

Docking phenomenon and subsequent acetabular development after gradual reduction using overhead traction for developmental dysplasia of the hip over six months of age

Hiroshi Kaneko¹
Hiroshi Kitoh¹
Akiko Kitamura¹
Kenta Sawamura¹
Tadashi Hattori¹

Abstract

Purpose This study aimed to explore the docking of the femoral head into the acetabulum after gradual reduction (GR) using traction for developmental dysplasia of the hip (DDH) and the impact on subsequent acetabular development.

Methods A total of 40 patients with DDH (42 hips) undergoing GR using overhead traction and spica casting were retrospectively reviewed. The presence of inverted labrum and the coronal and axial femoral-acetabular distances (FADs) were compared between MRI immediately and five weeks after spica casting. The change in the acetabular index on anteroposterior pelvic radiographs were compared between hips with inverted labrum (residual group) and with normally-shaped labrum (normalized group) on follow-up MRI.

Results The mean age at reduction was 13.1 months (7 to 33) and the mean follow-up duration was 7.7 years (4 to 11). The rate of inverted labrum and the FADs significantly decreased between the MRI scans (all p -values < 0.001), and previous Pavlik harness failure had no negative effect on these decreases. The acetabular indices at the ages of three and five years in the residual group were significantly larger than those in the normalized group (both p -values < 0.001). Residual acetabular dysplasia was seen in 84.2% of the residual group compared with 34.8% of the normalized group ($p = 0.002$).

Conclusion The docking phenomenon can occur during spica casting following GR using traction in children with DDH

between the ages of six months and three years. The remaining inverted labrum at the cast removal may negatively affect subsequent acetabular development.

Level of evidence: III - retrospective comparative study

Cite this article: Kaneko H, Kitoh H, Kitamura A, Sawamura K, Hattori T. Docking phenomenon and subsequent acetabular development after gradual reduction using overhead traction for developmental dysplasia of the hip over six months of age. *J Child Orthop* 2021;15:554-563. DOI: 10.1302/1863-2548.15.210143

Keywords: developmental dysplasia of the hip; gradual reduction; MRI; inverted labrum; residual acetabular dysplasia

Introduction

The primary goal of treatment for children with developmental dysplasia of the hip (DDH) is to achieve and maintain reduction of the femoral head in the acetabulum. Dislocated hips characteristically have morphological abnormalities including shallow acetabulum, inverted labrum, and hypertrophied pulvinar and ligaments, which are sometimes obstacles to a concentric, stable reduction.^{1,2} MRI can clearly detect these abnormalities in all of bony, cartilaginous and soft-tissue structures without radiation exposure and hence is increasingly being used to assess the quality of hip reduction in infantile DDH.¹⁻⁴

Gradual reduction (GR) using traction followed by spica casting is one of the non-surgical procedures for hip dislocation in infant and toddler. Several researchers have reported that GR using traction reduces the failure of reduction and the risk of avascular necrosis of the femoral head while having a slightly higher rate of residual acetabular dysplasia, compared with closed reduction (CR) by manual manipulation.⁵⁻⁸ In either reduction technique, it has been suggested that femoral head position within the acetabulum gradually improves over time after reduction, called a 'docking' phenomenon, leading to remodelling of the dysplastic acetabulum.^{4,9,10} Recently, a prospective MRI study quantitatively demonstrated the docking phenomenon following CR and revealed that inverted labrum at the time of CR delayed concentric reduction and ace-

¹ Department of Orthopaedic Surgery, Aichi Children's Health and Medical Center, Obu, Aichi, Japan.

Correspondence should be sent to Hiroshi Kaneko, Department of Orthopaedic Surgery, Aichi Children's Health and Medical Center, 7-426 Moriokacho, Obu, Aichi, 474-8710, Japan.
E-mail: hiroshi_kaneko@sk00106.achmc.pref.aichi.jp

tabular remodelling.¹¹ To date, however, no previous study using MRI has elucidated the docking phenomenon following GR using traction and its relation to subsequent acetabular development. Assessment of the natural course of acetabular development following reduction requires observation without surgery until skeletal maturity, but in actual clinical practice, if acetabular dysplasia does not show sufficient spontaneous correction by the age of five to seven years, the operative management by a pelvic osteotomy has been indicated for minimizing the risk of early-onset hip osteoarthritis.^{8,12-15}

We thus studied patients with DDH who successfully underwent GR using overhead traction (OHT) and five weeks of spica casting with a conservative follow-up until at least the age of five years. Patients routinely underwent MRI both the next day and five weeks after the cast immobilization to clarify the docking phenomenon in the period. We also aimed at investigating the impact of the remaining inverted labrum at the cast removal on acetabular remodelling until the age of five years.

Materials and methods

Patients

After the institutional review board approval was obtained, we retrospectively reviewed the medical records and imaging for a consecutive series of patients with DDH who had undergone the same protocol of GR using OHT at our institution between January 2009 and December 2016.

The inclusion criteria were: 1) hip dislocation treated with GR using OHT; 2) clinical and radiological data before and after the treatment, including pelvic radiographs and MRI scans.

The exclusion criteria were: 1) teratologic, paralytic and syndromic hip dislocation; 2) failure of GR using OHT; 3) lost to follow-up before the age of five years; 4) hip surgery before the age of five years; 5) incomplete clinical or radiological data.

GR and post-reduction management

We typically attempted to apply GR using OHT to patients with DDH who had failed Pavlik harness treatment following early detection or who were late-detected at the age of six months to three years. The OHT method consisted of three phases, according to a previous report.⁶ Briefly, the first phase of four-week horizontal skin traction was performed to obtain a gradual descent of the dislocated femoral head with stretching muscles and soft tissues around the hip joint. The second phase of one-week vertical traction began with the hip flexed in 90°, followed by in 100° at the second day. Hip abduction with the knee extended was increased daily up to 70°. The final phase of

one-week above-knee traction allowed the knees to move freely with the hips abducted. The dislocated hip was usually reduced at the final phase, which could be confirmed by ultrasound imaging. Dynamic arthrography under general anaesthesia was performed after successful GR to visualize the shape of the femoral head and the soft-tissue interpositions and to determine the most concentric position that was optimal for cast immobilization, usually 90° of flexion and 70° of abduction with 90° of knee flexion, and then bilateral hips were immobilized in a spica cast for five weeks. After the cast removal, we used a hip flexion-abduction brace for three months.

