The Effectiveness of External Rotators and Ischiofemoral Ligament for the Prevention of Hip Dislocation in Hip Flexion Position: A Cadaveric Study

Kazuyoshi Baba (kazuyoshi.baba.e3@tohoku.ac.jp)
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Daisuke Chiba
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Yu Mori
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Yoshiyuki Kuwahara
Sendai city hospital
Atsushi Kogure
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Takehiro Sugaya
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Kumi Kamata
Iwaki medical center
Itsuki Oizumi
Iwaki medical center
Takayuki Suzuki
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Hiroaki Kurishima
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Soshi Hamada
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Eiji Itoi
Tohoku Rosai Hospital: Tohoku Rosai Byoin
Toshimi Aizawa
Tohoku University School of Medicine: Tohoku Daigaku Daigakuin Igakukei Kenkyuka Igakubu

Research Article

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Abstract

Background

The purpose of this study was to examine the magnitude of the impact of each external rotator muscle and ischiofemoral ligament on prevention of joint dislocation, depending on the hip flexion angle.

Method

Nine normal hips were studied; the pelvis was fixed in the lateral decubitus position. An intramedullary nail was inserted into the femur and fixed using screws. A circular plate with a protractor was fixed on the nail. The circular plate was pulled by 3.15 Nm force in the direction of internal rotation, and this angle was defined as the baseline angle. External rotators of the right hip were resected stepwise using the posterior approach; in contrast, external rotators of the left hip were resected stepwise in the reverse order, and finally the ischiofemoral ligament was cut. After each muscle and ischiofemoral ligament resection, the increase in the angle by the traction of was measured at the neutral and 30° and 60° hip flexion positions.

Results

In posterior approach, there was a significant difference between measurements after piriformis and ischiofemoral ligament resection at 0° of flexion (p=0.02). At 30° of flexion, there were significant differences between measurements after each external rotator and ischiofemoral ligament resection (p<0.01). At 60° of flexion, there were significant differences between ischiofemoral ligament resection and piriformis or inferior gemellus resection (p=0.04, p=0.02, respectively).

In the reverse order of the posterior approach, there were significant differences between ischiofemoral ligament resection and the obturator externus, inferior gemellus, or obturator internus at 0° of flexion (p<0.01, p<0.01, p=0.01, respectively). At 30° of flexion, there was a significant difference between the ischiofemoral ligament and each external rotator (p<0.01).

Conclusion

The ischiofemoral ligament is the main restrictor of posterior dislocation. The combination of the piriformis and obturator internus may restrict internal rotation at 0°and 60° of flexion.

Introduction

Total hip arthroplasty (THA) is one of the most successful procedures for reducing pain and improving function in patients with osteoarthritis of the hip. The number of patients undergoing THA is increasing, and it is believed that this increasing tendency will continue in the future. However, dislocation and loosening after primary THA are serious adverse events. The most common causes of revision THA in United states are dislocation and instability [1,2]. Endogenous factors of patients, surgeon's skills, and prosthesis design are considered important factors inducing dislocation [3]. Mechanical factors, including the accuracy of prosthesis setting and soft tissue balance, have been demonstrated as other important factors affecting dislocation [4]. Navigation-assisted surgery systems have been developed and have been shown to contribute to improving the accuracy of the prosthesis setting. However, the optimal soft tissue balance to prevent hip dislocation has not been determined.

The surgical techniques to prevent dislocation have been developed. The anterior surgical approach preserving the posterior hip joint capsular ligament and external rotators demonstrated better results in preventing dislocations [5,6]. In contrast, the dislocation rate of patients who underwent a posterior surgical approach with capsular ligament repair was lower than that of patients without capsular ligament repair [6,7]. These studies suggested that preserved soft tissues, including the capsular ligament and external rotators, could contribute to the prevention of dislocation. The capsular ligaments of the hip are composed of the iliofemoral, ischiofemoral, and pubofemoral ligaments. Anatomically, the ischiofemoral ligament inserts in the ischium and posteroinferior areas of the acetabular rim and attaches to the posterior intertrochanteric line [8]. The ischiofemoral ligament is considered to be related to the control of internal rotation and extension balance [9].

