Clinical Analysis of Radiologic Measurements in Patients with Basilar Invagination

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■ OBJECTIVE: **To investigate correlations between radiologic measurements and clinical outcomes in patients with basilar invagination (BI).**

■ METHODS: **The medical records and radiologic data of 46 patients (27 women) who had undergone posterior atlantoaxial fusion or occipitocervical fusion for BI from January 2010 to June 2018 were retrospectively analyzed. Patients under 15 years old or with a polytraumatic, tumorous, or infectious pathology were excluded. The modified Ranawat method (MRM) and the Redlund-Johnell method (RJM) were used to obtain radiographic measurements of basilar invagination preoperatively, subacute postoperatively, and at 3-month and last follow-up. Visual analogue scale, Neck Disability Index, and Japanese Orthopedic Association (JOA) scores were also assessed. Correlations between MRM and RJM measurements and clinical outcomes were evaluated.**

■ RESULTS: **Mean age of patients was 59.9 ± 16.5 years, mean body mass index was 23.5 ± 4.6 kg/m^2, and mean follow-up was 37.9 ± 23.8 months. Postoperative radiologic measurements increased about 36% of preoperative radiologic measurements. Subsidence at the C1-2 joint occurred in most patients at 3 months postoperatively, but clinical outcomes did not deteriorate. JOA scores were linearly correlated with percentage increases in both radiologic measurements subacute postoperatively ($P < 0.05$), but this significance was not maintained until the last follow-up. Occipital numbness and neuralgia were most common postoperative complications. One case of neurovascular injury and 3 cases of postoperative dysphagia occurred postoperatively.**

■ CONCLUSIONS: **The subacute postoperative neurological outcomes of BI patients are significantly related to the amount of vertical reduction.**

INTRODUCTION

Basilar invagination (BI) is an abnormality at the craniovertebral junction, either congenital or degenerative, resulting in the odontoid prolapsing into the already limited space of the foramen magnum.[1] It is a potentially dangerous manifestation of the cervical spine because it leads to compression of the brainstem by the odontoid, labile blood pressures, arrhythmias, respiratory depression, and sudden death.[2] Thus, some studies about diagnostic methods and clinical outcomes have been reported.[3]

Recently, the diagnosis of BI is not demanding by advances in radiologic imaging modalities, such as computed tomography and magnetic resonance imaging. Despite advances in radiologic imaging technology, plain cervical radiograph remains invaluable because of its cost-effectiveness and accessibility. The modified Ranawat method (MRM) and Redlund-Johnell method (RJM) are easily applied to plain radiographs to diagnose BI and follow up as they can be frequently used, and have greater sensitivity and specificity than previously described methods,[2,4-7] which suggests that these methods might provide useful information for surgeons if the measurements obtained correlate with neurologic status.

Key words
- Atlantoaxial fusion
- Basilar invagination
- Correlation
- Modified Ranawat method
- Occipitocervical fusion
- Redlund-Johnell method

Abbreviations and Acronyms
AP: Anteroposterior
BI: Basilar invagination
CFB: Change from baseline
IOM: Intraoperative monitoring
JOA: Japanese Orthopedic Association
MRM: Modified Ranawat method
NDI: Neck Disability Index
PEEK: Polyetheretherketone
RA: Rheumatoid arthritis
RJM: Redlund-Johnell method
VAS: Visual analogue scale

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Few studies have sought to predict the clinical outcomes of BI.[5,6] Casey et al. concluded that the RJM predicted surgical outcomes of patients with BI.[8] However, this study simply showed that RJM measurements differed significantly between good and poor outcome groups. Thus, there is the potential that, with better understanding of the clinical progress and treatment effects on the clinical neurologic abnormalities, better informed and improved treatment and timing decisions can be made in patients with early BI. In the present study, radiologic measurements (MRM, RJM) and neurologic statuses were checked preoperatively, subacute postoperatively, and at 3-month and last follow-up. We evaluated correlations between these measurements and clinical outcomes during follow-up.