Radiological evaluation

We used a standard picture archiving and communication system software for radiological measurements. The first author (HKa) evaluated and measured the following radiological parameters. The International Hip Dysplasia Institute (IHDI) classification¹⁶ before OHT, the acetabular index (AI)¹⁷ before OHT and at the ages of three and five years, and the centre-edge angle¹⁸ at the age of five years were measured using anteroposterior pelvic radiographs. We used radiographs at the age of three years that had been taken at least one year after reduction. The lateral edge of the sourcil was used for the measurements. According to previous studies,^{9,19} residual acetabular dysplasia at the age of five years was defined as either the AI of $\geq 30^\circ$ or the centre-edge angle of $\leq 5^\circ$. The presence of avascular necrosis (AVN) of the femoral head was assessed according to the criteria established by Salter et al,²⁰ and the final decision of AVN occurrence was agreed upon by all authors.

The patients in a spica cast were placed in a supine position under sedation and underwent non-contrast initial and follow-up MRI the next day and five weeks after spica casting, respectively, to confirm maintenance of hip reduction and evaluate structures of the hip joint. Standardized MRI scans were performed using the Philips Ingenia 1.5T (Philips, Eindhoven, The Netherlands), including T1- and T2-weighted images obtained in the coronal and axial planes using the sequence as follows: T1, repetition time/echo time: 400/10 ms; T2, repetition time/echo time: 4000/100 ms; field of view: 150 mm; matrix: 156×224; slice thickness: 2 mm; interslice gap: 0.2 mm.

The presence of inverted labrum was assessed using the T2-weighted coronal images on the slice showing the largest diameter of the affected femoral head (Fig. 1). According to Talathi et al,⁴ the coronal and axial femoral-acetabular distances (FADs) were measured using the T2-weighted coronal and axial images, respectively, on the slice showing the largest diameter of the affected femoral head (Fig. 2). A normal value of FAD was defined as < 2 mm.¹¹

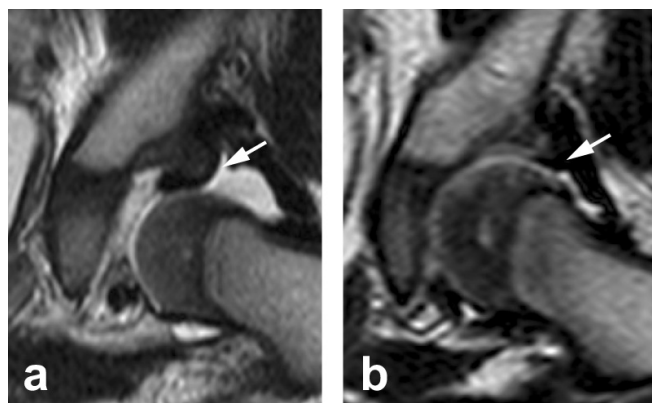


Fig. 1 T2-weighted coronal MRI images demonstrating: a) an inverted labrum (arrow); and b) a normally-shaped labrum (arrow).

Statistical analysis

Statistical analyses were performed using the SPSS version 25 software package (IBM, Armonk, New York) and a p-value < 0.05 was considered significant. First, we compared the MRI measurements between initial and follow-up MRI scans using the McNemar test for paired categorical variables and the Wilcoxon signed-rank test for paired continuous variables. Next, to investigate the impact of previous Pavlik harness failure on docking phenomenon following GR, we compared age and the MRI measurements between previously failed and untreated hips. And finally, the hips were divided into two groups according to the presence of inverted labrum on follow-up MRI: hips with residual inverted labrum (residual group) and those with normally-shaped labrum (normalized group). Age, the radiographic measurements, and complications were compared between the two groups. We used the Fisher exact test for categorical variables and the Mann-Whitney U test for continuous variables.

A total of 15 hips were randomly selected for reproducibility analysis of the radiological measurements. The three authors (HKa, AK and KS), who had eight to 20 years' experience of dealing with DDH, independently evaluated the radiographs and MRIs on two separate occasions with a one-month interval. The weighted kappa statistic was calculated to assess the intra- and interrater reproducibility of the IHDI classification and the presence of inverted labrum, and the intraclass correlation coefficient (ICC) was calculated to assess those of the AI, the centre-edge angle and the coronal and axial FADs.

Results

In all, 69 consecutive patients (79 affected hips) who had undergone GR using OHT were reviewed. A total of 29 patients (37 hips) were excluded: 14 patients (21 hips) who had either teratologic (two patients, four hips), paralytic (six patients, eight hips) or syndromic (six patients, nine

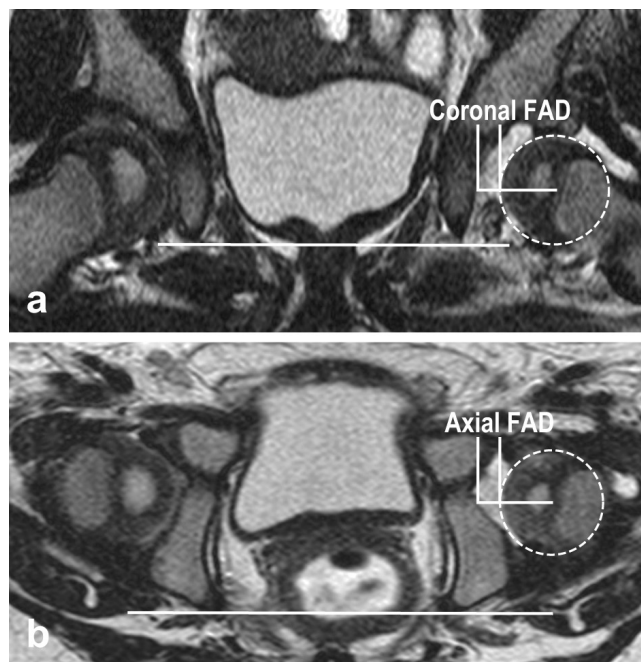


Fig. 2 a) The coronal femoral-acetabular distance (FAD). In T2-weighted coronal MRI, the measurement is made on the slice showing the largest diameter of the affected femoral head. The distance between the acetabular edge and the edge of the femoral head is parallel to the tangential line to the most inferior points of both teardrops and measured in millimetres at the level of the centre of the femoral head; **b)** the axial FAD. In T2-weighted axial MRI, the measurement is made on the slice showing the largest diameter of the affected femoral head. The distance between the acetabular edge and the edge of the femoral head was parallel to the tangential line to the most posterior points of both ischia and measured in millimetres at the level of the centre of the femoral head.

