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Diagnostic value of magnetic resonance imaging in neurovascular bundle injury during total hip arthroplasty

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Abstract. – OBJECTIVE: The objective of this study was to evaluate the diagnostic value of magnetic resonance imaging (MRI) in neurovascular bundle injury during total hip arthroplasty.

PATIENTS AND METHODS: The magnetic resonance imaging (MRI) examinations of the hip joints of 429 patients were reviewed. The distances on the left and right sides were measured and recorded using small, hydrophilic gadolinium (III)-based chelates as contrast agents. The data were analyzed and handled using Statistical Product and Service Solutions (SPSS).

RESULTS: The results showed that each measured distance in males was longer than in females, on both right and left sides ($p<0.001$). The coefficient of determination (R^2) of the influencing factors on the three distances was found to be 0.162, 0.038, and 0.104, respectively, in multiple linear regressions. The results of the Pearson's correlation coefficient also suggested that there was a significant correlation ($p<0.05$).

CONCLUSIONS: This study demonstrates that MRI can be a valuable diagnostic tool for neurovascular bundle injury during total hip arthroplasty. The gender difference in the measured distances indicates that sex should be considered when interpreting MRI findings.

Key Words:
Safe distance, Total hip arthroplasty (THA), Magnetic resonance imaging (MRI), Acetabulum, Neurovascular bundle, Iatrogenic injury.

Introduction

Total hip arthroplasty (THA) is a highly successful surgical method performed frequently to alleviate pain and ameliorate the condition of individuals with advanced arthritis or congenital dysplasia of the hip joint[1]. It has been predicted that there will be a 174% increase in THA in the USA by 2030[2]. Growing demand in THA, iatrogenic injuries have been reported to occur in 0.2-0.42% of patients during or following THA[3,4]. For example, as the most common type of neurovascular injury, femoral vascular injury is a well-documented, clinically rare, and potentially devastating complication of THA[4-9]. Research[10-12] on various types of injuries related to the vascular bundle has been performed, including lacerations, pseudoaneurysms, thrombosis, arteriovenous fistulas, and spontaneous rupture of the femoral artery. Although previous studies have shown that the risk of vascular damage has a higher probability in patients with pre-existent vascular insufficiency, the most common reason for vascular injury is iatrogenic trauma[9,10,13,14].

Because of the complicated structure of the acetabulum, precise knowledge of the anatomical position of the neurovascular bundles in the hip joint is vital in preventing inadvertent injuries[7,15-19].

In this study, the authors used magnetic resonance imaging (MRI) to identify the actual distance from femoral neurovascular, obturator neurovascular, and sciatic nerve bundles to their corresponding rim of the acetabulum and judge their influencing factors. To our knowledge, few papers have combined these parameters in the published literature.

Patients and Methods

The 858 MRI results (combination sequences of T1-weighted, T2-weighted, and contrast-enhanced images) of the anatomical relationships of the hemipelvis in 429 patients with the parameters, including the related distance measurements, were studied by reviewing previous examinations. All the MRI scans, in which the range included intact

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hip joints and proximal femur, came from the diagnosis of other systematic diseases, for example, urinary, rectal, and genital diseases, in our institution. Because of the incomplete development of the bone in individuals who were below 18 years, MRI scans of children and adolescents were excluded from the study. Furthermore, MRI scans of patients who had undergone hip operations or were suffering from developmental dysplasia of the hip (DDH), were also removed from the study as these individuals could have deformed the original version of hips. The information of the accepted patients, including height, weight, gender, and age, was obtained through the electronic medical records of the hospital. The acquisition of patients' relevant information has been allowed by the ethics committee of the hospital.

In the beginning, the survey in the transverse plane was conducted by drawing a horizontal line passing the center point of the femoral head on one side in the coronal plane, which was consistent with the common location of placement of retractors and screws during THA (Figure 1).

