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*Original Article*

# Analysis of the vacuum phenomenon in plain hip radiographs in children

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**Abstract:** Objectives: To find the accurate incidence of the vacuum phenomenon in the hip and the best projection position for producing the vacuum phenomenon in plain hip radiographs in children. Methods: All pediatric anteroposterior (AP)-view and frog-leg-position plain hip joint radiographs obtained in our hospital between January 2003 and March 2013 were examined. The subjects' ages ranged between 0 and 14 years (mean, 4.2 years). All of the plain radiographs showing crescent-, linear-, and irregular-shaped lucencies between the femoral head and acetabulum were included in the present study. Results: A total of 16,749 cases, including 12,422 cases (5,912 boys and 6,510 girls) with only AP-view plain radiographs and 4,327 cases (1,537 boys and 2,790 girls) with both AP-view and frog-leg-position plain radiographs that were assessed in our hospital between January 2003 and March 2013, were examined. None of the AP-view plain hip radiographs exhibited the vacuum phenomenon. Vacuum phenomenon of the hips was found in only 258 cases (321 hips) in the frog-leg-position plain radiographs of 4,327 cases, resulting in a constituent ratio of 5.96% (258/4327). A total of 1,738 normal children were assessed in the 4,327 frog-leg-position radiographs, and 150 cases of the vacuum phenomenon were found in the normal children; thus, the incidence of the vacuum phenomenon in normal children was 8.63% (150/1,738). In 2,360 children with developmental dysplasia of the hip (DDH) who were assessed in the 4,327 frog-leg-position radiographs, 98 cases of vacuum phenomenon were found, yielding an incidence of 4.15% in children with DDH (98/2,360). Thus, the 258 cases with vacuum phenomenon included 150 normal hips (58.14%), 98 cases with DDH (37.98%), 5 cases with Legg-Calvé-Perthes disease (1.94%), and 1 case each of solitary eosinophilic granuloma in the left ischium (0.39%), polyostotic fibrous dysplasia of the left and right proximal femurs (0.39%), 1 case of hereditary multiple exostoses (0.39%), 1 case of congenital coxa vara (0.39%), and 1 fracture of the femoral neck after surgery (0.39%). The 321 hips in the 258 cases were classified as complete (121 hips, 37.69%) or partial (200 hips, 62.31%) types according to the proportion of the lucency area in the hip joints and as linear (159 hips, 49.53%), crescent (151 hips, 47.04%), or irregular (11 hips, 3.43%) lucencies according to the shape of the lucency area in the hips. Conclusions: The vacuum phenomenon of the hip in children is found in frog-leg-position plain radiographs. It is easier to find the vacuum phenomenon in normal hips compared to cases with DDH. Frog-leg-position plain radiographs provide a better projection position for obtaining the vacuum phenomenon of the hip in children compared to AP-view plain radiographs.

**Keywords:** Vacuum phenomenon, hip, radiograph, children

## Introduction

In 1910, Fick described for the first time the linear photic zone in X-ray images as the vacuum phenomenon [1], which is a self-forming phenomenon of intrajoint gas [2]. Clinical and experimental studies have shown that the vacuum phenomenon occurs only when there is no liquid inside the joint [3, 4]. The intrajoint vacuum phenomenon is most common in intradiscal spine fractures that are caused by cartilage degeneration [5]. It may also occur in other joints, including the shoulder, wrist, hip, sacroiliac joint, ankle, subtalar joint, and knee [3, 6-9].

