

Are plain radiographic measurements still consistent with a diagnosis of basilar invagination in the era of cross-sectional images?

Jong-Hyeok Park^a, Jong Tae Kim^a, Il Sup Kim^b, Jae Taek Hong^c 

Abstract

Retrospective cross-sectional study To evaluate the validity and obtain optimal cutoff values of 3 radiologic measurements for the diagnosis of basilar invagination (BI). Two hundred seventy-six patients (46 patients who underwent atlantoaxial fusion for BI and 230 patients who were treated for minor cervical trauma) seen in a single institution from January 2010 to December 2016 were included in this study. Age, sex, and body mass index were adjusted for the patients. The Ranawat index (RI), modified Ranawat method (MRM), and Redlund-Johnell method (RJM) were used to diagnose BI on plain radiographs. The sensitivity, specificity, positive predictive value, negative predictive value, accuracy, and diagnostic odds ratio of 3 radiologic measurements were compared. We also calculated the optimized cutoff values of 3 radiologic measurements using the receiver operating characteristic curve in our patients. The mean age of the 130 women and 146 men was 58.3 ± 14.5 years. The mean values of RI, MRM, and RJM in the BI group were 12.5 ± 3.3 , 23.1 ± 3.8 , and 27.3 ± 3.6 in women and 13.6 ± 2.6 , 26.8 ± 4.2 , and 34.7 ± 5.1 in men. There was a significant difference between the sexes ($P < .05$). The accuracies of RI, MRM, and RJM were 95%, 89.6%, and 92.3% in women and 93%, 68.2%, and 85.4% in men, respectively. The optimized cutoff values of RI, MRM, and RJM were 14, 26, and 32 mm in women and 15, 29, and 38 mm in men. Three radiologic measurements (RI, MRM, and RJM) are reliable for the diagnosis of BI even in the era of cross-sectional images. The validity of these measurements depends on sex and particular radiologic measurement. The optimized cutoff values of RI, MRM, and RJM were 14, 26, and 32 mm in women and 15, 29, and 37 mm in men. These cutoff values showed high validity when compared to the CT and MRI findings.

Abbreviations: BI = basilar invagination, BMI = body mass index, CT = computed tomography, DOR = diagnostic odds ratio, FN = false negative, FP = false positive, MRI = magnetic resonance imaging, MRM = modified Ranawat method, NPV = negative predictive value, PPV = positive predictive value, RI = Ranawat index, RJM = Redlund-Johnell method, ROC = receiver operating characteristic, TN = true negative, TP = true positive.

Keywords: basilar invagination, Johnell method, modified Ranawat method, Ranawat index, Redlund, vertical atlantoaxial subluxation

1. Introduction

Basilar invagination (BI) has a complex pathology and can compress the cervicomedullary junction, causing neurologic deficits.^[1,2] The appearance of neurologic deficits is associated with poor prognosis and a dramatic increase in the mortality rate.^[3,4] In a postmortem study of 104 patients with rheumatoid arthritis, the incidence of sudden death due to unrecognized cord compression of BI was approximately 10%.^[5] Therefore, early diagnosis is important, and reliable radiologic measurements are needed.^[6]

Several radiologic parameters, such as the McGregor, McRae, and Chamberlain lines, have been used to diagnose BI based on plain cervical radiographs.^[7-9] These measurements have some limitations because the odontoid process, an important landmark, is frequently obscured and superimposed upon by other structures. The Ranawat index (RI), modified Ranawat method (MRM), and Redlund-Johnell method (RJM) were introduced to overcome these limitations.^[10-13] These radiologic measurements have similar features that do not use the tip of the odontoid as a landmark. Thus, they are widely used to diagnose BI.

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Owing to recent advances in radiologic imaging technologies, such as computed tomography (CT) and magnetic resonance imaging (MRI), the diagnosis of BI is not clinically demanding.^[14,15] Sagittal CT and MRI images readily demonstrate compression of the spinal cord.^[16] Nevertheless, plain radiographs are still widely used because of some advantages, including easy accessibility and cost-effectiveness. We can quickly and easily obtain plain radiographs more than CT and MRI. This is valuable not only for the screening BI but also for the follow-up evaluation in emergency and outpatient clinic. Computed tomography and MRI can make it easy to diagnose BI, but it is prohibitively expensive to use for every evaluation and radiation exposure from CT is associated with a subsequently elevated risk of cancer.^[17]