hips) hip dislocation, seven (eight hips) of whom failed GR using OHT; another patient (one hip) without underlying diseases who failed GR using OHT; another patient (one hip) who was lost to follow-up due to moving; and the other 13 patients (14 hips) who had incomplete MRI data due to sedation failure. Therefore, 40 patients were analyzed in this study. There were 38 female and two male individuals with 42 affected hips, including 26 left, 12 right and two bilateral sides. The mean total duration of traction was 6.1 weeks (SD 0.2; 5.6 to 6.6), the mean age at reduction was 13.1 months (SD 7.2; 7 to 33), and the mean follow-up duration was 7.7 years (SD 2.1; 4 to 11).

Comparison of the MRI measurements between initial and follow-up scans is shown in Table 1. In all, 40 hips (95.2%) had inverted labrum on initial scan whereas 19 hips (45.2%) did on follow-up scan. Both the coronal and axial FADs decreased between the scans in all hips, and the mean values were as follows: initial *versus* follow-up; coronal, 4.9 mm (SD 2.2; 1.4 to 11) *versus* 2.1 mm (SD 1.7; 0 to 6.8); axial, 4.8 mm (SD 2.1; 0.9 to 10.4) *versus* 2.2

mm (SD 1.8; 0 to 6.8). The number of the hips with normal both FADs increased from two (4.8%) to 24 (57.1%) between the scans. There were significant differences in all the MRI measurements between the scans (all p-values < 0.001; Table 1).

In all, 26 hips were diagnosed between the ages of one and four months and then failed Pavlik harness treatment at our institution or others, whereas the other 16 hips were diagnosed between the ages of six and 31 months and didn't get any treatments before OHT. The mean age at reduction in the hips with Pavlik harness failure was significantly younger than that in those without prior treatment: 8.8 months (SD 1.4; 7 to 12) versus 20.1 months

(SD 7.7; 7 to 33) ($p < 0.001$; Table 2). On follow-up MRI, inverted labrum and FADs significantly more frequently normalized in the hips with Pavlik harness failure than in those without prior treatment: residual inverted labrum, eight hips (30.8%) versus 11 hips (68.8%) ($p = 0.026$); normal both FADs, 21 hips (80.8%) versus three hips (18.8%) ($p < 0.001$; Table 2).

The residual group and the normalized group consisted of 19 hips and 23 hips, respectively. Two patients with bilateral involvement (four hips) were included in the normalized group. Patients in the residual group, including all ten patients (ten hips) older than 18 months, tended to be significantly older at reduction than those in the normalized

Table 1. Comparison between two time points after gradual reduction

MRI measurements	Initial scan*	Follow-up scan*	p-value
Inverted labrum, n (%)	40 (95.2)	19 (45.2)	< 0.001 [†]
Mean coronal FAD, mm (sd; range)	4.9 (2.2; 1.4 to 11)	2.1 (1.7; 0 to 6.8)	< 0.001 [‡]
Mean axial FAD, mm (sd; range)	4.8 (2.1; 0.9 to 10.4)	2.2 (1.8; 0 to 6.8)	< 0.001 [‡]
Both FADs < 2 mm, n (%)	2 (4.8)	24 (57.1)	< 0.001 [†]

*initial and follow-up scans indicate MRI taken at the next day and five weeks after reduction, respectively

[†]McNemar test

[‡]Wilcoxon signed-rank test

FAD, femoral-acetabular distance

Table 2. Comparison between hips with Pavlik harness failure and those without prior treatment

Variables	Pavlik harness failure (n = 26)	No prior treatment (n = 16)	p value
Mean age at reduction, mths (sd; range)	8.8 (1.4; 7 to 12)	20.1 (7.7; 7 to 33)	< 0.001 [†]
MRI measurements			
Inverted labrum, n (%)			
Initial scan*	24 (92.3)	16 (100)	0.517 [‡]
Follow-up scan*	8 (30.8)	11 (68.8)	0.026 [‡]
Both FADs < 2 mm, n (%)			
Initial scan*	1 (3.8)	1 (6.3)	1.000 [‡]
Follow-up scan*	21 (80.8)	3 (18.8)	< 0.001 [‡]

*initial and follow-up scans indicate MRI taken at the next day and five weeks after reduction, respectively

[†]Mann-Whitney U test

[‡]Fisher's exact test

FAD, femoral-acetabular distance

Table 3. Comparison between hips with and without inverted labrum after five weeks of spica casting following gradual reduction

Variables	Residual group (n = 19)	Normalized group (n = 23)	p-value
Mean age at reduction, mths (sd; range)	17.7 (8.5; 7 to 33)	9.3 (2.5; 7 to 18)	< 0.001 [†]
The IHDI classification, n (%)			
Grade III	12 (63.2)	15 (65.2)	1.000 [‡]
Grade IV	7 (36.8)	8 (34.8)	
Mean acetabular index, ° (sd; range)			
Before overhead traction	41.7 (4.2; 34 to 49)	40.7 (4.3; 34 to 48)	0.543 [†]
At the age of three yrs	34.6 (3.7; 26 to 39)	29.7 (3.4; 23 to 37)	< 0.001 [†]
At the age of five yrs*	31.5 (5.0; 22 to 40)	24.3 (5.7; 16 to 37)	< 0.001 [†]
Mean centre-edge angle, ° (sd; range)	1.9 (7.6; -25 to 15)	9.2 (7.7; -7 to 20)	0.003 [†]
Residual acetabular dysplasia,* n (%)	16 (84.2)	8 (34.8)	0.002 [‡]
Age at reduction, ≤ 18 mths	8/9	8/23	
Age at reduction, > 18 mths	8/10	-	
Re-dislocation, n (%)	0 (0)	1 (4.3)	1.000 [‡]
AVN, n (%)	2 (10.5)	1 (4.3)	0.581 [‡]