Studies on the hip-joint vacuum phenomenon are very rare. Generally, the hip-joint vacuum phenomenon only occurs when traction or other forces have been applied to the hip joint [10-13] or in patients with severe osteoarthritis who attempt extreme abduction of their hip joints

**Table 1.** The disease distribution of VP in frog-leg position radiographs of 4327 cases

| Disease | Number of Cases | VP Cases | Percentage of VP Cases (%) |
|---|---|---|---|
| Normal hip joint | 1738 | 150 | 8.63 |
| Developmental dysplasia of the hip | 2360 | 98 | 4.15 |
| Legg-Calvé-Perthes disease | 5 | 5 | 100 |
| Femoral fractures | 92 | 1 | 1.09 |
| Femur tumor | 25 | 2 | 8.00 |
| Congenital coxa vara | 4 | 1 | 25 |
| Ischial damage | 3 | 1 | 33.33 |
| Slipped capital femoral epiphysis | 56 | 0 | 0 |
| Pelvic fracture | 16 | 0 | 0 |
| Hip infection | 21 | 0 | 0 |
| Osteogenesis imperfecta | 3 | 0 | 0 |
| Myositis ossificans | 2 | 0 | 0 |
| Knee valgus | 1 | 0 | 0 |
| Hypochondroplasia | 1 | 0 | 0 |
| Total | 4327 | 258 | 5.96 |

VP: vacuum phenomena.

[14]. Some scholars believe that the occurrence of the hip-joint vacuum phenomenon in children can exclude suppurative arthritis of the hip [13, 14] , traumatic joint effusion, and recent severe hip trauma [3, 4], but this is controversial [15].

To date, the incidence rate of the hip-joint vacuum phenomenon in children and the best X-ray projection position for viewing the hip-joint vacuum phenomenon are not clear. We performed a retrospective analysis of the X-ray images of 258 children (321 hips) with the hip-joint vacuum phenomenon that were obtained in the frog-leg hip position. This is the first study to report the incidence of the vacuum phenomenon in hip-joint X-ray images. In addition, we propose a morphological classification of the vacuum phenomenon that is based on the percentage and morphology of the photic zone. According to the literature, this was the largest case study of the hip-joint vacuum phenomenon in the world.

## Material and methods

In a review of all hip-joint anteroposterior and frog-leg position X-ray images in children recorded at the Pediatric Orthopaedics Department in Shengjing Hospital of China Medical University from January 2003 to March 2013, the ages of the patients ranged from 0 to 14 years, with an average of 4.2 years.

Standard supine anteroposterior hip X-ray images and/or frog-leg position images were recorded. The distance between the films and the X-ray probes was 110 cm. The X-ray instrument was a Picture Archiving and Communications System and a Siemens digital X-ray workstation (Siemens AG, Munich, Germany). All of the X-ray images were collected by two pediatric orthopedic doctors (Zhenjiang Liu and Wei Yan) within one month at the same place.

All of the hip-joint X-ray images showing crescent, linear, or irregular radioactive photic zones between the femoral head cartilage and the acetabular cartilage were included in this study. Dr. Zhenjiang Liu carefully read all of the included X-ray images and reviewed the clinical medical records of all of the patients.

SPSS13.0 statistical software was applied, and Chi-square tests were used for the data analysis. P values less than 0.05 were considered statistically significant.

## Results

In the past 10 years, our hospital has recorded 16,749 hip-joint X-ray images in children, and these include 12,422 anteroposterior hip-joint X-ray images (5,912 male cases and 6,510 female cases) and 4,327 anteroposterior and frog-leg-position hip-joint X-ray images (1,537 male cases and 2,790 female cases). The disease distribution is shown in **Table 1**.

In all of the 16,749 anteroposterior hip-joint X-ray images, no images of the hip-joint vacuum phenomenon were found. The total constituent ratio of the vacuum phenomenon in anteroposterior hip-joint X-ray images was 0 (0/16,749).

In 4,327 frog-leg-position hip-joint X-ray images, we found 258 (321 hips) cases of the hip-joint vacuum phenomenon with a constituent

