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대퇴비구충돌증후군 진단을 위한 새로운 방사선학적 기준 수립을 위한 연구: 3차원 모델 시뮬레이션 연구

Novel radiological criteria for the diagnosis of femoroacetabular impingement based on a three-dimensional simulation study

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서울대학교 대학원

의학과 정형외과학 전공

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김 홍 석

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위 원 장	염 진 섭	(인)
부위원장	구 경 회	(인)
위 원	조 윤 제	(인)
위 원	임 재 영	(인)
위 원	이 영 균	(인)

Novel radiological criteria for the diagnosis of femoroacetabular impingement
based on a three-dimensional simulation study

Kyung-Hoi Koo

Submitting a Ph.D. Dissertation of
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Graduate School of Medicine
Seoul National University
Orthopedic Surgery Major

Hong Seok Kim

Confirming the Ph.D. Dissertation written by
Hong Seok Kim
July 2022

Chair	Jin Sup Yeom	(Seal)
Vice Chair	Kyung-Hoi Koo	(Seal)
Examiner	Yoon Je Cho	(Seal)
Examiner	Jae-young Lim	(Seal)
Examiner	Young-Kyun Lee	(Seal)

Abstract

Purpose

Femoroacetabular impingement (FAI) is diagnosed by symptoms, impingement test, and radiological findings. However, the reliability of radiological findings is debated. Thus, we defined excursion angle (EA), impingement free range of motion between the acetabular edge and the femoral neck. The aims of this study were to develop diagnostic criteria of FAI based on EA, to evaluate the reliability and validity of the criteria, and to determine the optimal cut-off value of EA discriminating FAI and non-FAI hips.

Methods

Thirty-three 3-dimensional hip models were reconstructed and 14 activities of daily living were simulated. Any colliding portions of the acetabular edge were removed, and lateral and anterior EAs were measured. The reliability and validity of the EA criteria were evaluated in a validation cohort of 411 hips. The optimal cut-off values discriminating FAI and non-FAI hips were determined using the receiver operating characteristic (ROC) curve analysis.

Results

The mean lateral EA was 50.4° (±10.2°), and the mean anterior EA was 29.9° (±5.1°). Hips were categorized into low-risk group (lateral EA>40° and anterior EA>25°), moderate-risk group (lateral EA: 30°-40° or anterior EA:20°-25°) and high-risk group (lateral EA< 30° or anterior EA<20°). The EA measurement was highly reliable (*k*=0.96 and 0.97 for inter-and intra-observer reliabilities, respectively). Among the 411 validation hips, 106 (26%) were diagnosed as FAI. There was a strong correlation between FAI and risk groups: 8% (22/279) in the low-risk group, 44% (28/64) in the moderate-risk group, and 82% (56/68) in the high-risk group ($x^2=183.674$, $p<0.001$). The EA criteria had excellent discrimination between FAI and non-FAI hips (area under the curve (AUC) 0.856[0.807-0.905], $p<0.001$). The optimal cut-off values for lateral EA were 51° in female and 43° in male; those for anterior EA were 29° in female and 25° in male.

Conclusion

We developed reliable and valid criteria to diagnose FAI by measuring two EAs on hip AP and modified Dunn views. The EA criteria appeared as reliable and valid radiological measurement for FAI diagnosis. Further studies are warranted to evaluate the performance of the EA criteria in the diagnosis of FAI.

Keyword: hip, femoroacetabular impingement, diagnostic criteria, excursion angle

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

Femoroacetabular impingement (FAI) is a common cause of hip pain. With time, FAI leads to tear of the acetabular labrum and damage of the articular cartilage(Ganz, Leunig et al. 2008). Recently, it has been recognized as a precursor of osteoarthritis of the hip (Ganz, Parvizi et al. 2003, Ganz, Leunig et al. 2008).

There are two distinct abnormal morphologies of FAI: (1) pincer deformity of the acetabulum and (2) cam deformity of the femoral neck. The pincer deformity has been defined as excessive coverage of the anterosuperior acetabulum, and cam deformity as flattened or protruded femoral neck(Tannast, Siebenrock et al. 2007). According to Warwick agreement, a diagnosis of FAI is made by a triad: (1) symptoms, (2) positive impingement test, and (3) radiological findings suggestive of FAI. Lateral center-edge angle larger than 39º and acetabular retroversion have been considered as the radiological criteria of pincer type FAI, while alpha angle larger than 55º and pistol grip deformity of the femoral neck as the radiological criteria of cam type FAI (Table 1) (Tannast, Kubiak-Langer et al. 2007, Tannast, Siebenrock et al. 2007, Griffin, Dickenson et al. 2016). However, a high percentage of FAI patients have combined deformity(Tannast, Kubiak-Langer et al. 2007), and the isolated diagnosis of either cam or pincer FAI is not adequate(Tannast, Kubiak-Langer et al. 2007).

Moreover, FAI is a motion-related interaction between the acetabular edge and femoral neck during flexion and/or abduction of the hip. Even when the acetabular coverage is excessive, FAI might not occur, if the femoral neck is concave. Likewise, even when the femoral neck is thick, impingement does not occur, if acetabular coverage is deficient. Thus, isolated measurement of acetabular coverage or femoral neck geometry is not sufficient to diagnose FAI. The angle between the femoral neck and the acetabular edge, which we named lateral and anterior excursion angles (EAs) (Fig. 1), is an ideal concept to define FAI rather than the coverage of acetabulum and the geometry of the femoral neck.

The aims of this study were (1) to develop radiological criteria of FAI based on EA using 3-dimensional hip models, (2) to evaluate the reliability and diagnostic validity of the new criteria and (3) to determine the cut-off value of EA to discriminate FAI and non-FAI hips.

Chapter 2. Materials and Methods

This study had five phases: (1) reconstruction of 3-dimensional hip model, (2) simulation study to identify excursion angle in impingement-free model during daily activity, (3) establishment of EA criteria of FAI, (4) reliability and validity test of the new criteria in a validation cohort, and (5) retrospective assessment to find out the cut-off value of EA to discriminate FAI and non-FAI hips.

The study was conducted after the approval by the Institutional Review Board of our hospital.

(1) Reconstruction of 3-dimensional hip model

According to our protocol for planning total hip arthroplasty (THA), all THA patients were studied with pre-operative CT scans (Ha, Yoo et al. 2012). We recruited subjects for the 3-dimensional hip modelling from contralateral uninvolved hips of 180 patients, who underwent unilateral THA due to osteonecrosis of the femoral head at the age from 20 to 70 years at our hospital from January 1, 2020 to December 31, 2020. We excluded (1) hips with any symptom, (2) those with previous trauma, infection, or surgery, and (3) those with radiological evidence of osteoarthritis.

Two authors (HSK and YKL) reviewed the radiographs, CT scans, and medical records of the 180 patients and selected 33 intact contralateral hips according to the inclusion/exclusion criteria. CT scan data of these 33 hips were used for the 3-dimensional modelling of the hip.

There were 17 men and 16 women, their mean age was 53.2 ± 7.5 years (range, 40 to 68 years), and their mean body mass index was 24.0 ± 3.9 kg/m^2 (range, 16.0 to 30.7 kg/m^2). Eighteen hips were right and 15 hips were left (Table 2).