*residual acetabular dysplasia is defined as either the acetabular index of $\geq 30^\circ$ or the centre-edge angle of $\leq 5^\circ$ at the age of five years

[†]Mann-Whitney U test

[‡]Fisher's exact test

IHDI, International Hip Dysplasia Institute; AVN, avascular necrosis of the femoral head

group: mean 17.7 months (SD 8.5; 7 to 33) versus 9.3 (SD 2.5; 7 to 18) ($p < 0.001$; Table 3). Before the start of OHT, 12 hips (63.2%) were IHDI grade III and seven (36.8%) were grade IV in the residual group, and 15 (65.2%) were grade III and eight (34.8%) were grade IV in the normalized group, and the IHDI classification was not significantly associated with residual inverted labrum ($p = 1.000$; Table 3).

The AI gradually decreased after reduction in all hips, and the mean values before OHT, at the age of three years and at the age of five years were 41.7° (SD 4.2°; 34° to 49°), 34.6° (SD 3.7°; 26° to 39°) and 31.5° (SD 5.0°; 22° to 40°), respectively, in the residual group, and 40.7° (SD 4.3°; 34° to 48°), 29.7° (SD 3.4°; 23° to 37°) and 24.3° (SD 5.7°; 16° to 37°), respectively, in the normalized group. The mean AI before OHT was similar between the groups ($p = 0.543$), but the indices at the ages of three and five years in the residual group were significantly larger than those in the normalized group (both p values < 0.001 ; Table 3 and Fig. 3). The mean centre-edge angle at the age of five years in the residual group was significantly smaller than that in the normalized group: 1.9° (SD 7.6°; -25° to 15°) versus 9.2° (SD 7.7°; -7° to 20°) ($p = 0.003$; Table 3). Sixteen hips (84.2%) in the residual group, including eight of ten hips older than 18 months, had residual acetabular dysplasia (Fig. 4), whereas eight hips (34.8%) in the normalized group did (Fig. 5), and there was a significant difference between the groups ($p = 0.002$; Table 3). These 24 hips underwent Salter innominate osteotomy for residual

acetabular dysplasia at the mean age of 5.7 years (SD 0.5; 5.1 to 7.6).

One hip (4.3%) in the normalized group re-dislocated after completion of the brace treatment and immediately underwent CR. Two hips (10.5%) in the residual group

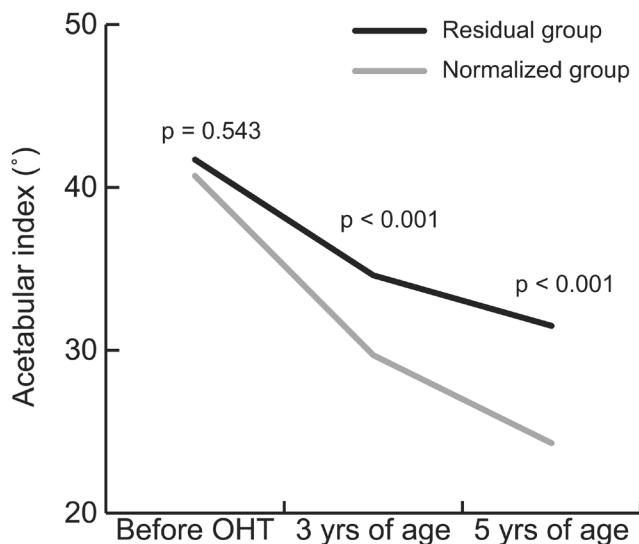


Fig. 3 Graph showing change in the acetabular index (AI) of the affected hip before and after gradual reduction using overhead traction. The AI at each time point was compared between the residual and normalized groups using the Mann-Whitney U test. The AI showed a significant difference between the groups at the ages of three and five years (both p -values < 0.001) (OHT, overhead traction).