RI and RJM were first introduced in 1979 and 1984, respectively.^[10,11] MRM was recently reported in 2011.^[12] When the center of the C2 pedicle is not observed, it is valuable. The reference value of these radiologic measurements are obtained from quite simple manner with a small sample. Therefore, it is necessary to identify whether these radiologic measurements are still valid in this era of cross-sectional imaging. This study evaluated the validity of 3 radiologic measurements (RI, MRM, and RJM) among patients, diagnosed with BI by CT and MRI, by applying previous reference values. We also obtained the optimal cutoff values of 3 radiologic measurements in South Koreans. We analyzed the differences between the previous reference values and optimal cutoff values.^[12,17–19]

2. Material and Methods

2.1. Patient selection

A retrospective analysis of radiologic data was performed on patients who had undergone posterior atlantoaxial fusion or occipitocervical fusion for treatment of BI from January 2010 to December 2016. Institutional review board approval was obtained for this study (2021-0284-0001). Patients' informed consents were exempted because this study was a retrospective and under minimal risk exposure. Sixty-five patients who met the above criteria were included in the BI group. We also obtained radiologic data without BI from 245 patients with mild neck pain who visited our hospital during the same time period. These patients did not have BI and were assigned to the non-BI group. We confirmed the diagnosis of BI using CT (Aquilion PRIME, CANON, JAPAN) and MRI (MAGNETOM Avanto, SIEMENS, GERMANY). Patients with incomplete physiologic bony fusion, those who were under 15 years old, and those with a previous history of cervical spine surgery were excluded. Tumorous and infectious pathologies were excluded. Finally, 46 and 230 patients were included in the BI and non-BI group, respectively. Age, sex, and body mass index (BMI) were matched between the 2 groups.

2.2. Radiologic measurements

Two neurosurgeons (J. T. H. and J. H. P.) measured the RI, MRM, and RJM on cervical standard lateral radiographs in the Picture Archiving Communication System with an electrical caliper. Lateral radiographs were taken with the patient in the neutral head position. A standard distance of 1.8 m was maintained between the tube and the patients. Radiologic technique was used by standard reference (Mean 83.5kVp and 23.4mAs). We measured 3 preoperative radiologic measurements in the BI and non-BI group.

Ranawat index—the distance between the center of the C2 pedicle and the transverse axis of the atlas is measured along the axis of the odontoid process (Fig. 1A).^[10]

Modified Ranawat method—when applying the Modified Ranawat method,^[12] the observer marked the midpoint of the

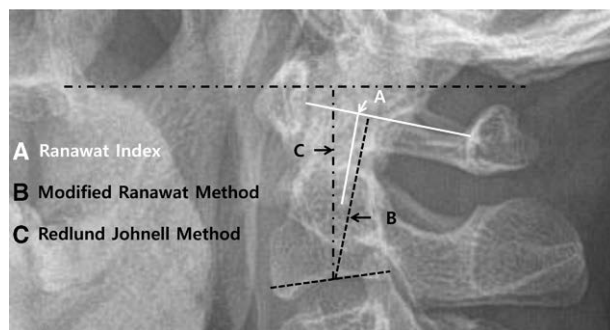


Figure 1. Three radiologic measurements taken on plain radiographs of the lateral cervical spine. (a) Ranawat index (white line) (b) Modified Ranawat method (dotted line) (c) Redlund Johnell method (dash-single dotted line).

base of C2 and drew a line from the center of the anterior arch of C1 to the center of the posterior arch. The distance between the 2 lines along the long axis of C2 was measured (Fig. 1B).

Redlund-Johnell method—when applying the Redlund-Johnell method,^[20] the observer marked the midpoint of the base of C2 and then measured the minimum distance between that point and the McGregor line which was drawn from the posterosuperior aspect of the hard palate to the most caudal point on the midline occipital curve (Fig. 1C).

2.3. Validity of radiologic measurements

In RI and RJM, reference values for the diagnosis of BI are known to be ≤ 13 mm in women, ≤ 15 mm in men and ≤ 29 mm in women, ≤ 34 mm in men, respectively. We calculated the validity of RI and RJM using the reference values. To the best of our knowledge, we couldn't find the normal range of MRM on plain radiograph, and then calculated the optimized cutoff values. The results of 3 radiologic measurements were classified into 4 categories: (1) True-positive (TP) cases presented the agreement with BI diagnosed by CT, MRI, and plain cervical radiograph; (2) False-positive (FP) cases presented with BI diagnosed by plain cervical radiography but not in CT and MRI.; (3) True-negative (TN) cases presented BI was not diagnosed by either according to CT, MRI, or plain cervical radiograph; and (4) False negative (FN) cases showed BI on CT and MRI but not plain cervical radiograph. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for 3 radiologic measurements. We also compared the validity of 3 radiologic measurements using the accuracy and diagnostic odds ratio (DOR). The optimized cutoff values of 3 radiologic measurements were also calculated using receiver operating characteristic (ROC) curves.