Then, because of a close relationship among the structures in the bundle, we picked three points, which is the closest position to the opposite acetabulum wall separately, in the femoral neurovascular bundle, the obturator neurovascular bundle, and the sciatic nerve bundle. Then, the shortest distance between the aforementioned points and the matching edges, which were the outer of the anterior wall, the inner of the fossa, and the outer of the posterior wall, were denoted as "d(F)", "d(O)", and "d(S)", respectively (Figure 2). Each part of the measurement was completed by a radiologist and two orthopedic surgeons independently, and the mean values of the three measurements were considered after intraclass correlation coefficient (ICC). Finally, we determined the relationship between the distance of the neurovascular bundles to the acetabulum and the body-related parameters *via* SPSS for Windows, version 25.0 software (IBM Corp., Armonk, NY, USA).

Statistical Analysis

Data conforming to normal distribution were arranged using Microsoft Excel 2019 (Microsoft, Redmond, WA, USA), and statistical analyses were processed in the SPSS. Descriptive statistics have been presented as mean±standard deviation (SD). As the samples were normally distributed, differences between gender groups were verified by the *t*-test for independent samples, and the results were expressed intuitively *via* figures produced by GraphPad Prism (version 8.4.2; San Diego, CA, USA). Multivariate linear regression was performed to evaluate the influence of age, height, and weight of the patients on various indicators; larger values for the coefficient of determination (R^2) denoted stronger correlations. Some factors that showed correlation with distance were further tested by Pearson's correlation, where the relationship was strong for correlation coefficient (r)>0. Statistical significance was considered at $p<0.05$.

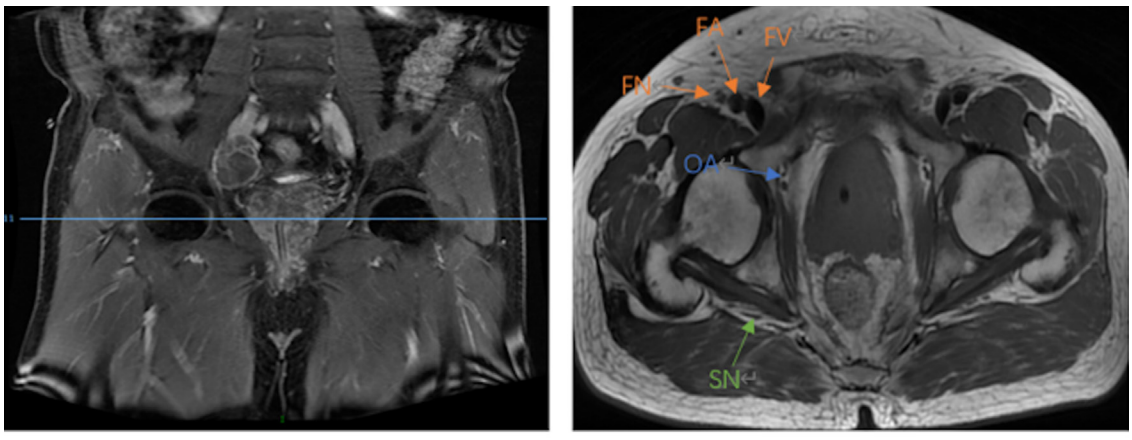

Figure 1. **A**, MRI scans of the acetabulum. In the left image, the blue line in the coronal plane, which passes through the superior margin of the greater trochanter and the center point of the femoral head, is close to the Hoffman retractors and acetabular screws in THA. **B**, the transverse plane corresponds to the blue line in the right one. FA: femoral artery; FV: femoral vein; FN: femoral nerve; OA: obturator artery; SN: sciatic nerve.

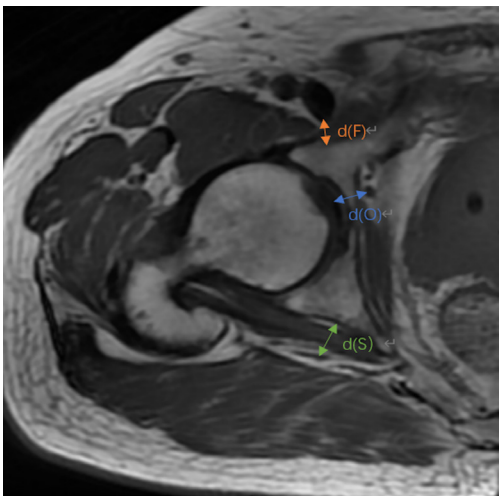

Figure 2. The three points shown here, which were selected in the three neurovascular bundles, are nearest to the lateral edges of the acetabulum; the corresponding distances are denoted as d(F), d(O), and d(S).