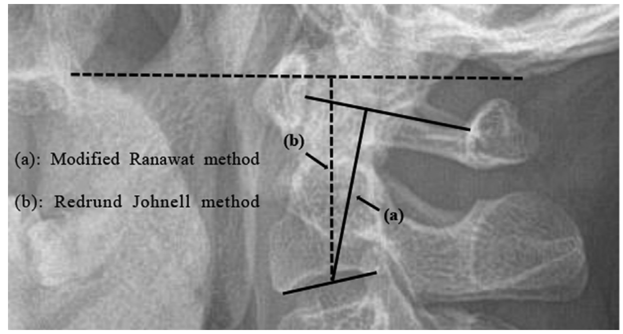

Figure 1. Radiologic measurements of vertical atlantoaxial dislocation on a cervical lateral plain radiograph. (**A**) Modified Ranawat method. (**B**) Redrund Johnell method.

METHODS

Patient Selection

Retrospective analysis of medical records and radiologic data was performed on patients who had undergone posterior atlantoaxial fusion or occipitocervical fusion for BI at a single center from January 2010 to June 2018. Institutional review board approval was obtained for the study. We diagnosed BI using plain radiograph firstly, and confirmed it based on computed tomography and magnetic resonance imaging. Patients with predicted incomplete physiologic bony fusion under 15 years old were excluded. In addition, patients with trauma involving other areas of the cervical spine or a tumorous or infectious pathology were also excluded. In total, 46 patients were included in the study.

Radiologic Measurements

Two neurosurgeons (J.T.H and J.H.P) measured MRM and RJM on cervical standard lateral radiographs displayed by a picture archiving communication system using an electrical caliper on 2 occasions. The 4 sets of measurements obtained were then averaged for statistical analysis. Lateral radiographs were obtained in the neutral head position. A standard distance of 1.8 m was maintained between the tube and patients. Measurements were made preoperatively, subacute postoperatively, and at 3-month and last follow-up.

Modified Ranawat method:[5] The observer marked the midpoint of the base of C2 and then measured the minimum distance from a line between the center of the anterior arch of C1 and the center of the posterior arch. The distance between the 2 lines along the long axis of C2 was measured (Figure 1A).

Redlund-Johnell method:[9] The observer marked the midpoint of the base of C2 and then measured the minimum distance between that point and McGregor's line, which was drawn from the posterosuperior aspect of the hard palate to the most caudal point on the midline occipital curve (Figure 1B).

Surgical Techniques

Forty-six patients were treated using posterior approach under intraoperative monitoring (IOM). Vascular anomalies were evaluated during preoperative assessments to avoid neurovascular injury. Atlantoaxial fixation was accomplished using a variety of surgical constructs combined with C1 lateral mass to C2 pedicle screw, C2 pars screw, or to C2 laminar screw fixation. Autograft bone was inserted into the interlaminar space of C1-2 to increase the fusion rate of C1-2. Autograft was harvested from the posterior superior iliac spine. C1-2 joint vertical distraction and fusion was usually performed to reduce vertical dislocation. A structural allograft or autograft block or a polyetheretherketone (PEEK) cage was used for C1-2 joint distraction and fusion. We sometimes inserted a unilateral spacer at the C1-2 facet joint according to the degree of osteoarthritis and loss of height at the C1-2 facet joint. One patient also underwent suboccipital craniectomy. An occipital plate was used to stabilize the surgical construct further, and when necessary, additional laminoplasty or extended posterior screw fixation was used to treat pathologies of the subaxial spine. Fluoroscopy was used during all surgical procedures to optimize hardware placement and to confirm reduction of horizontal and vertical atlantoaxial dislocation by direct manipulation of affected structures (Figure 2).

