Acta Medica Okayama

Volume 56, *Issue* 2 2002 *Article* 5

APRIL 2002

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Abstract

Two-directional arthrographic findings made during conservative treatment of developmental dislocation of the hip were compared with the femoral-head configurations and radiological results obtained from long-term follow-up examinations in this retrospective study. Sixty hips were followed until at least age 14. Arthrography was carried out according to Terazawa's method. The shape of the superior, anterior, and posterior limbus was evaluated based on a modified Fujii's classification. The femoral-head configuration was classified into 4 groups, and the radiological results were evaluated using Severin's classification at the final observation. There was a statistically significant relationship between the shape of the anterior limbus, the number of portions of deformed limbus (superior, anterior, posterior), and the femoral-head configuration. Also, a statistically significant relationship between the shape of the limbus and Severin's classification was observed. These results suggest that the deformed limbus seems to play an important role in triggering femoral-head deformities, possibly via mechanical compression, and negatively affects development of the hip joint.

KEYWORDS: femoral-head deformity, developmental dislocation of the hip, arthrographic findings

*PMID: 12002623 [PubMed - indexed for MEDLINE]

Acta Med. Okayama, 2002
Vol. 56, No. 2, pp. 91-97

Acta Medica Okayama
http://www.lib.okayama-u.ac.jp/www/acta/

Original Article

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Two-directional arthrographic findings made during conservative treatment of developmental dislocation of the hip were compared with the femoral-head configurations and radiological results obtained from long-term follow-up examinations in this retrospective study. Sixty hips were followed until at least age 14. Arthrography was carried out according to Terazawa's method. The shape of the superior, anterior, and posterior limbus was evaluated based on a modified Fujii's classification. The femoral-head configuration was classified into 4 groups, and the radiological results were evaluated using Severin's classification at the final observation. There was a statistically significant relationship between the shape of the anterior limbus, the number of portions of deformed limbus (superior, anterior, posterior), and the femoral-head configuration. Also, a statistically significant relationship between the shape of the limbus and Severin's classification was observed. These results suggest that the deformed limbus seems to play an important role in triggering femoral-head deformities, possibly via mechanical compression, and negatively affects development of the hip joint.

Key words: femoral-head deformity, developmental dislocation of the hip, arthrographic findings

The Lorenz method for initial conservative treatment for developmental dislocation of the hip at the authors' hospital was gradually replaced by use of the Pavlik harness during the 1970s. The Pavlik harness markedly reduced the incidence of femoral-head deformity (FHD) after conservative reduction, although the occurrence has not been eliminated entirely. Some patients with FHD, accompanying acetabular dysplasia, and joint incongruity, have developed progressive osteoarthritis [1]. The focus of the current conservative treatment is to achieve reduction that avoids FHD. Bucholz and Odgen as well as Kalamchi and MacEwen have shown that FHD occurred as a result of circulatory disturbance of nutrient blood vessels in the proximal femoral epiphysis [2, 3]. However, in some patients FHD cannot be explained by circulatory disturbance alone. Gotoh and Ando have demonstrated that the mechanical injury of the epiphysis of the femoral head in pigs occurred without circulatory disturbance [4]. The results of some studies have suggested that an inverted and interposed limbus could cause FHD [5, 6]. The causes of FHD, however, remain elusive. It is clear that if mechanical compression plays no role in FHD, there would be no significant difference in hip-joint congruity between groups with and

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without FHD. As such, the current retrospective study was conducted using two-directional arthrography to investigate the role of the acetabular limbus in the development of FHD.

Patients and Methods

The authors obtained two-directional arthrographs from 175 patients, born between 1974 and 1990 with 202 affected hips (148 unilateral, 27 bilateral) that underwent closed reduction at Okayama University Medical School. These patients had subsequently developed residual subluxation, acetabular dysplasia, or growth disturbance of the proximal femoral epiphysis. Sixty-one hips that had an enlarged femoral-head ligament or membranous substance in their arthrograph, and that had undergone surgical treatment at an early stage were excluded from the current study. Patients with neuromuscular disease and teratological dislocation were also excluded. Of the remaining 141, 60 hips (39 unilateral, 6 bilateral, 9 one side of bilateral), which were followed until a patient age of 14 or more years, were studied. The recall rate was 49.1%.