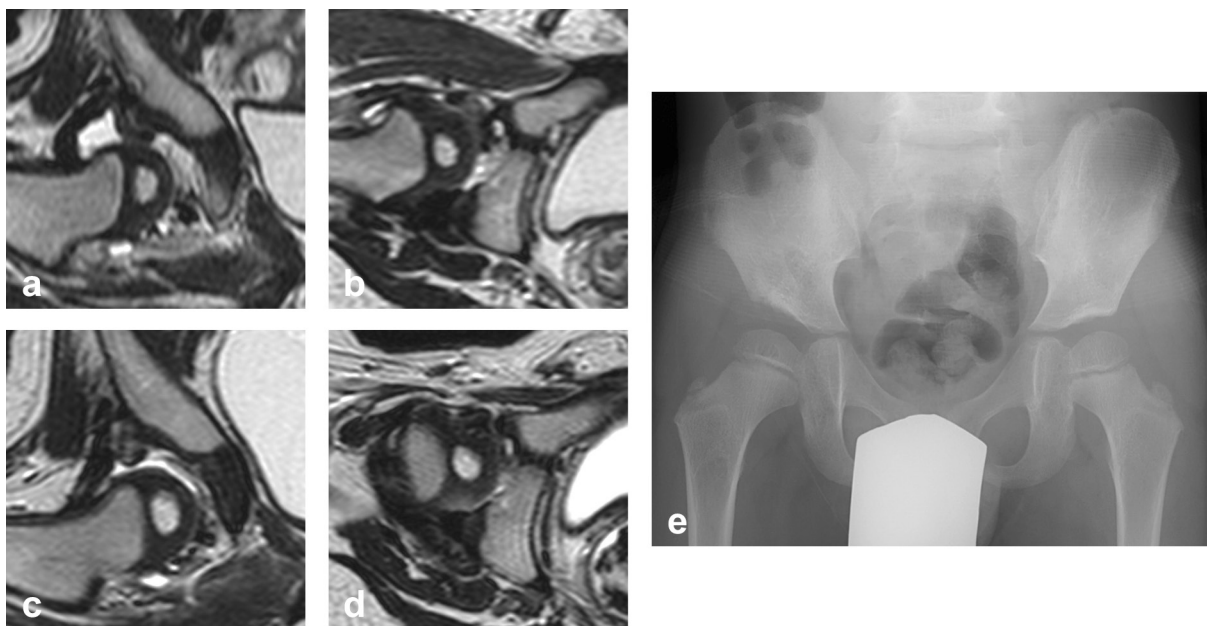


Fig. 4 A boy in the residual group with right hip dislocation reduced at the age of 25 months. T2-weighted coronal and axial MRI images the next day (a, b) and five weeks (c, d) after cast immobilization following gradual reduction using overhead traction. Follow-up scans demonstrating the remaining inverted labrum and soft-tissue interpositions. The pelvic radiograph at the age of five years (e) shows residual acetabular dysplasia of the right hip.

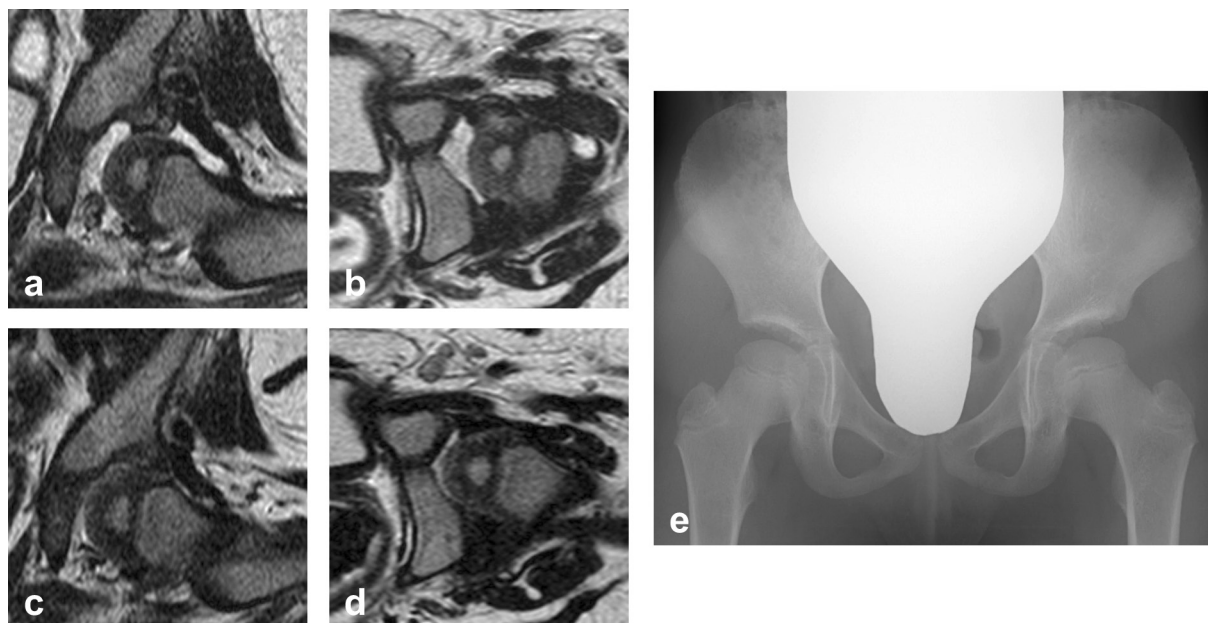


Fig. 5 A girl in the normalized group with left hip dislocation reduced at the age of ten months. T2-weighted coronal and axial MRI images the next day (**a, b**) and five weeks (**c, d**) after cast immobilization following gradual reduction using overhead traction. Follow-up scans demonstrating improvement of the femoral head position and inverted labrum. The pelvic radiograph at the age of five years (**e**) shows normal acetabular development of the left hip.

and one (4.3%) in the normalized group developed AVN of the femoral head at the latest follow-up. These four hips showed residual acetabular dysplasia at the age of five years. There were no significant differences in re-dislocation ($p = 1.000$) and AVN ($p = 0.581$) between the groups (Table 3).

The intra- and interrater reproducibility of the radiological measurements were good to excellent: intra- and interrater; the IHD classification, kappa 0.857 to 1.000 and 0.700 to 1.000; the presence of inverted labrum, kappa 1.000 and 1.000; the AI, ICC 0.722 to 0.971 and 0.794 to 0.806; the centre-edge angle, ICC 0.798 to 0.968 and 0.781 to 0.799; the coronal FAD, ICC 0.966 to 0.991 and 0.951 to 0.987; and the axial FAD, ICC 0.971 to 0.986 and 0.937 to 0.965.

Discussion

A concentric, stable reduction is necessary for the normal development of the affected hip in children with DDH, but it is unlikely to be achievable immediately after GR using traction, as well as CR, and thus the post-reduction management will play an important role in the docking of the femoral head into the acetabulum. This is the first study demonstrating that femoral head position and inverted labrum can improve during five weeks of spica casting following GR using OHT by serial MRI taken at the start and end of the cast immobilization. This study also suggests that the remaining inverted labrum at the cast removal,

which is more likely to be observed in older children, may lead to residual acetabular dysplasia at the age of five years.

Several researchers have studied the docking phenomenon after CR using serial MRI. Talathi et al,⁴ reviewing 30 hips treated by CR and spica casting, reported that femoral head position in the acetabulum improved for an average of three weeks, ranging from 13 to 46 days, after CR. A prospective study of 35 hips by Zhou et al¹¹ also demonstrated that concentricity of the femoral head dramatically improved between immediately and six months after CR and spica casting. More recently, Meng et al²¹ revealed that the abnormal labrum-cartilage complex gradually returned to normal shape with the gradual inward displacement of the femoral head in a spica cast for four to six months after CR in 63 hips and thus concluded that it was unnecessary to deal with the abnormal structures at the time of reduction. In the present study, almost all hips (95.2%) showed inverted labrum immediately after GR using OHT, but the number halved by five weeks of spica casting in optimal position. Furthermore, femoral head position tended to improve in all hips, and 57.1% obtained sufficient concentricity of the femoral head until the cast removal. These results indicate that the docking phenomenon can in fact occur even over a short immobilization period after GR using OHT, as well as CR.