In previous cadaveric studies, the ischiofemoral ligament has provided primary internal rotation restraint, particularly in flexion ≥ 30° and adduction [10]. However, these previous studies were performed only on the capsular ligament after the removal of muscles around the hip joint. The functional role of the ischiofemoral ligament in internal rotation restraint has not been evaluated with the preservation of both the capsular ligament and external rotator muscles. The synergistic effect of the ischiofemoral ligament and external rotator muscles for internal rotation restraint should be evaluated. Furthermore, the most important factors among the capsular ligaments and external rotators remain unclear in the prevention of hip dislocation. The purpose of this study was to determine the contribution of each external rotator muscle and ischiofemoral ligament to joint stability after THA at various angles of hip flexion.

Methods

Cadaveric study

The study protocol was approved by the Institutional Review Board of our institute. A total of ten normal hips (four right and six left hips) obtained from seven fresh frozen cadavers (six males and one female) were enrolled in this study. The age of the specimens at death ranged from 72 to 89 years (mean, 77.6 years). The pelvis was obtained by transection of the spine between the 4th and 5th lumbar spine, and the femur was cut at the mid-shaft level. All cadavers were thawed overnight at room temperature. The skin and subcutaneous adipose tissues were removed. In contrast, the muscles and capsular ligaments were left intact. The pelvis was fixed on a wooden plate by inserting K-wires at the anterior superior iliac spine and the ischial tuberosity. The pelvis was stabilized in the lateral decubitus position using this plate (Fig. 1). To handle the femur, a Phoenix Ankle Arthrodesis Nail (Zimmer Biomet, IN, USA) was inserted into the distal femur and fixed with two screws (Fig. 1). A circular plate of 90-mm diameter with a protractor was fixed at a point 350 mm away from the center of the femoral head (Fig.1). The hip center was confirmed using fluoroscopy. With the capsular ligament and external rotators intact, the circular plate was pulled vertically in the direction of the internal rotation of the hip at a constant force of 3.15 Nm applied by a digital pull tension gauge (DST-500N, IMADA, Japan), and the protractor was captured in clear photographs (Cyber-shot DSC-HX400V, Sony, Japan) (Fig.2). The protractor demonstrated an angle after traction by constant force between preserved external rotators and the capsular ligament, which was defined as the baseline angle. The hip was dissected via a posterior approach [11]. The external rotators, including the piriformis, superior gemellus, obturator internus, inferior gemellus, and obturator externus, were individually identified. The external rotators were released in this order from the piriformis to obturator externus in the right hips, and the reverse order from the obturator externus to the piriformis in the left hips (Fig.3 A, B). While an internal rotation torque of 3.15 Nm was applied to the hip joint, the protractor was photographed. The measurements were performed at the neutral position and at 30° and 60° of hip flexion by confirmation with a goniometer (Fig.1). Finally, the posterior ischiofemoral ligament was resected in an L shape after resection of all muscles (Fig.3 C). The labrum remained intact. The protractor measurement was repeated three times after each step of release, and the average angle of the three measurements was recorded. An increase in rotation angle was calculated as the difference between the baseline angle and the angle after each rotator muscle and posterior capsular ligament resection. All the procedures were performed on the same day. The angle was measured from the photograph using Image J software (National Institutes of Health, USA). Two hip surgeons, both with more than 10 years of experience, independently measured the angles of the protractor.

Statistical Analysis

Results are presented as the average ± standard deviation. The coefficient of variation was calculated in the point of precision of measurement using SPSS statistics 21.0 (IBM, USA). Statistical differences in the increased angle by the stepwise cut of external rotators and capsular ligament was performed using one-way analysis of variance with post hoc Tukey-Kramer test. Statistical significance was set at $P < 0.05$.

Results

One hip was excluded because of femur fractures that occurred during the procedures, leaving nine hips for analysis. In this study, no hips dislocated in any of the procedures. The results of resection from the piriformis to the obturator externus are shown in Table 1 and Fig. 4. The intra-class correlation coefficient of the measurements was 0.98. At 0° of hip flexion, there was a significant difference between measurements after piriformis resection and additional capsular ligament resection ($p=0.02$) (Fig.4A). At 30° of hip flexion, there were significant differences between the measurements after stepwise external rotators and additional capsular ligament resections ($p<0.01$, respectively). However, there was no significant difference between measurements after stepwise resection of external rotators (Fig.4B). At 60° of hip flexion, there were significant differences between capsular ligament resection and piriformis or inferior gemellus resection ($p=0.04$, $p=0.02$, respectively) (Fig.4C).