Of the patients included, there were 3 boys and 51 girls. The mean age at the first treatment was 7 months (range: 2–20 months). The mean age at the last follow-up was 18 years (range: 14–24 years). The mean follow-up period was 12 years (range: 3–23 years).

The data regarding reduction methods, age at reduction, age at arthrography, and age at the final follow-up were obtained from their clinical records. Two-directional arthrography of the hip was performed by Terazawa's method [7, 8]. The superior limbus was assessed in anteroposterior (AP) view in a flexion-abduction position, and the anterior and posterior limbi were assessed in lateral view in the same position. The authors evaluated the shapes of the limbus according to their modification of Fujii's classification [9], as the original classification was based on postoperative patients. The modifications are shown in Fig. 1. The superior limbus was classified into one of four types. Type 1 limbus conformed well to the cartilage surface of the acetabulum and was normal in its border, and Type 2 limbus was in good contact well with the femoral head, but its border was blunt. Type 3 limbus contacted the femoral head, but was flattened, and Type 4 limbus did not contact the femoral head due to an inversion or deformity of the limbus. The anterior and posterior limbi were classified as one of three types. In Type A, the limbus was in good contact with the femoral head, and its border was normal in appearance. In Type B, the border of the limbus appeared blunt. In Type C, the limbus did not contact the femoral head due to inversion or deformity of the limbus. In lateral-view arthrographs, a collapse on the femoral head facing the inverted anterior limbus was recorded as having a "compressed appearance" [10]. The corresponding limbus would be classified as Type 3 or 4 in the superior and as Type C in the anterior and posterior limbi.

Radiological assessments of the hip were evaluated on the plain AP radiographs at the latest follow-up. The shape of the proximal femur was classified as follows (Fig. 2). In the undeformed group, the femoral head was

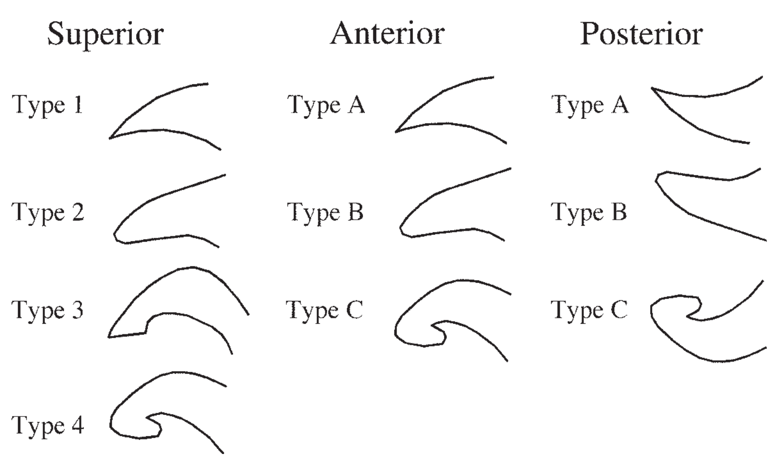

Fig. 1 Arthrographic classification of limbus.

totally rounded and without a shortened femoral neck. In group I, the femoral head and neck growth was disturbed in the long axis, but the articulo-trochanter distance was positive. In group II, severe growth failure in the epiphysis and metaphysis, as in coxa plana, was observed, and the articulo-trochanter distance was zero or negative. In group III, the growth was disturbed in lateral metaphysis rather than medial, as in coxa valga. The anatomical results were evaluated according to Severin's classification [11]. Groups I and II were regarded as good, and groups III and IV as poor. Radiographs taken just before surgery were used for evaluation in patients undergoing surgical intervention after skeletal maturation.