2.4. Statistical analysis

All data were compiled and analyzed using commercial software (IBM SPSS Statistics, version 23; IBM Corp., Armonk, NY). Student's *t*-test, paired *t*-test, and Mann-Whitney U test were used to analyze continuous and ordinal variables, as appropriate. The accuracy was calculated as:

$$\text{Accuracy} = \text{Sensitivity} * \text{Disease prevalence} + \text{Specificity} * (1 - \text{Disease prevalence})$$

Higher accuracy is indicative of better test performance. DOR was calculated as

$$\text{DOR} = \frac{\text{TP}/\text{FN}}{\text{FP}/\text{TN}}$$

The DOR, which is the ratio of the odds of the test being positive if the subject has a postoperative deficit ($TP/(1-TP) = TP/FN$) to the odds of the test being positive if the subject does not have a postoperative deficit ($FP/(1-FP) = FP/TN$), is a metric of the efficacy of a diagnostic test. Higher DORs are indicative of better test performance while ratios of < 1 indicate that the test can be improved by simply inverting the outcome of the test. A DOR equal to 1 means that the test is equally likely to predict a positive outcome regardless of the true condition. If any FN or FP were zero, we added 0.5 to all cells to calculate the DOR. The intrainter reliabilities of the radiologic measurements were compared. Intraclass correlation coefficients were used to analyze inter- and intraobserver agreements for angle measurements. Intraclass correlation coefficient values were rated as follows: 0 to 0.2, slight agreement; 0.21 to 0.4, fair agreement; 0.41 to 0.6, moderate agreement; 0.61 to 0.8, substantial agreement; and 0.81 to 1.0, excellent agreement. *P*-values of < 0.05 (two-tailed) were considered statistically significant.

3. Results

Clinical information is summarized in Table 1. The men to women ratio was 144–132, 20–26, and 124–106 in the BI and non-BI groups, respectively. The mean age was 57.3 ± 15.6 in BI and 58.8 ± 12.7 in non-BI group, and the difference was not significant ($P = .48$). Patients aged ≥ 65 years accounted for 34.8% (16 patients) of the BI group and 30.4% (70) of the non-BI group ($P = .39$). The mean BMI was 23.2 ± 4.6 in BI group and 23.7 ± 3.1 in non-BI group ($P = .42$). Patients with a normal BMI range accounted for 71.7% (33) of the BI group and 63.9% (147) of the non-BI group ($P = .46$).

3.1. Radiologic measurements

Table 2 shows values of 3 radiologic measurements in BI and non-BI groups. Three radiologic measurements significantly differed according to sex and the presence or absence of BI. In BI group, 3 radiologic measurements (RI, MRM, and RJM, respectively) were 12.5 ± 3.3 , 23.1 ± 3.8 , and 27.3 ± 3.6 mm in women and 13.6 ± 2.6 , 26.8 ± 4.2 , and 34.7 ± 5.1 mm in men. In non-BI group, the measurements were 16.9 ± 2.5 , 29.2 ± 3.0 , and 36.7 ± 4.0 mm in women and 18.7 ± 2.4 , 31.5 ± 2.5 , and 41.4 ± 4.4 mm in men. Three radiologic measurements showed an excellent degree of inter- and intracorrelation.

3.2. Validity of 3 radiologic measurements

Figure 2 illustrates the validity of RI and RJM. In women, TP, FP, TN, and FN of RI were 16, 0, 106, and 10, and the DOR was 335. In men, TP, FP, TN, and FN of RI were 15, 4, 120, and 5, and the DOR was 90. The DOR of RI higher in women than

Table 2

Radiologic measurements of RI, MRM, and RJM.