**Table 2.** The age distribution of the 258 cases with the hip-joint VP

| Age (years) | Number | Percentage (%) |
|---|---|---|
| ≤ 1 | 40 (31 Normal hip/9 DDH) | 15.50% (40/258) |
| 2 | 62 (42 Normal hip/20 DDH) | 24.03% (62/258) |
| 3 | 36 (17 Normal hip/19 DDH) | 13.95% (36/258) |
| 4 | 23 (14 Normal hip/9 DDH) | 8.91% (23/258) |
| 5 | 29 (14 Normal hip/14 DDH/1 LCPD) | 11.24% (29/258) |
| 6 | 17 (9 Normal hip/6 DDH/1 LCPD/1 Congenital coxa vara) | 6.59% (17/258) |
| 7 | 13 (8 Normal hip/3 DDH/1 LCPD/1 FD) | 5.04% (13/258) |
| 8 | 5 (3 Normal hip/2 DDH) | 1.94% (5/258) |
| 9 | 8 (2 Normal hip/4 DDH/1 LCPD/1 HME) | 3.10% (8/258) |
| 10 | 7 (4 Normal hip/3 DDH) | 2.71% (7/258) |
| 11 | 12 (4 Normal hip/6 DDH/1 LCPD/1 EG) | 4.65% (12/258) |
| 12 | 5 (2 Normal hip/2 DDH/1 fracture of femoral neck) | 1.94% (5/258) |
| 13 | 0 | 0% (0/258) |
| 14 | 1 (1 DDH) | 0.39% (1/258) |
| Total | 258 | 100% (258/258) |

VP: vacuum phenomena. DDH: developmental dysplasia of the hip. LCPD: Legg-Calvé-Perthes disease. FD: Fibrous dysplasia. HME: hereditary multiple exostoses. EG: eosinophilic granuloma.

ratio of 5.96% (258/4,327). The 4,327 frog-leg-position hip-joint X-ray images included 1,738 normal hip joints with 150 cases of the vacuum phenomenon [incidence rate, 8.63% (150/1738)] and 2,360 patients with developmental dysplasia of the hip with 98 cases of the vacuum phenomenon [incidence rate, 4.15% (98/2,360)]. The Chi-square test showed $P < 0.001$, which was a significant difference.

The age distribution of the 258 cases with the vacuum phenomenon is shown in **Table 2**. The medical records of all of the vacuum phenomenon patients showed no hip pain, swelling, or motion limitations, which excluded hip-joint infection and other diseases.

The 258 cases of the hip-joint vacuum phenomenon included 90 male cases (34.88%) and 168 female cases (65.12%) and 150 cases with a normal hip joint (58.14%) (**Figures 1** and **2**), 98 cases with developmental dysplasia of the hip (37.98%) (**Figures 3** and **4**), 5 cases with Legg-Calvé-Perthes disease (1.94%) (**Figure 5**), 1 case each of solitary eosinophilic granuloma in the left ischium (0.39%), polyostotic fibrous dysplasia of the left and right proximal femur (0.39%) (**Figure 6**), hereditary multiple exostoses (0.39%), congenital coxa vara (0.39%), and a fracture of the right femoral neck after surgery (0.39%).

The 321 hips included 153 left hips and 168 right hips. According to the proportion of photic zones in the hip joint, these can be divided into complete or partial types. The complete type is defined by a photic zone with length larger than 50% of the length of the articular cartilage between the femoral head and the acetabulum. The partial type is defined by a photic zone with length smaller than 50% of the length of the articular cartilage between the femoral head and the acetabulum. Thus, the 321 hips included 121 complete-type hips (37.69%) and 200 partial-type hips (62.31%).

According to the morphology of the hip-joint photic zone (linear, crescent, or irregular), the 321 hips included 159 hips with a linear-shaped photic zone (49.53%), 151 hips with a crescent-shaped photic zone (47.04%), and 11 hips with an irregular-shaped photic zone (3.43%).