CT data of the 33 hips were exported to Digital Imaging and Communication in Medicine (DICOM) format and 3-dimensional (3D) hip model was reconstructed using Mimics-19.0 (Materialise, Leuven, Beligium).

(2) Simulation study to identify excursion angle in impingement-free model

Fourteen activities of daily living, which were known to lead an FAI (Table 3)(Kim, Lee et al. 2018), were simulated on each of the thirty-three 3D hip models (Fig. 2) using a motion simulating software program Mimics-19.0 (Materialise, Leuven, Beligium) according to the recommendation of Standardization and Terminology Committee of the International Society of Biomechanics (ISB) (Wu, Siegler et al. 2002).

Edge of the acetabulum, which collided with the femoral neck during the simulated motions, were gradually removed until there was no collision (Fig. 3).

Then, lateral EA in impingement-free model was measured in hip extension and neutral rotation, which simulated the position of hip anteroposterior (AP) view. True anterior EA was hard to measure due to 1) lack of appropriate radiographs for anterosuperior hip joint view and 2) innate distortion within cross-table lateral radiographs. Thus, modified Dunn view was used to measure anterior EA in impingement-free model as when alpha angle was measured. To simulate the modified Dunn view, the hip model was positioned to 45° flexion, 20° abduction and 30° external rotation (Fig. 1).

Conventional criteria, which were lateral center-edge angle and alpha angle, were also measured. The lateral center-edge angle is the angle formed by a vertical line and a line connecting the femoral head center with the lateral edge of the acetabulum. Angle α is the angle between the femoral neck axis and a line connecting the head center with the point of beginning asphericity of the head contour.

(3) Establishment of EA criteria of FAI

We defined 3 categories according to lateral and anterior EAs: (1) low risk group: both of the lateral and anterior EAs were larger than - 1.0 standard deviation (SD) of the average EA values, (2) moderate risk group: lateral EA or anterior EA was between -1.0 and -2.0 SD of the average EA values, and (3) high risk group: both of lateral EA or anterior EA were smaller than -2.0 SD of the average EA values.

(4) Reliability and validity test of the new criteria in a validation cohort.

Validation cohort was recruited from 469 patients who visited our outpatient clinic from January 1, 2020 to December 31, 2020. The inclusion criteria for the validation cohort were (1) patients who complained inguinal pain and/or who had C-sign, (2) those with positive impingement test, and (3) those who were studied with all of the 3 radiographs: hip anteroposterior (AP) view, hip frog leg lateral view, and modified Dunn view.

Among the patients who met the inclusion criteria, we excluded 1) patients who were younger than 20 years, 2) those who were older than 70 years, 3) those with dysplastic hip, 4) those with Kellgren-Lawrence grade III or IV osteoarthritis, 5) those with osteonecrosis of the femoral head, 4) those with previous surgery, 5) those with sequelae of Legg-Calve-Perthes disease, 6) those with neglected femoral neck fracture, and 7) those with residual poliomyelitis (Fig. 4).

Four-hundred eleven patients, who met the inclusion/exclusion criteria, composed the validation cohort (Table 2). Among the 411 patients in the validation cohort, 121 patients had MR images, 76 patients had CT scans, and 13 had both of them.

Lateral and anterior EAs were measured on AP and modified Dunn views of the hip as well as lateral center-edge angle and alpha angle.

Two orthopaedic surgeons, who were blind to patient's information, measured lateral EA on hip AP view and anterior EA on modified Dunn view.

(5) Diagnosis of femoroacetabular impingement syndrome in the validation cohort

A triad of hip pain, signs and radiological features by Warwick agreement is generally used as the diagnostic criteria of FAI (Griffin, Dickenson et al. 2016). However, there is wide variation in the location, nature, and severity that characterize this pain. The impingement test is sensitive but not specific. Two orthogonal views of the hip: AP and modified Dunn views, are not sufficient to identify all instances of FAI morphology. These radiographs are specific but only moderately sensitive for identifying FAI syndrome (Griffin, Dickenson et al. 2016). Herniation pit has been known as a focal depression in the femoral neck due to repeated abutment between the acetabular edge and the femoral neck. Previous studies showed a close correlation with FAI (Guo, Xu et al. 2013, Kim, Han et al. 2020). So, we modified the Warwick agreement as follows: (1) inguinal or trochanteric pain, (2) positive impingement test, and (3) radiological findings suggestive of FAI: lateral center-edge angle > 39°, retroverted acetabulum, pistol grip deformity of the femoral neck, alpha angle > 55°, and herniation pit, and used the modified agreement as the gold standard for the diagnosis of FAI. Five expert physicians: 4 hip surgeons (HSK, JWP, YKL and KHK) and 1 rheumatologist (YJL), reviewed the medical records, radiographs, MR and/or CT images, if available, independently, and a diagnosis of FAI was made when at least 4 of them agreed.

(6) Determination of the most appropriate cut-off values for FAI and non-FAI patients in the validation cohort

From the validation cohort of 411 patients, receiver operating characteristic

(ROC) curve analyses were performed on the measured lateral and anterior EAs to determine the cut-off values for the best discrimination of FAI and non-FAI hips.

Statistical analysis

Inter- and intra-observer reliabilities of the EA measurement were evaluated using intraclass correlation coefficient. Validities of the three groups: low-risk group, moderate-risk group and high-risk group, to predict true FAI were evaluated by chi-square tests for trend and by the ROC curve analyses.

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 25.0. (IBM Corp., Armonk, NY).

Chapter 3. Results

Simulation of reconstructed hip models and criterion of lateral and anterior excursion angles

Seventeen (51.5%) of the 33 hip models had at least one collision between the acetabular edge and the femoral neck at the final flexion or abduction of the 14 ADL motions (Table 4). After removing the colliding portions at the acetabular edge, the mean lateral EA was 50.4° ± 10.2°, and the mean anterior EA was 29.9° ± 5.1°.

Three categories according to the risk of impingement

We defined two cut-off values of lateral EA: 40°: 50° (mean lateral EA) – 10° (1 SD of lateral EA) and 30°: 50° (mean lateral EA) – 20° (2 SDs of lateral EA), and two cut-off values of anterior EA: 25°: 30° (mean anterior EA) – 5° (1 SD of anterior EA) and 20°: 30° (mean anterior EA) – 10° (2 SDs of anterior EA) for the categorization of hips. According to lateral and anterior EAs, three categories were defined: (1) low-risk hips with lateral EA > 40°, and anterior EA > 25°, (2) moderate-risk hips with lateral EA of 30°-40° or anterior EA of 20°-25°, and (3) high-risk group with lateral EA < 30° or anterior EA < 20° (Fig. 5).

Among the 411 hips, 279 (68%) were classified as low-risk group, 64 (16%) as moderate-risk group, and 68 (17%) as high-risk group (Table 5).

Reliability and Validity test of the novel criteria

The EA measurement was highly reliable (inter-observer reliability = 0.96 and intra-observer agreement = 0.97).

Among the validation cohort, 25.8% (106/411) were diagnosed as having FAI. According to each risk group, 7.1% (6/85) in the low-risk group, 34.5% (10/29) in the moderate-risk group, and 88.1% (37/42) in the high-risk group were diagnosed as FAI hips in men; 8.2% (16/194) in the low-risk group, 51.4% (18/35) in the moderate-risk group, and 73.1% (19/26) in the high-risk group were diagnosed as FAI hips in women (Table 5).

