FROM THE ORTHOPAEDIC CLINIC OF LUND
CHIEF: PROF. GUNNAR WIBERG

THE VACUUM PHENOMENON IN THE HIP JOINT

BY

TORSTEN JERRE

The term 'articular space' as radiographically generally conceived and used is by no means an adequate expression to describe the radiographic visualization of a true articular space. As a rule, the true articular space is not apparent before the joint has been filled with a contrast substance, with a negative substance e.g. oxygen, seen as a rarefaction, or with a positive substance e.g., abrodil, seen as an opacity. In 1932, however, *Dittmar* succeeded in showing a true articular space in a radiograph without the use of contrast substances, it appeared in the form of a rarefaction reminiscent of those pictures obtained with the aid of negative contrast substances. It was during the X-ray examination of a knee joint of an eleven-year old boy, who had had a laterally lax knee from a previous accident that *Dittmar* first made this observation. The rarefaction appeared without any special, deliberate positioning of the knee joint, medially in the frontal view at the site of the true articular space. By means of a passive valgus displacement of the knee joint *Dittmar* was able to show a few more cases in which a true articular space, appeared as a rarefaction on the radiograph.

Since *Dittmar*'s publication several authors have observed and described this rarefaction not only in the knee joint but also in other joints, to wit, the shoulder, wrist, metacarpo-phalangeal and interphalangeal joints. Its occurrence in the symphysis bupis and in the intervertebral disc has also been recorded. Concerning hip joints *Ewans* (1940) showed that strong abduction can produce a rarefaction in fully healthy and normal children. Furthermore, *Heidsieck* (1939) described a very distinct rarefaction occurring in children at the moment of deliberate luxation of the hip joint.

On perusal of the literature available the author could find no mention of the above rarefaction in the hip joint of adults. On the contrary, some authors actually say that they have never

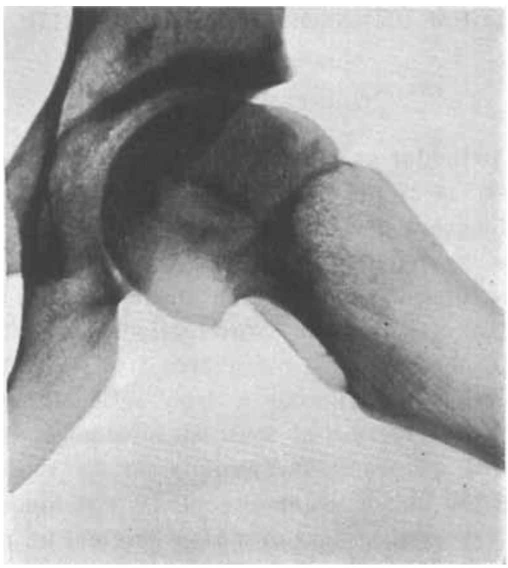

Fig. 1.

been able to discover such rarefactions in radiographs of the hip joint in spite of their searching for it. Thus *Widmann* and *Stecher* (1936), for example, who have themselves observed this type of rarefaction in the knee and shoulder joints, write: "To date we have been unsuccessful in visualizing the true articular space in other joints, and it seems strange that we have been unable to accomplish this, particularly in regard to the hip joint." *Hippe* and *Hähle* (1936) made a thorough perusal of all of their radiographs of joints taken over a period of 10 years.

Their inspection included 1,100 X-ray pictures of hip joints, not a single one of which however revealed a rarefaction of the kind under discussion.