The Pavlik harness is the first-line treatment for DDH in infants younger than six months and the incidence of treatment failure has been reported to range from 11% to 44%.²²⁻²⁶ White et al²⁶ sought unique ultrasonographic

markers in 43 failed hips and suggested that inverted labrum acted as a physical obstacle to reducing the femoral head into the acetabulum. More recently, Lin et al²⁵ also demonstrated that the presence of inverted labrum on ultrasound examination was strongly predictive of treatment failure in 229 hips initially treated by the harness. According to these suggestions, docking phenomenon following GR using OHT, including normalization of inverted labrum, would be unlikely to occur smoothly after Pavlik harness failure. However, a sufficient docking was more frequently observed in the hips with Pavlik harness failure than those without prior treatment. Since the harness has been used for younger infants, the unexpected results may be explained by differences in age at reduction rather than prior treatment. Previous Pavlik harness failure seems to have no negative effect on docking phenomenon after GR using OHT.

There is a well-established correlation between age at reduction and subsequent acetabular remodelling in DDH. Lindstrom et al²⁷ classically reported that the younger patient age at reduction was, the more rapidly the AI improved. Salter and Dubos²⁸ also stated that favourable acetabular remodelling could not be ensured in children older than 18 months. Albinana et al,²⁹ reviewing 72 hips with conservative follow-up until skeletal maturity, demonstrated that patients with residual acetabular dysplasia were significantly older at reduction than those with a well-developed hip (mean 21 versus 13 months of age). Rampal et al⁷ described that 91.5% of the patients who had undergone GR using traction at one to five years of age required a pelvic osteotomy for residual acetabular dysplasia. In the present study, the patients with inverted labrum at the cast removal were significantly older at reduction than those with normally-shaped labrum, and the former group included all patients older than 18 months. Interestingly, we found that the former group significantly more frequently had residual acetabular dysplasia at the age of five years than the latter group (84.2% versus 34.8%). Furthermore, 80% (8/10) of hips older than 18 months at reduction had residual acetabular dysplasia, whereas 50% (16/32) of those 18 months or younger did. Based on these results, we suppose that children older than 18 months can have a low remodelling potential of abnormal structures of the hip joint such as inverted labrum and hypertrophied pulvinar, leading to poor development of the bony acetabulum after reduction. Early treatment prior to the age of 18 months is recommended for better acetabular development.

The definition of residual acetabular dysplasia requiring surgical correction is debatable. Regarding natural acetabular remodelling after reduction, Albinana et al²⁹ demonstrated that if the AI at four years after reduction was $\geq 30^\circ$, the hips had a high probability ($\geq 80\%$) of residual acetabular dysplasia at skeletal maturity. Lalonde et al,¹³ whose

indication for a pelvic surgery was the AI of $> 20^\circ$ or the centre-edge angle of $< 20^\circ$, reported that children younger than eight years had better outcomes than those older than eight years. Morita et al¹⁴ have performed angulated innominate osteotomy to correct dysplastic hips with the AI of $\geq 30^\circ$, the centre-edge angle of $\leq 10^\circ$ and the acetabular head index of $\leq 70\%$ at the age of four to eight years. We generally agree with the previous studies. In this study, residual acetabular dysplasia (the AI of $\geq 30^\circ$ or the centre-edge angle of $\leq 5^\circ$) was determined three to five years after reduction, and then the patients underwent Salter innominate osteotomy at the age of five to seven years.

The question arises as to whether early open surgery for the remaining inverted labrum at the cast removal is the right choice for development of the hip joint. As for the surgical intervention for intra-articular structures, we are concerned about the disadvantages. During open reduction (OR), the hip joint is exposed to air, potentially leading to cartilage degeneration, chondrocyte death and longitudinally, early-onset osteoarthritis.³⁰⁻³² Gibson and Benson,³⁰ reviewing 149 hips treated by OR including excision of inverted labrum, reported that 44% radiologically showed evidence of degenerative changes at the ages of 16 to 31 years. Paterson et al³² demonstrated the negative effect of open joint drying on the properties of cartilage and chondrocytes in an *in vivo* animal model and emphasized the importance of maintaining cartilage hydration during surgery. Howard et al³¹ also described that articular cartilage was susceptible to drying and direct injury by surgical instruments, leading to significant chondrocyte death. On the other hand, it has been suggested that OR has an advantage that reduces the rate of secondary surgery for residual acetabular dysplasia. Bolland et al³³ and Morris et al³⁴ reported that OR had a lower rate of secondary surgery than CR (19% to 30% versus 28% to 47%). To minimize the risk of articular cartilage degeneration, we have used an extra-articular treatment strategy for late-detected DDH: GR using OHT with or without late Salter innominate osteotomy, which has been reported as a quite useful osteotomy in the treatment of residual acetabular dysplasia by several researchers.^{19,35,36} In this study, 57.1% of the hips received Salter innominate osteotomy. In contrast, the remaining inverted labrum as well as hypertrophied pulvinar is expected to further improve by long-term casting or brace wearing. Using six months' immobilization, Zhou et al¹¹ demonstrated that the proportion of a concentric reduction increased from 8.6% to 68.6% during the immobilization, and moreover reached 77.1% one year after CR. We have also observed the improvement on further MRI that a limited number of patients in the residual group underwent after a total of four months immobilization by spica casting and bracing in our treatment protocol (Fig. 6), but we do not have enough data yet to prove it. Further research is needed to