Radiologic measurements	RI(mm)	MRM(mm)	RJM(mm)
BI			
Women	12.5 ± 3.3	23.1 ± 3.8	27.3 ± 3.6
Men	13.6 ± 2.6	26.8 ± 4.2	34.7 ± 5.1
Non-BI			
Women	16.9 ± 2.5	29.2 ± 3.0	36.7 ± 4.0
Men	18.7 ± 2.4	31.5 ± 2.5	41.4 ± 4.4
Intracorrelation	0.90	0.97	0.94
Intercorrelation	0.84	0.91	0.88

BI = basilar invagination.

in men. In women, the sensitivity, specificity, PPV, and NPV of RI were 62%, 100%, 100%, and 91%, respectively, and the accuracy was 94%. In men, the sensitivity, specificity, PPV, and NPV of RI were 75%, 97%, 82%, and 95%, and the accuracy was 93%.

There have been no available reference values for MRM on plain radiographs. Kwong et al reported normal MRM values based on the CT images.^[12] These values are > 23.7 mm in men and > 24.2 mm in women. However, it is impossible to apply these values directly in our study. We obtained the cutoff values of MRM using the ROC curve, as shown in Figure 3. The cutoff value of MRM was 25.6 mm in women. The sensitivity, specificity, PPV, and NPV of RI were 94.3%, 88.5%, 66.8%, and 98.4%, respectively, and the accuracy was 89.6%. In men, the cutoff value of MRM was 28.5 mm, the sensitivity, specificity, PPV, and NPV of RI were 87.9%, 65%, 28.8%, and 97.1%, and the accuracy was 68.2%.

For RJM, TP, FP, TN, and FN were 17, 2, 104, and 9 in women, respectively, and the DOR was 98. In men, TP, FP, TN, and FN of RI were 9, 8, 116, and 11, and the DOR was 12. The results are summarized in Figure 2. RJM showed a greater DOR in women than in men. In women, the sensitivity, specificity, PPV, and NPV of RI were 65.4%, 98.1%, 87.4%, and 93.4%, respectively, and the accuracy was 92.3%. In men, the sensitivity, specificity, PPV, and NPV of RI were 45%, 93.6%, 58.3%, and 89.5%, and the accuracy was 85.4%.

We also analyzed the ROCs of 3 radiologic measurements (Fig 3). The areas under the curves of RI, MRM, and RJM were 0.895, 0.851, and 0.867, respectively. All 3 radiologic measurements showed excellent discriminatory power for the diagnosis of BI. We obtained optimized cutoff values using ROC for each measurement. The optimized cutoff values of RI, MRM, and RJM were 13.8, 25.6, and 31.9 mm in women and 14.9, 28.5, and 37.6 mm in men. Finally, with rounding to the nearest mm, the optimized cutoff values of RI, MRM, RJM were 14, 26, and 32 mm in women and 15, 29, and 38 mm in men.

4. Discussion

Basilar invagination shows the pathology that odontoid process invades into foramen magnum, and the presence of neurologic deficits is predictive factor for poor clinical outcomes.^[1,3] To treat patients with BI, a reliable and easily accessible diagnostic method is necessary. CT and MRI are good diagnostic tools, but are prohibitively expensive. Plain radiographs are still valuable because they are cost-effective and easily accessible for both screening and follow-up evaluation. RI, MRM, and RJM on plain radiographs are valuable radiologic measurement to screen BI. There are possibilities that these measurements are still diagnostically useful in the era of cross-sectional images.

As shown in Table 1, there was no significant difference in mean age, men-to-women ratio, and BMI between the BI and

Table 1

Clinical Information of the 276 Patients.

Characteristics	BI	Non-BI	<i>P</i> value
Men: women	20:26	124:106	0.258
Mean age (yr) (MD \pm SD)	57.3 ± 15.6	58.8 ± 12.7	0.477
< 65	30	160	0.456
≥ 65	16	70	0.385
BMI	23.2 ± 4.6	23.7 ± 3.1	0.419
< 18.5	4	11	0.238
18.5–24.9	33	147	0.458
25–29.9	4	65	0.354
> 30	5	2	0.210

BI = basilar invagination; BMI = body mass index.