The degree of risk: low, moderate and high risks, had a significant diagnostic validity for the FAI in the chi-square test ($x^2 = 82.297$, $p < 0.001$ for men and $x^2 = 82.297$, $p < 0.001$ for women) as well as in the trend test by linear by linear association ($x^2 = 80.018$, $p < 0.001$ for men and $x^2 = 182.829$, $p < 0.001$ for women).

Determination of optimal cut-off values for discrimination of FAI and non-FAI patients

In the ROC curve analysis, the novel criteria offered satisfactorily discriminated between non-FAI and FAI groups, with the highest area under the curve (AUC) value in excursion angle on modified Dunn view (AUC 0.856 [0.807 to 0.905], $p < 0.001$) (Figure 6).

In the retrospective analysis using the ROC curve and Youden’s index, the optimal cut-off values for the best discrimination between FAI hips and non-

FAI hips were 51.3° in female and 43.1° in male for lateral EA and 28.6° in female and 24.8° in male for anterior EA.

In female, the sensitivity of optimal cut-off value was 84.9% (95% CI: 72.4-93.3%); specificity was 59.4% (95% CI: 52.3-66.2%); the positive likelihood ratio was 2.09 (95% CI: 1.71-2.56) and the negative likelihood ratio was 0.25 (95% CI: 0.13-0.49).

In male, the sensitivity of optimal cut-off value was 88.7% (95% CI: 77.0-95.7%); specificity was 75.5% (95% CI: 66.0-83.5%); the positive likelihood ratio was 3.62 (95% CI: 2.54-5.15) and the negative likelihood ratio was 0.15 (95% CI: 0.07-0.32) (Table 6).

Chapter 4. Discussion

In this study, we implemented the concept of EA in the radiological criteria to diagnose FAI.

Impingement in the hip joint has gained attention since 1999. The number of FAI-related published papers has been gradually increasing: from one paper in 1999 to 555 papers in 2021. The hip joint impingement was serious not only in the natural hip joint but also in the patients with their hip replaced into total hip arthroplasty. Lee et al. first reported the impingement between the implants of total hip arthroplasty in 2010 (Lee, Ha et al. 2010); Kim et al. then reported the tolerable range of periacetabular osteophyte through a three-dimensional study (Kim, Lee et al. 2018). Kim et al. studied that the stem neck-liner impingement led to serious implant deformation with a prevalence of more than 10%. This impingement and notching might cause bearing component failure. The authors emphasized the importance of impingement-free range of motion, and subsequent implant design and choice were important (Kim, Park et al. 2022). Thus, the need for reliable radiologic criteria to evaluate the impingement both in natural hip and in replaced hip, has been continuously warranted and discussed.

The fourteen activities of daily living were simulated in this study. These activities were originally based on the study of Nadzadi et al. (Nadzadi, Pedersen et al. 2003) Nadzadi et al. evaluated 354 motion trials which were prone to impingement and dislocation of the hip. Based on this study, Kim et al. re-defined 14 activities of daily living which had high prevalence of impingement between femur and acetabulum (Kim, Lee et al. 2018).

The reported prevalence of FAI syndrome varied widely from 1% to 75% (Klingenstein, Zbeda et al. 2013, Mimura, Mori et al. 2017, Reiman, Peters et al. 2018, Kopec, Hong et al. 2020). During last two decades, the number of FAI diagnosis has been markedly increased along with the accumulation of knowledge on this disease (Ganz, Parvizi et al. 2003, Lavigne, Parvizi et al. 2004). A study in 2018 showed that 55.3% of adult patients, who were referred to a tertiary hospital by primary physicians due to undiagnosed or misdiagnosed hip pain, had FAI (Lee, Kim et al. 2018). This syndrome can lead to labral tear as well as secondary osteoarthritis of the hip (Ganz, Parvizi et al. 2003, Lavigne, Parvizi et al. 2004).

To date, four radiological findings: lateral center-edge angle > 40°, retroverted acetabulum, flat or protruded femoral neck, and alpha angle > 60°, have been used for the diagnosis of FAI(Tannast, Kubiak-Langer et al. 2007, Tannast, Siebenrock et al. 2007, Griffin, Dickenson et al. 2016).

However, these findings were isolated evaluation of either acetabular edge or femoral neck and did not encompass the mutual relationship between the two structures. Moreover, there have been continuous debates in the reliability of the alpha angle and other radiological variables. In 2008, Nouh et al. questioned the reliability of alpha angle and suggested that the subjective evaluation of alpha angles is suboptimal unless bone abnormality is certain(Nouh, Schweitzer et al. 2008). In 2015, Wright et al. conducted a systematic review, which showed a moderate association between increased alpha angle and the progression of FAI to labral tear, but a lack of association between other radiographic variables and the progression of FAI (Wright, Naze et al. 2015). In 2016, Luo et al. commented that strict diagnostic and classification criteria are crucial for clinical outcome evaluation of FAI(Luo and Zhang 2016). Thus, we tried to develop reliable and objective radiological criteria to diagnose FAI.

The novel radiological criteria of EA were derived from on CT based 3-D hip models and 14 ADL simulations. The novel criteria appeared highly reliable and valid. The optimal cut-off values yielded satisfactory discrimination between FAI and non-FAI hips.

There are some limitations in our study. First, our study was done in East Asian individuals. There might be an ethnic difference of EA in other regions. Second, we simulated 14 ADL motions and did not simulate excessive flexion or abduction. Third, we did not consider spino-pelvic tilt, which might have influenced to EA in a real world. Forth, we focused on pure geometrical osseous collision detection between the reconstructed femoral head-neck and acetabular edge model. This method might omit the effect of soft tissue structure damage such as labral tear or tendinitis, and the actual pain provoking impingement might be underestimated. To compensate this limitation, the EA was further analyzed via validation cohort. Fifth, measuring anterior EA in the modified Dunn view might have some limitations in reflecting a true anterior impingement-free range of motion.

However, our data showed the current anterior EA had diagnostic validity and reliability.

Chapter 5. Conclusion

We developed reliable and valid criteria to diagnose FAI by measuring two EAs on hip AP and modified Dunn views. The EA criteria appeared as reliable and valid radiological measurement for FAI diagnosis. Further studies are warranted to evaluate the performance of the EA criteria in the diagnosis of FAI.

Conflict of Interest

There is no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with this dissertation

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Bibliography

Ganz, R., M. Leunig, K. Leunig-Ganz and W. H. Harris (2008). "The etiology of osteoarthritis of the hip: an integrated mechanical concept." Clin Orthop Relat Res **466**(2): 264-272.

Ganz, R., J. Parvizi, M. Beck, M. Leunig, H. Notzli and K. A. Siebenrock (2003). "Femoroacetabular impingement: a cause for osteoarthritis of the hip." Clin Orthop Relat Res(417): 112-120.

