undergoing follow-up after successful closed or open hip reduction and spica casting, predictive data from Iowa (USA) use AI measurements at different time points after successful reduction to predict future risk of persistent dysplasia (1).

2.4.1. These data indicate that, while a hip joint without prior treatment for DDH and an AI within a reasonable range of the age-specific mean should have a good long term outcome, a hip with the same AI at the same age that has been treated for DDH by closed or open reduction may have residual acetabular dysplasia at skeletal maturity.

2.4.2. A recent study from Hong Kong confirmed the same in a cohort of children undergoing Pavlik harness treatment or closed hip reduction and casting for DDH (open reduction cases were excluded). In hips treated thus, an AI within two standard deviations of the age-specific mean at the age of 2-3 years could still be associated with a poor outcome at skeletal maturity (6). This is not to say that all DDH cases treated by Pavlik harness or closed reduction, with an AI at the upper limit of two standard deviations at 2-3 years of age, require immediate pelvic osteotomy; rather that a further period of observation is indicated for the small number within this subgroup that may go on to have persisting dysplasia.

2.4.3. It is critically important to apply the appropriate predictions, based on different AI datasets, to the correct groups of DDH treated and untreated children based on their prior history.

2.5. Centre edge angle (CEA) is potentially unreliable in younger children under the age of 5 years who have not ossified sufficient of the acetabular anlage (immature cartilage model) for this to be measured on plain X rays. It was not therefore used in this audit as a primary measure for quantifying risk of persisting dysplasia. However it was considered reassuring when it measured above 20-25 degrees in older cases within the audit age range. It is important, nonetheless, to follow up children undergoing closed or open reduction and casting, and especially those requiring pelvic osteotomy, to skeletal maturity to confirm that an adequate CEA has been achieved at an age when this measurement is reliable and can be used as a predictor of outcome.

2.6. Some of the surgeons cited a “short sourcil” as a concerning feature to justify pelvic osteotomy. This qualitative description *per se* is not established as a valid qualitative means to predict persisting dysplasia in

this young age group, to my knowledge, for children with no prior history of treatment for DDH.

2.7. The original method of measuring AI has been modified and updated datasets have been developed.

2.7.1. Measuring the AI to the edge of the sourcil, rather than the lateral edge of the ossified socket as originally described by Tonnis (8) and used for the Iowa (1) and Hong Kong (6) studies, is considered better to characterise true acetabular depth based on studies looking at correlation with CT scans (7). The lateral sourcil method was therefore used in this audit after 2 years of age with the appropriate dataset (5), set out graphically above, that is more granular than the older Tonnis data.

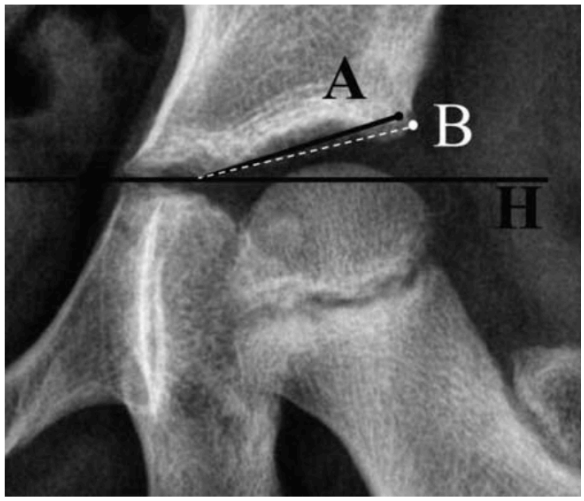


FIGURE 4. Two different landmarks for measurement. The current study uses the lateral sourcil (point A), whereas more classic methods use the lateral margin (point B). H indicates Hilgenreiner's line.

2.7.2. The disadvantages are that the sourcil can be difficult to identify in younger children and the lateral margin method must still be used to extrapolate with the Iowa and Hong Kong data. Comparable and good reliability is reported for both the sourcil and lateral

margin methods after the age of 2 years when the sourcil is more reliably seen. The 2-5 year age range for which the sourcil method is validated (7) covers the time point of decision making for children undergoing pelvic osteotomy in this audit with only a few exceptions.