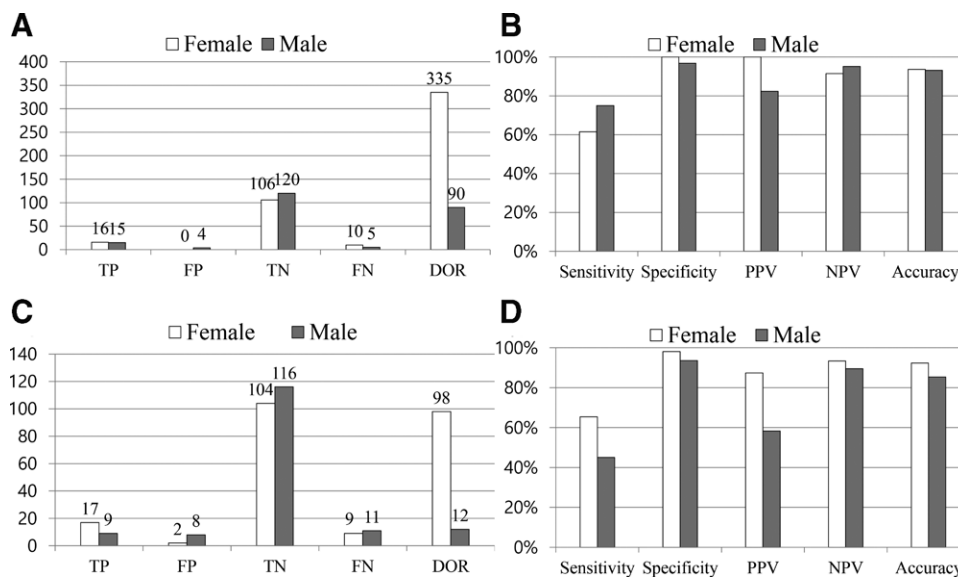


Figure 2. Validities of the Ranawat index and Redlund Johnell method for diagnosis of basilar invagination in 276 patients. (a), (b) Validity of the Ranawat index in women and men. (c), (d) Validity of the Redlund Johnell method in women and men. TP, true positive; FP, false positive; TN, true negative; FN, false negative; DOR, diagnostic odds ratio.

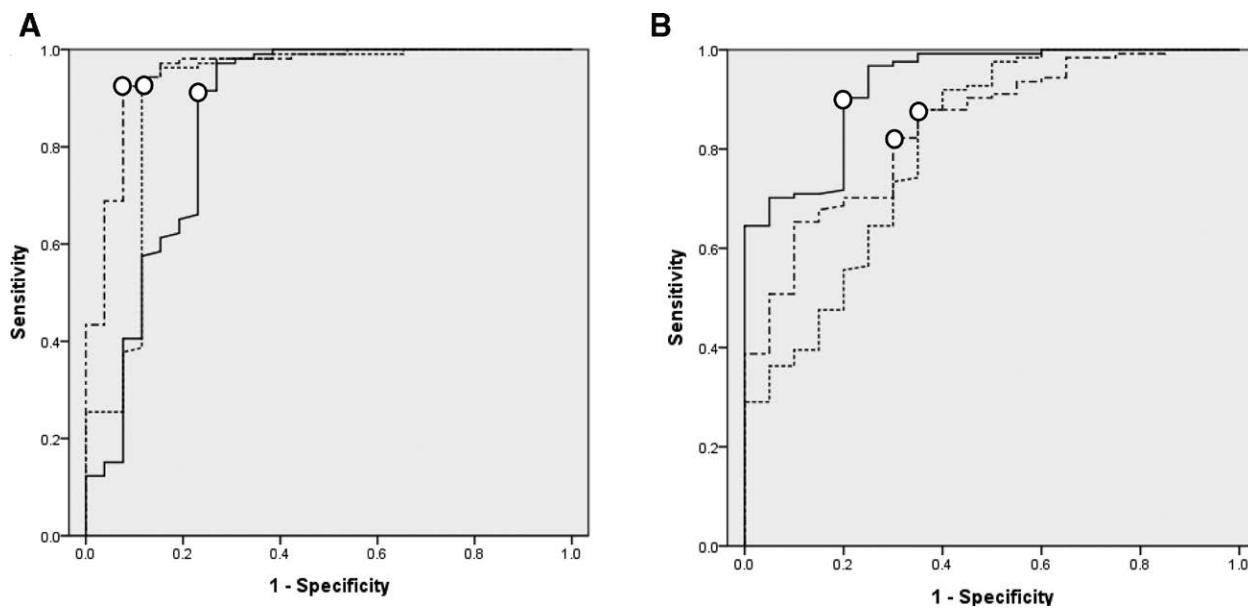


Figure 3. Optimal cutoff values of 3 radiologic measurements according to receiver operating characteristic (ROC) curves (Ranawat index, solid line; Modified Ranawat method, dotted line; Redlund Johnell method, Dash-single dotted line; Hollow circle, cutoff value). (a) ROC curves of 3 radiologic measurements in women (b) ROC curves of 3 radiologic measurements in men.