It might therefore seem worthy of mention that this rarefaction was observed at the Orthopaedic Clinic of Lund in the hip joint of adults during an after-examination of a series of 38 cases of epiphyseolysis capitis femoris operated on *ad modum Wilson*

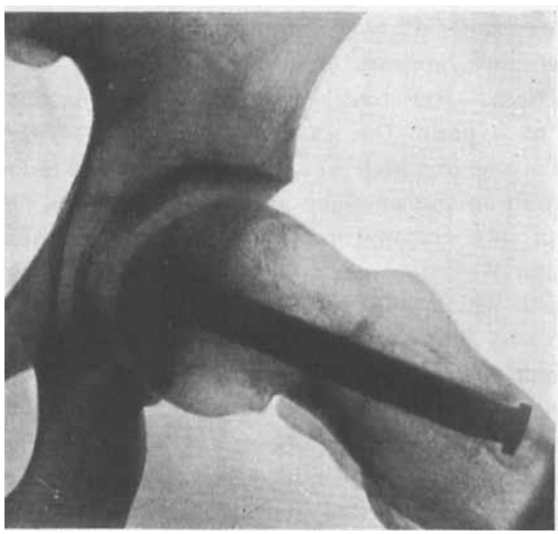

Fig. 2.

(osteosynthesis with a three-flanged nail). Both frontal views and pictures in Lauenstein's position were taken across both hip joints of each of these 38 patients. In no fewer than six cases there was a more or less distinct rarefaction in the superior portion of the joint radiographed in Lauenstein's position (Figs. 1 and 2), whereas neither on the healthy side nor in any of the frontal views, could a single case of such rarefaction be detected.

Much has been speculated on the cause of this rarefaction at the site of the true articular space.

Thus, *Dittmar* (1932) considered that an articular space that is widened medially in a knee joint forced into valgus position is filled with synovia, which, in his opinion, is so much less radiopaque than cartilage that it may be responsible for the rarefaction in the radiograph.

v. Pfannewitz (1933) thought it possible that rarefactions of the kind under discussion, which he could discern only in cases of clinically established arthrosis deformans, are due to the fact that the cartilage in these cases has undergone such changes as render it more radiopaque and that the articular space therefore appears by contrast in the radiograph as a rarefaction. After *Grashey* (1933), who himself makes no attempt to explain the cause of the rarefaction, reported *inter alia* a case in which an articular space was radiographically discernible in the shoulder joint of a 7-year old boy, without the aid of any contrast means, *v. Pfannewitz* admited that this did not fit very well into the picture of his assumption, according to which arthrosis deformans is the cause.

Hippe and *Hähle* pointed out that by forcing a joint into certain positions (e.g. abduction of the knee joint) the articular surface can be separated. The articular space, which is normally very narrow and therefore radiographically unobservable, now widens and can be visuabled as a rarefaction.

At a conference of radiologists *Widmann* and *Stecher* (1936) demonstrated a case of a shoulder joint in which this rarefaction was detectable. In view of the fact that none of those present had ever seen such a rarefaction in a joint not previously filled with air, the question as to how gas could enter the joint, was discussed. The authors, however, gave no report of this discussion.

Magnusson (1937) showed that it is possible radiographically to show a rarefaction at the site of the true articular space in the shoulder joint of children, if the latter are X-rayed with their arms stretched up and as far back as possible. Bu pulling on the fingers, *Magnusson* was able to produce a radiographically observable rarefaction in the metacarpophalangeal joints, its appearance being most distinct in children. This rarefaction occurs momentarily and concomitantly with the assumption of the above-mentioned position of the shoulder joint and with the extension of the fingers respectively, only to disappear simultaneously with the occurrence of a change in the position of the shoulder and the release of the pull on the finger, respectively. *Magnusson* offers the following explanation for this rarefaction. As soon as the shoulder joint assumes the above position, in which the acromion has the effect of a fulcrum, or at the moment of extension of a finger, a relative vacuum is produced in the joint in question. He goes on to say that with decreasing pressure in a joint gases dissolved in the synovia will be liberated, and when the pressure drops below 1/20 atm. an evaporation of the joint fluid itself will take place, and that it is the released gases that account for the radiographically discernible rarefaction. In order to produce this vacuum in a joint a pull is necessary to overcome both the elasticity of the soft parts and the outer atmospheric pressure. That the elasticity of the metacarpophalangeal joints, for example, can be overcome by pulling the finger is readily evidenced in the radiograph, where a separation of the articular surfaces is demonstrable. That the outer pressure on so small a joint can be overcome is self-evident, as only about 1 kgm. per cm^2 of the articular surface is necessary.

