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ORIGINAL ARTICLE

Hounsfield units value is a better predictor of pedicle screw loosening than the T-score of DXA in patients with lumbar degenerative diseases

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Abstract

Purpose To compare the performance of using Hounsfield units (HU) value derived from computed tomography and T-score of dual-energy X-ray absorptiometry (DXA) to predict pedicle screw loosening.

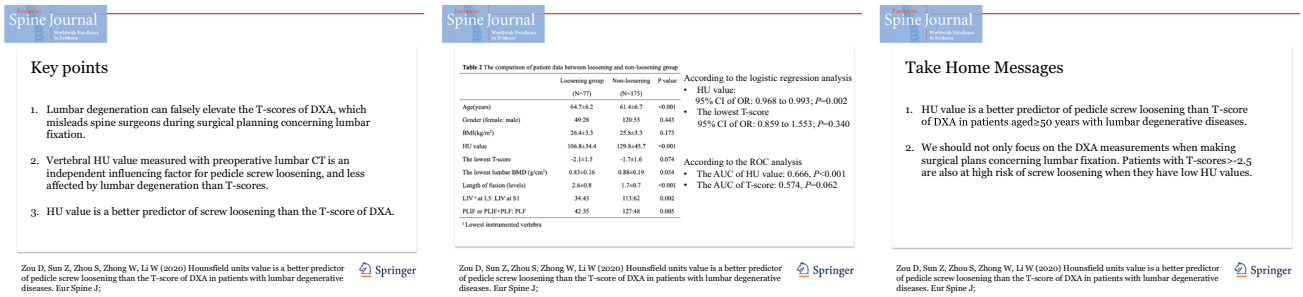
Methods We reviewed 253 patients aged ≥ 50 years undergoing pedicle screw fixation for lumbar degenerative diseases (LDD). The evaluation of screw loosening: radiolucent zones of ≥ 1 mm thick in X-ray. The criterion for osteoporosis: the lowest T-score ≤ − 2.5. The average HU value of L1–L4 was used to represent lumbar bone mineral density (BMD). The area under receiver operating characteristics curve (AUC) was used to evaluate the performance of predicting screw loosening.

Results One patient underwent reoperation for screw loosening at 9 months follow-up. At 12 months follow-up, the loosening rate was 30.6% (77/252) in the remaining 252 patients. Osteoporotic patients had higher loosening rate than non-osteoporotic patients (39.3% vs. 25.8%, $P = 0.026$). The T-score showed no significant difference between loosening group and non-loosening group (-2.1 ± 1.5 vs. -1.7 ± 1.6, $P = 0.074$), and so is the lowest lumbar BMD of DXA (0.83 ± 0.16 g/cm^2 vs. 0.88 ± 0.19 g/cm^2, $P = 0.054$). The HU value was lower in the loosening group (106.8 ± 34.4 vs. 129.8 ± 45.7, $P < 0.001$). The HU value (OR, 0.980; 95%CI 0.968–0.993; $P = 0.002$) was the independent influencing factor of screw loosening. The AUC of predicting screw loosening was 0.666 ($P < 0.001$) for HU value and 0.574 ($P = 0.062$) for T-score.

Conclusions HU value is a better predictor of pedicle screw loosening than T-score of DXA in patients aged ≥ 50 years with LDD. We should not only focus on the DXA measurements when making surgical plans concerning lumbar fixation.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



Keywords Pedicle screw loosening · Hounsfield units · T-score · Dual-energy X-ray absorptiometry · Lumbar degenerative diseases

Introduction

Pedicle screw fixation is a widely used technique for the surgical treatment of thoracolumbar diseases, which can stabilize the spine before solid fusion and restore spinal

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balance [1]. However, because of population aging and the high rate of osteoporosis in the elderly with lumbar degenerative diseases (LDD) [2], the screw loosening has become a frequently reported complication after pedicle screw fixation [3, 4]. The loose screws may cause chronic back, nonunion, and fixation failure, needing revision surgery [5–8]. Osteoporosis is a well-known risk factor for screw loosening. According to biomechanical studies [9], the bone–screw interface in osteoporotic spine is unstable, leading to reduced pullout force and cutout force. Clinical research showed that the pedicle screw loosening rate was less than 15% in non-osteoporotic patients and even up to 60% in osteoporotic patients [4].