The data from clinical records were statistically analyzed with the unpaired *t*-test, and the data from radiographs with Spearman's rank correlation. To analyze statistical correlations regarding FHD with this ranking scale method, the FHD classification needed to be changed to a ranking scale from a categorical scale. The authors' group III deformity was not appropriate as a ranking scale, as this deformity was localized in the lateral part of the femoral head. The authors therefore excluded group III from the FHD classification. A P value of < 0.05 was considered statistically significant.

Results

All hips were divided into 2 groups based on the plain AP radiographs at the final examination. Thirty-one hips were assigned to the undeformed group, and the other 29 hips to the deformed group (group I: 20 hips, group II: 7, group III: 2). The mean age at reduction was 6 months (range: 2–19 months) in the undeformed group and, 7 months (range: 2–20 months) in the deformed group. The undeformed group consisted of 27 complete dislocations and 4 subluxations, while the deformed group consisted of 25 complete dislocations and 4 subluxations. In the undeformed group, 11 hips were treated by manual reduction followed by fixation in a flexion-abduction position (4 with casts, 7 with braces), and 20 using the Pavlik harness. Therefore, in the deformed group, 10 were reduced manipulatively and fixed in a flexion-abduction position (7 with casts, 3 with braces) and 19 with the Pavlik harness. The mean age at arthrography was 5 years (range: 5 months - 13 years and 4 months) in the undeformed group and 5 years and 5 months (range: 8 months - 16 years and 4 months) in the deformed group. The mean age at the final examination was 18 years (range: 14–24 years) in the undeformed group and 18 years (range: 14–29 years) in the deformed group. Ten patients included in the current study had initially been treated at other medical facilities, and some details of that treatment such as the period of fixation after reduction could not be studied. There were no statistically significant differences between the undeformed and deformed groups regarding these items. Nevertheless, a comparison and evaluation of these 2 groups was thought to be possible.

Arthrographic findings and shape of the femoral head (Table 1). In the superior limbus, 16% (5 out of 31) of the undeformed group was Type 3 or 4, as was 34% (10 out of 29) of the deformed group. In the anterior limbus, 19% (6 out of 31) of the undeformed group was Type C, as was 66% (19 out of

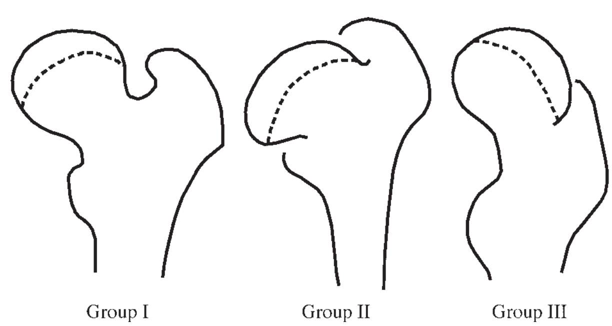

Fig. 2 Typical deformation of the femoral head.

Table 1 Classification of limbus and femoral-head shape

Classification of limbus		Femoral-head groups			
		UD	I	II	III
Superior	1	16	10	1	1
	2	10	5	1	1
	3	3	3	3	0
	4	2	2	2	0
Anterior	A	12	4	1	0
	B	13	8	0	0
	C	6	8	6	2
Posterior	A	20	12	1	0
	B	11	8	5	2
	C	0	0	1	0

UD, undeformed

29) of the deformed group. In the posterior limbus, none were inverted in the undeformed group, and only one was Type C in the deformed group. In the anterior limbus, there was a statistically significant difference between the undeformed and deformed groups ($P = 0.0055$), and there were significant correlations between the shape of the anterior limbus and the femoral-head configuration ($P = 0.0048$). In the superior and posterior limbi, there was no significant correlation with the femoral-head configuration. As for whole limbus, 22 hips had no deformed portions of the limbus, 7 had one deformed portion, 2 had 2 deformed portions, and none had 3 deformed portions in the undeformed group. However, in the deformed group, only 7 hips had no deformed portions, 18 had one deformed portion, 3 had 2 deformed portions, and 1 had 3 deformed portions (Table 2). There was a significant correlation between the number of portions of flattened or inverted limbus and the femoral-head configuration ($P = 0.0001$). In the undeformed group, 13% (4 out of 31), and 38% (11 out of 29) in the deformed group showed a compressed appearance at the femoral head, but there was no significant difference between the 2 groups.