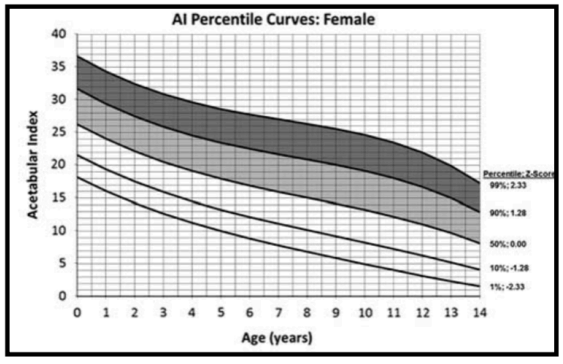
2.7.3. Children had a series of X rays over time for decision making prior to pelvic osteotomy, during which period errors arising from poorly centred or mal rotated X rays should be ironed out. There is nonetheless potential for error when switching between datasets and methods of measurement for multiple datapoints. A 2 degree difference between the sourcil and lateral edge measurements is typical in the published datasets; for example, in the 2-3 year age range for a female left hip, the mean AI plus one standard deviation is 25 degrees using the lateral sourcil method (5) and 23 degrees using the lateral margin method (8). At 3-5 years the Tonnis data for a right hip seem anomalously to dip and then increase back up in the next range; otherwise the data below correlate fairly well.

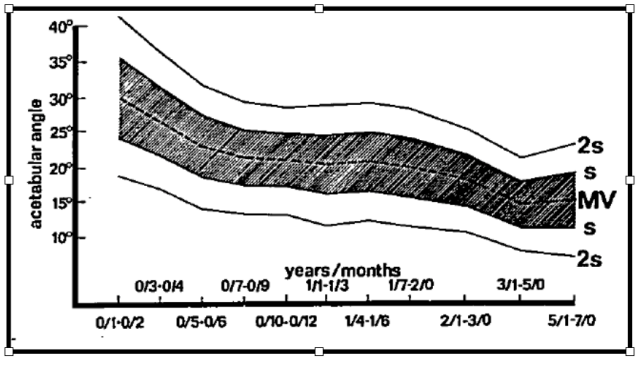
TABLE 1. Normal Values of Acetabular Index (n = Hips)

		Females			Males	
Age (y)	n	Right ± SD	Left ± SD	n	Right ± SD	Left ± SD
0-0.5	48	24.04 ± 3.7	25.64 ± 4.0	28	24.14 ± 1.8	23.43 ± 3.0
0.5-1	118	24.60 ± 4.2	25.67 ± 3.9	112	23.41 ± 3.7	23.91 ± 4.0
1-2	164	23.84 ± 3.4	25.46 ± 4.0	174	22.95 ± 3.9	23.00 ± 4.0
2-3	84	21.48 ± 3.8	21.81 ± 3.6	78	19.82 ± 4.0	19.87 ± 4.1
3-4	48	19.58 ± 4.0	19.42 ± 3.6	86	17.23 ± 4.0	18.09 ± 4.3
4-5	54	19.07 ± 4.1	18.52 ± 3.8	74	16.92 ± 2.7	16.27 ± 3.4
5-6	70	16.80 ± 5.1	17.86 ± 4.7	98	14.88 ± 3.5	15.08 ± 4.1
6-7	50	16.64 ± 3.8	16.96 ± 4.6	74	15.30 ± 4.4	15.53 ± 4.0
7-8	62	14.45 ± 3.0	15.94 ± 4.0	58	13.79 ± 2.8	14.24 ± 3.2
8-9	48	15.0 ± 5.1	14.83 ± 4.1	84	13.00 ± 3.6	12.71 ± 4.2
9-10	62	14.03 ± 3.9	13.97 ± 3.3	84	13.07 ± 4.0	12.74 ± 4.2
10-11	42	14.29 ± 4.5	15.52 ± 4.1	72	12.14 ± 4.1	12.33 ± 3.7
11-12	72	10.36 ± 3.2	10.56 ± 4.4	78	10.51 ± 3.3	11.77 ± 3.6
12-13	72	11.36 ± 3.90	10.00 ± 3.6	82	12.16 ± 3.9	11.34 ± 3.2
13-14	56	9.43 ± 4.1	9.32 ± 3.6	72	10.78 ± 2.0	10.47 ± 3.8