Dual-energy X-ray absorptiometry (DXA) is nowadays the gold standard for the evaluation of bone mineral density (BMD), and its criterion for osteoporosis was the lowest T-score ≤ -2.5 [10, 11]. In order to prevent screw loosening, many spine surgeons have chosen patients with T-score of ≤ -2.5 as the target population for using pedicle screw augmentation techniques [3, 12–14]. Nevertheless, the lumbar degenerative changes of patients with LDD can overestimate T-scores and lead to false negative results [15, 16]. Consequently, the reports of DXA may mislead spine surgeons during preoperative surgical planning. Since 2011, the vertebral Hounsfield units (HU) value derived from clinical computed tomography (CT) has been regarded as a valid tool to evaluate BMD and detect osteoporosis [16–20]. It is less affected by lumbar degeneration than DXA by avoiding cortical bone and degenerative changes [16]. Furthermore, since lumbar CT is a common preoperative examination for patients requiring lumbar fusion, the HU value can be measured with lumbar CT images at no extra cost and radiation. Previous studies have also proved that HU value is a good predictor for pedicle screw loosening [7, 19, 21]. However, there is no study comparing the ability of predicting screw loosening between HU value and T-score. Given the influence of lumbar degeneration on DXA, this study hypothesized that HU value was a better predictor of screw loosening than T-score in patients aged ≥ 50 years with LDD.

Materials and methods

Patients

This study was approved by the Ethical Committee of our hospital, the informed consent was waived because this was a retrospective study. We reviewed patients undergoing posterior lumbar fusion with conventional pedicle screw fixation by a single surgical team between July 2011 and December 2015, at our orthopedic department. There were mainly three fusion types, including posterolateral fusion (PLF), posterior lumbar interbody fusion (PLIF), and the combination of PLF and PLIF. The autograft was harvested from decompression.

The inclusion criteria were (1) patients aged ≥ 50 years; (2) patients underwent posterior lumbar fusion with conventional pedicle screw fixation for lumbar degenerative diseases, including degenerative lumbar spinal stenosis, degenerative lumbar spondylolisthesis, lumbar disc herniation, and degenerative lumbar scoliosis; (3) the lowest instrumented vertebra was at L5 or S1; (4) the length of fusion with fixation was ≤ 4 levels (segments); (5) patients underwent lumbar CT and DXA at our hospital within 3 months before the surgery; (6) patients who were followed up 3, 6, and 12 months after the surgery.

The exclusion criteria were (1) patients with history of spinal surgery; (2) patients with bone tumor, ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis, rheumatoid arthritis, tuberculosis, or secondary osteoporosis; (3) patients with grade 3 or 4 spondylolisthesis; (4) patients with screw redirection or malposition; (5) patients underwent reoperation within 12 months after the surgery for any complication other than screw loosening.

BMD evaluation

All the patients underwent preoperative three-dimensional reconstructive lumbar CT (Siemens, DEFINITION, tube voltage 120 kV) and DXA scans (Discovery A densitometers, Hologic Inc, Bedford, MA, USA). The HU values of L1–L4 were measured independently by the first author (D. Z.) for every patient according to the method of previous studies [16, 18]. An oval region of interest (ROI) was placed in the middle-axial CT image of vertebral body (Fig. 1). Trabecular bone was included in the ROI, the cortical bone, and posterior venous plexus were excluded. Then, the picture archiving and communication system (PACS) calculated the HU value automatically. The average HU value of L1–L4 was used to represent the BMD of lumbar spine.