## Discussion

In conventional X-ray images, small amounts of gathered gas are noticed in normal joints, and this is called the spontaneous vacuum phenomenon. This phenomenon is usually seen in babies and children. Ewans has suggested that healthy and normal children may show the vacuum phenomenon when they perform a strong hip abduction [10]. When traction is applied to the joint, the incidence rate of the vacuum phenomenon significantly increases [14]. In this study, among the 4,327 patients with frog-leg-position hip-joint X-ray images, 258 showed dif-

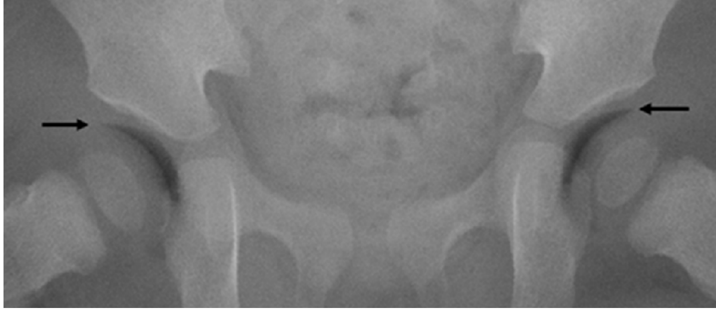

**Figure 1.** Typical frog-leg-position plain-film radiographic appearance of the vacuum phenomenon in the normal hips of a 2-year-old boy. Note the crescent lucency and the complete type (arrows).

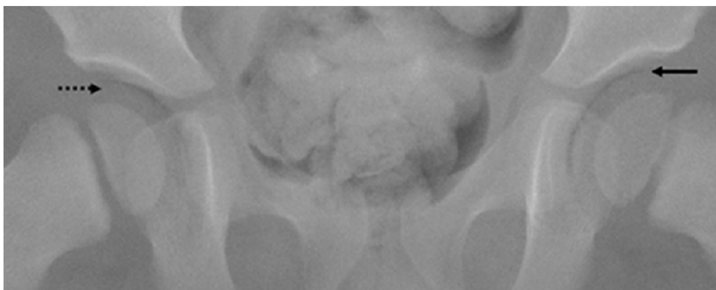

**Figure 2.** Radiographic appearance of the vacuum phenomenon in the normal hips of a 2-year-old boy. Note the linear lucency of the left hip (solid arrow) and the crescent lucency of the right hip (dotted arrow). Both are complete types.

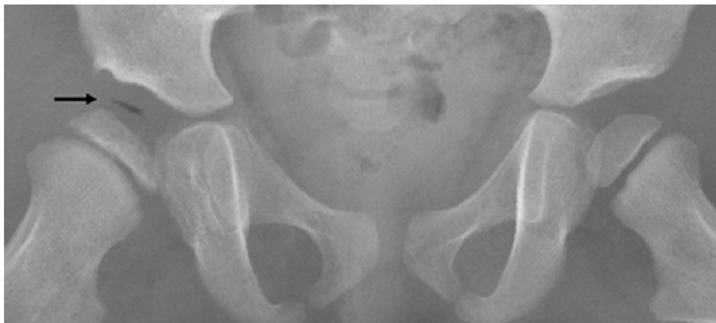

**Figure 3.** Radiographic appearance of the vacuum phenomenon in the right hip of a 2-year-old girl with developmental dysplasia of the hip after close reduction in the right hip with avascular necrosis of the right femoral head. Note the irregular lucency and the partial type (arrow).

ferent levels of the hip-joint vacuum phenomenon, which was seen in the intrajoint photic zones with different sizes. The total constituent ratio of the hip-joint vacuum phenomenon case in hip-joint frog-leg-position X-ray images in children was 5.96% (258/4,327), indicating that the vacuum phenomenon was not rare in hip-joint frog-leg-position X-ray images. The incidence rate of the vacuum phenomenon in normal hip joints was 8.63%, which was much higher than the 4.15% incidence rate found in patients with developmental dysplasia of the hip, indicating that the hip-joint vacuum phenomenon more often occurred in normal hip joints. We did not detect even one vacuum phenomenon case in any of the anteroposterior hip-joint X-ray images, indicating that the vacuum phenomenon is hard to produce in hip-joint anteroposterior X-ray images without applying traction to the hip joint. Thus, we concluded that the external traction that is applied to the hip joint is a prerequisite of the vacuum phenomenon in hip-joint anteroposterior X-ray images. Compared to the hip-joint anteroposterior X-ray images, the hip-joint frog-leg position is a better X-ray projection position for observing the vacuum phenomenon. Our research results support the conclusions obtained by Ewans.