TABLE 2. Acetabular Index of Slight and Severe Dysplasias in Different Years of Life

	(mos)	Girls				Boys			
		Light dysplasia above (s)		Severe dysplasia above (2s)		Light dysplasia above (s)		Severe dysplasia above (2s)	
Age		right	left	right	left	right	left	right	left
1+ 2		35.8	36.1	41.6	41.6	27.7	31.2	31.8	35.2
3+ 4		31.4	33.2	36.3	38.7	27.9	29.1	32.4	33.7
5+ 6		27.3	29.3	31.8	34.1	24.2	26.8	29.0	31.6
7– 9		25.3	26.6	29.4	31.1	24.6	25.4	28.9	29.5
10–12		24.7	27.1	28.6	31.4	23.2	25.2	27.0	29.1
13–15		24.6	26.9	29.0	31.7	23.1	24.0	27.5	27.7
16–18		25.0	26.1	29.3	30.4	23.8	25.8	28.1	30.0
19–24		24.1	26.4	28.4	30.8	20.6	23.2	24.4	27.3
2–3 yrs		21.8	23.3	25.6	27.1	21.0	22.7	25.3	26.9
3–5 yrs		17.9	21.2	21.3	25.8	19.2	19.8	23.5	23.8
5–7 yrs		19.3	19.8	23.4	23.8	16.8	19.3	20.9	23.2





2.7.4. In any event, the Tonnis data were not used for this audit. The sourcil method was recorded after 2 years of age and extrapolated to the dataset of Novais et al (5) to assign an age and gender-specific percentile for the AI. The lateral edge measure was used to extrapolate to the Iowa data (1) for hips that had undergone closed or open reduction.

2.8. A lateral acetabular notch was also cited by some surgeons as a potential justification for pelvic osteotomy. This has been studied in the peer reviewed literature as potentially indicative of prior neonatal hip instability when seen on hip X rays in the first few months of life (9). It is not a valid predictor for persisting dysplasia and probably represents a biological failure of ossification rather than a true deficiency (10). Hip arthrography is typically reassuring in confirming a stable hip joint with adequate coverage by an immature cartilage anlage.

2.9. Acetabular floor thickness was not cited by surgeons to justify pelvic osteotomy in the records that I reviewed. This was not measured in this audit. Acetabular depth ratio (ADR) was occasionally used to sense check the AI but not routinely measured and therefore not recorded. ADR and AI are complementary measures of acetabular morphology because AI strongly correlates to acetabular depth. AI was used because early measurements of this specific index are independently predictive for persisting acetabular dysplasia after treated unstable DDH and because there are more published series of reference normal values for AI than for ADR. It is not likely that the ADRs would be substantially different, in relation to their normative data (5), from the AIs in this age group.

2.10. Reviewing the redacted patient records and making accurate radiological measurements is time consuming and I was tasked with producing a report

as soon as possible because of the concerns raised. The audit form planned to analyse a “snapshot” of 20-50 cases from each surgeon.

2.10.1. A sample of 10 cases was taken at random for every surgeon operating at each of the centres. For those surgeons performing less than 10 pelvic osteotomies at an institution, all the cases were reviewed.

2.10.2. Only 10 cases were reviewed for each of the CRH (H-N) surgeons. Most of the TSH surgeons A-G had also done pelvic osteotomies at NOHC during the audit period. More cases of the TSH surgeons were therefore sampled but a higher percentage of all pelvic osteotomies at CRH were sampled because of the smaller total number being done there.

2.10.3. I was satisfied that the analysis of 10 cases for the CRH surgeons was sufficient for me to understand their decision making. They were mostly operating for children with persisting acetabular dysplasia after closed or open hip reduction. This simplified the task of analysing the indications because the pre-planned methodology in the audit form could be applied.