non-BI groups in this study. All measurements (RI, MRM, and RJM) showed significant differences between men and women. According to previous studies, the difference between men and women should be considered in radiologic measurements of the upper cervical spine.^[10,12,17,18,20] We attempted to compare 2 radiological measurements in our study with the results of previous studies, such as Ranawat et al^[10] and Redlund-Johnell et al^[20]

RI was first reported in 1979 in a study of rheumatoid arthritis patients.^[10] The reference values of RI were obtained by subtracting the standard deviation from the average values of 26 healthy individuals. In a study by Ranawat, 15 ± 2 mm in women and 17 ± 2 mm in men were the average values of 26 normal people, and 13 mm in women and 15 mm in men were defined as the reference values of RI, the lower limit of normal value. This assessment is quite simple, and we doubt that it remains

valuable even today. In our study, the average values of RI were 16.9 ± 2.5 mm in women and 18.7 ± 2.4 mm in men in non-BI group. These values are only slightly different from those of Ranawat et al, but it is difficult to compare our results directly to Ranawat's results because the previous authors did not consider the patients' BMI and height. Nevertheless, the average RI values in the BI group were quite similar to the reference values of RI, which were 12.5 ± 3.3 mm in women and 13.6 ± 2.6 mm in men in the BI group, and there were no FPs in women and only 4 FPs in men. The reference values of RI showed high validity in our study even though several decades have passed.

The MRM showed the lowest accuracy among 3 radiologic measurements. Nevertheless, the NPV of the MRM represented a high degree of validity. Therefore, this method can be reliably used to rule out BI. Patients with BI frequently show obscure

and vague findings near the center of the C2 pedicle on plain radiographs. MRM may be a good alternative method of RI for diagnosing BI in these patients.

RJM was first reported in 1984 in a study of 200 normal and 61 rheumatoid arthritis patients in Sweden.^[11] The relationship between the McGregor line and the tip of the dens was measured in patients with BI, and the reference values of RJM were obtained through linear logistic regression according to the distance between the McGregor line and the tip of the dens. In that study, the average RJM values in patients with BI were 28.7 ± 4.3 mm in women and 32.3 ± 4.9 mm in men. The value for women was similar to that in the current study, but the value for men is slightly different between the 2 studies. For this reason, the use of RJM in men has less diagnostic power than that in women. Nevertheless, RJM presents good accuracy for the detection of BI, even though several decades have passed.

RJM showed lower accuracy than RI in both sexes. There are several possible reasons for this finding. First, RI represents the spatial relationship of only the C1-C2 joint, while RJM represents the spatial relationship of both the C0-C1 and C1-C2 joints. Patients with rheumatoid BI inevitably have a narrow distance between the C1 and C2 joints due to inflammatory changes. RI reflects this change in the C1-C2 joint better than the RJM. BI patients also have a narrow space between the C0 and C2 joints, but most rheumatoid BI show preservation of the C0-C1 joint. The RJM value in these patients was greater than expected. This increases the possibility of FN. Second, the patients included in the present study were all Asian, mostly South Koreans. RI was also devised using data from Asian patients, in India, while RJM was designed on the basis of patients in Sweden, all of whom were European. Differences between the study populations may have caused differences in validity based on the patients' BMI.

Finally, we determined the optimum values of RI, MRM, and RJM using ROC curves. The optimized cutoff values of RI, MRM, and RJM (rounded to the nearest mm) were 14, 26, and 32 mm in women and 15, 29, and 37 mm in men. These cutoff values showed high validity when compared to the CT and MRI findings. These cutoff values are still valuable and consistent in the cross-sectional imaging era.

Our study has several limitations. First, it had a retrospective design and a small sample size. This retrospective design inherently increases the risk of selection bias in patient sampling. Second, we only included patients with BI who were treated with surgery alone. We did not include patients with mild BI or those who did not need to undergo surgical treatment. As a result, the validity of 3 radiologic measurements may be slightly exaggerated. Third, we compared our study to those of Ranawat et al and Redlund-Johnell et al, but 3 studies included patients of different races. Therefore, the characteristics of each race could have affected the validity of 3 radiologic measurements. Finally, we did not consider the aging process when taking 3 radiologic measurements. Degenerative changes are more common with increasing age, and it is possible that these changes markedly affect the radiologic measurements.

Three radiologic measurements are still reliable tools for the diagnosis of BI, even in the cross-sectional era of CT and MRI.

There are some differences in validity depending on sex and radiologic measurement, but all 3 (RI, MRM, and RJM) are still valuable tools.

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