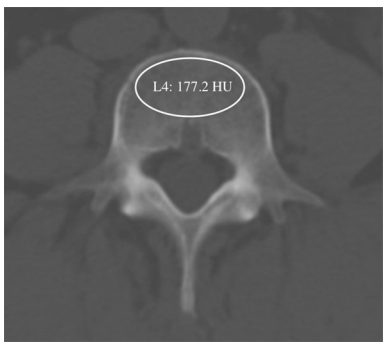

Fig.1 Example of the measurement of HU value: the HU value of L4 was 177.2

A total of 30 patients were randomly picked for the evaluation of reliability of HU measurements, and the L1 was chosen as the representative vertebrae. One month after the first author (D. Z.) measured the HU values of LI–L4 for every patient, he measured the HU values of L1 of the randomly picked 30 patients to evaluate intra-observer reliability. The co-first author (ZR. S.) also measured the HU values of L1 of these 30 patients to evaluate inter-observer reliability. When measuring the HU values, the two observers were blinded to the DXA results and the measurements of the other observer.

DXA scans were performed at L1–4, femoral necks, and total hips, the T-scores were derived using the NHANES III database. The criterion for osteoporosis was the lowest T-score ≤ -2.5 [10]. The lowest T-score and lowest lumbar BMD were recorded for the following analysis.

Follow-up assessment

The patients in this study were routinely followed up at 3, 6, and 12 months. The lumbar X-ray (anterior–posterior, lateral, and flexion–extension views) was performed preoperatively and at 3, 6, and 12 months postoperatively. The criterion of screw loosening was the presence of radiolucent zones of ≥ 1 mm thick around any pedicle screw in X-ray image [22, 23]. The first author (D. Z.) independently judged screw loosening for every patient. The randomly picked 30 patients mentioned above were also used for the evaluation of intra-observer reliability of judging screw loosening for D. Z., and the inter-observer reliability between D. Z. and the co-first author (ZR. S.). At 12 months follow-up, the patients diagnosed with screw loosening were divided into loosening group, the other patients were divided into non-loosening group. Lumbar CT was not routine examination for follow-up in our hospital, thus, we evaluated the fusion status with lumbar X-ray instead of CT at 12 months follow-up. The criterion of pseudarthrosis was the presence of segmental motion of $\geq 3°$ or intervertebral translation of ≥ 3 mm on lateral flexion–extension X-ray images, or without continuous fusion mass at bone graft site [24]. Clinical outcomes were assessed using the visual analog scale (VAS) and the Oswestry Disability Index (ODI) score during follow-up.

Statistical analysis

Statistical analysis was conducted using SPSS software (version 20, USA). Shapiro–Wilk tests were used to verify the normal distribution of continuous variables. The independent samples Student's *t* test was used for variables which followed normal distribution (the lowest T-score and BMI). The Mann–Whitney *U* test was used for those not following normal distribution (age, HU value, the lowest lumbar BMD, and levels of fusion). Intra-class correlation coefficient (ICC) was used to evaluate inter-observer and intra-observer reliability of HU measurements. (ICC ≥ 0.8 was considered to indicate excellent reliability.) The agreement of judging screw loosening on the X-rays was tested by kappa statistics. Chi-squared test was used for categorical data. Logistic regression analysis was used to identify the independent factors of screw loosening, and the results were presented as odds ratios (OR), with 95% confidence intervals. The receiver operating characteristics curve (ROC) was used to evaluate the value of predicting screw loosening, and the area under the curve (AUC) was calculated. $P < 0.05$ was considered to indicate a statistically significant difference.

Results

A total of 253 patients were included in the final analysis. One patient had reoperation for screw loosening at 9 months follow-up. This was a male patient aged 58 years who underwent lumbar decompression, and fusion with pedicle screw fixation at L2–L5. The lowest T-score of his DXA was −2.3, the lowest lumbar BMD was 0.816 g/m^2, but his HU value was 76.0. His ODI score before reoperation was 62.