2.11. Some surgeons’ samples indicated a very high rate of bilateral, rather than unilateral, pelvic osteotomies.

2.11.1. This audit references the epidemiological data of Loder et al that predict: one third of DDH cases will be bilateral, two thirds of unilateral cases will affect the left hip and three quarters of all DDH cases will be female (11).

2.11.2. There is good anecdotal and some peer reviewed evidence (12) that bilateral DDH has a higher risk of persistent dysplasia. Some excess of bilateral pelvic osteotomies, above the predicted incidence of bilateral DDH, would therefore reasonably be anticipated.

2.12. For hips undergoing Pavlik harness (or equivalent abduction brace) treatment after early identification of instability on ultrasound, successful reduction and stabilisation are likely in 95% of all hips based on benchmark European and North American data (13-15).

2.12.1. A 2-5% rate of late dysplasia (actual and borderline) at 5 years after successful reduction in the harness is typical with an anticipated requirement for pelvic osteotomy in around 2% (13,15).

2.12.2. A 1991 study reported a 17% rate of acetabular changes on radiographs at skeletal maturity in a group of 74 hips treated in a Pavlik harness (16). The changes reported were of uncertain significance. A more recent systematic review (17), of late acetabular dysplasia after successful DDH treatment in a Pavlik harness, included 6029 hips. There was late dysplasia in 280 (4.6%) and a requirement for additional surgery in 109 (1.8%).

3. SUMMARISED RESULTS BY INSTITUTION

3.1. Totals

3.1.1.147 cases audited of 14 surgeons across 3 institutions.

3.1.1.1.497 cases* at TSH & NOHC; records & X rays of 241 cases provided for audit.

3.1.1.2.132 cases* at CRH; records & X rays of 101 cases provided for audit.

3.2. TSH

3.2.1.49 cases sampled of a total 127 cases (39%).

3.2.2.85 pelvic osteotomies; 34 indicated based on audit criteria (40%).

3.3. NOHC

3.3.1.51 cases sampled of a total 114 cases (44%).

3.3.2.70 pelvic osteotomies; 15 indicated based on audit criteria (21%).

3.4. CRH

3.4.1.47 cases sampled of a total 101 cases (47%).

3.4.2.63 pelvic osteotomies; 62 indicated based on audit criteria (98%).

* Estimated numbers provided by CHI of children aged 1-7 years undergoing pelvic osteotomy between 01/2021-12/2023. These have been revised since the first draft based on CHI factual accuracy checking.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Summary

4.1.1. CRH surgeons perform pelvic osteotomies, mostly for children with previously treated DDH, that are reasonably indicated, with one exception (one side of a bilateral case), according to consensus published radiological and clinical criteria that have been retrospectively applied for the purposes of this audit.

4.1.1.1. In many cases the radiological criteria are recorded and tracked by CRH surgeons over time. There is sometimes documented discussion with colleagues +/- arthrography for cases with borderline indications for surgery.

4.1.1.2. Follow-up to skeletal maturity after pelvic osteotomy was variable but often appeared to be done.

4.1.1.3. Record keeping in some of the CRH clinic correspondence that I have seen is poor. In the event that complications were to arise it would not be possible, in some cases, to establish the risk/benefit analysis behind the decisions to operate or whether the families had been involved in an exploration of their attitudes to and tolerance of the risks.

4.1.2. Some of the TSH and NOHC surgeons have been performing significant numbers of pelvic osteotomies for children that are not indicated based on the criteria that have been retrospectively applied for the purposes of this audit. This is especially so for the surgeons performing large numbers of pelvic osteotomies, the majority bilateral, at those hospitals.

4.1.2.1. Declaring that the criteria I have set were not reached in certain percentages of pelvic osteotomies does not prove that none of them were indicated. It is well known that there is worldwide variability between surgeons in their

recommendations for pelvic osteotomy in DDH. There will inevitably be variation between observers when recording radiological measurements. Differences also arise between the classic lateral and sourcil methods of AI measurement (7). The variance identified in this audit cannot be accounted for by measurement error or observer variability alone. That the percentages of pelvic osteotomies not reaching the criteria at TSH and NOHC are so high mandates further inquiry. This should be done by open engagement from the TSH and NOHC surgeons with the external experts that have now been appointed to assist with the development of multidisciplinary decision making as well as their Crumlin peers and the report recommendations.