Griffin, D. R., E. J. Dickenson, J. O'Donnell, R. Agricola, T. Awan, M. Beck, J. C. Clohisy, H. P. Dijkstra, E. Falvey, M. Gimpel, R. S. Hinman, P. Holmich, A. Kassarjian, H. D. Martin, R. Martin, R. C. Mather, M. J. Philippon, M. P. Reiman, A. Takla, K. Thorborg, S. Walker, A. Weir and K. L. Bennell (2016). "The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement." Br J Sports Med **50**(19): 1169-1176.

Guo, Z., L. Xu, Y. B. Su and X. G. Cheng (2013). "Correlation between the prevalence of herniation pits and the alpha angle of the hip: computed tomography evaluation in healthy Chinese adults." BMC Musculoskelet Disord **14**: 288.

Ha, Y. C., J. J. Yoo, Y. K. Lee, J. Y. Kim and K. H. Koo (2012). "Acetabular component positioning using anatomic landmarks of the acetabulum." Clin Orthop Relat Res **470**(12): 3515-3523.

Kim, C. H., S. Han, C. J. Yang and J. H. Kim (2020). "Correlation between the presence of herniation pit and femoroacetabular impingement: a systematic review and meta-analysis." Knee Surg Sports Traumatol Arthrosc **28**(10): 3365-3373.

Kim, H. S., J. W. Park, S. J. Lee, Y. K. Lee, Y. C. Ha and K. H. Koo (2022). "High Risk of Neck-liner Impingement and Notching Observed with Thick Femoral Neck Implants in Ceramic-on-ceramic THA." Clin Orthop Relat Res **480**(4): 690-699.

Kim, J. T., J. Lee, Y. K. Lee, Y. C. Ha, Y. Y. Won, K. Lee, V. Khanduja and K. H. Koo (2018). "What is the tolerated width of periacetabular osteophytes to avoid impingement in cementless THA?: a three-dimensional simulation study." Arch Orthop Trauma Surg **138**(8): 1165-1172.

Klingenstein, G. G., R. M. Zbeda, A. Bedi, E. Magennis and B. T. Kelly (2013). "Prevalence and preoperative demographic and radiographic predictors of bilateral femoroacetabular impingement." Am J Sports Med **41**(4): 762-768.

Kopec, J. A., Q. Hong, H. Wong, C. J. Zhang, C. Ratzlaff, J. Cibere, L. C. Li, H. Prlic, D. R. Wilson, B. B. Forster, J. M. Esdaile and I.-H. S. Team

(2020). "Prevalence of Femoroacetabular Impingement Syndrome among Young and Middle-aged White Adults." J Rheumatol **47**(9): 1440-1445.

Lavigne, M., J. Parvizi, M. Beck, K. A. Siebenrock, R. Ganz and M. Leunig (2004). "Anterior femoroacetabular impingement: part I. Techniques of joint preserving surgery." Clin Orthop Relat Res(418): 61-66.

Lee, Y. J., S. H. Kim, S. W. Chung, Y. K. Lee and K. H. Koo (2018). "Causes of Chronic Hip Pain Undiagnosed or Misdiagnosed by Primary Physicians in Young Adult Patients: a Retrospective Descriptive Study." J Korean Med Sci **33**(52): e339.

Lee, Y. K., Y. C. Ha, J. J. Yoo, K. H. Koo, K. S. Yoon and H. J. Kim (2010). "Alumina-on-alumina total hip arthroplasty: a concise follow-up, at a minimum of ten years, of a previous report." J Bone Joint Surg Am **92**(8): 1715-1719.

Luo, D. and H. Zhang (2016). "Classification and Diagnostic Criteria of Femoroacetabular Impingement Are Essential for Clinical Outcome Evaluation: Commentary on an article by Rachel M. Frank, MD, et al., "Outcomes for Hip Arthroscopy According to Sex and Age: A Comparative Matched-Group Analysis"." J Bone Joint Surg Am **98**(10): e42.

Mimura, T., K. Mori, S. Itakura, Y. Furuya, T. Kawasaki and S. Imai (2017). "Prevalence of pincer, cam, and combined deformities in Japanese hip joints evaluated with the Japanese Hip Society diagnostic guideline for femoroacetabular impingement: A CT-based study." J Orthop Sci **22**(1): 105-111.

Nadzadi, M. E., D. R. Pedersen, H. J. Yack, J. J. Callaghan and T. D. Brown (2003). "Kinematics, kinetics, and finite element analysis of commonplace maneuvers at risk for total hip dislocation." J Biomech **36**(4): 577-591.

Nouh, M. R., M. E. Schweitzer, L. Rybak and J. Cohen (2008). "Femoroacetabular impingement: can the alpha angle be estimated?" AJR Am J Roentgenol **190**(5): 1260-1262.

Reiman, M. P., S. Peters, J. Sylvain, S. Hagymasi and O. R. Ayeni (2018). "Prevalence and Consistency in Surgical Outcome Reporting for Femoroacetabular Impingement Syndrome: A Scoping Review." Arthroscopy **34**(4): 1319-1328 e1319.

Tannast, M., M. Kubiak-Langer, F. Langlotz, M. Puls, S. B. Murphy and K. A. Siebenrock (2007). "Noninvasive three-dimensional assessment of femoroacetabular impingement." J Orthop Res **25**(1): 122-131.

Tannast, M., K. A. Siebenrock and S. E. Anderson (2007). "Femoroacetabular impingement: radiographic diagnosis--what the radiologist should know." AJR Am J Roentgenol **188**(6): 1540-1552.

Wright, A. A., G. S. Naze, A. E. Kavchak, D. Paul, B. Kenison and E. J. Hegedus (2015). "Radiological variables associated with progression of femoroacetabular impingement of the hip: a systematic review." J Sci Med Sport **18**(2): 122-127.

Wu, G., S. Siegler, P. Allard, C. Kirtley, A. Leardini, D. Rosenbaum, M. Whittle, D. D. D'Lima, L. Cristofolini, H. Witte, O. Schmid, I. Stokes, Standardization and B. Terminology Committee of the International Society of (2002). "ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion--part I: ankle, hip, and spine. International Society of Biomechanics." J Biomech **35**(4): 543-548.

Table 1. Radiological findings suggestive of femoroacetabular impingement

Type of impingement	Location of impingement	Radiological criteria
Pincer type	Lateral	Lateral center-edge angle > 39°
	Anterior	Retroverted acetabulum
Cam type	Lateral	Pistol grip deformity
	Anterior	Alpha angle > 55°

Table 2. Demographics of 33 hips used for 3-dimensional hip modelling

Parameter	Numbers
Age (years)	53.2±7.5 (range, 40 – 68)
Sex	
Male	17
Female	16
Side	
Right	15
Left	18

Table 3. Fourteen activities of daily living motions, which were known to lead to hip impingement (Kim, Lee et al. 2018)

	Flexion (+)/ Extension(-)	Internal rotation (+)/ external rotation (+)	Adduction (+)/ Abduction (-)
1. Pure flexion, rising from lower seat	110°	0°	0°
2. Rising from a normal sitting position	100°	15°	-5°
3. Stooping	90°	25°	10°
4. Tying shoes	95°	15°	15°
5. Crossing legs in normal seat	100°	-15°	15°
6. Internal rotation in 90° of flexion and neutral abduction	90°	20°	0°
7. Pure extension, swing leg back and forth	-20°	0°	0°
8. Pivoting in a standing position	-15°	-30°	-5°
9. Rolling over in bed	-5°	-30°	5°
10. Sitting on the floor cross-legged	85°	-40°	-35°
11. Kneeling with ankles dorsi-flexed	75°	-30°	-25°
12. Kneeling with ankles plantar-flexed	60°	-35°	-30°
13. Squatting with feet flat	95°	-25°	-30°
14. Squatting balancing on flexed toes	90°	-35°	-30°

Table 4. Collision between the acetabulum and the femoral neck during the 14 activities of daily living and excursion angle in impingement-free 33 hip models.