The results of resection in reverse order from the obturator externus to the piriformis are shown in Table 2 and Fig.5. The intra-class correlation coefficient of the measurements was 0.90. At 0° of hip flexion, there was a significant difference between capsular ligament resection and obturator externus, inferior gemellus, and obturator internus resections ($p<0.01$, $p<0.01$, $p=0.01$, respectively) (Fig. 5A). At 30° of hip flexion, there were significant difference between the capsular ligament and external rotators ($p<0.01$, respectively); however, there were no differences between the external rotators (Fig. 5B). At 60° of hip flexion, there was no significant difference in any of the combinations (Fig. 5C).

Discussion

Soft tissue repair, including of the posterior capsular ligament and external rotators, is recommended to reduce the risk of dislocation after THA via the posterior approach [6,7,12]. Previous anatomical and biomechanical studies have investigated the contribution of the capsular ligament to hip joint stability [8,13,14], however, no experimental study has focused on the selective stepwise resection of external rotators and capsular ligaments, or on the restraint of passive internal rotation. The results of the present cadaveric study demonstrated that the ischiofemoral ligament was the main restrictor of posterior dislocation with the suppression of excessive internal rotation, especially at 30° of hip flexion. The combination of piriformis and obturator internus restricted internal rotation at 0° and 60°; in contrast, the external rotators showed no effect on internal rotation of the flexed hip.

In the reproducibility of the angle measurement, the intraclass correlation coefficient of the results was over 0.90. The values were in almost perfect agreement [15]. The authors concluded that these results demonstrated the high reproducibility and reliability of the measurements. In the present study, it was suggested that the capsular ligament and external rotators synergistically contributed to the restriction of internal rotation; however, each external rotator did not contribute to the prevention of hip dislocation by itself. The ischiofemoral ligament was the most crucial factor restricting internal rotation between 0° and 60° of hip flexion, especially at 30°.

The ischiofemoral ligament is one of the posterior capsular ligaments of the hip joint. The ligament is tense in internal rotation [16] and adduction [17]. When the hip is in deep flexion and internal rotation, the tension of the ischiofemoral ligament increases and pulls the femoral head into the acetabulum. The tight ischiofemoral ligament protects posterior dislocation during internal rotation [10]. The present study showed that the ischiofemoral ligament mainly contributed to hip stability by limiting the internal rotation between 0° and 60° of hip flexion, especially at 30°. A previous study reported that the strain on the hip joint capsular ligament using a CT-based imaging technique showed that the ischiofemoral ligament was elongated during hip internal rotation. The length of the ischiofemoral ligament indicated the maximum length occurred at hip flexion of 30°, increasing from -15° to 30°, and decreasing from 30° to 90° [18]. These anatomical data were consistent with our findings.

In recent years, the importance of not only the ischiofemoral ligament but also external rotators in reducing the risk of dislocation after THA performed with a posterior surgical approach have been reported [12,20,21]. External rotators include the piriformis, superior gemellus, obturator internus, inferior gemellus, and obturator externus. Anatomically, the piriformis inserts immediately medial and inferior to the superomedial border of the greater trochanter. The obturator internus and the superior and inferior gemellus insert into the anterior tip of the greater trochanter as a conjoint tendon. The obturator externus inserts on the medial face of the greater trochanter [19]. The piriformis and conjoint tendons were demonstrated to be crucial for stabilization of THA in the posterior approach [20-22]. External rotators were mainly attached in three places; however, it was unclear which muscle resisted the dislocation of THA and how much compared to the ischiofemoral ligament, especially at 0°and 60° of hip flexion, where the ischiofemoral ligament was not most stretched. In this study, the conjoint tendon and obturator externus were demonstrated to be important in the restriction of internal rotation of the hip in hip flexion at 0°and 60°. In contrast, the results of reverse order resection indicated that the piriformis could restrict internal rotation of the hip only at hip flexion angles of 0°. These results could be explained by the changes in muscle length and strength due to the hip flexion angle. The length and strength of the piriformis muscle were decreasing with the increase of hip flexion angle. As a result, the piriformis did not restrict internal rotation at hip flexion angles greater than 60°. In contrast, the obturator internus was indicated to have the function of restriction of internal rotation even at 90° hip flexion [23,24]. Therefore, the function of the piriformis as an external rotator was valid at hip flexion 0° and not valid at hip flexion 60°, due to a decrease in muscle length and strength. Furthermore, the importance of the obturator internus contributing to restricting internal rotation at hip flexion 60° might be higher than that of piriformis.

There were limitations in the present study. First, the sample size was small. Second, physiological muscle contraction did not occur during the cadaveric study. Even the muscle tension of the external rotators might be different from that in the living body. Third, the deep flexion, such as 90°, did not examined because the wooden plate on which the pelvis was fixed interfered the femur in deep hip flexion.