Analysis of Radiologic Measurement and Clinical Outcomes

We measured MRM and RJM and assessed visual analogue scale (VAS), Neck Disability Index (NDI), and Japanese Orthopedic Association (JOA) scores preoperatively, subacute postoperatively, at 3 months, and at last follow-up. We especially assessed clinical outcomes subacute postoperatively to exclude operation-site pain after surgery. Subacute period was defined from postoperative day 3 to 7. To evaluate the correlation between changes in radiologic measurements and clinical outcomes, we expressed postoperative changes as percentages of preoperative measurements. The change from baseline (CFB) of 2 radiologic measurements was calculated using following formula.

$$\text{The change from baseline of radiologic measurement} = \frac{\text{Radiologic measurement during follow}-\text{up} - \text{Preoperative radiologic measurement}}{\text{Preoperative radiologic measurement}} \times 100(\%)$$

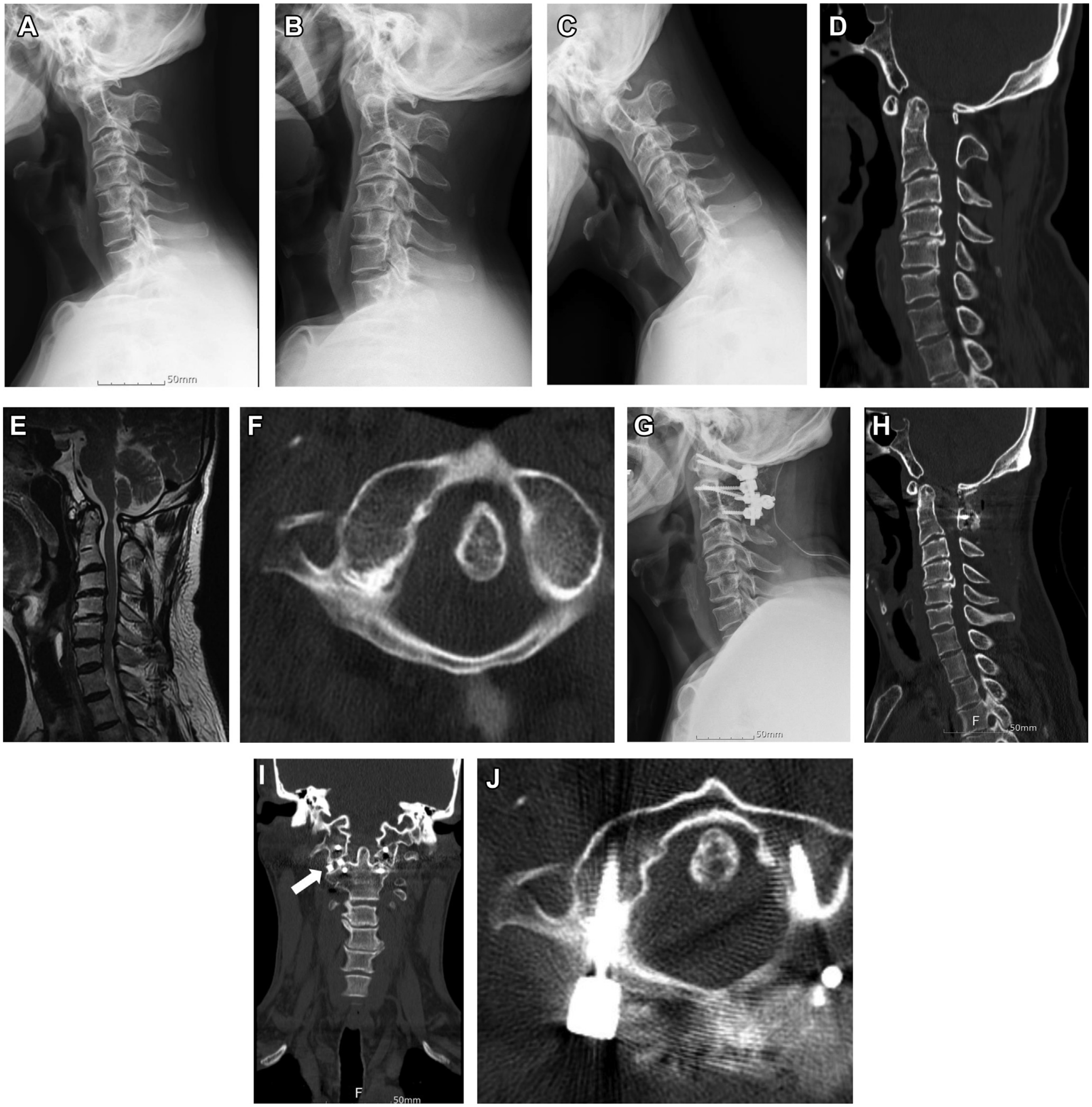

Figure 2. Preoperative and postoperative images showing a 54-year-old patient with vertical atlantoaxial dislocation. (**A**, **B**, **C**) Lateral and dynamic cervical radiograph. (**D**) computed tomography (CT) image showing vertical atlantoaxial dislocation combined with horizontal atlantoaxial dislocation. (**E**) Sagittal T2-weighted magnetic resonance image showing spinal cord compression by the posterior arch of the atlas and the dense of the axis. (**F**) Axial CT image showing horizontal atlantoaxial dislocation. (**G**) Postoperative lateral cervical radiograph. (**H**) Sagittal reconstruction of a postoperative CT scan showing spinal canal widening after atlantoaxial posterior fixation and posterior fusion using a wiring technique. (**I**) Coronal reconstruction of a postoperative CT scan showing a polyetheretherketone cage (*white arrow*) used as a spacer between C1 and C2 to reduce vertical atlantoaxial dislocation. (**J**) Axial postoperative CT scan showing reduce horizontal atlantoaxial dislocation after surgery.