Parameters	Numbers
Presence of collision	
Yes, there was at least one collision.	17 (10 males, 7 females)
No, there was no collision.	16 (7 males, 9 females)
Simple radiographs	
Lateral center-edge angle	31.3° ± 6.2° (range, 18.5° to 44.7°)
α angle	43.3° ± 10.8° (range, 31.3° to 75.5°)
3-dimensional model	
Lateral center-edge angle	33.7° ± 7.3° (range, 23.1° to 48.8°)
α angle	45.7° ± 7.6° (range, 33.2° to 62.8°)
Excursion angle on reconstructed views	
Anteroposterior view	50.4° ± 10.2° (range, 27.7° to 71.6°)
modified Dunn view	29.9° ± 5.1° (range, 19.5° to 52.0°)

Table 5. Diagnosis of FAI in three risk groups according to excursion angles

	Low-risk group	Moderate-risk group	High-risk group	*p*-value
Female				
Numbers (n)	194	35	26	
Age (years)	57.4±7.9	60.2±7.3	59.5±7.0	0.088
Lateral center-edge angle (°)	32.6±6.8	40.5±6.3	39.1±7.0	0.000
α angle (°)	47.2±6.5	48.8±7.4	50.5±7.1	0.045
Lateral EA on AP view (°)	58.2±9.6	44.8±10.8	47.0±11.4	0.000
Anterior EA on modified Dunn view (°)	39.9±8.9	25.9±5.4	15.6±5.2	0.000
FAI diagnosis, n (%)	16 (8.2%)	18 (51.4%)	19 (73.1%)	0.000
Male				
Numbers (n)	85	29	42	
Age (years)	57.3±8.1	58.7±7.1	57.8±8.2	0.725
Lateral center-edge angle (°)	32.6±6.4	37.6±6.9	37.3±7.7	0.000
α angle (°)	49.7±5.6	49.1±6.3	55.0±7.9	0.000
Lateral EA on AP view (°)	55.1±7.7	44.6±9.8	44.9±10.8	0.000
Anterior EA on modified Dunn view (°)	35.2±7.2	25.3±6.3	15.0±4.2	0.000
FAI diagnosis, n (%)	6 (7.1%)	10 (34.5%)	37 (88.1%)	0.000

EA: excursion angle, FAI: femoroacetabular impingement, AP: anteroposterior

Table 6. Sensitivity, specificity and likelihood ratio of the optimal cut-off values of excursion angle

	Female	Male
Sensitivity	84.90% (72.4-93.3%)	88.70% (77.0-95.7%)
Specificity	59.40% (52.3-66.2%)	75.50% (66.0-83.5%)
Positive likelihood-ratio	2.09 (1.71-2.56)	3.62 (2.54-5.15)
Negative likelihood-ratio	0.25 (0.13-0.49)	0.15 (0.07-0.32)

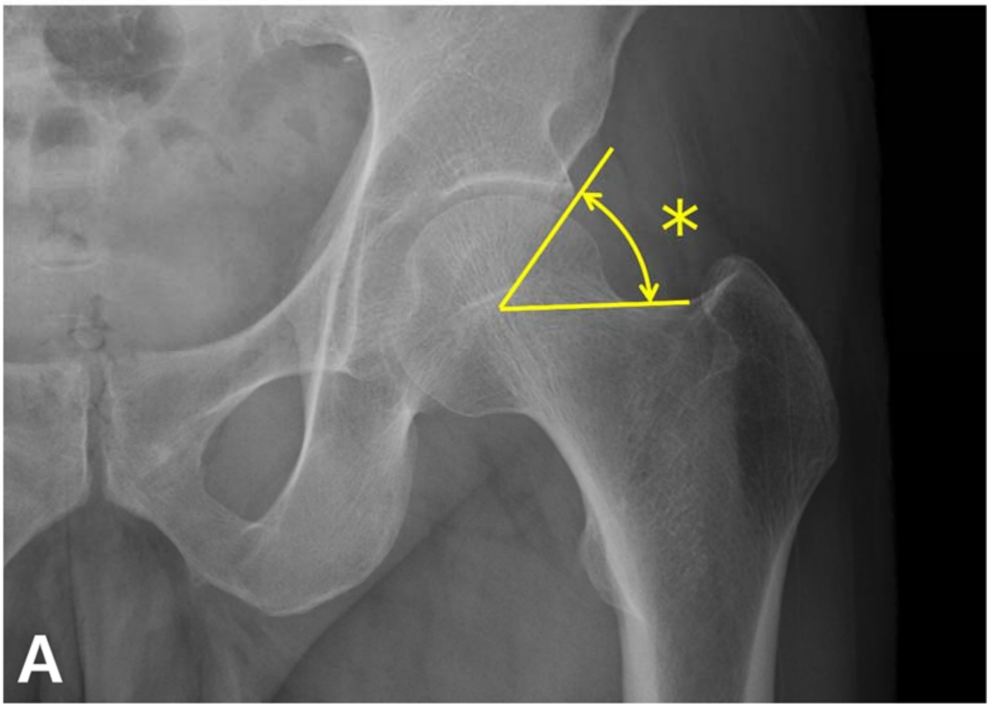

Figure 1. (A) Lateral excursion angle is the angle between the lateral acetabular edge and the femoral head-neck junction in hip anteroposterior view.