The characteristics of the remaining 252 patients are summarized in Table 1. At 12 months follow-up, the rate of screw loosening was 30.6% (77/252). There were 179 loose screws in total. Most of (96.1%, 172/179) the loose screws were at the two ends of the fixation construct, with

Table 1 General information

Characteristics	All ($n=252$)
Age (years)	62.4 ± 6.7 (50–83)
Gender	
Female	169
Male	83
BMI (kg/m^2)	25.8 ± 3.4
HU value	122.8 ± 43.8
Average of the lowest T-score	− 1.79 ± 1.59
Average BMD of L1–L4 (g/cm^2)	0.92 ± 0.35
Length of fusion	
1 level	78
2 levels	112
3 levels	45
4 levels	17
The level of LIV[a]	
L5	147
S1	105
Fusion type	
PLIF or PLIF + PLF	169
PLF	83

[a]Lowest instrumented vertebra

41.9% (75/179) at the cranial end and 54.2% (97/179) at the caudal end.

The intra-observer and inter-observer reliability in measuring HU value was excellent with ICCs of 0.994 and 0.985, respectively. The kappa statistics values of the intra-observer and inter-observer reliability of judging screw loosening were 0.861 and 0.714, respectively.

The comparison of patient data between loosening and non-loosening group is shown in Table 2. The factors with P value of <0.1 in Table 2 were chosen as potential screw loosening influencing factors and put into the logistic regression, including age, HU value, the lowest T-score, length of fixation, level of LIV, and fusion method. The lowest lumbar BMD was not included in the logistic regression because it was highly correlated with T-score. According to the logistic regression, the length of fixation (OR, 3.504; 95% CI, 2.250–5.457; $P<0.001$) and HU value (OR, 0.980; 95% CI 0.968–0.993; $P=0.002$) were the independent influencing factor of screw loosening. The OR of the lowest T-score was 1.155 (95% CI, 0.859–1.553; $P=0.340$).

Based on ROC analysis, the HU value had significant ability in predicting screw loosening in spite of a relatively low AUC of 0.666 (95% CI, 0.598–0.735; $P<0.001$). The HU value with balanced sensitivity (62.3%) and specificity (62.3%) of predicting screw loosening was chosen as the cut-off value for identifying the high-risk patients, which was 108 HU. For the ease of clinical use, the cut-off value of 108 HU was adjusted to its next "multiple of ten" to 110 HU.

Table 2 The comparison of patient data between loosening and non-loosening group

	Loosening group ($N=77$)	Non-loosening group ($N=175$)	P value
Age (years)	64.7 ± 6.2	61.4 ± 6.7	< 0.001
Gender (female: male)	49:28	120:55	0.443
BMI (kg/m^2)	26.4 ± 3.3	25.8 ± 3.3	0.173
HU value	106.8 ± 34.4	129.8 ± 45.7	< 0.001
The lowest T-score	− 2.1 ± 1.5	− 1.7 ± 1.6	0.074
The lowest lumbar BMD (g/cm^2)	0.83 ± 0.16	0.88 ± 0.19	0.054
Length of fusion (levels)	2.6 ± 0.8	1.7 ± 0.7	< 0.001
LIV[a] at L5: LIV at S1	34:43	113:62	0.002
PLIF or PLIF + PLF: PLF	42:35	127:48	0.005

[a]Lowest instrumented vertebra

The lowest T-score and the lowest lumbar BMD of DXA were not significant predictors for screw loosening with the AUC of 0.574 (95% CI, 0.498–0.649; $P=0.062$) for the lowest T-score, and the AUC of 0.576(95% CI, 0.502–0.650; $P=0.054$) for the lowest lumbar BMD.

The prevalence of osteoporosis was 35.3% (89/252). The rate of screw loosening was higher in osteoporotic patients than non-osteoporotic patients (39.3% vs. 25.8%, $P=0.026$). Among the 89 osteoporotic patients, the 73 patients with HU value of ≤ 110 had higher loosening rate than the 16 patients with HU value of > 110 (43.8% vs. 18.8%), but the difference was not statistically significant ($P=0.063$). Among the 163 patients diagnosed with non-osteoporosis by DXA, there were 45 patients with HU value of ≤ 110, and they had significantly higher loosening rate than the rest 118 patients having HU value of > 110 (44.4% vs. 18.6%, $P<0.001$).