Clinical outcomes were assessed using VAS, NDI, and JOA scores. Postoperative improvements in VAS and NDI scores were also expressed as percentages of preoperative scores.[10,11]

$$\text{Improving rate of VAS (NDI)} = \frac{|\text{VAS(NDI) during follow} - \text{up—Preoperative VAS(NDI)}|}{\text{Preoperative VAS (NDI)}} \times 100(\%)$$

Improving rate of JOA score was also calculated, as previously described, using the following formula.[12]

$$\text{Improving rate of JOA score} = \frac{\text{JOA score during follow} - \text{up—Preoperative JOA score}}{(17\text{—Preoperative JOA score})} \times 100(\%)$$

Statistical Analysis

The Student t test, the paired t test, and the Mann-Whitney U test were used to analyze continuous and ordinal variables, as appropriate. Correlation test and a linear logistic regression model were used to evaluate the natures of correlations between MRM and RJM measures and clinical outcome. The intra-inter reliabilities of 2 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.[13] P values of less than 0.05 (two-tailed) were considered statistically significant, and SPSS version 20.0 (SPSS Inc, Chicago, IL) was used for the statistical analysis.

RESULTS

Clinical information is summarized in Table 1. There were 19 men and 27 women, with mean age 59.9 ± 16.5 years and mean body mass index 23.5 ± 4.6 kg/m^2. Mean height and weight were 1.6 ± 0.1 m and 59.4 ± 13.5 kg. Mean follow-up was 37.9 ± 23.8 months. Twenty-four (52%) patients had rheumatoid arthritis (RA), and 13 (28.3%) had a congenital anomaly. In 9 patients (19.6%), BI was attributed to spondylosis. Twenty-five patients were fixed with a C1 lateral mass—C2 pedicle screw construct, 15 with a C1 lateral mass—C2 hybrid construct, and 6 with C1 lateral mass—C2 pars construct. Occipital plates were used to obtain additional fixation in 11 patients. An allograft or autograft bone block was used for C1-2 joint distraction and fusion in 24 patients, and a PEEK cage was used in 22 patients.

