Optimizing preoperative bone health assessment for adult spinal deformity: a prospective correlation analysis of intraoperative pedicle screw insertion torque and imaging modalities in Japan

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Study Design: Prospective cohort study.

Purpose: This study aimed to identify the optimal preoperative bone health assessment for adult spinal deformity (ASD) surgery through correlation analysis between intraoperative pedicle screw (PS) insertion torque and various bone quality measures, including bone mineral density (BMD) assessed by dual-energy X-ray absorptiometry (DEXA), Hounsfield unit (HU) by computed tomography (CT), and vertebral bone quality (VBQ) score by magnetic resonance imaging.

Overview of Literature: Existing data on optimal assessment tools for ASD surgery are limited.

Methods: The study included patients with ASD aged >60 years who underwent spinal corrective fusion surgery from the lower thoracic spine to the pelvis. The intraoperative PS insertion torque was measured using a torque meter. Pearson correlation coefficients were calculated between the PS insertion torque and the BMD, HU, and VBQ score. Preoperative bone quality was compared between the proximal junctional failure (PJF) and non-PJF groups.

Results: Thirty-one patients with 177 PS at T10, T11, and T12 were analyzed. The PS insertion torque showed a moderate positive correlation with lumbar spine BMD (r=0.59–0.69, p<0.01), total hip BMD (0.58–0.62, p<0.01), and HU value (r=0.58–0.66, p<0.01). However, the VBQ score did not show significant correlation (r=−0.28 to −0.23, p>0.05). Notably, a strong correlation was found between the PS insertion torque and the HU value for screws of the same size (r=0.71 and 0.74, p<0.01). The HU value at T12 and the PS insertion torque at T10 were significantly lower in the PJF group than in the non-PJF group.

Conclusions: This study demonstrates a positive correlation between the PS insertion torque and HU value in the lower thoracic spine and a moderate correlation with BMD but not the VBQ score. Preoperative assessment using DEXA and CT is crucial for optimizing bone health management in ASD surgery.

Keywords: Hounsfield unit; Bone mineral density; Spinal deformity
Introduction

Preoperative assessment of osteoporosis is crucial in adult spinal deformity (ASD) surgery because low bone mineral density (BMD) is a major risk factor for proximal junctional kyphosis (PJK) or proximal junctional failure (PJF) development after surgery [1-3]. Although dual-energy X-ray absorptiometry (DEXA) remains the gold standard for diagnosing osteoporosis, it tends to overestimate degenerative changes, particularly in patients with ASD [4-6]. Hounsfield unit (HU) values in computed tomography (CT) emerged as a valuable add-on for diagnosing osteoporosis [7]. A recent meta-analysis revealed that both low BMD and low HU values at the upper instrumented vertebra (UIV) are significant risk factors for PJK in patients with ASD [1]. This reinforces the notion that DEXA alone may be insufficient for preoperative assessment. Recent advancements in imaging offer further promise. Magnetic resonance imaging (MRI)-based vertebral bone quality (VBQ) score has shown independent predictive potential for both fragility fractures and PJK [8,9]. In addition, the pedicle screw (PS) insertion torque was found to correlate positively with BMD [10]. Measuring the PS insertion torque in the lower thoracic spine enables direct assessment of bone quality at the UIV and may hold promise for predicting PJK after ASD surgery. Therefore, this study aimed to investigate the correlations between the intraoperative PS insertion torque and bone quality measured by DEXA, HU by CT, and VBQ score by MRI.

Materials and Methods

Study design and patients

This prospective study was conducted at Hyogo Medical University from May 2022 to April 2023 and investigated the relationship between the intraoperative PS insertion torque and bone quality in ASD surgery. This study was approved by the institutional review board (IRB) of Hyogo Medical University Hospital (IRB approval no., 4172). Informed consent was obtained from all patients. Patients (1) age ≥60 years (2) with ASD and sagittal vertical axis >50 mm or a pelvic tilt >25°, or pelvic incidence minus lumbar lordosis exceeding 10° and (3) long corrective spinal fusion surgery (>5 vertebrae) extending to the pelvis were included. Patients with (1) malignant bone tumors, (2) infections, (3) trauma, and (4) Parkinson’s disease were excluded.