At 12 months follow-up, the rate of pseudarthrosis was 40.3% in loosening group and 3.4% in non-loosening group ($P<0.001$). The preoperative and postoperative VAS or ODI score showed no significant difference between loosening group and non-loosening group (Table 3).

Discussion

This study showed that the T-score of DXA was not sensitive enough to assess the risk of pedicle screw loosening in patients aged ≥ 50 years with LDD. The HU value derived from preoperative lumbar CT was a better predictor of screw loosening. Although previous studies have examined the relationship between pedicle screw loosening and BMD measured by DXA or HU, to the best of our knowledge, this is the first study comparing the ability of predicting screw loosening between these two methods of BMD evaluation. Moreover, our results indicated that patients with T-scores > − 2.5 were also at high risk of screw loosening when they had lower HU values of ≤ 110, thus, we should not only focus on the DXA measurements when making surgical plans concerning lumbar fixation.

The screw loosening rate (30.6%) in our study was a little higher than that of other studies. Tokuhashi et al. [25] found that screw loosening rate was 26.8% at 12 months follow-up in patients undergoing 1–4 levels of fixation. Ohtori et al. [26] and Kim et al. [27] reported that the loosening rate was 7–25% at 12 months follow-up for patients who mainly underwent short levels of fixation (1, 2 levels). The difference in loosening rate could be caused by the characteristics of patients and surgery procedures. In our study, the patients were at higher

Table 3 The comparison of clinical outcomes between loosening and non-loosening group

	Pre-operation			12 months follow-up		
	VAS (Back)	VAS (Leg)	ODI (%)	VAS (Back)	VAS (Leg)	ODI (%)
Loosening group	5.2 ± 2.2	6.2 ± 1.9	42.1 ± 21.7	2.9 ± 2.1	2.1 ± 2.2	22.8 ± 18.6
Non-loosening group	5.0 ± 2.0	5.6 ± 2.2	37.0 ± 18.7	2.4 ± 2.1	2.0 ± 2.1	19.7 ± 14.8

risk of screw loosening than those of the studies mentioned above, because they had a high prevalence of osteoporosis, and a relatively higher proportion of them underwent ≥ 3 levels of fixation.

The risk factors for pedicle screw loosening have been widely reported. In line with previous studies, we found that the potential risk factors for screw loosening included older age, low BMD, multi-level fixation, fixation to S1, and nonuse of PLIF [4, 8, 28–30]. In addition, the logistic regression analysis showed that the BMD measured in HU value and length of fixation were the only two independent influencing factors for screw loosening. Osteoporosis is the most frequently discussed cause of screw loosening. Our study showed higher rate of screw loosening in osteoporotic patients than non-osteoporotic patients, but the T-scores and BMD values of DXA had poor performance in identifying patients with screw loosening. Kim et al. reviewed patients aged ≥ 50 years undergoing lumbar fusion for LDD, they also found that the measurements of DXA were comparable between patients with screw loosening and those without (Lumbar BMD: 0.835 vs. 0.842 g/cm^2) [28]. On the contrast, other studies showed significantly lower DXA measurements in patients with screw loosening (Lumbar BMD: 0.720 vs. 0.922 g/cm^2; T-score: − 1.6 vs. − 0.8) [29, 31]. The most likely cause of these conflicting results is lumbar degeneration. It has been reported that lumbar degeneration can overestimate DXA measurements, and this problem can become more serious in patients with severe lumbar degeneration than patients with mild lumbar degeneration [16].