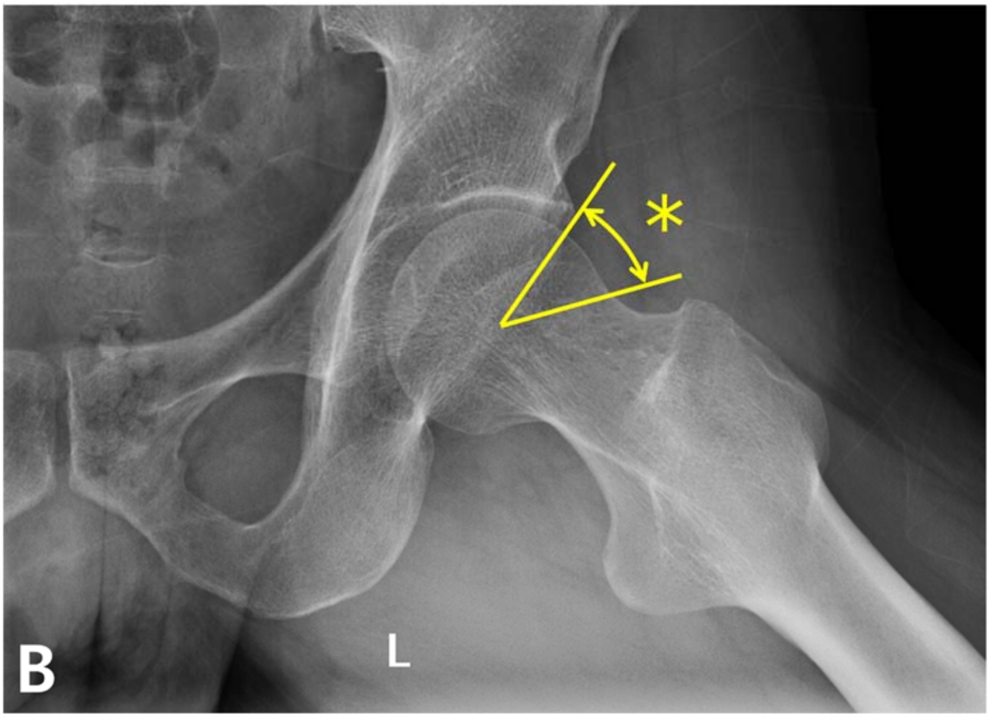

Figure 1. (B) Anterior excursion angle is the angle between the lateral acetabular edge and the femoral head-neck junction in modified Dunn view.