Preoperative assessment of bone quality

Preoperative bone quality assessment was conducted within 3 months of surgery using a multimodal approach. DEXA using a Hologic Discovery device measured the BMD of the lumbar spine (L2–L4) and total hip. CT of the thoracolumbar spine was performed using a SOMATOM Definition Edge scanner (Siemens Healthcare, Erlangen, Germany). HU values were measured in the T10–T12 vertebrae as key levels of PJK and PJF. All measurements were acquired using Picture Archiving and Communication Software (Synapse; Fujifilm Corp., Tokyo, Japan). Regions of interest for the HU analysis were identified in axial CT images of the vertebra at three points, following a previously established method [7]. Averaging the measurements from these points on each vertebra yields the mean HU value that represents bone quality. Lumbar MRI was performed on a Siemens Magnetom Skyra 3.0T scanner to assess the VBQ using a previously described method [8]. This method calculates the VBQ score by dividing the median signal intensity (SI) of the L1–L4 vertebrae by the SI of the cerebrospinal fluid at the L3 level on sagittal T1-weighted MR images. Two independent authors (K.M. and Y.T.) measured HU values on CT scans and calculated the VBQ score on MRI scans. In this study, preoperative osteoporosis medication (teriparatide or romosozumab) was administered >90 days for patients with either the percentage of young adult mean (% YAM) <70% or T10–12 HU values <120 based on their risk for PJK [11,12].

Intraoperative measurement of the pedicle screw insertion torque

The intraoperative PS insertion torque was measured at the T10–T12 vertebrae using a torque meter (DTC-CN500REV; Nakamura Mfg. Co. Ltd., Nagoya, Japan) (Fig. 1). Preoperative CT scans were used to determine the PS diameter, and the same PS system (Reline; Navisave, San Diego, CA, USA) was used in all study patients. Considering the influence of the screw size on torque measurement, it was standardized at 6.5-mm diameter whenever possible. After the partial removal of the transverse process to avoid contact with the screw head, the maximum insertion torque was recorded during the final phase before touching the cortical bone. To confirm that the screw heads was not in contact with the cortical bone, we made sure that the polyaxial screw heads could move freely. To confirm the screw position, postoperative CT was performed on all patients.
Definition of proximal junctional failure

PJF was defined as the presence of one or more of the following: (1) fracture at the UIV or UIV+1, (2) need for revision surgery, and (3) UIV pullout or fixation failure [3]. Preoperative bone quality was compared between the PJF and non-PJF groups.

Statistical analysis

Continuous variables are presented as means±standard deviations, whereas categorical variables are presented as percentages (%). Group differences were assessed using Student t-test. Pearson correlation coefficients were calculated to evaluate the relationships between the insertion torque and BMD, HU, and VBQ score. Correlation coefficients were interpreted as weak (<0.4), moderate (0.4–0.7), strong (0.7–0.9), and very strong (0.9–1.0). Statistical analyses were performed using JMP Pro ver. 15.0 (SAS Institute Inc., Cary, NC, USA). All p-values <0.05 were considered statistically significant.

Results

Patients

The study included 31 patients (mean age, 75.1±6.3 years; 10 males and 21 females). Preoperative diagnoses were diverse; 20 patients presented with degenerative kyphoscoliosis, eight with kyphotic deformity after osteoporotic vertebral fractures, and three with iatrogenic flatback syndrome. The mean height was 153.6±7.4 cm; weight, 51.3±12.3 kg; and body mass index, 21.6±4.2 kg/m² (Table 1). Preoperative DEXA scans revealed osteoporosis (YAM ≤70%) in the lumbar spine or total hip in 30% (9/30) of the patients. One patient who underwent bilateral total hip arthroplasty and spinal fusion surgery was excluded from the analysis. Based on HU values <120 (64.5%, n=20) were diagnosed with osteoporosis. In addition, four patients exhibited severe vertebral collapse using a semiquantitative method. To address osteoporosis, 22 patients received preoperative medications such as osteoanabolic agents, namely, teriparatide (n=16) and romosozumab (n=6). The average duration of preoperative medication was 145.2±107.4 days (median, 110 days).