4.1.2.2. For two surgeons at NOHC there were missing records and X rays that excluded some cases.

4.1.2.3. It is likely that the TSH/NOHC surgeons would benefit from peer review across all 3 sites for decision making to agree and confirm reasonable clinical and radiological indications and timings for pelvic osteotomy. This should be a routine part of surgical planning going forward.

4.1.2.4. Qualitative assessments of the radiographs, including terms such as “short sourcil” and “acetabular notching”, have been used to justify intervention with no evidence linking these descriptions in this young age group to persistent adolescent hip dysplasia or adult hip arthritis. The orientation and shape of the sourcil reflects the biomechanical development of the hip in the paediatric and adolescent pelvis and so using it to measure acetabular index is preferred to the older lateral edge method. Using qualitative descriptions of the sourcil as the documented reason for pelvic osteotomy in this young age group, in the

face of normal acetabular indices in centred, well covered hips with no history of DDH treatment, is not reasonable in my view.

4.1.2.5.Some surgeons at TSH/NOHC have set out percentage risks of persistent dysplasia and hip arthritis, for children with no prior history of DDH and/or normal neonatal hip ultrasound, by extrapolating the Iowa AI-based predictions of residual dysplasia to hips that have not undergone closed or open reduction (1) or by using radiological measures taken from studies of adult pelvis radiographs to infer osteoarthritis risk in these young children (18). This is not reasonable in my view.

4.1.2.6.It is a reasonable hypothesis, set out by one of the surgeon responses to the first draft of this report, that screening could have filtered out a missed group of more mild instability at birth that spontaneously resolves but causes subsequent “stable acetabular dysplasia”. The difficulties remain around defining that and linking varying degrees of it to a risk of problematic persisting dysplasia to justify a pelvic osteotomy.

4.1.2.7.Children appear often to be discharged from TSH/NOHC by some surgeons at those institutions at around one year after pelvic osteotomy. Planned review of ongoing acetabular development and assessment of the outcome at skeletal maturity appear to be lacking. There may be follow-up at other centres from which records were not provided for the audit.

4.1.2.8.The high rates of bilateral pelvic osteotomy exceed the predicted incidence of bilateral DDH (11); even accounting for a higher anticipated rate of complications and residual dysplasia in bilaterally affected hips (12). In one case, there

was an adverse outcome from the osteotomy in a bilateral case; on the side for which surgery was not indicated according to the criteria used for this audit.

4.1.3. This audit raises concerns about the indications for pelvic osteotomy in many of the cases at TSH/NOHC but some of those pelvic osteotomies were reasonably indicated. The surgeons there have been able to review and articulate their reasons for recommending additional surgery in all the cases sampled. Some areas of the first draft of this report have been amended to clarify points raised by those responses. The conclusions and recommendations have not changed.

4.2. Recommendations for follow-up

4.2.1. The majority at TSH/NOHC has undergone pelvic osteotomy using a novel technique. Published follow-up for this less invasive osteotomy is for 50 hips in 49 children (46 female) to an average of only 24 months (19). All but one was osteotomy was unilateral in this published series. The longer term outcome to skeletal maturity is critically important but has not been submitted for peer review and publication to my knowledge. The outcome of the less invasive osteotomy is not characterised for the significant numbers of children sampled that underwent bilateral surgery with radiological indices that were within an acceptable range of normal in my opinion.

4.2.2. All 497 cases that have undergone pelvic osteotomy at NOHC/ TSH between 2021-2023 require ongoing follow-up to skeletal maturity. These families should all be recalled and informed that this is a matter of routine good practice. It is critically important to confirm satisfactory acetabular development at skeletal maturity with measurements that should include (lateral) centre edge and Tonnis angles on pelvic X rays (1,21).