What is the reason for the intra-joint vacuum phenomenon in the hip-joint frog-leg position? When the hip joint is in the frog-leg position, the stretch of the endogenous muscles, such as the muscles around the hip joint, leads to a sudden increase in the hip-joint-cavity volume. The pressure in the joint cavity suddenly decreases, and the gases that are dissolved in the nearby tissues around the hip joint diffuse into the low-pressure joint cavity, thus producing the vacuum phenomenon. Thus, when the hip or shoulder joints are placed in an extreme abduction position for X-rays, the vacuum phenomenon is usually more obvious. However, although the traction continues for a period of time, the gas that is diffused into the joint will be absorbed very quickly or replaced by liquids. Then, the vacuum phenomenon will disappear quickly [10].

Magnusson has suggested that, along with the decrease in intrajoint pressure, the gas that is

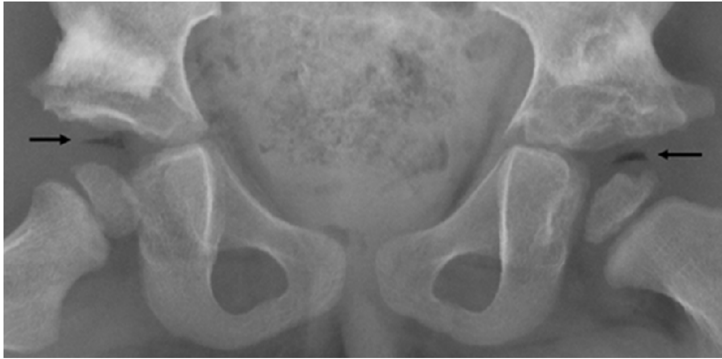

**Figure 4.** Radiographic appearance of the vacuum phenomenon in the right and left hips of a 3-year-old girl with developmental dysplasia of the hip after an open reduction, a Dega pelvis osteotomy, and a femoral shortening osteotomy in both hips. Note the irregular lucency of both hips, which are both partial types (arrows).

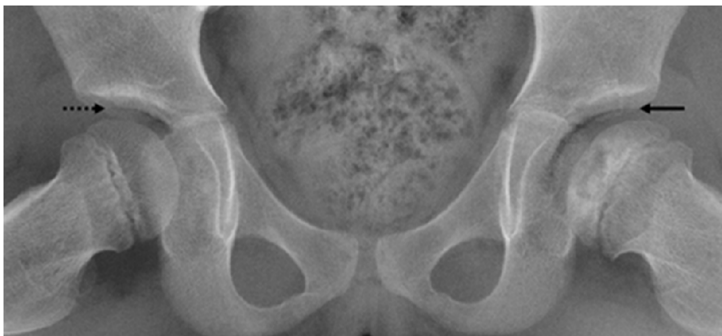

**Figure 5.** Radiographic appearance of the vacuum phenomenon in the right and left hips of a 6-year-old girl with Legg-Calvé-Perthes disease in the left femoral head. Note the crescent lucency in the left hip, which is a complete type (solid arrow). The linear lucency in the right hip is a partial type (dotted arrow).

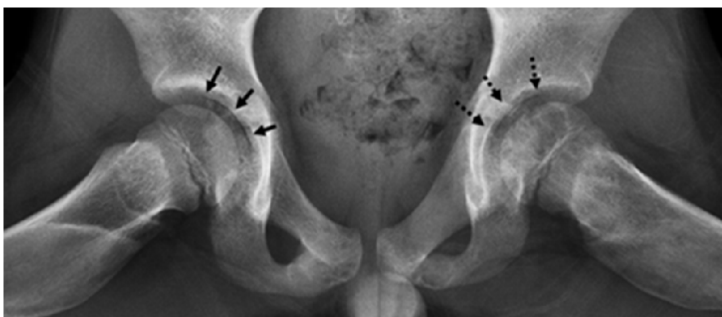

**Figure 6.** Radiographic appearance of the vacuum phenomenon in the right and left hips in a 7-year-old boy with polyostotic fibrous dysplasia in the left and right proximal femur. Note the linear lucency of the left hip (dotted arrows) and the linear lucency of the right hip (solid arrows), which are both partial types.