The measurement of CT HU value excludes the regions of cortical bone and degenerative structures, making the HU value less affected by lumbar degeneration. Previous studies reported that lower HU value was correlated with higher risk of screw loosening, and the average HU value of patients with screw loosening ranged from 77.3 to 116.4 [7, 21, 32]. In our study, the HU value had significant ability of distinguishing patients with screw loosening from those without screw loosening, but the value of AUC was lower than 0.75. This could be because that the occurrence of screw loosening is due to multifactors, such as length of fixation. HU value alone is not enough for a very accurate prediction. To reflect the real risk of screw loosening in patients who could have spurious T-scores, we established a cut-off value of 110HU for identifying high-risk patients. Our results showed that patients with HU value of ≤ 110 had much higher loosening rate than patients with HU value of > 110 in spite of T-scores of > − 2.5. Furthermore, the loosening rate of non-osteoporotic having HU value of ≤ 110HU was even comparable to that of the osteoporotic patients (44.4% vs. 39.3%). The possible cause was that the T-scores of these non-osteoporotic patients were falsely elevated by lumbar degeneration, and those having lower HU values were very likely to have osteoporotic lumbar spine [16]. However, recent studies only applied pedicle screw augmentation techniques to patients with T-scores of ≤ − 2.5, without considering the influence of lumbar degeneration on DXA measurements [3, 12–14]. Therefore, we recommend routinely measuring the HU value for surgical planning in patients with LDD when they had preoperative lumbar CT scans. If the spine surgeons plan to use special techniques to prevent screw loosening, the patients with HU value of ≤ 110 should also be chosen as candidates.

In spite of the positive correlation between screw loosening and pseudarthrosis, the clinical outcomes were comparable between loosening group and non-loosening group in our study. Tokuhashi et al. also reported that radiographic screw loosening was an important marker for pseudarthriosis, but had no significant correlation with postoperative JOA scores [25]. However, there is still no definite conclusion regarding the clinical relevance of screw loosening identified by radiolucent zones in lumbar in X-ray [4, 25, 28]. Therefore, more studies are needed to explore this issue further.

There are three main limitations of this study. Firstly, this is a retrospective study, more prospective studies are needed to verify the relationship between HU value and the risk of screw loosening. The validity of using HU value to guide surgical decision making also should be investigated. Secondly, we chose the 12 months follow-up as the time point for detecting screw loosening, a longer follow-up may offer more information about the clinical relevance of HU value and pedicle screw loosening. However, a follow-up of 12 months was already enough to achieve the aim of this study, which was to compare the ability of predicting screw loosening between HU value and T-score. Of note, the BMD usually has better correlation with the initial stability of lumbar fixation, the long-term stability is determined by fusion status rather than BMD [25]. Thirdly, this study recommends measuring HU values for patients with preexisting lumbar CT scans, we should not have the patients undergo routine lumbar CT scans only for the HU measurements. However, in some medical centers, lumbar CT scans are not routinely performed for every patient requiring lumbar surgery, in which case the HU value cannot be measured.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All data collection and analysis conducted in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