4.2.3. The first step should be to recall all the 497 cases that underwent pelvic osteotomy at TSH/NOHC between 2021-2023. They should undergo a standardised independent clinical review and radiological assessment. X rays should then be reviewed, with the history obtained, by appropriately experienced paediatric orthopaedic surgeons from a different institution to NOHC or TSH. Follow-up with a suitably experienced and independent paediatric orthopaedic surgeon may be required in some cases.

4.2.3.1. The majority is likely to be functioning well but the outcome after pelvic osteotomy, performed for those

children with acetabular indexes within acceptable limits of a normal range, is not known.

4.2.3.2. There is a risk, for example, of symptomatic hip impingement arising from the altered orientation of the socket. Over-coverage or an overly “deep” socket have been identified as significant risk factors for the development of osteoarthritis in adults (23).

4.2.4. Any complications that have arisen from pelvic osteotomy must be acknowledged and discussed with the families. There should be an assessment of the original decision making, in any such cases, based on the appropriate radiological indices and clinical history informing the decision to operate. The appropriate datasets to use depend upon whether there was any previous history of treated DDH and, if so, whether this was management in a harness or an open/closed reduction. The appropriate methodology is set out in the preamble to this audit and in the further recommendations below.

4.2.5. Intermittent clinical and radiological follow-up should continue for all cases until skeletal maturity at 12-16 years of age to assess for persisting acetabular dysplasia. This should be a matter of routine after pelvic osteotomy. In my view, this could reasonably be done at the original treating institution if families are agreeable to ongoing follow-up there. The leakage of the first draft of this report, marked not for disclosure, to the public may make some families uncomfortable with this in which case arrangements for follow-up at a different institution should be made.

4.2.6. The bilateral case that had a complication on the side that did not fulfil the audit criteria for pelvic osteotomy should be recalled

for clinical and radiological assessment now. It should be explained to the family that: the side that developed a symptomatic hip joint effusion did not meet the criteria of this audit for pelvic osteotomy; the intervention performed was novel and the bone cuts were not symmetrical which may be relevant to the observed complication. If this case is or becomes symptomatic, an MRI scan may be helpful for prognosis to assess the affected hip joint and pelvic bone immediately above the socket.

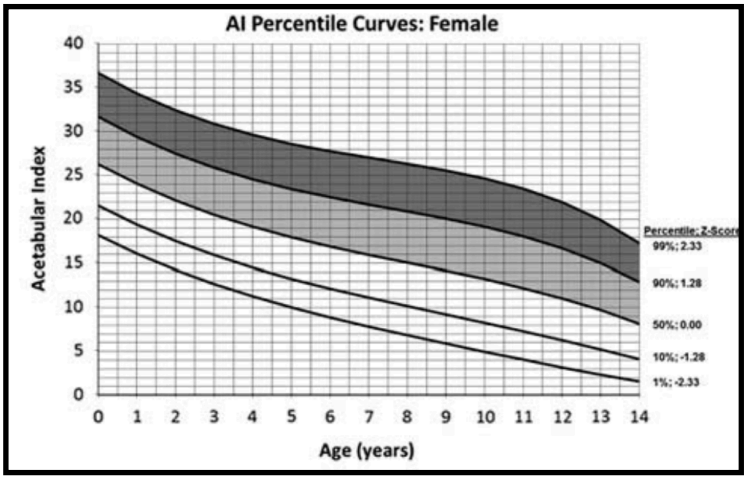
4.3.Recommendations for ongoing practice at all institutions

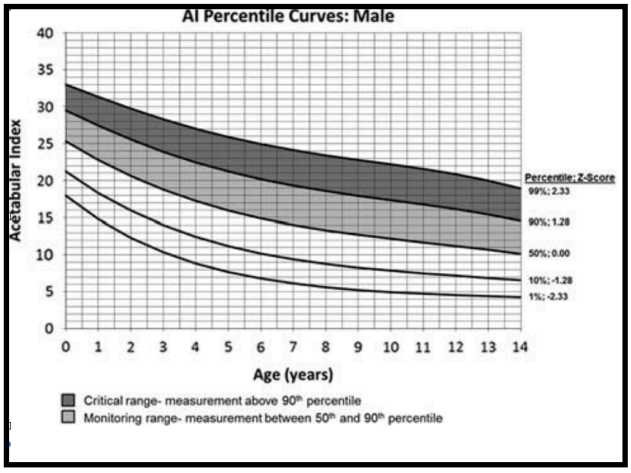
4.3.1.Children with "stable acetabular dysplasia" on pelvic X ray in the first 6-18 months of life, after serendipitous referral in from the community for concerns such as a hip click or thigh crease asymmetry:

