Ligament of Head of Femur in Elephant

Ligament of Head of Femur in the Acetabulum of the Asian Elephant

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アジアゾウの寛骨臼における大腿骨頭靱帯

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ABSTRACT. The ligament of head of femur in the Asian elephant (Elephas maximus) was examined anatomically and histologically. Collagen fibers formed a thick ligament, which was tightly attached to the acetabular fossa in an area approximately 60 mm long, 20 mm wide, and 10-15 mm deep. The proximal part of the ligament was buried in a deep ditch in the acetabular fossa, and the margin of the lunate surface enveloped the origin ligament. The ligament originated dorso-lateral to the acetabular center, and ran ventro-medially over the mediolateral surface of the acetabulum along the notch to reach the femoral head. Based on these findings, we advocate a mechanical model in which the thick ligament and its enlarged attachment act to restrict adduction of the femur in this animal, as in humans. Unlike humans, however, we suggest that in the Asian elephant this ligament is not directly involved in restricting extension and flexion.

Key words: acetabulum, Asian elephant, femur, functional morphology, ligament of head of femur.

INTRODUCTION

Since the Asian elephant is one of the largest living mammals, morphological characters related to adaptation to its heavy body should be seen in a macroscopic examination. The ligaments of the limbs are key structures that restrict the movement of bones in this extraordinary large mammal. We postulated that the well-developed ligaments may enable the elephants to walk and run; however, the origin, attachment and running have not been morphologically examined in the ligament. Since the histology of this ligament is unknown, the functional peculiarities of the elephant hip joint cannot be discussed from the perspective of adaptation to heavy body weight. We were able to examine the ligament of head of femur from a dead Asian elephant, and here describe its structure to clarify the functional adaptation of this ligament. The aims of the study were to confirm the attachment of the ligament in the acetabulum and running, to describe the form and structure of the ligament anatomically, and to observe the histology of the ligament.

MATERIALS AND METHODS

We studied one dead Asian elephant (Elephas maximus) and four skeleton specimens, that were donated to the National Science Museum, Tokyo, from Ueno Zoological Gardens and Tama Zoological Park (Tokyo, Japan). The biological data, including sex, age, origin, and cause of death, are summarized in Table 1. After finishing a pathological examination and separating the hind limbs from the pelvis, we visually observed the ligament of head of femur attached to the acetabular fossa and acetabular notch in the carcass. In addition, we examined part of the ligament of head of femur by light microscopy, using excised tissues that were fixed in 10% formalin. After 5 days of fixation, the tissues were dehydrated in ethanol, treated with xylene, and embedded in paraffin. The blocks were sectioned to 4μm thickness, and the sections were stained with hematoxylin and eosin, and analyzed under light microscopy. The region of the acetabulum was observed macroscopically in the pelvis of the four skeleton specimens (Table 1). We describe the attachment area of the ligament of head of femur in the pelvis...
to clarify the attachment mechanism of the ligament to the acetabulum.

**RESULTS**

The acetabulum consisted of the ilium, pubis and ischium forming the shallow and oval hollow in the pelvis. The acetabular fossa was filled with the origin of the ligament of head of femur (Fig. 1). The ligament of head of femur originated from in the acetabular fossa and was surrounded by the margin of the lunate surface. It ran along acetabular notch and left the acetabulum (Fig. 2). The ligament was strongly attached to the acetabular fossa and acetabular notch. After removing the ligament from the acetabulum, a deep ditch was observed in the acetabular fossa (Figs. 2 and 3). The lunate surface in the acetabulum was circular in shape from the ventral aspect, and the acetabular fossa and acetabular notch incompletely separated the lunate surface into the two parts: the ischium and ilium-pubis (Fig. 3).

The ligament of head of femur was approximately 20 mm wide and 10-15 mm thick in the acetabular fossa in the carcass (Fig. 4). Connective tissues formed a thick ligament, with much adipose tissues on the ventral side of the ligament (Fig. 5). The origin of the ligament was enlarged fitted the acetabular fossa tightly; well-developed collagen fibers on the dorsal side of the ligament connected it to the deep ditch (Fig. 4). The area of attachment to the acetabulum was about 60 mm long in this carcass.

Well-developed collagen fibers were seen in the ligament tissue (Fig. 6). The orientation of the collagen fibers was complex. We observed many blood vessels running among bundles of collagen fibers. The artery walls consisted of thick collagenous tissue (Fig. 7).