Results

We analyzed data from 858 hemipelvis from 429 patients, consisting of 196 females and 233 males. The average age, weight, and height of individuals were 60.33±14.74 years, 63.36±11.07 (kilograms, kg), and 163.94±7.26 (centimeters, cm), respectively, which were higher in males than those in the women (p<0.001) (Figure 3).

The ICC of d(F), d(O) and d(S) measured by three doctors were 0.995, 0.996 and 0.995 respectively (p<0.001). Therefore, the mean d(F), d(O), and d(S) (in mm) were 6.04±2.27, 11.81±2.66 and 12.43±2.39, which in males were 6.59±2.18, 12.64±2.7, and 12.98±2.39, respectively, for the left (L) side of the body and 7.22 ±2.35, 12.11±2.55, and 12.9±2.25, respectively, for the right (R) side of the body. As for females, the values were 4.79±1.68, 11.22±2.6, and 12.12±2.38 mm, respectively, on the left, and 5.22±1.81, 11.03±2.46, and 11.52±2.26 mm, respectively, on the right. There were significant differences in the parameters between the two groups (p<0.001) (Figure 4).

The other factors, such as height, weight, and age, were analyzed using multivariate linear regression, and the R^2 for d(F), d(O), and d(S) were 0.163, 0.038, and 0.091, respectively, which indicated that these factors had a significant effect on the distance between the neurovascular bundles and the acetabulum. The age of individuals was not significantly related to d(F) (p=0.178>0.05) or d(O) (p=0.096>0.05); therefore, the influencing factor of age will be eliminated. The linear regression equations are presented as follows (Figure 5):

- d(F) = –7.101 + 0.057*weight (p<0.0001) + 0.058*height (p<0.0001).
- d(O) = 2.438 + 0.022*weight (p=0.017) + 0.048*height (p=0.0007).
- d(S) = 3.728 + 0.052*weight (p<0.0001) + 0.033*height (p=0.008).

The equations indicated that weight and height had positive relationships with the mean distance between the three neurovascular bundles and the acetabulum, and the relationship with age was not strong. Additionally, the value of Pearson's correlation coefficient (r) also showed a similar pattern (Table I).

Discussion

Neurovascular injury during THA is one of the most severe complications, and the most common cause of damage is the abnormal retractor position[20,21]. Due to the tension in soft tissues, like gluteus muscles and the tensor fascia, some vi-

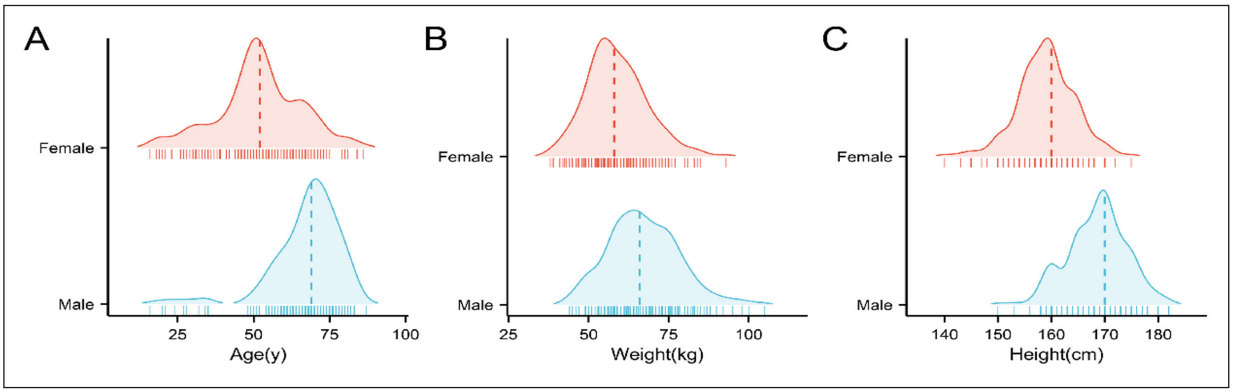

Figure 3. A-C, Sex comparisons of patients; age, weight, and height, and all indexes are significantly higher in males than in females (p<0.001).