Another condition necessary for the development of a relative vacuum in a joint besides the application of sufficient tension is, however, that the environmental soft parts of the joint can withstand the outer pressure without being pressed into the widened articular space. This question is not discussed by *Magnusson*.

In an examination of healthy experimental subjects *Nordheim* (1938) produced a medial rarefaction at the site of the true articular space in 71 per cent of the cases by forcing the knee joint into valgus attitude. This rarefaction, which occurs momentarily, becomes hazy after a few minutes and after ten minutes it has disappeared completely on account of exudation into the joint. *Nordheim*, like *Magnusson*, contends that the rarefaction is to be attributed to the development of gas inside the joint on account of a relative vacuum. This gas formation, in his opinion, is to be ascribed to evaporation of the synovial fluid which occurs at 47 mm. Hg at 37° C. (provided that synovial fluid is comparable in this respect with water). *Nordheim* mentions the following physical experiment in support of his vacuum theory: In an ordinary 20 cc. record syringe whose plunger is sealed with a few drops of parraffin, about 1 cc. water is sucked up. The opening of the syringe is pressed against a rubber plate. An increasing pull is then applied to the plunger and when the pull is great enough to overcome the outer atm. pressure a vacuum will be produced in the syringe. If the pull is now sufficiently decreased, the plunger will spring back to its original position, and only a small gas bubble, about the size of a pin-head, remains, due to leakage. According to *Nordheim* the conditions inside the joint are in principle analogous, because a joint is generally enveloped in an unstretchable capsule strengthened by ligament. In *Nordheim's* opinion not only the evaporation of the joint fluid, but also the diffusion of gases dissolved in the blood and tissues play a part.

This vacuum theory brought forward by *Magnusson* is unreservedly advocated by later authors on this subject (*Heidsieck* 1939, *Evans* 1940, *Kohlbach* 1941, *Knutsson* 1942).

Knutsson proposed the term 'vacuum phenomenon' for this radiographically visible rarefaction.

In order to procure further evidence for the correctness of *Magnusson's* vacuum theory the present author performed a few simple experiments on corpses. A large calibered puncture needle was soldered to an ordinary 10 cc. record syringe. Between the handle and the cap, the plunger-rod was provided with a stop-collar so that the plunger could not be pushed in further than to the 2 cc. mark, where it was arrested by the collar. The plunger was then sealed with paraffin after which water at a temp. of 37° C. was sucked up into the syringe, any possible air and superfluous water being thereafter ejected until further inward movement of the plunger was prevented by the stop-collar. In order to prevent a possible entrance of air from without, the space behind the plunger was also filled with water.

A knee joint of a corpse was then punctured from the medial side with the subject lying on one side to that the record syringe was erect and thus the escape of the water behind the plunger was prevented. When the knee was then abducted, a gas bubble momentarily appeared in the glass cylinder of the record syringe. As soon as the abduction of the knee joint ceased, almost the whole of the gas bubble disappeared momentarily. Only a bubble the size of a pin-head remained.

In his physical experiment with the record syringe *Nordheim* attributed the bubble to a leak in the instrument. The present author, however, disputes this supposition. If *Nordheim's* experiment is performed with a record syringe totally submerged in water so that the entrance of air is effectively rendered impossible, there will nevertheless be a residual bubble about the size of a pin-head after the plunger has sprung back. In the opinion of the present author this residual bubble may be explained as follows: As soon as a vacuum is created, gases dissolved in the water are momentarily liberated. When this vacuum ceases to exist, the released gases are immediately re-dissolved in the water, the process being initially very rapid, but slow when the water begins to be saturated with the gases.