4.3.1.1.Children in this age group will have a high rate of apparent acetabular immaturity on plain X ray related to physiological ossification of the cartilage anlage of the acetabulum (9).

4.3.1.2.If the hip joints are concentrically located and there is no prior treatment for DDH then these cases require a further X ray at 2 years and reassurance once the acetabular index (AI) is within one standard deviation of the age-specific mean (Z score of 1). This corresponds to most of the light grey area in the figures below (5).

4.3.1.3.The rate of pelvic osteotomy in this group should be very low. Cases deemed to require it, because of an AI persistently above the 90th centile in the dark grey ranges below, should be peer reviewed with other DDH surgeons from all 3 institutions. Families should also be involved in a thorough discussion of decision making.





Percentile reference curves, Novais et al 2018 (5)

4.3.2. Children undergoing successful treatment early in life in a Pavlik harness for DDH identified on neonatal hip ultrasound:

4.3.2.1. This group requires pelvic X rays at walking age. Reassurance and discharge is appropriate once the acetabular index is within one standard deviation of the age and sex-specific mean (Z score of one). On that basis, the majority can be discharged at 2 years of age but some will require ongoing follow-up to 5 years (13-15).

4.3.2.2. For the minority with residual significant dysplasia on X rays at 2 years, most will have resolved by 5 years. Pelvic osteotomy should be required in only around 2% of this group (14-17). Audit of this rate, based on the denominator of children treated in a Pavlik harness which should be recorded in a registry, would be straightforward and is recommended.

4.3.2.3. Cases deemed to require pelvic osteotomy should undergo peer review as part of surgical planning, with surgeons from all 3 institutions, and families should be involved in decision making.

4.3.2.4. Based on recently published data, children with acetabular indices at or above 24 degrees at 2-3 years of age may benefit from ongoing follow-up but pelvic osteotomy should not be recommended unless the AI exceeds 25 degrees at 4 years or 24 degrees at 5 years (6).

4.3.3.Children with delayed diagnosis of DDH or failure of harness treatment undergoing successful closed or open hip reduction:

4.3.3.1.This group requires close follow-up for the first 2 years after successful reduction to assess the acetabular index. The Iowa evidence base of Albinana et al should be used to assess the risk of persisting acetabular dysplasia at skeletal maturity according to time from successful reduction (1):

Table III. Tests using age at reduction to diagnose residual dysplasia

Cut-off value	Minimum probability of dysplasia (Severin III/IV)	Sensitivity	Specificity	False + (%)	False - (%)	Diagnostic accuracy (%)*	Likelihood ratio
6 mths +	0.20	0.84	0.30	*61*	*22*	*49*	1.2
18 mths +	0.36	0.60	0.66	*52*	*24*	*60*	1.8
32 mths +	0.60	0.20	0.96	*29*	*31*	*69*	5.0

* total % correct (true positive + true negative)

Table IV. Tests using the acetabular index to diagnose residual dysplasia at 2, 4 and 6 years after reduction

Years after reduction	Cut-off value	Minimum probability of dyplasia (Severin III/IV)	Sensitivity	Specificity	False + (%)	False - (%)	Diagnostic accuracy (%)*	Likelihood ratio
2	26+	0.20	0.84	0.60	*48*	*13*	*68*	2.1
	32+	0.60	0.44	0.92	*27*	*25*	*75*	5.5
	35+	0.80	0.16	0.94	*43*	*30*	*67*	2.7
4	23+	0.20	0.92	0.59	*45*	*7*	*70*	2.2
	28+	0.60	0.52	0.91	*24*	*22*	*78*	5.8
	30+	0.80	0.20	0.96	*29*	*31*	*69*	5.0
6	21+	0.20	0.83	0.59	*49*	*13*	*67*	2.0
	26+	0.60	0.65	0.93	*17*	*16*	*84*	9.3
	28+	0.80	0.30	0.98	*13*	*27*	*75*	15.0