Conclusions

The ischiofemoral ligament was the main restrictor of posterior dislocation with the suppression of excessive internal rotation, especially at 30° of hip flexion. The combination of the piriformis and obturator internus also restricted internal rotation at 0° and 60° of hip flexion. However, the external rotators did not restrict internal rotation in hip flexion. The restriction of the internal rotation by the obturator internus might be more important than that of the piriformis at 60° of flexion.

Abbreviations

THA: Total hip arthroplasty

Declarations

Disclosures

None

Ethics approval

This study was approved by the Institutional Review Board of Tohoku University Graduate School of Medicine.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Competing Interests

The authors declare that they have no competing interests.

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Credit Author contribution statement

KB, TS, YK and DC mainly collected clinical data. KB, YM, and EI interpreted the data through discussion. All authors participated in manuscript writing. All authors approved the final version of the manuscript.

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Not applicable

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Tables

Due to technical limitations, table 1 and 2 is only available as a download in the Supplemental Files section.

Figures

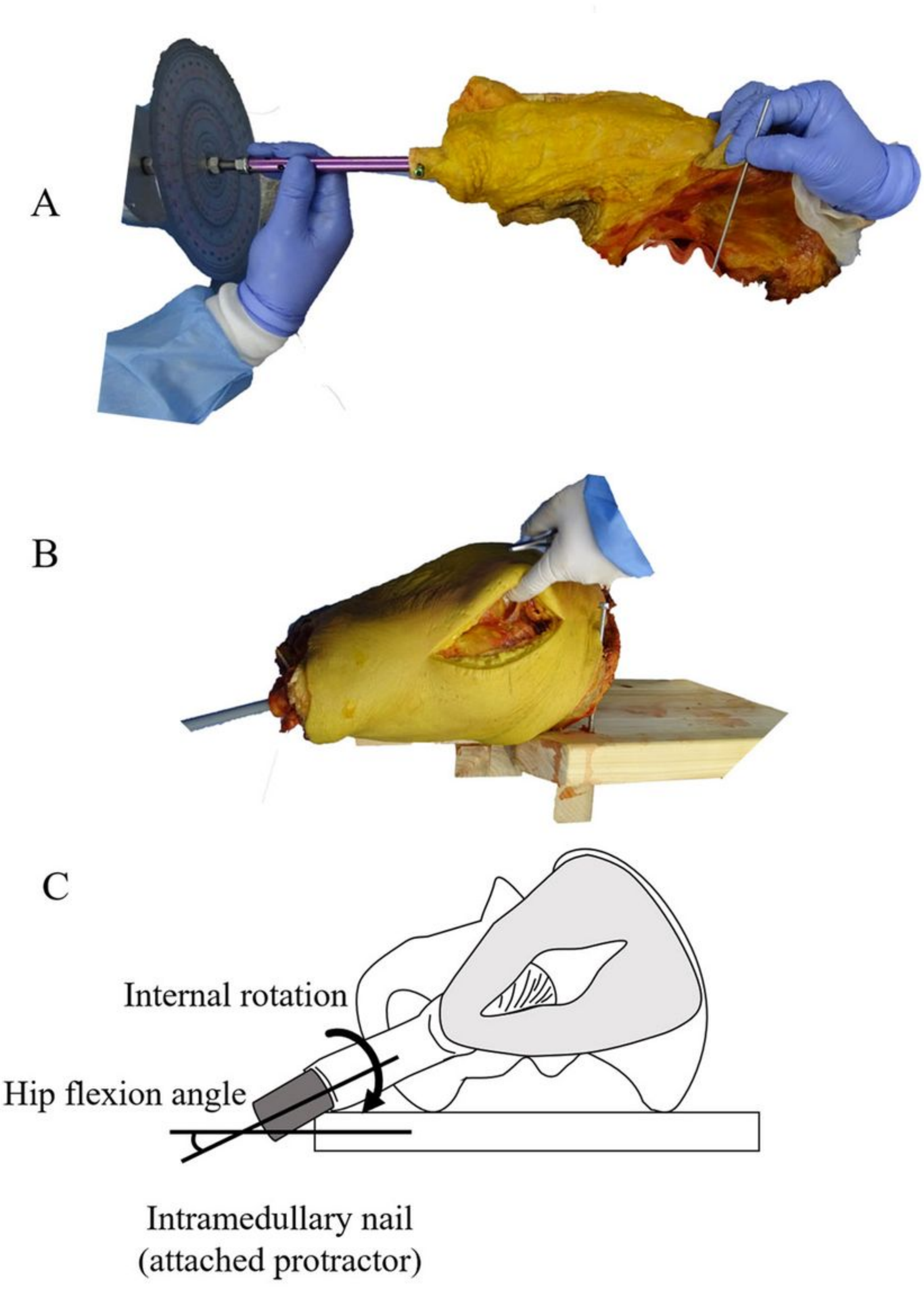

Figure 1

The setting of cadavers in the present biomechanical study A: The photograph shows the insertion of Phoenix Ankle Arthrodesis Nail to the right femur. The protractor was attached to the nail. B: The photograph shows the fixation of the pelvis. The posterior approach was performed. C: The schematic model shows an overview of the setting of this study. The hip flexion angle was defined as the angle between femur and anterior pelvic plane.

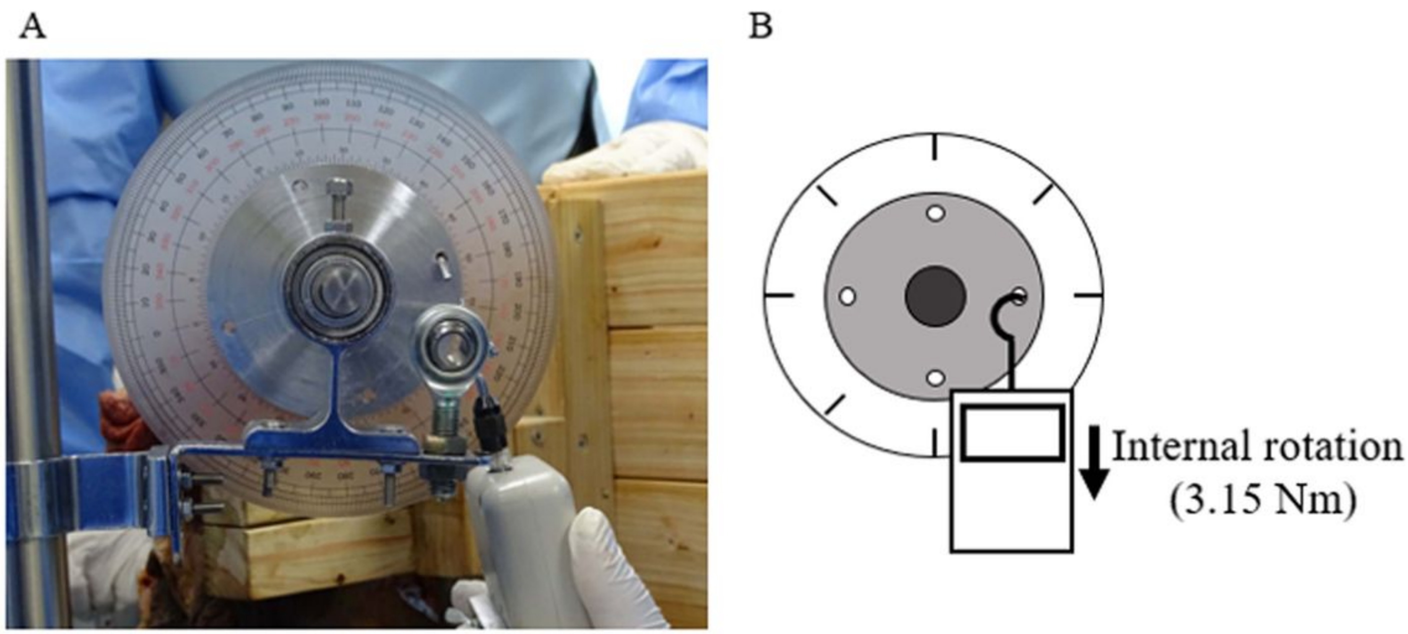

Figure 2

Angle measurement method using a digital pull tension gauge The photograph (A) and schematic model (B) show the methods used to measure the increase angle using a digital pull tension gauge.