Clinical evaluation. In the undeformed group, 11 hips were classified as Severin's group I, none as group II, 18 as group III, and 2 as group IV. In the deformed group, none were classified as group I, 6 as group II, 13 as group III, and 10 as group IV. The rate for positive good results was 28.3% (17 out of 60) of the total. In the hips with superior limbus classified as Type 3 or 4, 75% (12 out of 16) were evaluated as having poor results, and all hips except one classified as Type 4 had poor results. In the hips with anterior limbus classified as Type C, 82% (18 out of 22) had poor results. There were significant correlations between the shape of the anterior limbus and Severin's classification ($P = 0.017$). The correlation between Severin's classification and the number of deformed portions of the limbus, classified as Type 3 or 4 in the superior limbus, Type C in the anterior and posterior, can be observed in Table 3 ($P = 0.008$).

Discussion

The purpose of the present study was to assess the possibility of mechanical compression by the limbus. Generally, the superior limbus is evaluated in the neutral position. To observe the correlation between the limbus and femoral head, the authors evaluated the superior limbus from the AP view in the flexion-abduction position as well as from the lateral view. In this retrospective study, the authors found a significant correlation between the limbus shape and the degree of FHD. The anterior limbus was inverted in 19% of the undeformed group and 66% of the deformed group. Possible causes of FHD have been speculated upon in many studies. Tönnis had summarized the causes of ischemic necrosis as follows: the circulatory occlusion of the nutrient vessels, direct-pressure damage to the medial circumflex artery, and the circumscribed pressure of the soft structure [6]. Bucholz and Odgen as well as Kalamchi and MacEwen have shown that FHD occurs as a result of circulatory disturbance of nutrient blood vessels in the proximal femoral epiphysis [2, 3]. Because in some patients the FHD could not be explained by circulatory disturbance alone, the authors looked for other possible contributory factors. Intra-articular compressive factors at the reduction site are considered to be primarily inverted limbus and hypertrophied ligamentum teres. The authors excluded the patients for whom concentric reduction was obstructed by

Table 2 Number of deformed limbus portions and classification of femoral-head shape

Number of deformed limbus portions	Femoral-head groups			
	UD	I	II	III
0	22	7	0	0
1	7	13	3	2
2	2	0	3	0
3	0	0	1	0

UD, undeformed

Table 3 Number of deformed limbus portions and Severin's classification

Number of deformed limbus portions	I	II	III	IV
0	8	2	18	1
1	2	4	11	8
2	1	0	2	2
3	0	0	0	1

interposition of hypertrophied ligamentum teres or membranous tissues in the acetabular floor in arthrography, as patients who had undergone open reduction were considered to not be suitable subjects for the current study. Hattori *et al.* have reported that the limbus shape is not directly related to the incidence of avascular necrosis based on repeated arthrographs [12]. However, they only evaluated the superior limbus. The authors used two-directional arthrography in the current study, which is able to assess the configuration of the superior, anterior and posterior limbus. In fact, 25% (15 out of 60) of the hips examined were evaluated as Type 3 or 4 in the superior limbus, whereas 47% (25 out of 60) were evaluated Type C in the anterior limbus. The anterior portion might be important in evaluating the congruity of the hip joint at diagnosis and during conservative reduction. Hirai has reported a "compressed appearance" of the inverted anterior limbus, consisting of the bi-polar FHD compressed by the anterior limbus, in his operative findings [10]. *In vitro,* Greco *et al.* had shown that the growth-plate cartilage of the New Zealand white rabbit can be injured by excessive force, even if loading occurs for only a short time [13]. Moreover, Gotoh and Ando have demonstrated that the knee menisci inserting into the pig's hip can injure the proximal femoral epiphysis without circulatory disturbance [4]. Mitani *et al.* have found that patients whose femoral head does not completely over-ride the posterior limbus in two-directional arthrography have more severe FHD [8]. The authors' present findings thus strongly suggest that the inverted limbus compress the femoral head and may contribute to the development of FHD.