* total % correct (true positive + true negative)

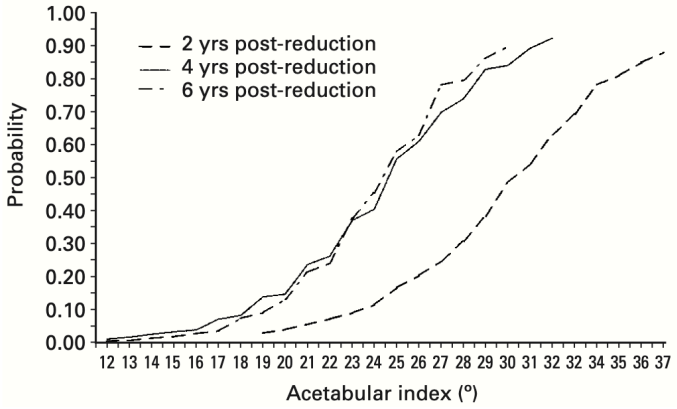


Fig. 3

Graph showing the risk of Severin III/IV related to the acetabular index at 2, 4, and 6 years after reduction.

4.3.3.2.At 2 years from successful reduction, the risk of persisting dysplasia should be approximated from the table and graph above, discussed with the family and peer reviewed with DDH surgeons from all 3 institutions if pelvic osteotomy is advised. AI values should be recorded in the medical notes with an estimated risk of residual dysplasia that is communicated to families as part of the process of decision making and subsequent consent.

4.3.3.3.In cases where pelvic osteotomy is advised by the surgeon, agreed by the peer review process and accepted by the family after discussion of the potential risks and benefits, a further appointment should be arranged for a

proper process of consent. The minimum standards to document are:

4.3.3.3.1. An explanation of the condition of the hip and the approximate percentage likelihood of a poor outcome (persistent acetabular dysplasia) at skeletal maturity with and without any intervention.

4.3.3.3.2. Description of the proposed intervention and the anticipated benefit. If the modified osteotomy is recommended, it must be disclosed that it is a novel procedure with limited published follow-up currently. The advantages and disadvantages in comparison to the standard open procedure should be set out.

4.3.3.3.3. A discussion of the postoperative course including immobilisation and any anticipated requirements for rehabilitation.

4.3.3.3.4. Disclosure and explanation of all important risks.

4.3.4. Less invasive pelvic osteotomy

4.3.4.1. The procedure described as a modified Salter osteotomy at TSH and NOHC is substantially different to the open procedure originally described by Salter (20). It would be better described as a less invasive pelvic osteotomy with either no eponym or a different name attached to it.

4.3.4.1.1. The original open procedure provides a predictable correction based on direct identification of anatomical landmarks (22).

4.3.4.1.2. The modified procedure is performed through a smaller incision using radiological guidance and bioresorbable pins. 50 procedures in 49 cases have been reported with average 2 year follow-up (19).

4.3.4.1.3. Bioresorbable pins avoid the need for surgical removal but can cause osteolysis with the formation of bone cysts or a sterile abscess.

4.3.4.2. Parents should be informed that the modified osteotomy is novel, has specific risks and currently lacks longer term follow-up. The option of an alternative procedure with longer follow-up should be provided. Most are likely to accept a shorter procedure through a smaller scar but time should be set aside for a balanced, documented discussion of the potential risks, benefits and current uncertainties of the less invasive osteotomy.

4.3.4.3. There should be a prospective registry to collect data on outcomes and adverse events with the less invasive osteotomy. These data should be published at appropriate time intervals. A retrospective clinical and radiological review of cases already performed is also recommended when the TSH/NOHC cohorts are recalled.

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