Analysis of Radiologic Measurement

Radiologic MRM and RJM measurements obtained during follow-up are summarized in Table 2. Preoperative and subacute postoperative mean MRM values for all 46 study patients were 24.1 ± 3.9 mm and 32.1 ± 3.0 mm, respectively, and this difference was significant ($P < 0.01$). Mean CFB in MRM was 36.4% ± 24.7% after surgery. At 3 months this value decreased to 16.0% ± 18.0%, and at last follow-up it fell to 10.3% ± 14.4%. A similar trend was observed for RJM values. Preoperative and postoperative mean RJM values were 29.9 ± 5.6 mm and 39.9 ± 5.9 mm, which was also significant ($P < 0.01$). Mean CFB in RJM was 35.6% ± 20.4% after surgery, at 3 months it decreased to 15.9% ± 14.6%, and last follow-up it fell to 9.8% ± 15.0%. The subsidence was observed remarkably at 3 months, and was found to depend on the graft material—that is, it was 5.9 ± 3.1 mm for autografts and allografts and 3.4 ± 2.4 mm for PEEK cages, and this difference was significant ($P < 0.05$).

Analysis of Clinical Outcomes

VAS, NDI, and JOA scores improved significantly subacute postoperatively (Table 3). Mean improving rates in VAS, NDI, and JOA scores were 66.2%, 64.0% and 61.5%, respectively. As mentioned earlier, the significant subsidence was evident at 3 months, but it did not adversely affect clinical outcomes. Slight improvements in VAS, NDI, and JOA scores were observed at 3 months, and this improvement was maintained until the last follow-up.

Table 1. Clinical Information of the 46 Patients with Basilar Invagination

Characteristic	Number
Male: Female	19 (41.3): 27 (58.7)
Mean age, years	59.9 ± 16.5
Mean follow-up, months	37.9 ± 23.8
Mean body mass index	23.5 ± 4.6
Mean height, m	1.6 ± 0.1
Mean weight, kg	59.4 ± 13.5
Pathology	
Spondylosis	9 (19.6)
Rheumatoid arthritis	24 (52.2)
Congenital anomaly	13 (28.2)
C1-2 constructs	
Lateral mass-Pedicle screws	25 (54.3)
Lateral mass-Hybrid screws*	15 (32.6)
Lateral mass-Pars screws	6 (13.1)
Occipital plate	11 (23.9)
Space for atlantoaxial facet joint fusion	
Allograft bone	16 (34.8)
Autograft bone	8 (17.4)
Polyetheretherketone cage	22 (47.8)

Values are presented as mean ± standard deviation or n (%).
*Hybrid screws means C2 pedicle—pars or translaminar screws.

Table 2. Radiologic Measurements of the 46 Patients During Follow-Up

Radiologic Measurement	Preoperative	Postoperative	3 Months	Last Follow-Up	Intercorrelation	Intracorrelation
MRM, mm	24.1 ± 3.9	32.1 ± 3.0	27.6 ± 4.2	27.1 ± 3.2	0.91	0.97
Change rate of MRM, %	—	36.4 ± 24.1	16.0 ± 18.0	10.3 ± 14.4	—	—
RJM, mm	29.9 ± 5.6	39.9 ± 5.9	34.4 ± 6.6	33.2 ± 5.7	0.88	0.94
Change rate of RJM, %	—	35.6 ± 20.4	15.9 ± 14.6	9.8 ± 15.0	—	—

Values are presented as mean ± standard deviation.
MRM, modified Ranawat method; RJM, Redlund-Johnell method.

No correlation was found between CFB in MRM or RJM measurements and VAS or NDI scores. Nevertheless, JOA scores (after excluding 7 patients with a full JOA score) showed linear correlations with CFB of MRM and RJM subacute postoperatively ($r^2 = 0.344$, $P = 0.036$, $r^2 = 0.214$, $P = 0.043$, respectively). Figure 3 shows a statistical significance between 2 values in linear logistic regression. In other words, we could calculate the amount of vertical reduction in order to improve JOA score after surgery by measuring 2 radiologic measurements on cervical lateral radiographs preoperatively and postoperatively. JOA score was not significantly correlated with CFB of both radiologic measurements at 3 months and last follow-up. Nevertheless, a linear trend between radiologic measurements and JOA scores was maintained during follow-up, although it failed to be statistically significant. Finally, changes in MRM and RJM values were significantly correlated with JOA score before and after surgery. We could make the following equation, rounding off the offset (Figure 3).

