An Anatomical Study of the Anterosuperior Capsular Attachment Site on the Acetabulum

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Background: Despite the fact that many surgeons perform partial capsular detachment from the anterosuperior aspect of the acetabulum to correct acetabular deformities during hip arthroscopy, few studies have focused on whether these detachments influence hip joint stability. The aim of this study was to investigate the capsular attachment on the anterosuperior aspect of the acetabulum. We hypothesized that the attachment on the inferior aspect of the anterior inferior iliac spine (AIIS) is wide and fibrocartilaginous and might have a substantial role in hip joint stability.

Methods: Fifteen hips from 9 cadavers of Japanese donors were analyzed. Eleven hips were analyzed macroscopically, and the other 4 were analyzed histologically. In all specimens, the 3-dimensional morphology of the acetabulum and AIIS was examined using micro-computed tomography (micro-CT).

Results: Macroscopic analysis showed that the widths of the capsular attachments varied according to the location, and the attachment width on the inferior edge of the AIIS was significantly larger than that on the anterosuperior aspect of the acetabulum. Moreover, the capsular attachment on the inferior edge of the AIIS corresponded with the impression, which was identified by micro-CT. Histological analysis revealed that the hip joint capsule on the inferior edge of the AIIS attached to the acetabulum adjacent to the proximal margin of the labrum. In addition, the hip joint capsule attached to the inferior edge of the AIIS via the fibrocartilage.

Conclusions: The capsular attachment on the inferior edge of the AIIS was characterized by an osseous impression, large attachment width, and distributed fibrocartilage.

Clinical Relevance: It appeared that the capsular attachment on the inferior edge of the AIIS was highly adaptive to mechanical stress, on the basis of its osseous impression, attachment width, and histological features. Anatomical knowledge of the capsular attachment on the inferior edge of the AIIS provides a better understanding of the pathological condition of hip joint instability.

Femoroacetabular impingement is a condition that results when extra bone grows along the bones that form the hip joint, leading to abnormal contact between the femur and acetabulum during hip movement. Femoroacetabular impingement is one of the most common indications for hip arthroscopy and may lead to the development of hip osteoarthritis. The aim of hip arthroscopy is to correct osseous abnormalities and repair any associated soft-tissue damage.

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Although hip instability after hip arthroscopy is generally considered a rare complication,\textsuperscript{6,7} its prevalence has increased in recent years.\textsuperscript{8-16} In clinical cases and biomechanical studies, management of the hip joint capsule has been regarded as critical and has garnered more attention in recent years.\textsuperscript{2,17-19} During some surgical procedures for femoroacetabular impingement, the hip joint capsule is partially detached from the anterosuperior aspect of the acetabulum for the purpose of labral repair\textsuperscript{20,21} and decompression of the anterior inferior iliac spine (AIIS)\textsuperscript{22,23}. Although these partial detachments of the anterosuperior part of the joint capsule have been usually left without repair, few studies have focused on how these detachments potentially influence hip instability.\textsuperscript{24}

The part originating from the inferior edge of the AIIS of the anterosuperior part of the capsule is known as the iliofemoral ligament and has an important role in hip joint stability.\textsuperscript{25,26} However, few studies have investigated the capsular attachment of the anterosuperior aspect of the acetabulum. According to Wolff’s law, the osseous structure is sensitive to the mechanical stresses loaded on it.\textsuperscript{27} In addition, the presence of fibrocartilage at the entheses, which are the connective tissues where tendons, ligaments, and joint capsules attach to bone, has been shown to be a response to the mechanical stresses.\textsuperscript{28,29} Therefore, knowing the anatomy of the capsular attachment on the anterosuperior aspect of the acetabulum on the basis of its osseous structure and histological features may be important to understanding the key elements of hip joint stability.

This aim of this study was to investigate the capsular attachment of the anterosuperior aspect of the acetabulum on the basis of the osseous morphology, macroscopic findings, and histological anatomy. We hypothesized that the attachment of the hip joint capsule on the inferior edge of the AIIS is wide and fibrocartilaginous and is thus important for hip joint stability.

**Materials and Methods**

**Cadaveric Specimen Preparations**

Seventeen hips from 9 cadavers (5 Japanese men and 4 Japanese women; mean age at the time of death, 80.8 years), which were donated to the Department of Anatomy, were used in this study. All cadaver specimens were fixed in 8% formalin and preserved in 30% ethanol. The skin and subcutaneous tissues were removed for dissection of the proximal side of the hip joint capsule. After removal of the gluteus maximus and hip adductor muscles, the proximal osseous shape of the femur was identified and all specimens were cut at the level of the femoral neck using a diamond saw. One specimen was excluded because of previous hip joint surgery.