Preoperative assessment of bone quality and intraoperative pedicle screw insertion torque values

A total of 177 PS insertion torque values were analyzed. At T10, 50 screws were 6.5 mm in diameter, and 12 were 5.5 mm. At T11, 54 were 6.5 mm, and eight were 5.5 mm. T12 had 50 screws of 6.5 mm, six of 5.5 mm, and four of 7.5 mm. Seven screws were excluded because of malposition. The mean lumbar spine and total hip BMD were 0.87±0.2 g/cm² and 0.73±0.14 g/cm², respectively. The mean HU values at T10, T11, and T12 were 119.1±34.2, 113.1±29.2, and 101.8±27.4, respectively. The mean VBQ score was 3.64±0.86 (Table 2). The mean maximum insertion torque values at T10, T11, and T12 were 112.8±27.8 cNm, 110.9±31.9 cNm, and 110.2±36.6 cNm, respectively.

Correlation between the pedicle screw insertion torque and bone quality

The PS insertion torque positively correlated with...
lumbar spine BMD (T10, $r=0.59$, $p<0.01$; T11, $r=0.61$, $p<0.01$; T12, $r=0.69$, $p<0.01$), total hip BMD (T10, $r=0.61$, $p<0.01$; T11, $r=0.62$, $p<0.01$; T12, $r=0.58$, $p=0.01$), and HU values at all levels (T10, $r=0.58$, $p<0.01$; T11, $r=0.64$, $p<0.01$; T12, $r=0.66$, $p<0.01$) (Figs. 2–4). Notably, no significant correlation was found between the screw insertion torque and the VBQ score (T10, $r=-0.21$, $p=0.29$; T11, $r=-0.18$, $p=0.36$; T12, $r=-0.23$, $p=0.26$) (Fig. 5). Interestingly, for a 6.5-mm diameter screw, the PS insertion torque strongly correlated with T11 HU (r=0.71, p<0.01) and T12 HU (r=0.74, p<0.01) (Fig. 6).

Comparison of bone quality between the non-proximal junctional failure and proximal junctional failure groups

Of the 31 patients, PJF developed in five. All five patients with PJF had UIV fractures, although none required revision surgery. No significant differences were found in the YAM of the lumbar spine and total hip or the VBQ score between the non-PJF and PJF groups (Table 3). The HU value at T12 was significantly lower in the PJF group than in the non-PJF group. The HU values at T10 and T11 tended to be lower in the PJF group than in the non-PJF group. The PJF group tended to have lower PS insertion torque values at T11 and T12. Furthermore, the PS insertion torque at T10 was

Table 2. Preoperative assessment of bone quality

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hounsfield unit value</td>
<td></td>
</tr>
<tr>
<td>T10</td>
<td>119.1±34.2</td>
</tr>
<tr>
<td>T11</td>
<td>113.1±29.2</td>
</tr>
<tr>
<td>T12</td>
<td>101.8±27.4</td>
</tr>
<tr>
<td>Bone mineral density (g/cm²)</td>
<td></td>
</tr>
<tr>
<td>Lumbar spine (L2–4)</td>
<td>0.87±0.2</td>
</tr>
<tr>
<td>Total hip</td>
<td>0.73±0.14</td>
</tr>
<tr>
<td>Vertebral body quality score</td>
<td>3.64±0.86</td>
</tr>
</tbody>
</table>

Values are presented as mean±standard deviation.
Fig. 4. (A–C) Correlation between the Hounsfield unit (HU) and pedicle screw (PS) insertion torque.