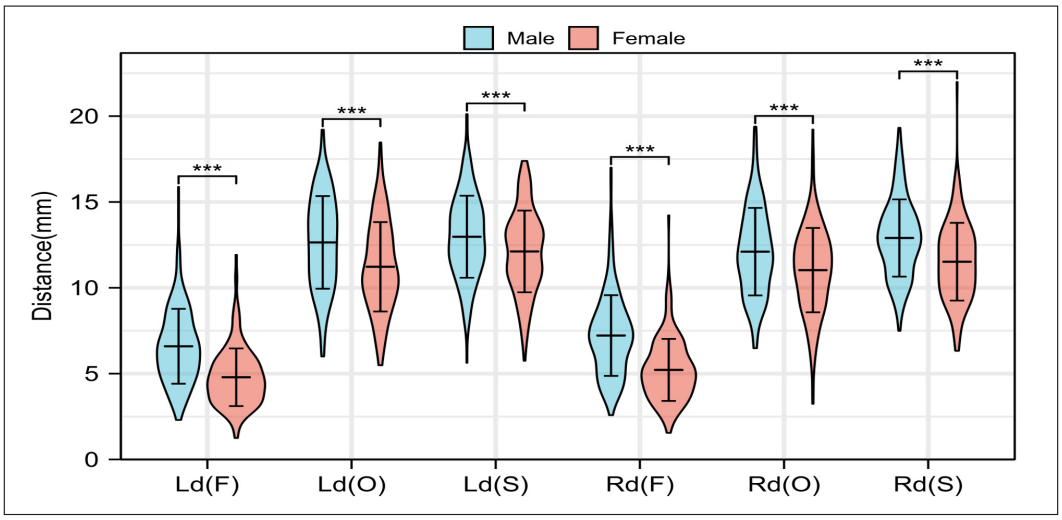

Figure 4. Comparison of the mean distance from the neurovascular bundles to the acetabulum between males and females. Ld: left and Rd: right; d(F): femoral neurovascular bundle, d(O): obturator neurovascular bundle, d(S): sciatic nerve bundle. Shown are bar plots with the mean (±SD). ***: $p<0.001$.

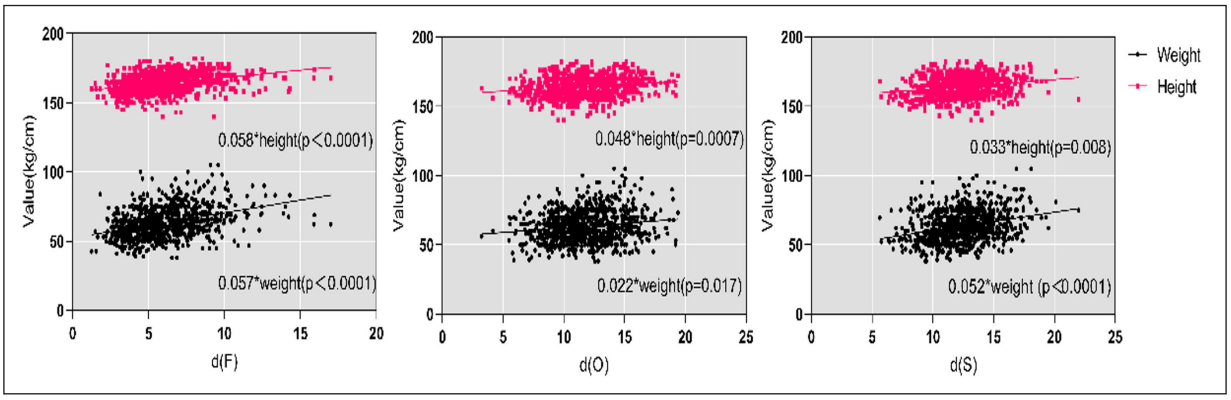

Figure 5. Shown are the plots of the multiple linear regression analysis between d(F), d(O), and d(S), and the weight and height of individuals.

tal structures cannot be seen, and the retractors need to fight against great resistance during the surgery, which would increase the risk in surgeries, especially in minimally invasive approaches[22]. Compared with the traditional posterolateral approach, which is conducive to fully exposing the tissue structure, the emerging direct anterior approach (DAA) has the advantages of reducing postoperative pain, faster recovery, and less probability of dislocation[23]. However, there are reports[24-26] in the literature showing that DAA had a higher risk of neurovascular injury compared to the traditional method, especially for the femoral nerve; thus, this kind of operation may not avoid

Table I. The table shows the correlation coefficients between the factors and the distances of the three neurovascular bundles from the acetabulum (Pearson's correlation test, *$p<0.05$; **$p<0.01$).