Thus, by abduction of a knee joint, a relative vacuum of such an order was created that gas developed from water at a temp. of 37° C. Whether this formation of gas is to be ascribed to an escape of previously dissolved gases in the water, or to a true evaporation of the water itself cannot be determined by the present experiment, but at least part of the gas does definitely consist of gases previously dissolved in and now liberated from the water, as this phenomenon always occurs when a pressure is decreased. Concomitantly with the liberation of the dissolved gases there occurs an aqueous volatilization from the surface of the water. This obeys fundamental laws of physics, and as an example in which for simplicity's sake this volatilization will at first be disregarded, it might be mentioned that 1 cc. water with a temp. of 40° C. and with its surface exposed to ordinary atmospheric conditions, contains about 0.015 cc. dissolved gases. If the pressure is reduced to 1/10 atm. pressure, 9/10ths of the volume of dissolved gases will be liberated, i.e., about 0.013 cc., which, at least initially, while there is a great difference between the partial pressure of the gases dissolved in the water and that of the liberated gases, occurs very rapidly. At a pressure of 1/10 atm. the volume of the liberated gases is increased tenfold, i.e. to 0.13 cc. If we now take into account the volatilization of the water, which undeniably occurs under the conditions in question, the volume of the liberated gases will in reality be about three times as large. From this it will be evident that a substantial liberation of gas from a liquid can take place already at a pressure lying considerably above that pressure at which a real evaporation of the liquid in question takes place, which in the case of water with a temp. of 37° C. is about 1/20 atm. Various gases however exhibit very different degrees of solubility in a liquid, their solubility being given as the absorption coefficient of the gases. For water at 40° C. the coefficient of carbonic acid is, for example, 0.53, the corresponding figure for oxygen being 0.023. This means that water in a gas chamber containing only carbonic acid at atm. pressure contains about 20 times as much gas as does the same quantity of water in a gas chamber containing only oxygen at the same pressure. As the partial pressure of carbonic acid in the blood is essentially higher than in the air, it is consequently probable that the joint fluid will contain a greater amount of dissolved gases per unit of volume than does a liquid, whose surface is open to the atmosphere. In view of this fact it is quite probable that a quantity of gas sufficient to produce the vacuum phenomenon is liberated already at a pressure higher than that at which an actual aqueous evaporation takes place. At any rate, there is no reason to assume that a lower pressure is necessary to produce a liberation of gas from the joint fluid than from water whose surface is exposed to the atmosphere. Thus, since in the above puncture experiment a clear formation of gas is produced in the record syringe, it may surely be concluded that this liberation of gas will also occur within joints subjected to the same experimental conditions. As the vacuum phenomenon occurring on abduction of the knee of a corpse and of a living subject has exactly the same radiographic appearance, and in view of the fact that the vacuum phenomenon is manifested by a similar rarefaction in the radiograph of a number of other joints in which it has been discerned, it may be considered that this puncture test constitutes further evidence for the correctness of the theory brought forward by *Magnusson*, who maintains

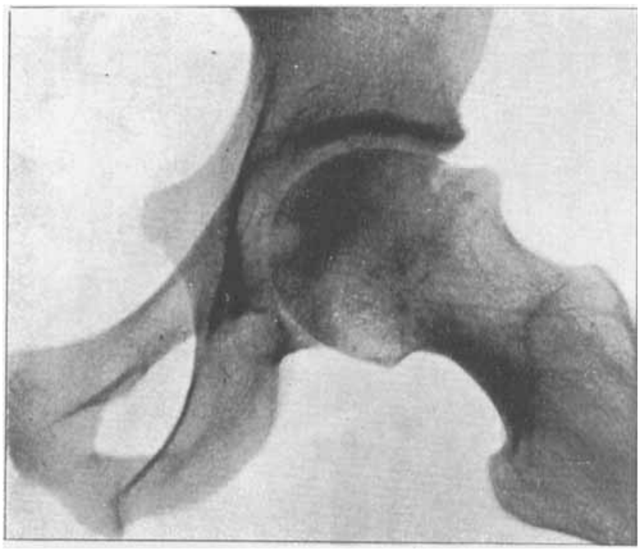

Fig. 3.
Hip joint in Lauenstein's position. The collar-like protuberance is conspicuous. Also the vacuum phenomenon is discernible.

that the vacuum phenomenon is produced by a negative pressure in the joint and a consequent development of gas.