Fig. 5. (A–C) Correlation between the bone quality score and pedicle screw (PS) insertion torque.

Fig. 6. (A–C) Correlation between the Hounsfield unit (HU) and a 6.5 mm diameter pedicle screw (PS) insertion torque.
significant lower in the PJF group than in the non-PJF group.

**Discussion**

Previous studies have established a correlation between the screw insertion torque and BMD when assessing bone quality [10]. Accordingly, this study aimed to identify the optimal bone quality assessment method for predicting screw insertion torque in patients with ASD. Age, screw diameter, pedicle diameter, BMD, and osteoporosis are known to influence the screw insertion torque [10,13]. However, only a few studies have evaluated the PS insertion torque in patients with ASD. Oda et al. [13] demonstrated a positive correlation between YAM and screw insertion torque ($r=0.456$) and observed lower torque values in the lumbar spine of patients with ASD compared to those with adolescent idiopathic scoliosis. They attributed this association to the screw-to-pedicle ratio. The present study found a higher correlation coefficient between the PS insertion torque and DEXA-measured BMD than those reported previously (0.58–0.66). We focused on PS insertion torque in the lower thoracic spine because of its direct effect on PJF. In this region, the PS insertion torque (6.5 mm) strongly correlated with the HU values at T11 and T12 and moderately correlated with both lumbar and femoral BMD. Notably, the VBQ score did not correlate with the PS insertion torque. Possible explanations for these findings are as follows: (1) thoracic spine cadaveric studies have suggested that the mean pedicle widths at T11 and T12 exceed 6.5 mm [14], and (2) the known dependence of PS insertion torque on the screw-to-pedicle ratio [13] may have influenced torque at T10 but not at T11 or T12 because of their larger pedicle diameter.

Our results align with those of Bernatz et al. [15], who found significant correlations between the CT-HU value and the DEXA T-score but not between the VBQ or the trabecular bone score and HU value. This suggests that VBQ, which reflects fat infiltration in the vertebral body, may not be a reliable indicator of the PS insertion torque. The relatively high mean VBQ score in this study (3.6±0.8) compared with those in recent meta-analyses (2.20–3.80) [16] could be attributed to factors such as scoliosis, osteophytes, and Modic changes, which are common in ASD and can artificially increase the VBQ scores. These findings suggest that the HU values in the lower thoracic spine are most suitable for preoperative assessment of bone quality.

Osteoporosis significantly contributes to PJK and PJF development [3]. The HU values at the UIV have been recognized as a valuable tool for assessing bone quality and predicting PJF development [11,17-20]. Despite DEXA scans being the gold standard for osteoporosis diagnosis, previous studies often skipped performing them because a preoperative DEXA scan was not a routine protocol. Recent best practices in adult spinal reconstruction surgery now recommend DEXA if the lumbar HU value is <150 [21]. Interestingly, Yoshie et al. [11] found similar DEXA-BMD in the PJK and non-PJK groups, whereas the HU value in the UIV was significantly lower in the PJK group, suggesting a cutoff HU value of 120 as a better predictor of PJF. This study found that T12 HU value was significantly lower in the PJF group than in the non-PJF group. Furthermore, the PS insertion torque tended to be lower in the PJF group than in the non-PJF group. These results suggest that the PS insertion torque may be directly related to PJF development with UIV fracture.

Improving bone quality is crucial for PJF prevention [3]. Therefore, preoperative administrations of teriparatide or abaloparatide are first-line options for patients with ASD and poor bone quality [21]. Maruo et al. [12] demonstrated that teriparatide increased the UIV+1 HU value by an average of 20.8% annually, and patients with PJF require significantly longer treatment duration (86.9 days versus 34.7 days, $p=0.004$). In addition, Inoue et al. [22] found that preoperative teriparatide therapy for at least a month enhanced the PS insertion torque. Recent studies have also highlighted the bone-building potential of romosozumab [23]. Consequently,
we opted to administer teriparatide or romosozumab at least 3 months before surgery.