	Ld(F) (mm)	Ld(O) (mm)	Ld(S) (mm)	Rd(F) (mm)	Rd(O) (mm)	Rd(S) (mm)
Age (years)	0.085	0.124*	0.119*	0.165**	0.067	0.252**
Weight (kg)	0.384**	0.163**	0.289**	0.364**	0.156**	0.292**
Height (cm)	0.138**	0.043	0.101*	0.118*	0.023	0.156**

these damage complications effectively. In summary, although THA is considered a comparative matured surgical method, fatal complications still occur sometimes. Thus, precise knowledge of the normal anatomical position of the body tissue surrounding the native hip joint is the first step in preventing inadvertent injuries.

In the femoral neurovascular bundle, the femoral nerve originates from the lumbar plexus and runs along with the femoral artery and vein in the pelvic cavity at the inner margin of the iliopsoas muscle, which then crosses the anterior edge of the superior branch of the pubic bone in parallel through the femoral canal and continues down to the posterior margin of the sartorius quadriceps femoris. Being the primary blood supply trunk of the lower extremities, the injury of the femoral artery easily results in a poor prognosis. Once an injury occurs, it should be judged as soon as possible by vascular ultrasound and pulse of dorsalis pedis artery and remedied by revascularization within 6 hours; otherwise, it would cause irreversible soft tissue injury[27]. As opposed to the femoral artery and vein, the probability of injury of the femoral nerve may be relatively smaller due to the surrounding anatomical factors with muscle protection. However, once damaged, the patient faces the problems of long recovery time and a large probability of lifetime sensory defects, which will greatly affect the surgical outcome and quality of life of patients[28]. These consequences also make nerve injury the most common cause of medical litigation after THA[29].

In the obturator neurovascular bundle, the obturator nerve derives from the lumbar plexus, merges with the obturator artery and vein into a bundle, and then descends along the medial surface of the acetabula fossa, entering the femoral part *via* the obturator canal, which is composed of obturator internus muscle. The prevalence of obturator nerve palsy is low, but because of apparent symptoms, the diagnosis is comparatively difficult[30]. Compared with the femoral and sciatic nerves, injuries to the obturator nerve are obviously rare and mostly caused by the protrusion of bone cement and penetration of the medial wall of the acetabular[31]. However, due to the development and popularity of biological prostheses, the application of bone cement in THA in our region has become rare. Therefore, the penetration of screws into the acetabula wall has become the most important factor for the cause of the injury to the obturator bundle, and this is why the inner wall of the acetabular fossa was selected as the d(O) measurement point in this study. During THA surgery, screw fixation could only be observed directly on the lateral side of the acetabulum during the drilling process, so operators can only judge the relationship between the screws and the obturator bundle based on their experience. This also foreshadows the occurrence of intraoperative complications. It is believed[15] that the acetabular-quadrant system, as first explained, is advantageous to understand the neurovascular anatomy surrounding the acetabulum; nonetheless, it is difficult to apply flexibly to clinical work due to the lack of specificity and accuracy. With accurate measurement, the results of this study can effectively remedy a defect and avoid the occurrence of such accidents to a certain extent by adjusting the location of holes in the bottom of the acetabulum cup and selecting the appropriate length of screws.