$$\text{Improving rate of JOA score} = 1.25 \times \text{percentage change in MRM} + 40 \text{ or } 0.85 \times \text{percentage change in RJM} + 40$$

This linear relationship allows us to predict postoperative neurologic status based on the amount of radiological change. We were also able to calculate the amount of reductions in BI using MRM and RJM measurements if we could determine expected subacute postoperative JOA scores. We believe that this value obtained using this equation may not be consistent with neurologic outcomes, but it does provide us with a guideline on how much vertical reduction is necessary to obtain an expected postoperative JOA score during surgery.

Complications

There was 1 neurovascular injury (i.e., a right lateral medullary infarction), which caused left-side hemiparesis. The patient recovered 3 months later. Three patients experienced postoperative dysphagia after surgery. In 2 patients postoperative dysphagia improved after rehabilitation, but in 1 patient dysphagia persisted, and the patient required revision surgery to rearrange the occipito-C2 angle.[14] One patient developed a wound infection, which responded to antibiotic therapy. One case of peri-screw halo of instrumentation and subaxial subluxation were detected by computed tomography during follow-up. In our study, the resection of C2 root was necessary to insert a spacer or bone block into the C1-2 facet joint. In this patient, C2 root-related complications were inevitable after surgery. Occipital neuralgia and numbness occurred in 27 (65.9%) and 37 (90.2%) patients subacute postoperatively, and at 3 months, 8 (19.5%) and 15 (36.6%) patients complained of occipital neuralgia and numbness. However, only 1 patient (2.4%) complained of occipital neuralgia after 6 months. In occipital numbness, 7 patients recovered up to 6 months and the others (19.5%) complained occipital numbness after 1 year.

Table 3. Clinical Information in the 46 Patients During Follow-Up

Clinical Outcome	Preoperative	Subacute Postoperative	3 Months	Last Follow-Up
VAS	7.1 ± 1.7	2.2 ± 1.5	1.2 ± 1.0	1.2 ± 1.0
Improving rate of VAS (%)	—	66.2 ± 26.6	82.6 ± 14.9	81.1 ± 16.1
NDI	27.8 ± 7.8	9.0 ± 4.7	6.2 ± 3.9	5.7 ± 4.4
Improving rate of NDI (%)	—	64.0 ± 35.1	75.5 ± 18.8	77.7 ± 19.3
JOA score	12.3 ± 3.9	15.0 ± 2.4	15.6 ± 2.4	14.8 ± 2.4
Improving rate of JOA score (%)	—	61.5 ± 31.1	65.3 ± 31.7	51.4 ± 39.3

Values are presented as mean ± standard deviation.
VAS, visual analogue scale; NDI, Neck Disability Index; JOA score, Japanese Orthopedic Association score.