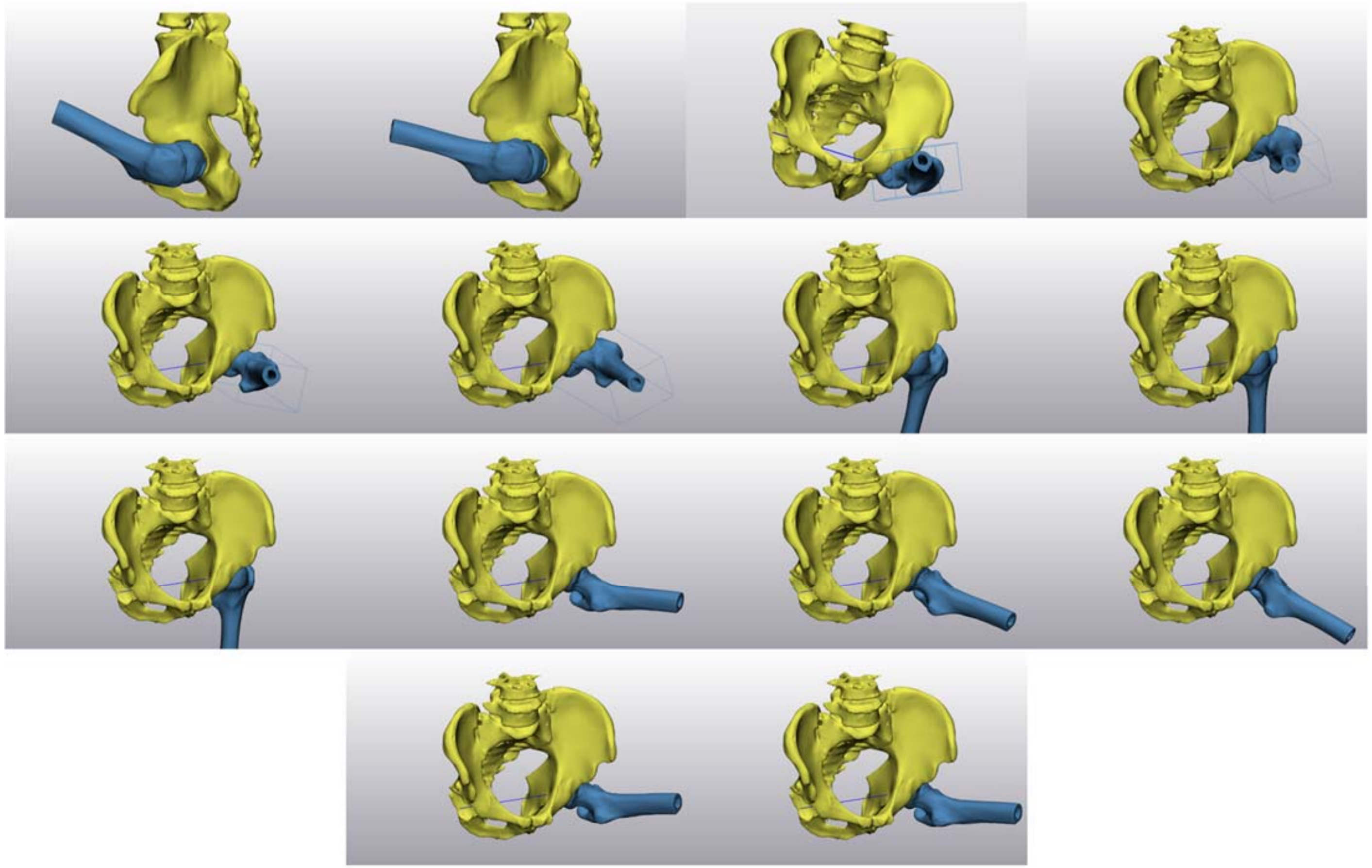

Figure 2. Simulation of fourteen activities of daily living motion

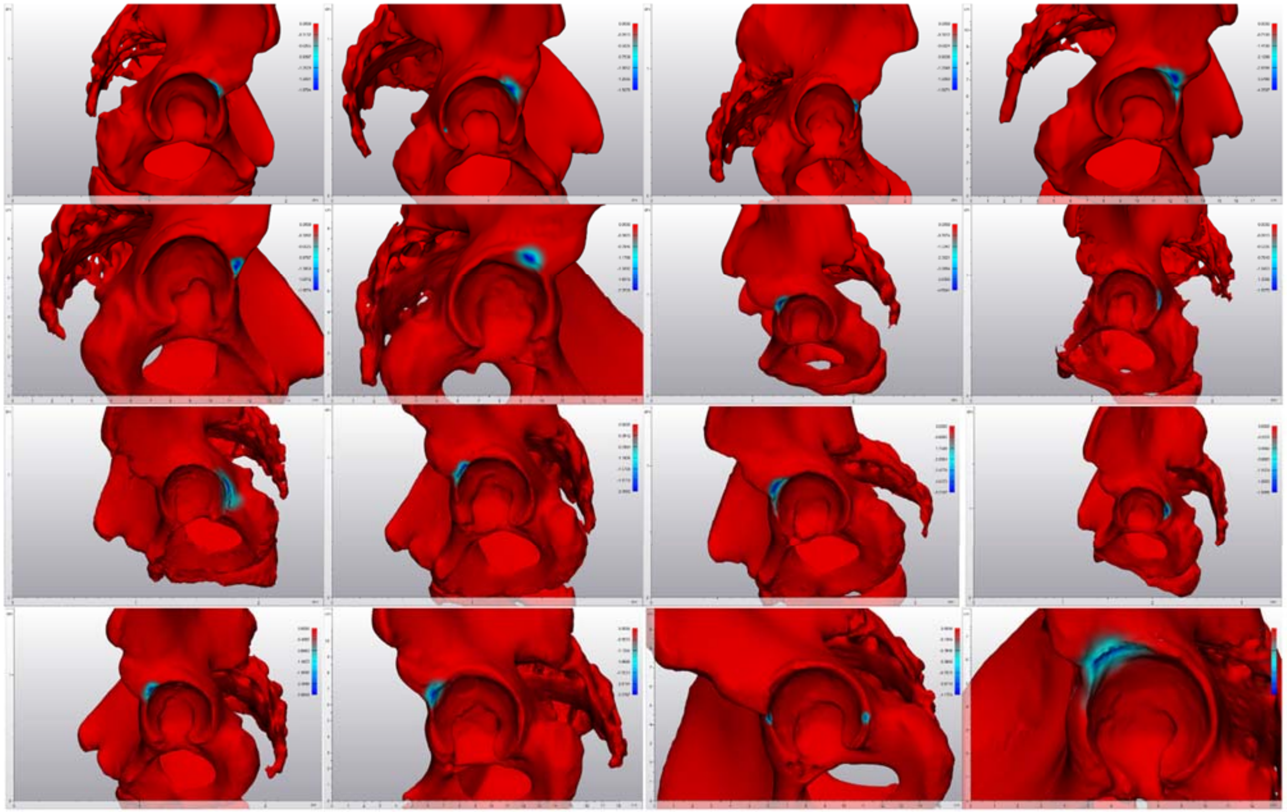

Figure 3. Edge of the acetabulum, which collided with the femoral neck during the simulated motions, were gradually removed until there was no collision.

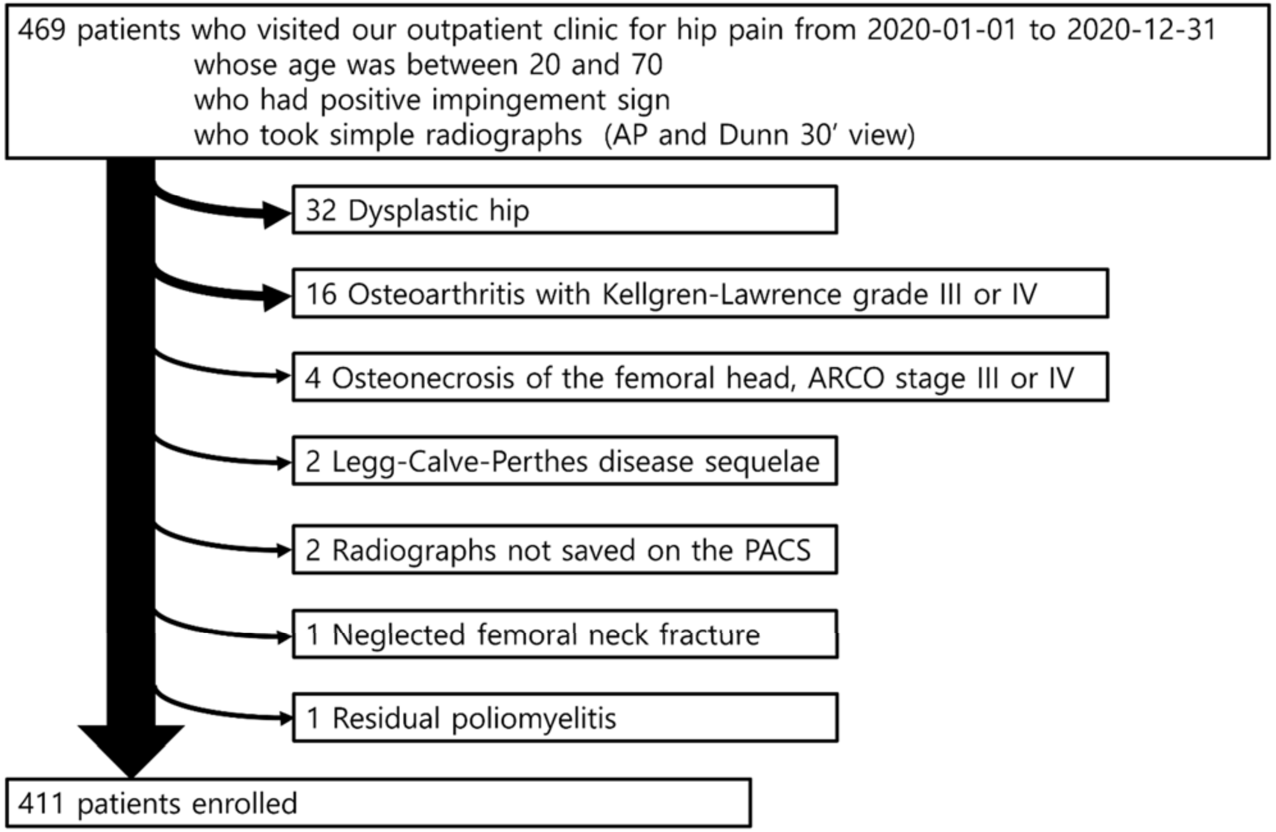

Figure 4. Flow chart of cohort selection.

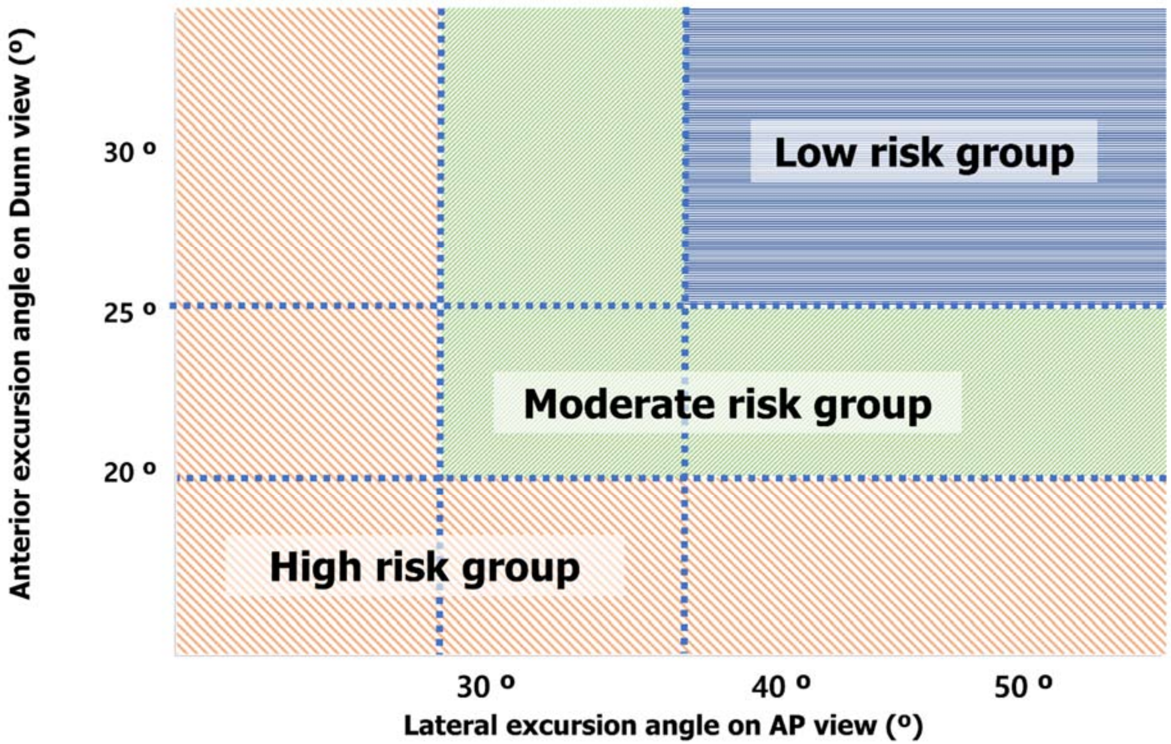

Figure 5. According to lateral and anterior EA values, three categories were defined: (1) low-risk hips with lateral EA > 40° and anterior EA > 25°, (2) moderate-risk hips with lateral EA of 30°-40° or anterior EA of 20°-25°, and (3) high-risk group with lateral EA < 30° or anterior EA < 20°.