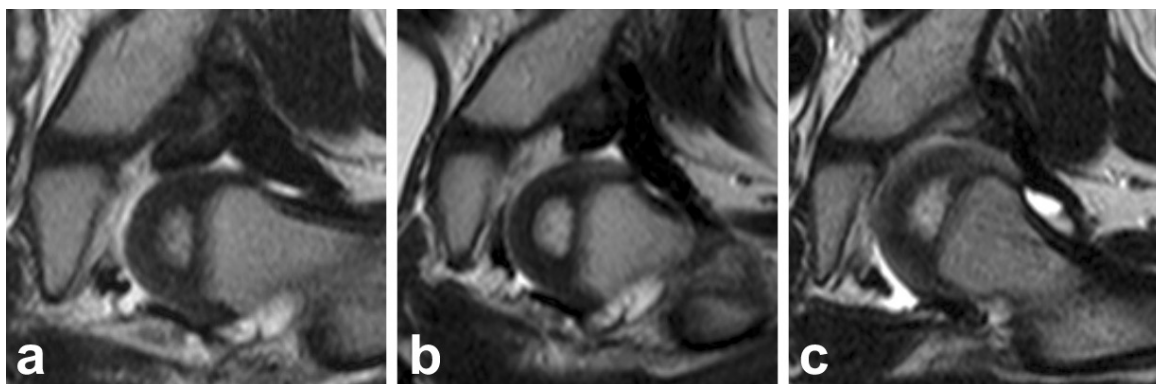


Fig. 6 A girl in the residual group with left hip dislocation reduced at the age of 21 months. T2-weighted coronal MRI images the next day (**a**); five weeks (**b**); and six months (**c**) after gradual reduction using overhead traction, showing continuous improvement of the inverted labrum and hypertrophied pulvinar.

clarify the positive effect of long-term casting or bracing on docking of the femoral head into the acetabulum and the subsequent acetabular remodelling.

The strength of this study was to compare between initial and follow-up MRI scans taken at the same interval for the same patients at the same institution, thereby minimizing variability. On the other hand, this study has some limitations. First, there was the range of the interval between pelvic radiographs before traction and at the age of three years due to different ages at reduction, ranging from seven to 33 months. Second, hip flexion and abduction angles in a spica cast varied. Optimal angles for immobilization after reduction seem to slightly differ between individual patients, and thus we dynamically confirm the most concentric position of the femoral head in the acetabulum using arthrography just before spica casting. Third, 15 patients without underlying diseases were excluded, thereby resulting in a smaller number of subjects. One patient, who was diagnosed at the age of 19 months, failed GR using OHT and required CR under general anaesthesia. Overall, patients without underlying diseases obtained a higher success rate (57/58, 98.2%) of the treatment than those with underlying diseases (13/21, 61.9%). Another patient succeeded GR using OHT with no complications during the follow-up, but she moved one year after reduction and thereby was lost to follow-up. With regard to the others, we used oral or intravenous sedative drugs for children unable to lie,³⁷ but movement due to poor sedation interfered with clear MRI for the analysis of this study. Fukuda et al³⁸ has developed an ultrafast MRI for infantile DDH that can provide excellent image quality within a total study time of ≤ 7 mins without sedation, which is worth considering replacing with a conventional MRI under sedation.

Conclusion

This study clearly demonstrates by serial MRI that the docking phenomenon can occur during five weeks of spica

casting following GR using OHT in children with DDH between six months and three years of age, supporting the important role of cast immobilization in obtaining a concentric reduction. However, the remaining inverted labrum at the cast removal, which is usually observed in children older than 18 months, may negatively affect subsequent acetabular development until the age of five years.

Received 13 July 2021; accepted after revision 16 October 2021.

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

OA LICENCE TEXT

This article is distributed under the terms of the Creative Commons Attribution-Non Commercial 4.0 International (CC BY-NC 4.0) licence (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed.

ETHICAL STATEMENT

Ethical approval: Approval from our institutional review board was obtained for this retrospective study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

ICMJE CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI Grant Number JP21H03063.

AUTHOR CONTRIBUTIONS

HKa: Study design, Data collection, Statistical analysis, Manuscript preparation and revision, Final manuscript approval.

HKi: Data analysis, Manuscript revision, Final manuscript approval.
AK: Data collection, Manuscript review, Final manuscript approval.
KS: Data collection, Manuscript review, Final manuscript approval.
TH: Study design, Manuscript revision, Final manuscript approval.