In the remaining specimens, the osseous configuration of the acetabulum and AIIS was examined using microcomputed tomography (micro-CT) (inspeXio SMX-100CT; Shimazdu) with a 200-μm resolution, and the 3-dimensional (3-D) images were reconstructed using application software (VGStudio Max 2.0; Volume Graphics). One hip with severe calcification seen on the 3-D image was excluded. Then, 11 and 4 hips were randomly assigned to macroscopic and histological analyses, respectively.

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**Fig. 1**

Osseous configuration of the AIIS and acetabulum shown by micro-CT. The dashed lines indicate the rough impression at the superior portion of the AIIS and anterolateral wall of the ilium. The arrowheads indicate the shallow groove at the anteromedial surface of the AIIS. The star indicates the smooth impression at the inferior portion of the AIIS. Ant = anterior, Med = medial, Post = posterior, and Sup = superior. The anteromedial (Fig. 1-A), anterior (Fig. 1-B), and anterolateral (Fig. 1-C) aspects of the right hip are shown.
Macroscopic Analysis: Attachment of the Hip Joint Capsule and Its Superficial Muscles
For macroscopic analysis of 11 hips, the hip joint capsule and its superficial muscles were carefully removed and their attachment was observed. Initially, the iliopsoas, sartorius, tensor fasciae latae, and gluteus medius and minimus were removed to expose the rectus femoris. During removal of each muscle, the deep fascia was also observed. Second, the direct and reflected heads of the rectus femoris were removed to expose the hip joint capsule. Finally, the hip capsular attachment on the acetabulum was detached and the attachment width of the articular capsule was measured. Measurements were conducted by 2 independent observers.

Interclass correlation coefficients (ICCs) for each value were calculated to evaluate measurement validity between the 2 observers for each group of measurements.

Histological Analysis of the Attachment of the Hip Joint Capsule
We performed histological examinations of the attachment of the hip joint capsule in the 4 randomly selected hips. The AIIS and acetabulum with the hip joint capsule and its superficial muscles were harvested as en bloc specimens using a diamond saw, perpendicular to the acetabular margin in 3 small regions: the middle position between the iliopubic ramus and the anteroinferior edge of the AIIS, the center of the AIIS, and the anterior edge of the AIIS.

Fig. 2
Spatial geometry of the rectus femoris and its superficial structures on the anteromedial aspect of the AIIS. Ip = iliopsoas, Sa = sartorius, Ic = iliocapsularis, RF = rectus femoris, RFd = direct head of the rectus femoris, Med = medial, Post = posterior, and Sup = superior. Fig. 2-A Anteromedial aspect of the right Ip. Fig. 2-B The Ip was partly detached from the iliac fossa and reflected to the lateral side. Fig. 2-C The origin site of the Ic is indicated by the white dashed line. Fig. 2-D The RFd after removal of the fasciae of the Ip on the surface of the RFd. Fig. 2-E Positional relationship between the origin site of the RFd and that of the Ic (indicated by the white dashed line).
origin site of the reflected head of the rectus femoris. These regions were identified by 3-D conformations of the micro-CT images. The en bloc specimens were decalcified for 1 week with Plank-Rychlo solution (AlCl₃:6H₂O [126.7 g/L], HCl [85.0 mL/L], and HCOOH [50.0 mL/L]) and were dehydrated. After fixation, the specimens were embedded in paraffin solution. Subsequently, the blocks were serially sectioned (5-μm thickness) and were stained using the Masson trichrome staining protocol.

Statistical Analyses
Statistical tests were performed using JMP 14.0 software (SAS Institute). Statistical comparisons of the attachment widths of the hip joint capsule were performed using a 1-way analysis of variance (ANOVA) with the Bonferroni correction for multiple comparisons, and the significance level was set at p < 0.00017. ICCs were determined using a measurement process analysis. A score above 0.75 was considered to indicate excellent agreement. All ICCs were ≥0.86 (range, 0.86 to 0.97). Data were given as the mean and standard deviation.

Results
Osseous Configuration of the Acetabulum and AIIS
Facets of the AIIS were separated into 2 (superior and inferior) regions (Figs. 1-A, 1-B, and 1-C). The superior...
AIIS region had a teardrop-shaped impression, and its anteromedial aspect was surrounded by a shallow groove. This groove extended to the inferior AIIS region. The inferior region of the AIIS had a distinct impression and extended anteromedially and anterolaterally to the acetabular margin.