One is then tempted to ask why the vacuum phenomenon should occur in the hip joint of adults only in epyphyseolysis capitis femoris. The author offers the following answer to this question. In this disease a collar-like protuberance is often encountered at the border between the caput and the collum; a more or less prenounced swelling of this kind was met in each of the six cases in which the vacuum phenomenon was visualized (Figs. 3 and 4). In the abducted position assumed by the hip joint in Lauenstein's position the protuberant collar is pressed against the edge of the acetabulum where it has the effect of a hypomochlion forcing the caput from the acetabulum and thereby producing a negative pressure inside the joint.

Now, is the radiographic visualization of the vacuum phenomenon only of theoretical interest or can it be utilized in practice?

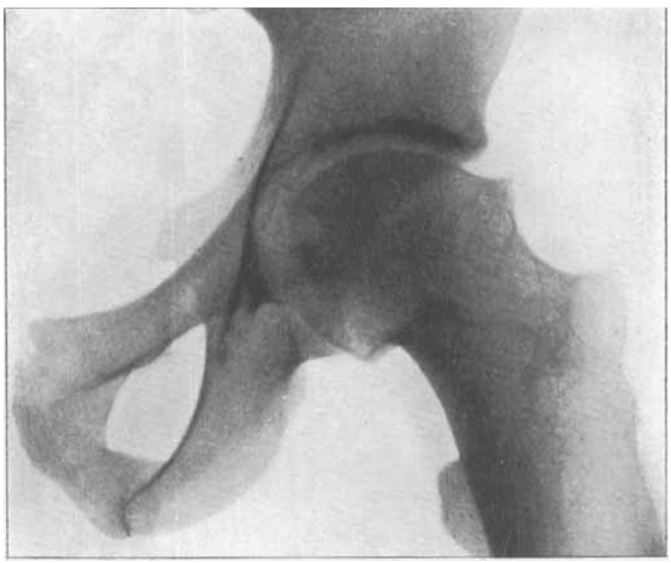

Fig. 4.
Frontal view of the same hip joint. The collar-like protuberance is conspicuous. The vacuum phenomenon is not visualizable in a frontal view.

Magnusson (1937), who had observed the vacuum phenomenon in the shoulder joint, metacarpophalangeal joints, symphysis pubis and in the intervertebral disc, found this phenomenon of no practical value but considered it to be of only theoretical interest.

Dittmar (1932) and later *inter alia Nordheim* (1938) assert that the vacuum phenomenon in the knee joint can be utilized for the study of the cartilage and the meniscus.

Knutsson (1942) showed that the vacuum phenomenon in the intervertebral disc has a different appearance in degeneration of the disc from that in spondylosis deformans and that it moreover occurs at a very early stage, so early that it may sometimes be the only radiological sign of disc degeneration.

Kohlbach (1941) considers that if an X-ray examination of a joint discloses a strip or line of gas in the articular space, this is a sign of distortion. He contends that in such cases the joint must at some earlier date have been exposed to a pull causing a transient vacuum which in turn produced a development of gas. He goes on to say that this gas is gradually resorbed and after a few days it is no longer apparent. The present author considers this conclusion of *Kohlbach's* to be wrong in two respects. First of all, gas liberated on the creation of a vacuum disappears momentarily and almost completely as soon as the force giving rise to the vacuum, ceases, and secondly, it is possible to produce the vacuum phenomenon in *inter alia* those joints observed by *Kohlbach*, to wit, the shoulder joint and the knee joint, in fully normal joints when the latter are placed in certain attitudes, e.g. outward rotation of the shoulder joint (*Magnusson*), and abduction of the knee joint (*Nordheim* et al). In his publication *Kohlbach* makes no mention of the position the joints were in during the X-ray examination. It is quite possible that the phenomenon observed by him occurred simply on account of the joint being in such a position as to create a vacuum during the X-ray examination.