In the sciatic nerve bundle, it stems from the lumbar and sacral plexus, downward passes through the orifice, and travels from the gap between the piriformis and gemellus superior muscle to the hip and then walks to the back of the thigh along the posterior edge of the acetabular wall. Sciatic nerve injury, is the most kind of nerve injury in THA[30], accounting for about 90%. Compared with the femoral nerve, which can easily be injured in the DAA, the posterolateral approach adopted in THA operation obviously increases the risk of sciatic nerve injury due to posture[30]. Because sciatic nerve injury commonly leads to disastrous consequences such as sensation, dyskinesia, and even disability of lower limbs, effective intraoperative prevention is extremely important[32]. Indicated that motor-evoked potential (MEP) detection could monitor the status of the sciatic nerve in time, which is able to avoid injury effectively, especially in THA with the posterolateral approach. Except for the direct injury of the sciatic nerve caused by various sharp instruments during operation, the nerve traction caused by the change in the lower limb length after operation in patients with severe hip deformity, like DDH, has also begun to attract people's attention[33]. This also requires the operators to reduce the amount of osteotomy to the utmost, choose an individualized prosthesis that is suitable for the patient, and determine the best placement angle to restore the original anatomical relationship as much as possible. A previous study[34] suggested that nerve decompression could achieve the maximum recovery of lower limb function for patients who have been confirmed to be exposed to sciatic nerve

injury during operation. Besides, the relevant literature also confirms that for patients with nerve injury during the operation, the postoperative subcutaneous injection of erythropoietin (EPO) combined with oral glucocorticoids (GC) could effectively alleviate the discomfort of patients and accelerate the recovery of sensory and motor functions, which may provide a new idea for the treatment of nerve injury in the future[35].

In addition to the past knowledge, we are still far from achieving perfect surgeries in THA due to uncertain elements. Therein, aberrant blood vessels, such as those that are curved, or the tortuous external iliac vessels, have been shown to get closer to the pelvis in some cases of THA compared to the natural conditions[6,36]. When blood vessels have such an abnormal course, the chance of an injury during surgery increases.

Therefore, just having theoretical anatomy knowledge before surgery may not be sufficient to cope with the unexpected circumstances during the surgery fully. With the advancement of biotechnology, computer-assisted navigation has gradually become popular in clinical surgery, such as computed tomography (CT)-based, fluoroscopic navigation systems, and so on[37]. There have been a large number of reports that computer-guided total hip replacement can significantly intensify the accuracy of the placement and reduce the probability of postoperative complications such as prosthesis dislocation and reduced postoperative joint mobility caused frequently by surgical errors[38-45]. Therefore, with the enrichment of computer navigation content and the surgeon's proficiency, the probability of neurovascular injury during surgery is likely to be extensively reduced.

Measured the corresponding distances of the femoral neurovascular, superior gluteal neurovascular, and sciatic nerve bundles on the basis of 32 pre-operative CT images and 16 autopsies and speculated that the distance about the femoral neurovascular bundle decreases along with the anterior wall inferiorly of the anterior inferior iliac spine (AIIS)[20]. The above similar conclusion was drawn in another research[28], where it was considered that it was safest to place the retractor as high as possible in the acetabulum at 12 o'clock, and these conclusions have provided new ideas for future research to a certain degree. However, due to the objective limitations, such as unclear imaging of blood vessels and nerves under CT, fewer data points were included in the measurement; furthermore, changes in the anatomical relation of cadavers and more perfect and accurate verification are needed for its complete clinical application. In another study[7], the measured average distance from the femoral nerve, artery, and vein to the hip joint, was 23.62±5.44, 19.62±4.17, and 17.47±4.41 (mm), respectively, therefore considering that patients with lower body weight and older age were more inclined to suffer an iatrogenic injury of femoral bundles in Australian patients, and their conclusions were consistent with some of ours in a certain sense. But due to a difference in body structure between different ethnic groups, we can find that there exists a notable difference in distance measurement, which is maybe coupled with the difference in the choice of measurement plane[17]. This research also indicated some safe parts of the acetabulum for screw fixation, yet the lack of information on the position of the retractor reflected the imperfections in the design and limitations of the study. Thus, an exact measurement of the body parts in the native population is necessary.

Our study was a retrospective analysis of the data from MRI scans of the acetabulum and obtained the related information intentionally. The femoral bundle, obturator bundle, and sciatic bundle are located close to the anterior, posterior, and medial edges of the acetabulum, respectively. Coincidentally, the position of the retractors and screws is close to the vulnerable parts above, which increases the possibility of iatrogenic injury (Figure 6).