References

1. Boos N, Webb JK (1997) Pedicle screw fixation in spinal disorders: a European view. Eur Spine J 6:2–18
2. Chin DK, Park JY, Yoon YS, Kuh SU, Jin BH, Kim KS, Cho YE (2007) Prevalence of osteoporosis in patients requiring spine surgery: incidence and significance of osteoporosis in spine disease. Osteoporos Int 18:1219–1224. https://doi.org/10.1007/s00198-007-0370-8
3. Hoppe S, Keel MJB (2017) Pedicle screw augmentation in osteoporotic spine: indications, limitations and technical aspects. Eur J Trauma Emerg Surg 43:3–8. https://doi.org/10.1007/s00068-016-0750-x
4. Galbusera F, Volkheimer D, Reitmaier S, Berger-Roscher N, Kienle A, Wilke H-J (2015) Pedicle screw loosening: a clinically relevant complication? Eur Spine J 24:1005–1016. https://doi.org/10.1007/s00586-015-3768-6
5. Alanay A, Vyas R, Shamie AN, Sciocia T, Randolph G, Wang JC (2007) Safety and efficacy of implant removal for patients with recurrent back pain after a failed degenerative lumbar spine surgery. J Spinal Disord Tech 20:271–277. https://doi.org/10.1097/01.bsd.0000211283.14143.ad
6. Berjano P, Bassani R, Casero G, Sinigaglia A, Cecchinato R, Lamartina C (2013) Failures and revisions in surgery for sagittal imbalance: analysis of factors influencing failure. Eur Spine J 22:853–858. https://doi.org/10.1007/s00586-013-3024-x
7. Bredow J, Boese CK, Werner CML, Siewe J, Löhrer L, Zarghooni K, Eysel P, Scheyerer MJ (2016) Predictive validity of preoperative CT scans and the risk of pedicle screw loosening in spinal surgery. Arch Orthop Trauma Surg 136:1–5. https://doi.org/10.1007/s00402-016-2487-8
8. Röllinghoff M, Schlüter-Brust K, Groos D, Sobottke R, Michael JW-P, Eysel P, Delank KS (2010) Mid-range outcomes in 64 consecutive cases of multilevel fusion for degenerative diseases of the lumbar spine. Orthop Rev 2:3–4. https://doi.org/10.4081/or.2010.e3
9. Okuyama K, Sato K, Abe E, Inaba H, Shimada Y, Murai H (1993) Stability of transpedicle screwing for the osteoporotic spine. An in vitro study of the mechanical stability. Spine 18:2240–2245
10. Shepherd JA, Schousboe JT, Broy SB, Engelke K, Leslie WD (2015) Executive summary of the 2015 ISCD position development conference on advanced measures from DXA and QCT: fracture prediction beyond BMD. J Clin Densitom 18:274–286. https://doi.org/10.1016/j.jocd.2015.06.013
11. Hamdy RC, Petak SM, Lenchik L (2002) Which central dual X-ray absorptiometry skeletal sites and regions of interest should be used to determine the diagnosis of osteoporosis? J Clin Densitome 5(Suppl):S11–S18
12. Xie Y, Fu Q, Chen ZQ, Shi ZC, Zhu XD, Wang CF, Li M (2011) Comparison between two pedicle screw augmentation instrumentations in adult degenerative scoliosis with osteoporosis. BMC Musculoskelet Disord 12:286. https://doi.org/10.1186/1471-2474-12-286
13. Pinera AR, Duran C, Lopez B, Saez I, Correia E, Alvarez L (2011) Instrumented lumbar arthrodesis in elderly patients: prospective study using cannulated cemented pedicle screw instrumentation. Eur Spine J 20:408–414. https://doi.org/10.1007/s00586-011-1907-2
14. Dai F, Liu Y, Zhang F, Sun D, Luo F, Zhang Z, Xu J (2015) Surgical treatment of the osteoporotic spine with bone cement-injectable cannulated pedicle screw fixation: technical description and preliminary application in 43 patients. Clinics 70:114–119. https://doi.org/10.6061/clinics/2015(02)08
15. Muraki S, Yamamoto S, Ishibashi H, Horiuchi T, Hosoi T, Orimo H, Nakamura K (2004) Impact of degenerative spinal diseases on bone mineral density of the lumbar spine in elderly women. Osteoporos Int 15:1–5. https://doi.org/10.1007/s00198-004-1600-y
16. Zou D, Li W, Deng C, Du G, Xu N (2019) The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases. Eur Spine J 28:1758–1766. https://doi.org/10.1007/s00586-018-5776-9
17. Pompe E, de Jong PA, de Jong WU, Takx RAP, Eikendal ALM, Willemink MJ, Oudkerk M, Budde RPJ, Lammers J-WJ, Hoesein FAAM (2016) Inter-observer and inter-examination variability of manual vertebral bone attenuation measurements on computed tomography. Eur Radiol. https://doi.org/10.1007/s00330-015-4145-x
18. Pickhardt PJ, Pooler BD, Lauder T, del Rio AM, Bruce RJ, Binkley N (2013) Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. Ann Intern Med 158:588–522. https://doi.org/10.7326/0003-4819-158-8-201304160-00003
19. Zaidi Q, Danisa OA, Cheng W (2019) Measurement techniques and utility of Hounsfield unit values for assessment of bone quality prior to spinal instrumentation: a review of current literature. Spine 44:E239–E244. https://doi.org/10.1097/BRS.0000000000002813
20. Anderson PA, Polly DW, Binkley NC, Pickhardt PJ (2018) clinical use of opportunistic computed tomography screening for osteoporosis. J Bone Joint Surg Am 100:2073–2081. https://doi.org/10.2106/JBJS.17.01376
21. Schwaiger BJ, Gersing AS, Baum T, Noel PB, Zimmer C, Bauer JS (2014) Bone mineral density values derived from routine lumbar spine multidetector row CT predict osteoporotic vertebral fractures and screw loosening. Am J Neuroradiol 35:1628–1633. https://doi.org/10.3174/ajnr.A3893
22. Spirig JM, Sutter R, Götschi T, Farshad-Amacker NA, Farshad M (2018) Value of standard radiographs, CT and MRI of the lumbar spine in detection of intraoperatively confirmed pedicle screw loosening—a prospective clinical trial. Spine J. https://doi.org/10.1016/j.spinee.2018.06.345
23. Sanden B, Olerud C, Petren-Mallmin M, Johansson C, Larsson S (2004) The significance of radiolucent zones surrounding pedicle screws. Definition of screw loosening in spinal instrumentation. J Bone Jt Surg Ser B 86:461–457
24. Larsen JM, Rimoldi RL, Capen DA, Nelson RW, Nagelberg S, Thomas JC Jr (1996) Assessment of pseudarthrosis in pedicle screw fusion: a prospective study comparing plain radiographs, flexion/extension radiographs, CT scanning, and bone scintigraphy with operative findings. J Spinal Disord 9:117–120
25. Tokuhashi Y, Matsuzaki H, Oda H, Uei H (2008) Clinical course and significance of the clear zone around the pedicle screws in the lumbar degenerative disease. Spine 33:903–908
26. Ohtori S, Inoue G, Orita S, Yamauchi K, Eguchi Y, Ochiai N, Kishida S, Kuniyoshi K, Aoki Y, Nakamura J, Ishikawa T, Miyagi M, Kamoda H, Suzuki M, Kubota G, Sakuma Y, Oikawa Y, Inage K, Sainoh T, Takaso M, Toyone T, Takahashi K (2013) Comparison of teriparatide and bisphosphonate treatment to reduce pedicle screw loosening after lumbar spinal fusion surgery in postmenopausal women with osteoporosis from a bone quality perspective. Spine 38:E487–E492. https://doi.org/10.1097/BRS.0b013e31828826dd
27. Kim JW, Park S-W, Kim Y-B, Ko MJ (2018) The effect of postoperative use of teriparatide reducing screw loosening in osteoporotic patients. J Korean Neurosurg Soc 61:494–502. https://doi.org/10.3340/jkns.2017.0216
28. Kim HJ, Kim SG, Lee HM, Kim HS, Moon ES, Park JO, Seol NH, Moon SH (2008) Risk factors associated with the halo phenomenon after lumbar fusion surgery and its clinical significance. Asian Spine J 2:22–26. https://doi.org/10.4184/asj.2008.2.1.22