Evidence of the vacuum phenomenon in the hip joint of adults is surely of no great practical importance. Should repeated examinations however show that it is intimately connected with epiphyseolysis capitis femoris and that it occurs also in old cases of this disease in which the details in the radiograph are obliterated and the whole picture looks like an advanced deformative process whose etiology cannot be determined, under such circumstances the vacuum phenomenon might be of diagnostic importance.

SUMMARY

The author describes the vacuum phenomenon in the hip joint of adults, which was observed in six cases during an after examination of a group of 38 cases of ephyseolysis capitis femoris operated on ad modum *Wilson* (osteosynthesis with a three-flanged nail). The conditions under which the vacuum phenomenon occurs are also discussed.

ZUSAMMENFASSUNG

Der Verfasser beschreibt das *Vakuumphänomen in den Hüftgelenken Erwachsener,* das bei einer Nachuntersuchung einer aus 38 Fällen ad modum *Wilson* operierten ephyseolysis capitis femoris bestehenden Gruppe, sechs Mal beobachtet worden ist. Auch die Bedingungen, unter welchen das Vakuumphänomen auftritt, sind beschrieben worden.

RÉSUMÉ

L'auteur décrit un phénomène de vacuum chez l'adulte, observé dans 6 cas au cours d'un postexamen de 38 cas d'epifyseolysis capitis femoris opérés par la méthode Wilson (osteosynthèse avec clou à trois ailes). A ce sujet l'auteur discute les conditions d'apparition du phénomène de vacuum.

SURVEY OF LITERATURE

Dittmar, O.: Der Kniegelenks-Meniskus im Röntgenbilde. Röntgenpraxis 4. 442. 1932.

— Zur Röntgenologie des Kniegelenks. Verhandl. d. deutsch. orthop. Gesellsch. 27. 255. 1933.

Evans, W.: The roentgenological demonstration of the true articular space Am. J. Roentgenol. 43. 860. 1940.

Grashey, R.: Sichtbarer Schultergelenkspalt. Röntgenpraxis. 5. 700. 1933.

Heidsieck, E.: Gasbildung im frischluxierten Gelenk. Zentralbl. f. Chir. 66. 2544. 1939.

— Willkürliche Subluxation des Hüftgelenks beim Kleinkinde mit Gasfüllung des Gelenkes. Ztschr. f. Orthop. 74. 235. 1943.

Hippe, H. and *Hähle, K.:* Gelenkspaltdarstellung. Röntgenpraxis. 8. 98. 1936.

Knutsson, F.: The vacuum phenomenon in the intervertebral discs. Acta radiol. 23. 173. 1942.

— Instability associated with disc degeneration in lumbar spine. Acta radiol. 25. 593. 1944.

Kohlbach, W.: Gasbildung im Gelenkspalt, ein röntgenologisches Distorsionszeichen. Fortschr. a. d. Geb. d. Röntgenstrahlen. 63. 47. 1941.

Magnusson, W.: Über die Bedingungen des Hervortretens der wirklichen Gelenkspalte auf dem Röntgenbilde. Acta radiol. 18. 733. 1937.

Nordheim, Y.: Eine neue Methode, den Gelenkknorpel, besonders die Kniegelenkmenisken, röntgenologisch darzustellen (ohne Zuhilfenahme eingespritzten Kontrastmittels). Fortschr. a. d. Geb. d. Röntgenstrahlen. 57. 479. 1938.

Pannewitz, v. G.: Sichtbarwerden des wahren Gelenkspaltes bei Arthritis deformans. Röntgenpraxis. 5. 809. 1933.

Widmann, B. and *Stecher, W.:* Roentgenographic demonstration of the true articular space. Radiology. 27. 541. 1936.