Muscular Attachment Around the Hip Joint Capsule
The iliopsoas was observed from the anteromedial aspect of the hip (Fig. 2-A). After detachment of the iliopsoas from the iliac fossa, the surface of the iliocapsularis was revealed (Fig. 2-B). The iliocapsularis occupied the deepest portion of the iliopsoas and originated from the anteromedial surface of the AIIS. Removal of the muscular portion of the iliopsoas, including the iliocapsularis, allowed the deep fascia of the iliopsoas to be observed because it connected to the anteromedial surface of the hip joint capsule (Fig. 2-C). The deep fascia of the iliopsoas widely covered the anteromedial surface of the hip joint capsule and the deep and medial surfaces of the rectus femoris. In addition, the origin of the iliocapsularis corresponded with the shallow groove at the anteromedial surface of the AIIS, which was identified by micro-CT. Removal of the deep fascia of the iliopsoas on the medial surface of the rectus femoris allowed the origin of the direct head of the rectus femoris to be observed on the AIIS (Figs. 2-D and 2-E). Its origin corresponded with the teardrop-shaped impression at the superior aspect of the AIIS, which was also identified by micro-CT.

After removal of the gluteus medius, the gluteus minimus was observed on the anterolateral surface of the hip joint capsule (Figs. 3-A and 3-B). Removal of the muscular portion of the gluteus minimus revealed the surface of the deep fascia of the gluteus minimus because it covered and was connected to the distal part of the anterolateral surface of the hip joint capsule (Fig. 3-C). After removal of the proximal part of the deep fascia of the gluteus minimus, the origin of the reflected head of the rectus femoris was observed (Figs. 3-D and 3-E). The deep fascia of the proximal part of the rectus femoris covered and was connected to the proximal part of the anterolateral surface of the hip joint capsule.

Capsular Attachment on the Acetabulum and AIIS
The widths of the capsular attachments to the acetabulum varied according to their location. The hip joint capsule attached with a relatively narrow width between the iliopubic ramus and the anterior edge of the AIIS (Fig. 4-A). The width of the capsular attachments inferior to the AIIS gradually increased from anterior to posterior (Fig. 4-B). The footprint of the hip joint capsule inferior to the AIIS corresponded with the impression at the inferior part of the AIIS, as identified by micro-CT. Additionally, the width of the capsular attachments posterior to the AIIS gradually decreased toward the region...
inferior to the origin of the reflected head of the rectus femoris (Fig. 4-C).

The measurements of the widths of the capsular attachments are shown in Figure 5 and Table I. The widths of the capsular attachments at the anteroinferior and posteroinferior edges of the AIIS (L2 and L3, respectively, in Fig. 5 and Table I) were 12.9 ± 1.9 and 14.4 ± 1.8 mm, respectively. The attachment widths at the inferior edge of the AIIS were significantly larger than those at the middle position between the iliopubic ramus and the anteroinferior edge of the AIIS (L1) and at the anteroinferior edge of the AIIS (L2), at the posteroinferior edge of the AIIS (L3), and at the anterior edge of the origin site of the RFr (L4).

**Histological Features of the Attachment of the Hip Joint Capsule**

The hip joint capsule between the iliopubic ramus and the anterior edge of the AIIS was in close contact with the outer surface of the labrum and directly continued to the periosteum of the acetabulum (Figs. 6-A and 6-B). The hip joint capsule inferior to the AIIS was attached to the acetabulum through fi

# Discussion

The present study revealed that a distinct impression inferior to the AIIS provided an attachment site for the hip joint capsule. The width of the attachment was significantly larger than that on the anterosuperior aspect of the acetabulum. In addition, histological analysis revealed that the hip joint capsule on the inferior edge of the AIIS attached to the acetabulum adjacent to the proximal margin of the labrum, and its capsular attachment was fi
cartilaginous. Therefore, these findings—i.e., that the inferior capsular attachment corresponded to the osseous impression and fibrocartilage—supported our hypothesis that the inferior attachment was important for hip joint stability.

Previous studies have focused on the osseous morphology of the inferior edge of the AIIS. Hetsroni et al. reported that the morphology of the AIIS in patients with hip impingement can be classified into 3 types based on the relationship between the distal extension of the AIIS and the acetabulum. On the basis of this classification, Balazs et al. reported that osseous prominences on the inferior region of the AIIS or the extension of the inferior region of the AIIS to the acetabular margin were observed in the majority of cases without a history of hip pain or hip impingement. In the present study, a distinct impression was identified at the inferior edge of the AIIS. According to Wolff’s law, which indicates that mechanical stresses determine bone architecture, we postulate that the osseous morphology inferior to the AIIS might result from high mechanical stresses transmitted by the hip joint capsule attached to it.