Preoperative detection of poor bone quality is crucial for preventing PJK and PJF after ASD surgery. This study revealed that 30% of patients with ASD were diagnosed with osteoporosis by DEXA and 64.5% had poor bone quality based on low HU values in the lower thoracic spine. Notably, lumbar HU value proved less effective in identifying osteoporosis in patients with ASD. Kohan et al. [6] showed that hip DEXA more frequently detects osteopenia (54.2%) than lumbar DEXA (17.4%) or lumbar HU value (12.5%) in patients with ASD. In addition, forearm DEXA may be more sensitive to osteoporosis or osteopenia (41.2%) than hip DEXA in this population [24]. These findings, along with evidence that DEXA alone may be insufficient for PJK prevention [1], highlight the value of measuring the HU value in the lower thoracic spine.

Various cutoff values of the UIV HU as a PJK risk factor have been reported, ranging from 104 to 122 [9,11,17,20]. This study adopted a threshold of 120 for preoperative osteoanabolic agent administration, with HU identifying a higher proportion of patients with preoperative poor bone health (64.5%) than DEXA (30%). Although a recent study identified the VBQ score as an independent predictor of PJK [9], Hiyama et al. [25] reported no significant difference in the VBQ scores between the PJF and non-PJF groups while highlighting significantly lower HU values at the UIV and L4 in the PJF group. In addition, the VBQ score thresholds for PJK prediction vary widely, ranging from 2.39 to 3.08 [16]. In this study, only four of 31 patients had a VBQ score below the reported PJK predictor threshold of 2.85 [9]. Our findings, in line with those of Chen et al. [1], suggest that combined evaluation using DEXA and CT-HU as supplementary methods offers the most comprehensive approach for assessing preoperative bone quality in patients with ASD and decreasing the risk of PJK and PJF.

This study has several limitations. First, the sample size is relatively small because of the prospective design of the study and the complexity of measuring the PS insertion torque on all enrolled patients. This was necessary to investigate the intricate relationship between the PS insertion torque and bone quality assessed through various modalities. Second, the timing of preoperative CT, MRI, and DEXA varied slightly. Third, the preoperative use of osteoanabolic agents in 22 patients (71%) may have influenced the intraoperative torque measurements. Finally, the HU value and VBQ score were each measured by only two authors. Although several studies have shown excellent intraobserver and interobserver reliabilities for these measures [7], calculating the intraclass correlation coefficients would further strengthen the assessment of reliability in this study. Despite these limitations, this is the first study to compare quantitative intraoperative bone quality with BMD using diverse modalities in patients with ASD. Our findings suggest that the HU values in the lower thoracic spine may be a more valuable tool for assessing osteoporosis than both BMD and VBQ scores. Future studies with larger sample sizes and longer follow-up periods are warranted to solidify the association between lower PS insertion torque and screw loosening or other mechanical complications.

**Conclusions**

The findings highlight the potential of HU values in the lower thoracic spine as superior to both the lumbar spine and hip BMD in assessing osteoporosis in patients with ASD. This is further supported by the weaker influence of lumbar spine degeneration on the thoracic HU value and its stronger correlation with the PS insertion torque. Preoperative BMD and HU assessments can significantly optimize the care of patients with osteoporosis undergoing ASD surgery.

**Key Points**

- The study demonstrated the potential of Hounsfield unit (HU) values at the lower thoracic spine as superior to both lumbar and hip bone mineral density in the assessment of osteoporosis in patients with adult spinal deformity (ASD).
- Lower HU values at T12 and lower pedicle screw insertion torque at T10 were linked to higher rates of proximal junctional failure, emphasizing the importance of accurate bone quality assessment.
- Preoperative HU assessments at the lower thoracic spine can optimize care for osteoporotic patients undergoing ASD surgery.

**Conflict of Interest**

No potential conflict of interest relevant to this article was reported.
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