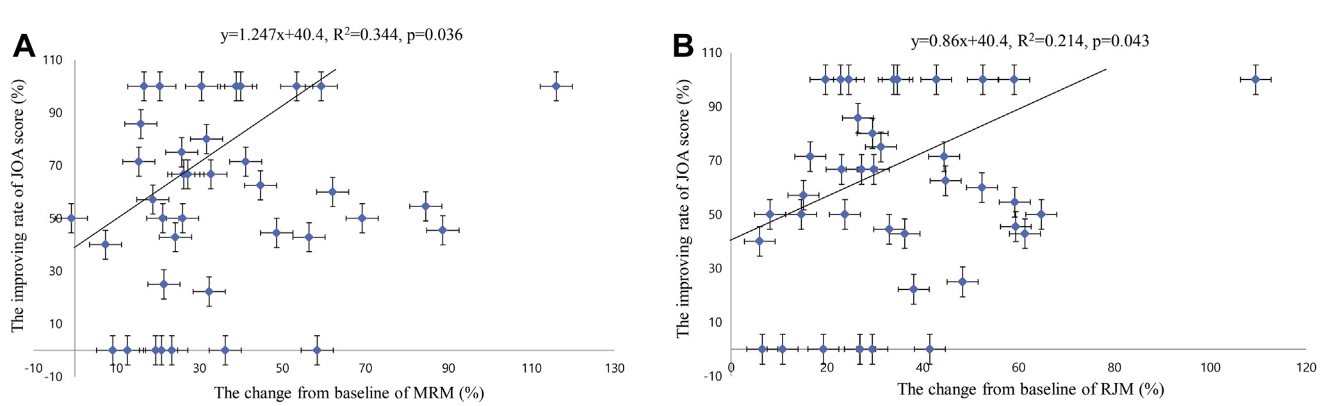

Figure 3. Linear logistic regression plots of modified Ranawat method (**A**) and Redlund-Johnell method (**B**) values versus Japanese Orthopedic Association scores at postoperative time.

DISCUSSION

Basilar invagination can result in severe neurologic deficits, severe neck pain, and cardiopulmonary complications due to brain stem compression.[2] It is important for surgeons to prevent these complications and recover the neurological symptoms of BI. Nevertheless, a few studies have been reported to predict the clinical outcomes of BI. Therefore, we evaluated the relationship between tw2o radiologic measurements (MRM and RJM) to predict neurologic outcomes in patients with BI.

In the present study, the proportion of female petients was high (58.7%) due to including patients with RA. Sex is an important factor when considering radiologic measures of the cervical spine, which are larger in men than in women. We used CFB in radiologic measurements to address sex-dependent differences. Therefore, thesequations derived from our results can be applied to both sexes without any modification. The mean body mass index of our 46 patients was 23.3 kg/m^2, which was within the normal range; thus, it is probably inappropriate to apply our results to obese or underweight patients. In a previous study on the relationship between Ranawat indices[6] and body mass index, a linear relationship was found whereby a 1 kg/m^2 increase corresponded to a 0.1 mm reduction in Ranawat index.[12]

Notably, we found that CFB of MRM and RJM were correlated with JOA score changes subacute postoperatively (Figure 3), and the linear relationships enabled us to calculate the amount of reduction of vertical dislocation on plain radiographs. For example, 1 patient had 19.5 mm of preoperative MRM value and presented 10 points of JOA score. If surgeons expected 16 points of expected JOA score for this patient subacute postoperatively, a improving rate of JOA score would be 85.7%. Inserting this value into above-mentioned equation, we can obtain 36.6% of CFB of MRM, and 26.6 mm of postoperative MRM. Therefore, we can work out that at least 7.1 mm of vertical reduction was necessary to obtain the expected JOA score.

We sometimes distracted the atlantoaxial joint up to 134% of preoperative radiologic measurement during surgery. We frequently experienced declines of the amplitude of IOM when distracting the atlantoaxial interspace or inserting a cage into the atlantoaxial joint. Therefore, surgeons should be aware of significant changes of IOM during distraction. This declines of the amplitude of IOM recovered after release of C1-2 distraction in most cases.[15]

Radiologic measurements of MRM and RJM decrease to about 22% at 3 months as compared with subacute postoperative values, but this subsidence did not deteriorate clinical outcomes. Subsidence after bone grafting and PEEK cage placement was significantly different, and subsidence occurred more severely in the bone graft group, which agrees with experiences in the subaxial cervical spine.[16] Despite this early subsidence, MRM and RJM values were maintained in the normal range in all 46 patients until last follow-up. Therefore, it is essential for surgeons to recognize the subsidence when performing atlantoaxial facet fusion to reduce BI. Although subsidence did not affect postoperative clinical outcomes, our results show that the placement of PEEK cage better maintains the reduction of basilar invagination. For this reason, a serial observation is required to check the amount of subsidence.