To the best of our knowledge, this was the first study to research the influence of body height, gender, and age on the distances from the edge of the acetabulum to adjacent vessels and nerves, determined from MRI data in the Asian population. MRI can display soft tissues and the distribution of various parts in the acetabulum clearly, which cannot be visualized by surgeons intraoperatively. Showed that during THA, the blood vessel closer to the bone were more likely to be damaged by a retractor or screw[36]. By referring to the equations indicated in the "Results" section, orthopedic surgeons can now calculate the exact values of distance individually and estimate the degree of operational risk according to the characteristics of each person's height and weight. And then, the calculation results can be used to select screws with appropriate lengths, and the retractors can be marked with corresponding lengths to remind the operator. As for the high-risk groups whose d(F), d(O), and d(S) are less than the mean-standard deviation (3.8 mm, 9.2 mm, and 10.6 mm), careful preoperative preparations, like MRI and CT-angiography (CTA), could be used to significantly reduce the risk of iatrogenic injury in a way of determining

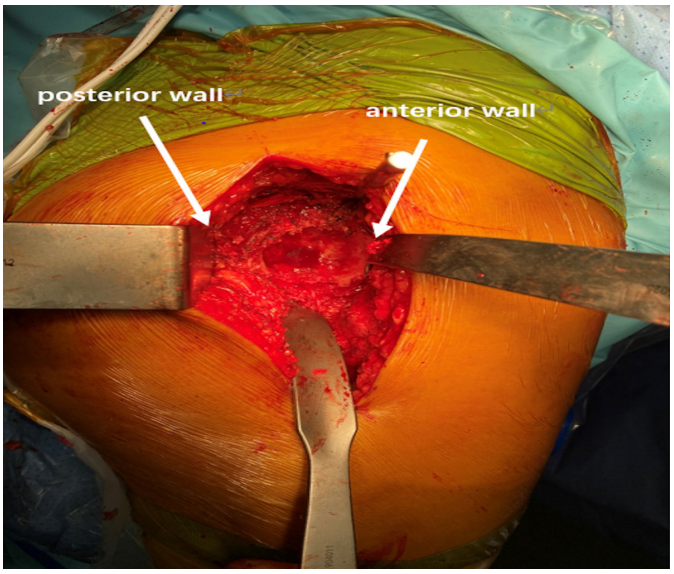

Figure 6. During THA, two retractors are used to expose the acetabulum completely. In this image, the retractors are placed at the 3 and 9 o'clock positions of the acetabulum, which provide the probability of neurovascular injuries in operation.

the actual spatial relationship and the precise distance value. Compared to previous investigations, our study had a larger sample size, which increased the reliability of the results and conclusions.

Limitations

Although this study might help to decrease the morbidity of neurovascular injuries during THA, there are some limitations in our research. First, the population of this study was entirely from China, so it does not represent the outcomes at global levels because of the existing differences in the racial body types. Second, all data were from patients in the supine position during the MRI process. Therefore, the methods, results, and risks might be biased in this study and might differ for other positions during operations, for example, in the lateral decubitus view with external femur rotation. Third, because the course of blood vessels is three-dimensional, and this paper only selects the plane that is most often exposed and most likely to be damaged during the operation, further multi-dimensional measurement in space may be needed in the future if we want to apply it more comprehensively.

Conclusions

This study explored objective relationships between three neurovascular bundles and the hip joint based on MRI results. Our data marked out the safe distance and showed that patients with female gender, shorter sizes and lighter weights very likely confronted a higher risk of iatrogenic injuries during THA. This research will provide surgeons with specific references for the safe operating area during surgery, as well as methods for predicting pre-operative high-hazard patients, and also present a new direction for prospective innovation.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declared that they have no conflicts of interest regarding this work.

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Informed Consent

Informed consent was obtained from all individual participants included in the study.

Ethics Approval

The retrospective study was approved by the Ethics Committee of the Anhui Medical University and performed according to the Declaration of Helsinki (Ethical code: PJ2022-10-34).

Authors' Contributions

Conceptualization, H.X, X.-P. Z, and L.W; methodology, H.X; software, Y.-J. Z; validation, J.W, H.Z, and L.W.; formal analysis, H.Z; investigation, J.W-; resources, H.Z; data curation, J.W, Y.-J. Z; writing-original draft preparation, L.W; writing-review and editing, X.-P.Z; supervision, H.X; All authors have read and agreed to the published version of the manuscript.

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