### TABLE I Widths of the Capsular Attachments

| Location of the Measurements* | Width† (mm) |
|------------------------------|-------------|
| Middle position between iliopubic ramus and anteroinferior edge of AIIS (L1) | 7.0 ± 1.6 |
| Anteroinferior edge of AIIS (L2) | 12.9 ± 1.9† |
| Posteroinferior edge of AIIS (L3) | 14.4 ± 1.8† |
| Anterior edge of origin of reflected head of rectus femoris (L4) | 8.8 ± 1.3 |

*The locations of the measurements are demonstrated in Figure 5. †The width is given as the mean and standard deviation. ‡P < 0.00017 as compared with L1 and L4.
The inferior edge of the AIIS provides the attachment site of the anterosuperior aspect of the capsule. Cooper et al. measured the capsular attachment width at 8 locations on the acetabulum using the hemiquadrant system and reported the greatest width (8.8 mm) in the region posterior to the inferior edge of the AIIS. Philippon et al. also reported that the capsular attachment was widest (10.9 mm) at the posteroinferior region of the AIIS, which corresponded with the arthroscopic anatomy at the 2 o’clock position. In the present study, the widths of the capsular attachments on the posteroinferior and anteroinferior aspects of the AIIS were significantly wider than the attachment on the anterosuperior aspect of the acetabulum. The anterosuperior aspect of the hip joint capsule was covered with the deep fascia of the iliopsoas, rectus femoris, and gluteus minimus. These deep fasciae could be considered a reinforcing part of the hip joint capsule. Since we included the reinforcing part of the hip joint capsule in the analysis, we could precisely show the wide attachment of the hip joint capsule and labrum extended inferior to the AIIS. We recognize that some confusion remain regarding terminology; that is, some authors have used “subspine” or “subspinal decompression” for the anatomical area. We propose that the distinct impression at the inferior region, where the anterosuperior aspect of the capsule attaches, be identified as the “subspine.”

Some previous reports on the proximity between the attachment of the hip joint capsule and labrum indicated that the anterosuperior aspect of the hip joint capsule distantly attached proximal to the labrum. The present study revealed that the proximity between the attachment of the hip joint capsule and labrum varied according to location, even on the anterosuperior aspect of the acetabulum. Furthermore, it was found that the hip joint capsule inferior to the AIIS was attached to the acetabulum without any distance from the proximal margin of the labrum.

Regarding the histological features of the capsular attachment, Wagner et al. previously described a fibrocartilaginous capsular attachment at the superior region of the acetabular margin. According to Benjamin and Ralphs, there is a high correlation between the distribution of fibrocartilage within an enthesis and the levels of mechanical stress on it. Some anatomical studies showed that, in other joints, histological features of the capsular attachment varied according to location and suggested that the fibrocartilage distributed in the region was highly subject to mechanical stress. In the current study, the histological features of the capsular attachment inferior to the AIIS showed a fibrocartilaginous structure, in contrast to the hip joint capsule between the iliopubic ramus and the anteroinferior edge of the AIIS, which directly continued to the periosteum of the acetabulum. Therefore, we concluded that the fibrocartilaginous nature of the capsular attachment inferior to the AIIS should be correlated with the mechanical stresses loaded there.
Our findings highlight a few important clinical insights. It is generally accepted that the iliofemoral ligament has an important role in hip joint stability. In this study, we determined that the capsular attachment inferior to the AIIS, which is the same as that of the origin of the iliofemoral ligament, was highly adaptive to mechanical stress. If hip surgeons place a suture anchor on the edge of the acetabulum, they have to partially detach the articular side of the hip capsule to expose the acetabular bone. At the inferior edge of the AIIS—namely, between the 1 and 2 o'clock positions, where labral tears are commonly seen in clinical situations—we observed no gap between the labrum and capsule. This anatomical finding might, to some extent, be related to an iliofemoral ligament injury during the exposure of the acetabulum rim. If surgeons extend the exposure of bone more proximally to perform AIIS decompression, the damage to the iliofemoral ligament can increase. Thus, when anticipating the outcomes of hip surgery such as labral repair or AIIS decompression, the surgeon must balance consideration of the results of the surgical procedures themselves with the possible loss of ligamentous stability caused by detachment of the proximal part of the capsule.

This study has some limitations. First, it was a purely anatomical investigation and was limited to uninjured specimens; therefore, we cannot prove the cause of hip instability after surgery and our explanations remain speculative. Second, our lack of radiographic evaluation meant that we could not exclude some osseous abnormalities, such as acetabular dysplasia. Third, the mean age of the study population was >80 years, which is considerably older than the general population of patients undergoing hip arthroscopy. Additionally, the anatomical measurements were not adjusted for the overall size of the donor or related anatomical structures. We also cannot exclude the possibility that the advanced age of the donors affected our findings, as previous reports suggested that the fibrocartilaginous composition changes with age. Finally, we did not investigate the histological features of the capsular attachment on the whole acetabulum; thus, we could not conclude that the fibrocartilage was unique to the capsular attachment at the inferior edge of the AIIS. Additional biomechanical studies or studies with clinical case imaging are needed to validate our findings.

In conclusion, the capsular attachment on the inferior edge of the AIIS was characterized by an osseous impression, large attachment width, and distributed fibrocartilage. Anatomical knowledge of the capsular attachment on the inferior edge of the AIIS provides a better understanding of the pathological condition of hip joint instability.

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