Severin has reported that many limbi are interposed between the femoral head and acetabulum, and are gradually remodeled after reduction in repeated hip arthrographs [14]. However, arthrographic findings in the current study showed that the interposed limbi are changed to various forms after reduction. Staheli *et al.* have shown an incidence of avascular necrosis of 15% in groups with and without an inverted limbus [15]. Other studies have suggested that an inverted and interposed limbus can cause FHD [5, 6]. However, they only evaluated the limbi prior to reduction. Ponseti has shown histologically that a labrum covering the acetabular cartilage was very hypertrophic and inverted, consisting primarily degenerative fibrocartilage [16]. The limbus with high plasticity may normalize itself, while one with low plasticity may remain inverted. The inverted limbus might play a role similar to that of the knee menisci in Gotoh's experiment at reduction. Carlioz and Filipe also have suggested that when treatment is imperfect, inversion of the limbus is frequent and irreversible, and that this condition is provoked by pressure of the femoral epiphysis on the limbus [17]. In the current study, there

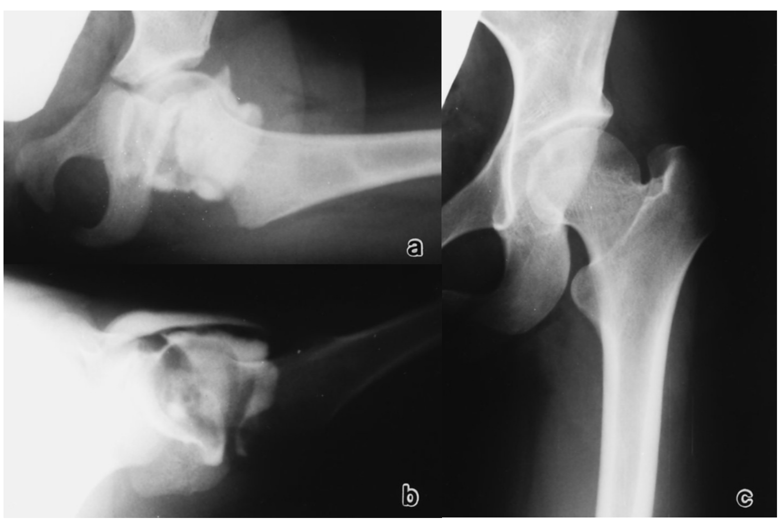

Fig. 3 Radiographs of 20-year-old woman who had a left subluxated hip treated with a Pavlik harness at 4 months old, and arthrography was performed at an age of 2 years and 1 month. **a**, Superior limbus was classified as Type 1. **b**, Anterior Limbus was Type C, posterior was Type B. **c**, At the latest follow-up, the hip joint was evaluated as Severin's group II, with the femoral head classified as group I.

was significant correlation between the assessment of the limbus, especially the anterior limbus and the number of portions of the inverted limbus, and FHD. If the plasticity of the limbus might be defined as the potential for remodeling, the degree of degeneration in the limbus's fibrocartilage may reflect the quality of that plasticity in the following manner. The epiphyseal cartilage compressed by the low-plasticity limbus will bring about a growth disturbance of the femoral head, as in group I (Fig. 3). When the femoral head receives stronger mechanical compression, a wider portion is injured and the growth disturbance spreads as far as the femoral neck, resulting in coxa plana, as in group II (Fig. 4). The authors' group III deformity occurs when the growth disturbance is localized in the lateral part of the femoral head.

Based on the findings of the current study, it appears that the superior and posterior as well as the anterior portion of the limbus play a role, probably via compression, in the development of FHD of the hip joint.

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Fig. 4 Radiographs of a 14-year-old girl who had a right complete dislocated hip treated with a Pavlik harness at 4 months old, and arthrography was performed at an age of 6 years and 7 months. **a**, Superior limbus was classified as Type I. **b**, Anterior limbus was Type C, posterior was Type A. **c**, The femoral head was evaluated as group II, the hip joint as Severin's group IV at the latest follow-up.

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