REFERENCES

- Lu W, Li L, Zhang L, Li Q, Wang E.** Development of acetabular anteversion in children with normal hips and those with developmental dysplasia of the hip: a cross-sectional study using magnetic resonance imaging. *Acta Orthop* 2021;92:341-346.
- Studer K, Williams N, Studer P, et al.** Obstacles to reduction in infantile developmental dysplasia of the hip. *J Child Orthop* 2017;11:358-366.
- Jia H, Wang L, Chang Y, et al.** Assessment of irreducible aspects in developmental hip dysplasia by magnetic resonance imaging. *BMC Pediatr* 2020;20:550.
- Talathi NS, Chauvin NA, Sankar WN.** Docking of the femoral head following closed reduction for DDH: does it really occur? *J Pediatr Orthop* 2018;38:e440-e445.
- Fukiage K, Futami T, Ogi Y, et al.** Ultrasound-guided gradual reduction using flexion and abduction continuous traction for developmental dysplasia of the hip: a new method of treatment. *Bone Joint J* 2015;97-B:405-411.
- Kaneko H, Kitoh H, Mishima K, Matsushita M, Ishiguro N.** Long-term outcome of gradual reduction using overhead traction for developmental dysplasia of the hip over 6 months of age. *J Pediatr Orthop* 2013;33:628-634.
- Rampal V, Sabourin M, Erdeneshoo E, et al.** Closed reduction with traction for developmental dysplasia of the hip in children aged between one and five years. *J Bone Joint Surg [Br]* 2008;90-B:858-863.
- Wicart P, Seringe R, Glorion C, Brassac A, Rampal V.** Closed reduction in late-detected developmental dysplasia of the hip: indications, results and complications. *J Child Orthop* 2018;12:317-322.
- Hattori T, Ono Y, Kitakoji T, Takashi S, Iwata H.** Soft-tissue interposition after closed reduction in developmental dysplasia of the hip. The long-term effect on acetabular development and avascular necrosis. *J Bone Joint Surg [Br]* 1999;81-B:385-391.
- Severin E.** Congenital dislocation of the hip; development of the joint after closed reduction. *J Bone Joint Surg [Am]* 1950;32-A:507-518.
- Zhou W, Sankar WN, Zhang F, et al.** Evolution of concentricity after closed reduction in developmental dysplasia of the hip. *Bone Joint J* 2020;102-B:618-626.
- Kitoh H, Kitakoji T, Katoh M, Ishiguro N.** Prediction of acetabular development after closed reduction by overhead traction in developmental dysplasia of the hip. *J Orthop Sci* 2006;11:473-477.
- Lalonde FD, Frick SL, Wenger DR.** Surgical correction of residual hip dysplasia in two pediatric age-groups. *J Bone Joint Surg [Am]* 2002;84-A:1148-1156.
- Morita M, Kamegaya M, Takahashi D, et al.** Proposal of a new type of innominate osteotomy without the use of bone graft in children: a preliminary study. *JBJS Open Access* 2019;4:e0016.
- Omeroğlu H, Ağuş H, Biçimoğlu A, Tümer Y.** Evaluation of experienced surgeons' decisions regarding the need for secondary surgery in developmental dysplasia of the hip. *J Pediatr Orthop* 2012;32:58-63.
- Narayanan U, Mulpuri K, Sankar WN, et al.** Reliability of a new radiographic classification for developmental dysplasia of the hip. *J Pediatr Orthop* 2015;35:478-484.
- Kotlarsky P, Haber R, Bialik V, Eidelman M.** Developmental dysplasia of the hip: what has changed in the last 20 years? *World J Orthop* 2015;6:886-901.
- Wiberg G.** Studies on dysplastic acetabula and congenital subluxation of the hip joint. With special reference to the complication of osteoarthritis. *Acta Chir Scand* 1939;83(suppl 58):1-135.
- Kaneko H, Kitoh H, Mishima K, et al.** Factors associated with an unfavourable outcome after Salter innominate osteotomy in patients with unilateral developmental dysplasia of the hip: does occult dysplasia of the contralateral hip affect the outcome? *Bone Joint J* 2014;96-B:1419-1423.
- Salter RB, Kostuik J, Dallas S.** Avascular necrosis of the femoral head as a complication of treatment for congenital dislocation of the hip in young children: a clinical and experimental investigation. *Can J Surg* 1969;12:44-61.
- Meng X, Yang J, Wang Z.** Magnetic resonance imaging follow-up can screen for soft tissue changes and evaluate the short-term prognosis of patients with developmental dysplasia of the hip after closed reduction. *BMC Pediatr* 2021;21:115.
- Aarvold A, Schaeffer EK, Kelley S, et al.** Management of irreducible hip dislocations in infants with developmental dysplasia of the hip diagnosed below 6 months of age. *J Pediatr Orthop* 2019;39:e39-e43.
- Harris IE, Dickens R, Menelaus MB.** Use of the Pavlik harness for hip displacements. When to abandon treatment. *Clin Orthop Relat Res* 1992;281:29-33.
- Kitoh H, Kawasumi M, Ishiguro N.** Predictive factors for unsuccessful treatment of developmental dysplasia of the hip by the Pavlik harness. *J Pediatr Orthop* 2009;29:552-557.
- Lin AJ, Siddiqui AA, Lai LM, Goldstein RY.** An inverted acetabular labrum is predictive of Pavlik harness treatment failure in children with developmental hip dysplasia. *J Pediatr Orthop* 2021;41:479-482.
- White KK, Sucato DJ, Agrawal S, Browne R.** Ultrasonographic findings in hips with a positive Ortolani sign and their relationship to Pavlik harness failure. *J Bone Joint Surg [Am]* 2010;92-A:113-120.
- Lindstrom JR, Ponseti IV, Wenger DR.** Acetabular development after reduction in congenital dislocation of the hip. *J Bone Joint Surg [Am]* 1979;61-A:112-118.
- Salter RB, Dubos JP.** The first fifteen year's personal experience with innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip. *Clin Orthop Relat Res* 1974;98:72-103.
- Albinana J, Dolan LA, Spratt KF, et al.** Acetabular dysplasia after treatment for developmental dysplasia of the hip. Implications for secondary procedures. *J Bone Joint Surg [Br]* 2004;86-B:876-886.
- Gibson PH, Benson MK.** Congenital dislocation of the hip. Review at maturity of 147 hips treated by excision of the limbus and derotation osteotomy. *J Bone Joint Surg [Br]* 1982;64-B:169-175.
- Howard TA, Murray IR, Amin AK, Simpson AH, Hall AC.** Damage control articular surgery: maintaining chondrocyte health and minimising iatrogenic injury. *Injury* 2020;51:S83-S89.
- Paterson SI, Eltawil NM, Simpson AH, Amin AK, Hall AC.** Drying of open animal joints in vivo subsequently causes cartilage degeneration. *Bone Joint Res* 2016;5:137-144.

33. **Bolland BJ, Wahed A, Al-Hallao S, Culliford DJ, Clarke NM.** Late reduction in congenital dislocation of the hip and the need for secondary surgery: radiologic predictors and confounding variables. *J Pediatr Orthop* 2010;30:676-682.
34. **Morris WZ, Hinds S, Worrall H, Jo CH, Kim HKW.** Secondary surgery and residual dysplasia following late closed or open reduction of developmental dysplasia of the hip. *J Bone Joint Surg [Am]* 2021;103-A:235-242.
35. **Böhm P, Brzuske A.** Salter innominate osteotomy for the treatment of developmental dysplasia of the hip in children: results of seventy-three consecutive osteotomies after twenty-six to thirty-five years of follow-up. *J Bone Joint Surg [Am]* 2002;84-A:178-186.
36. **Ito H, Ooura H, Kobayashi M, Matsuno T.** Middle-term results of Salter innominate osteotomy. *Clin Orthop Relat Res* 2001;387:156-164.
37. **Lawson GR.** Controversy: sedation of children for magnetic resonance imaging. *Arch Dis Child* 2000;82:150-153.
38. **Fukuda A, Fukiage K, Futami T, Miyati T.** 1.0 s Ultrafast MRI in non-sedated infants after reduction with spica casting for developmental dysplasia of the hip: a feasibility study. *J Child Orthop* 2016;10:193-199.