dissolved in the synovium will be released. When the intrajoint pressure decreases to 1/20 atm, the intrajoint liquid evaporates. The released gas leads to the vacuum phenomenon on X-ray images. In order to produce the intrajoint vacuum, it is necessary to overcome the soft-tissue elasticity and the external atmosphere traction [10]. Another prerequisite is that the soft tissues around the joint should be able to withstand the external pressure rather than be pressed into the enlarged joint cavity [10]. Nordheim has suggested that the intrajoint gas should include the evaporated synovial liquid that is at 37°C and 47 mmHg and previously dissolved gases in the blood and tissues, which diffused into the joint afterwards [10].

The factors involved in intrajoint gas formation mainly include traction applied to the joint, the extent of the joint capsule folding when the intrajoint vacuum forms, the relative inconsistency of the joint facets, and the existence of excessive intrajoint liquids and exudated or abnormal soft tissues [14]. When traction is applied, the joint capsule is folded, which can reduce the negative intrajoint pressure. Excessive liquids in the articular depression can replace the potential vacuum voids. Due to the effects of the liquid pressure, the facing joint facets are closely attached, with a resistance to external tractions. The vacuum phenomenon will not occur at this time. However, in patients with osteoarthritis, their rigid joint capsules restrict the applied tractions on the joint. When the traction is applied, their joint capsules cannot fold inward, which forms the joint vacuum and intrajoint gas release [14]. Radiation film technology has shown that the vacuum phenomenon is instantaneous. When the applied traction is great enough,

intrajoint gas will be produced and then disappear very fast [14].

The major component of the intrajoint gas is a mixture of oxygen, carbon dioxide, and nitrogen, which is a similar constituent ratio as the ratio of the gas components in the circulating blood [2]. In fact, the term *vacuum* means the lack of gas, which is not accurate. Perhaps, the term *spontaneous joint inflatable angiography* that has been proposed by Fuiks and Grayson is more appropriate [3].

Does the hip-joint vacuum phenomenon have practical clinical value? Some scholars have proposed that the existence of the vacuum phenomenon can exclude the possibility of intrajoint exudates [2, 3]. Martel and Poznanski [14] have explained the diagnostic value of the hip-joint vacuum phenomenon. When the distance between the femoral head and the acetabulum is larger than 1 mm and no intrajoint gas appears, the intrajoint exudate or other joint diseases can exist [15]. In a later study that was conducted by Martel et al. [16], traction applied to the hip joint can lead to intrajoint gas formation even when the intrajoint exudate exists, but the photic zone is not crescent-shaped. If a crescent-shaped photic zone appears, the existence of exudate can be excluded [16]. In our clinical cases, 96.12% of the hip-joint vacuum phenomenon cases occurred in normal hip joints (58.14%) and in the follow-up period of cases with developmental dysplasia of the hip (37.98%). These cases did not involve any clinical manifestation of hip-joint exudate. For the vacuum phenomenon cases with non-crescent-shaped photic zones, their medical records did not provide any evidence of intrajoint exudates. Thus, we inferred that the hip-joint vacuum phenomenon was just an X-ray radiographic sign that occasionally occurred in X-rays. The hip-joint vacuum phenomenon has no special relationship with hip-joint diseases, and it has no practical clinical value.

In this study, we were the first to propose a morphological classification of the hip-joint vacuum phenomenon, including the complete and partial types and the crescent, linear, and irregular-shaped photic zones. This morphological classification may be beneficial to future studies on the hip-joint vacuum phenomenon. This study was a preliminary investigation of the hip-joint vacuum phenomenon, and it could not determine its long-term clinical significance. Further studies on the hip-joint vacuum phenomenon are needed.

### Disclosure of conflict of interest

None.

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