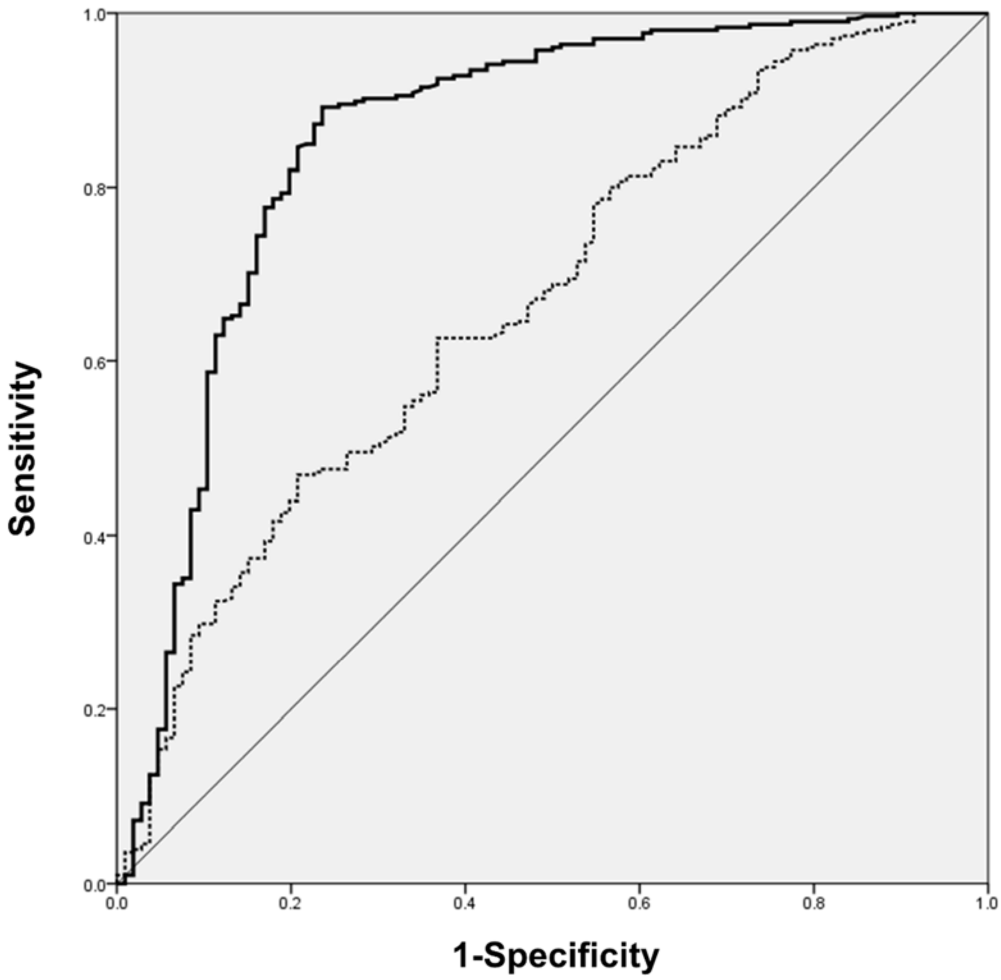

Figure 6. Receiver operating curve (ROC) of novel diagnostic criteria of femoroacetabular impingement (Bold line represents ROC curve for anterior excursion angle and dotted line for lateral excursion angle).

국문 초록

목 적:

대퇴비구 충돌증후군(Femoroacetabular impingement: FAI)은 임상 증상, 이학적 충돌 검사 그리고 방사선 소견으로 진단한다. 그러나 방사선학적 소견의 신뢰성에 대해서는 지속적인 논란이 있어왔다. 따라서, 저자들은 비구 가장자리와 대퇴 경부 사이의 충돌 없는(impingement-free) 운동 범위를 나타내는 excursion angle (EA)을 새로이 개발 및 정의하고자 한다. 본 연구의 목적은 FAI의 진단기준으로 사용할 수 있는 EA 값을 개발하고, 이 새로운 기준의 신뢰도와 타당도를 평가하며, FAI와 non-FAI hip을 구분하는 EA의 최적의 절단값을 결정하는 것이다.

대상 및 방법:

33개의 3차원 고관절 모델을 구성하고 충돌이 잘 발생한다고 알려진 14개의 일상 생활 활동 (Activity of daily living)을 시뮬레이션했다. 충돌이 일어나는 비구 가장자리의 부분을 제거한 모델에서 측면 (lateral) 및 전면 (anterior) EA를 측정했다. EA 기준의 신뢰성과 타당성은 411개의 고관절로 이루어진 검증 코호트에서 평가하였다. FAI와 non-FAI 를 구별하는 최적의 절단값은 수신자 조작 특성 (Receiver Operating Characteristic) 곡선 분석을 사용하여 구하였다.

결 과:

평균 외측 EA는 50.4° (±10.2°), 평균 전방 EA는 29.9° (±5.1°)였다. 이에 따라 각각의 고관절을 세 군으로 나누었다; 저위험군 (측면 EA >40° 및 전방 EA >25°), 중간 위험군 (측면 EA: 30° -40° 또는 전방 EA: 20° - 25°) 및 고위험군으로 분류하였다. (측면 EA < 30° 또는 전방 EA <20°). 관찰자 간 및 관찰자 내 신뢰도는 각각 k =0.96 및 0.97로 EA 측정은 신뢰할 수 있었다. 411개의 고관절로 이루어진 검증 코호트 중 106개의 고관절이 (26%) FAI로 진단되었다. FAI와 세 군 사이에는 강한 상관관계가 있었다; 저

위험군에서 8% (22/279), 중간 위험군에서 44% (28/64), 고위험군에서 82% (56/68)가 FAI로 진단되었다 (x^2=183.674, p <0.001). EA 기준은 FAI와 non-FAI 환자를 구별하는데 용이했다 (Area under the curve, 0.856 [0.807-0.905], p <0.001). 측면 EA에 대한 최적의 절단값은 여성에서 51° , 남성에서 43° 였다. 전방 EA의 경우 여성의 경우 29° , 남성의 경우 25° 로 나타났다.

결 론:

이번 연구를 통해 개발한 EA가 FAI를 진단에 유용하게 쓰일 수 있다는 것을 확인하였다. EA 기준은 FAI 진단을 위한 유효하고 신뢰성이 있는 방사선학적 측정값으로 나타났다. 후속 연구를 통해 FAI 진단에서 EA 기준의 성능을 평가하는 것이 필요하겠다.

색인 단어: 고관절, 대퇴비구 충돌, 진단 기준, excursion angle

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