Some previous studies have also addressed relations between radiologic measurements and clinical outcomes.[17-20] Kulkarni et al.[21] found vertical atlantoaxial index, a measure of the vertical relationship between atlas and axis, reflected the severity of basilar invagination, although this index was designed for non-RA patients. The lower the atlas placed at dens of axis, the more severity increased as the index decreased. Chandra et al.[19] devised new joint indexes to predict the severity of BI, and stated that the more joint inclination and craniocervical tilt, the more severe BI. Despite several limitations, these studies support our result that vertical translocation is a major predictor of clinical outcome.

Patients with irreducible BI occasionally needed ventral decompression, and, traditionally, ventral compressive lesions are treated using a transoral approach. Fortunately, we did not need to perform ventral decompression of a craniocervical junction in this series. Advances in surgical technique enable ventral decompression to be obtained by craniocervical realignment using a screw and rod system.[15,22] The principle of the surgical procedure is to pull the odontoid process downward away from the cervicomedullary junction after releasing the C1-2 facet joint.[15,23,24] Previous studies suggested that this technique might be safe and efficacious for the treatment of BI.[15] When additional decompression was necessary, we performed suboccipital craniectomy, consequently only 1 of the 46 study patients needed suboccipital craniectomy.

Furthermore, we did not consider anteroposterior (AP) diameter of the craniocervical junction. Craniocervical junction AP diameter has been considered an important radiologic measure in patients with horizontal atlantoaxial subluxation, but some studies have concluded that it is not associated with clinical outcomes in patients with BI combined with other comorbidities. Furthermore, these studies reported an inverse log linear relationship between craniocervical junction AP diameter and the degree of BI, and no correlation between craniocervical junction AP diameter and clinical outcomes.[8,25] It is a low possibility that AP diameter of craniocervical junction could predict clinical outcomes when BI is present.

Atlantoaxial fusion is a procedure with accompanying dangerous complications. In the present study, 1 neurovascular injury occurred during instrumentation of C2 pedicle screws. The patient presented left hemiplegia due to a right lateral medullary infarct and was discharged in an ambulatory state after rehabilitation for 3 months. Surgeons should meticulously dissect the pars interarticularis of C2 and understand the need for sufficient anatomical orientation between the vertebral artery and axis. In the present study, 3 out of 10 patients who needed occipital fixation suffered from postoperative dysphagia, and 1 of the 3 underwent revision surgery to correct the occipitoaxial angle.[14] Incidences of occipital neuralgia and numbness are not uncommon after atlantoaxial fusion. In the present study, persistent occipital neuralgia and numbness rates at 1 year were 2.4% and 19.5%, respectively.

Limitations

The most obvious weaknesses of this study are its retrospective design, possible selection bias, and small sample size. A multicenter prospective study could be necessary to overcome these limitations. In addition, patients had heterogenous pathologies, which included RA, congenital anomalies, and osteoarthritis. The mean preoperative JOA score of our patients was 12.2 ± 4.0, which indicates relatively mild neurologic deficits, and patients with poor neurologic status before surgery are probably likely to result poor clinical outcomes. Furthermore, few patients had a preoperative JOA score of less than 8 or greater than 16, and thus our derived equation may not function well for patients with scores beyond this range. Also, we simplified the relationships between radiologic measurements and clinical outcomes—that is, many factors not considered in the present study, such as underlying medical condition, rehabilitation, and osteoporosis, are likely to affect clinical outcomes. Accordingly, we caution for these factors be kept in mind when interpreting our results. Despite these limitations, we believe the derived equation provides surgeons a valuable understanding for the surgical treatment of BI and an approximate value for the amount of C1-2 vertical reduction.

CONCLUSIONS

A linear correlation was found between CFB in MRM or RJM measurements and JOA scores improvement subacute postoperatively. We believe this correlation might provide surgeons helpful understanding of C1-2 vertical reduction.

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