29. Okuyama K, Abe E, Suzuki T, Tamura Y, Chiba M, Sato K (2001) Influence of bone mineral density on pedicle screw fixation: a study of pedicle screw fixation augmenting posterior lumbar interbody fusion in elderly patients. Spine J 1:402–407
30. Orita S, Ohtori S, Eguchi Y, Kamoda H, Arai G, Ishikawa T, Miyagi M, Inoue G, Ochiai N, Kishida S, Takaso M, Aoki Y, Takahashi K (2010) Radiographic evaluation of monocortical versus tricortical purchase approaches in lumbosacral fixation with sacral pedicle screws: a prospective study of ninety consecutive patients. Spine 35:E1230–E1237
31. Kim J-B, Park S-W, Lee Y-S, Nam T-K, Park Y-S, Kim Y-B (2015) The effects of spinopelvic parameters and paraspinal muscle degeneration on S1 screw loosening. J Korean Neurosurg Soc 58:356–357. https://doi.org/10.3340/jkns.2015.58.4.357
32. Bokov A, Bulkin A, Aleynik A, Kutlaeva M, Mlyavykh S (2018) Pedicle screws loosening in patients with degenerative diseases of the lumbar spine: potential risk factors and relative contribution. Global Spine J. https://doi.org/10.1177/2192568218772302

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