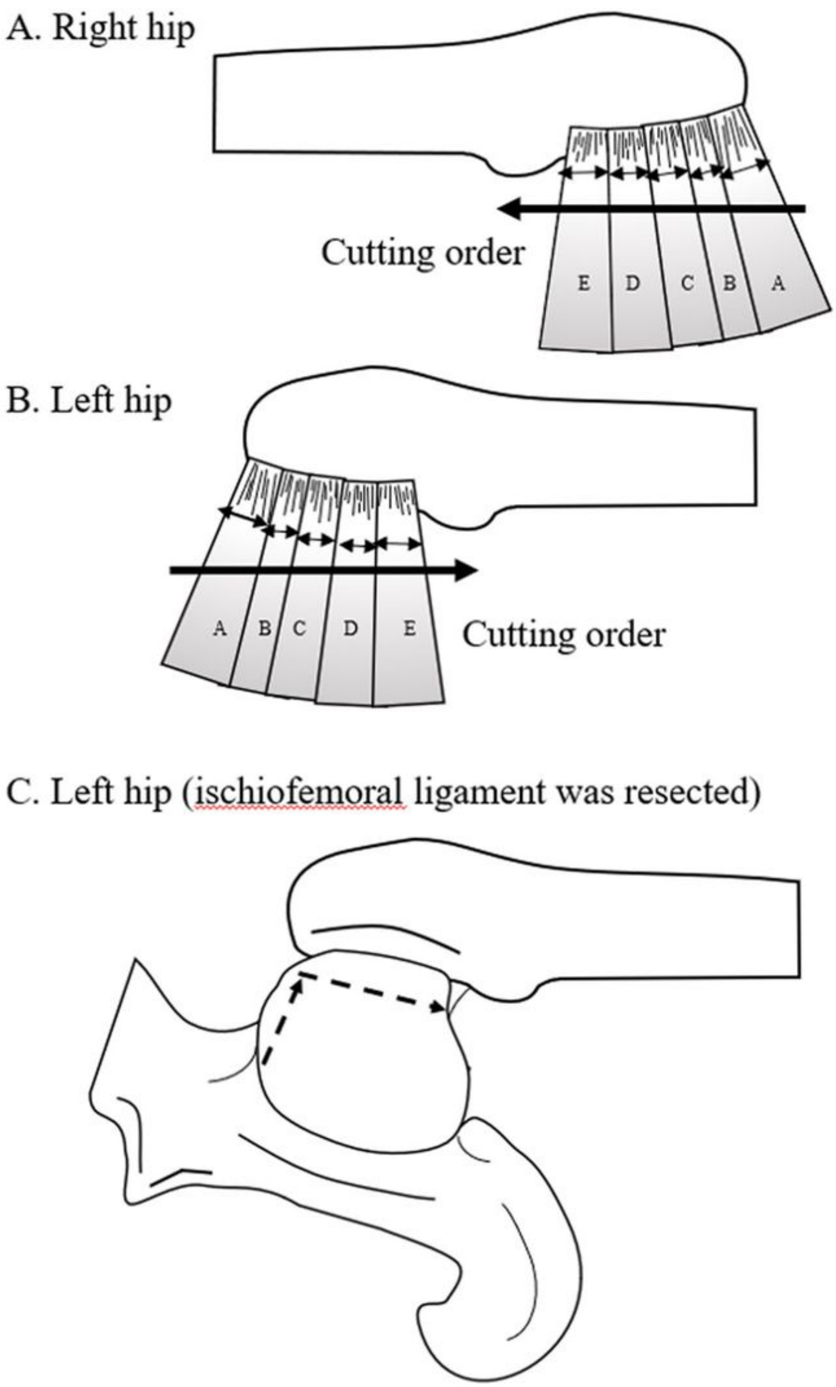

Figure 3

Schematic models of stepwise dissections of the hip rotator muscles and ischiofemoral ligament in the methods of posterior hip approach and its reverse order A: The cutting order of right hip via posterior approach. The direction of the arrow indicates the order of cutting. B: The cutting order of left hip in reverse order from the right hip. The direction of the arrow indicates the order of cutting. C: The cutting order of ischiofemoral ligament. The direction of the dotted arrow indicates the order of cutting.A: piriformis , B: superior gemellus, C: obturator internus, D: inferior gemellus, E: obturator externus

Image not available with this version

Figure 4

The increase in angle via the posterior approach. The name of the muscles indicates the increase angle measured after resection of the muscle. * $p < 0.05$ by one-way analysis of variance with post hoc Tukey-Kramer test.

Image not available with this version

Figure 5

The increase angle via the reverse of the posterior approach. The name of the muscles indicates the increase in angle measured after resection of the muscle. * $p < 0.05$; ** $p < 0.01$ by one-way analysis of variance with post hoc Tukey-Kramer test.

Supplementary Files

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- Table1.tif
- Table2.tif