**DISCUSSION**

The blood supply to the femur is maintained by the femoral artery and its branches thorough femoral canal in various large livestock mammals [1]. The arterial system buried in the tissue of the ligament of head of femur does not supply blood to the femur in the livestock. By contrast, many small blood vessels were seen in the elephant ligament. We postulate that the arteries supply blood to the restricted areas of the femoral head, the hip joint capsule, and the tissues of the ligament of head of femur itself. The skeletal musculature requiring blood supply could not be found in the tissues of the ligament in this study. The well-developed collagen fibers formed a thick ligament unlike the elastic tissues in the nuchal ligament of giraffe or other mammals [2]. The strength and the mobility required by the ligament of head of femur in the elephants may necessitate the accumulation of the collagen fibers seen in this study. Although no developmental approach yet possible with elephant material, the thick collagen tissues and related branching arteries to the femoral head region have been examined histologically and embryologically in human embryos and children [3, 4]. In the future, we will discuss the development of the ligament of head of femur in the elephants, in which the hip joint supports a heavy body weight.

Adaptations to a large body weight could also be seen macroscopically in the thickness of the ligament of head of femur. We postulate that this ligament is thicker in elephants than in other mammals. The deep acetabular fossa and the attachment area of 60 × 20 × 10 to 15 mm contribute to supporting the large body weight of elephants. The acetabulum opens ventrally and we postulate that the direction of opening is another adaptation to heavy body weight [5].

In the human mechanical model, the ligament of head of femur restricts adduction of the femur [6-11]. The ligament of head of femur prevents the femur from being dislocated during adduction of the thigh. Since the acetabulum opens ventrally in the elephant (Fig. 3), the acetabular notch is located medially in the acetabulum. The ligament originates dorso-lateral to the acetabulum center, and runs ventro-medially along the acetabular notch. After leaving the notch, the ligament runs dorso-laterally to attach to the surface of the head of femur. Based on these findings, we advocate a mechanical model in which the function of this ligament of the elephant is to restrict adduction and rotation of the femur in its taut state; it does not restrict extension or flexion in the elephant [11].

In cattle, the lunate surface is clearly separated into two parts in the acetabulum: the ischium and ilium-pubis [5]. The acetabulum is shaped similarly in Equus, although the separation of the lunate surface is incomplete [1]. In the Asian elephant examined, the acetabular fossa did not split the lunate surface completely; however, a deep fossa enveloped the proximal part of the ligament of head of femur. From these
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Fig. 1. The right acetabulum. Ventral aspect. Cranial direction to the left. The ligament of head of femur runs in the ditch of the acetabular fossa (large arrows) and leaves the acetabulum through the acetabular notch (small arrow). Asterisks, lunate surface.

Fig. 2. A view similar to Figure 1. The thick ligament of head of femur (arrowhead) has been removed from the acetabular fossa (arrows).

Fig. 3. Ventral aspect of the right acetabulum in a pelvis specimen. The specimen No. is NSMT-M31593. Cranial direction is to the left. The deep ditch of the acetabular fossa (large arrows) and acetabular notch (small arrow) are observed. 1, ilium. 2, pubis. 3, ischium.
Fig. 4. The right ligament of head of femur. The side of the attachment to the acetabular fossa. Proximal direction is to the right. The collagen fibers appear gray (large arrow), and the white part is adipose tissue (small arrow).

Fig. 5. The right ligament of head of femur. The reverse view of Figure 4. Proximal direction is to the right. There is more white adipose tissue (arrows) in this view.

Fig. 6. The ligament of head of femur consists of well-developed collagen fibers. An artery (arrow) is observed among the collagen fibers. Stained with hematoxylin and eosin. Scale bar = 100 μm.

Fig. 7. An area similar to Figure 6. The artery in the ligament tissue at higher magnification. A longitudinal section shows many layers of collagen fibers (C) around the artery. Stained with hematoxylin and eosin. Scale bar = 50 μm.
findings, we suggest that the separation of the lunate surface
by the acetabular fossa does not reflect an adaptation to the
body weight in animals, although its deep, distinct shape
serves to fix the ligament of head of femur in the hip bone of
elephants.

要約

アジアゾウ（Elephas maximus）の大腿骨頭靱帯を肉眼解剖
学的および組織学的に検討した。膝帯総線が厚い大腿骨頭靱帯
を形成していた。靱帯は寛骨臼窩に長さ約60mm、幅20mm、
厚さ10-15mmの範囲で密着していた。靱帯の近位端は寛骨臼
窩の深く埋まり、月状面の変位が靱帯の起始部を埋めてい
た。靱帯は外側により位置する寛骨臼の中央から起始し、寛骨臼
の内面を溝内側方向に走行、寛骨臼切縁を経て大腿骨頭に達し
ていた。これらの場合から、厚い靱帯とその広い付着面が、ヒ
トで見られるのと同様に、大腿骨の内転を制限する機能として
働いているという機能的モデルを提示することができた。一方
で、ヒトと異なり、大腿骨の伸展と屈曲には直接の機能的関連
がないことが示唆された。

キーワード：寛骨臼、アジアゾウ、大腿骨、機能形態学、大腿
骨頭靱帯

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