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# Characteristics of CT Hounsfield Unit Values in Lumbar Vertebrae and Lumbar Pedicl–A comparative study based on CT Scans and Dual-Energy X-ray Absorptiometry (DEXA)

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Research Article

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## ABSTRACT

**Purposes**: The purpose of this study was to evaluate CT HU value in specific regions of the Lumbar Spine and investigate the correlation between their CT HU values and the corresponding bone quality index provided by Dual-Energy X-ray Absorptiometry (DEXA).

**Methods**: A total of 32 Chinese adults with lumbar degenerative disc disease requiring diagnostic lumbar CT and DEXA at our hospital were retrospectively reviewed in this study. The HU value of medial cortical area (mHU), lateral cortical area (lHU) and trabecular area (tpHU) of the pedicle and superior portion, middle portion, inferior portion of the vertebral body (sHU, mbHU, iHU, respectively) were measured on CT images. T score and BMD score of each vertebra were also measured by DEXA. The HU value was compared between sex groups, vertebra and the correlations of HU value with DEXA T-score; DEXA BMD-score were analyzed.

**Results:**In vertebral body, the value of mHU is the lowest ($p<0.001$) while mbHU and iHU are not significantly different. The tpHU had the lowest HU value compared to mHU and lHu. mHU had significantly higher value than lHU at all levels ($p<0.001$). The value of mHU and lHU is found correlated with T-scores ($p<0.01$) at all lumbar levels. The value of tpHU is not correlated with either T-scores or BMD ($p>0.05$). The HU values of all vertebral body regions at all lumbar levels (sHU,mbHU,iHU) correlate strongly with T-scores and BMD($r>0.6$, $p<0.01$).

**Conclusions:** CT HU value could be a reliable indicator for regional bone quality, especially in people with lumbar degenerative changes. The superior portion of the lumbar vertebra had the lowest bone density in comparison with other regions of the vertebra at L1-L4. In lumbar pedical, the medial lateral cortical bone area had higher bone density than the lateral cortical bone and trabecula bone area.

## INTRODUCTION

Osteoporosis is a skeletal disorder characterized by loss of bone mass and weakness in bone strength [1]. This condition, especially in elderly population, has become a serious health problem all around the world. It is

estimated that the prevalence of osteoporosis in people over 50 has risen closer to 30% in the past 10 years in China [2]. Patients who suffered from osteoporosis are at an increased risk of vertebral compression fracture, motor dysfunction and mortality compared to those that have normal bone quality [3]. In addition, it also leads to some certain complication after spine surgery, such as loosening of pedicle screw [4,5], which can result in sagittal imbalance, failure in fusion and revision surgery. Surgeons usually estimate the pullout strength of pedicle screw based on the intraoperative feeling of screw insertion. However, it was subjective and not that accurate.

As Bone Mineral Density (BMD) is an objective and important factor that affects the pullout strength, the evaluation of BMD by Dual-Energy X-Ray Absorptiometry (DEXA) and Quantitative Computed Tomography (QCT) is often performed clinically and has proven its efficacy but also some limitations [6-8]. DEXA cannot differentiate cortical bone and trabecular bone, and its result is easily influenced by osteophytes and calcification of the abdominal aorta [9,10]. QCT brings additional cost and radiation, and has not been popularized in hospital at all levels yet [11,12]. Currently, CT Hounsfield Unit (HU) measurement has shown its ability to predict the pedicle screw fixation and had correlation with and QCT indices. It is convenient and does not need extra cost and radiation, as lumbar spine CT is a routine examination preoperatively for those patients needing fusion surgery [13-15].

The Diagnostic Computed Tomography (CT) has been proved to be an effective alternative tool to measure regional bone quality. Although previous studies have focused on the feasibility of CT HU measurement and demonstrated its value of estimation on the screw trajectory, no precedent research have provided CT HU values in different regions of the lumbar spine. Thus, in this study we aimed to evaluate CT HU value in specific regions of the Lumbar Spine and investigate the correlation between their CT HU values and the corresponding bone quality index provided by Dual-Energy X-ray Absorptiometry (DEXA).

## MATERIALS AND METHODS

### Study participants

The population of this study consisted of the patients with lumbar degenerative disc disease coming to our hospital to receive lumbar spine surgery from November 2018 to March 2019. All routine preoperative CT images and data were retrospectively reviewed. The inclusion criteria were (1) men over 60 year's old or postmenopausal women and (2) lumbar spine CT and were performed within 1 month before surgery. Patients were excluded if (1) there were any type of Modic changes; (2) suspected metastatic lesions, scoliosis, lumbar spine infections, vertebral fractures, ankylosing spondylitis, lumbar surgery; (3) Grade III or IV osteophytes in vertebral body [16]; (4) obvious calcification of abdominal aorta. Finally, a total of 32 patients were eligible and included for further analysis. As we retrospectively assessed patients' imaging and data, the study was conducted with the human subjects' understanding and consent. The Ethical Committee of Huashan Hospital affiliated to Fudan University approved the experiments.

### Image acquisition

The participants of this study were scanned using Siemens CT scanner (Dual Source Computed Tomography, DEFINITION, tube voltage 120 kV) with 1.5 mm slice thickness and a Dual-Energy X-Ray Absorptiometry (DEXA) scanner (Discover A Densitometers, Hologic Inc, USA). The bone density of all given lumbar vertebra was expressed by T-scores and BMD scores. The CT images of L1-L4 from all the participants were derived though the Picture Achieving And Communication System (PACS). On the midsagittal plane, we place a rectangle Region of Interest (ROI) on L1-L4 vertebra to measure the mean HU value of the superior portion (sHU), the middle portion (mbHU) and the inferior portion (iHU) of each vertebra. The principle of ROI placement in this case is to include as much trabecular bone as possible and to avoid cortical bone and heterogeneous areas (Figure 1). The mid-axial images of the any given vertebral pedical from L1 to L4 were derived and followed by locating the sagittal images of the largest supra-inferior diameter. The mean HU value of the trabecula bone area (tpHU), medial cortical bone area (mHU) and lateral cortical bone area (lHU) were measured on the mid-axial images of each vertebral pedical through PACS (Figure 2). The HU value remains the same in different CT windows.

**Figure 1.** Example of CT HU value measurement in specific regions of lumbar vertebra: a rectangle region of interest (ROI) were placed on L1-L4 vertebra to measure the mean HU value of the superior portion (sHU), the middle portion (mbHU) and the inferior portion (iHU) of each vertebra. PACS software automatically shows mean HU value of the ROI.

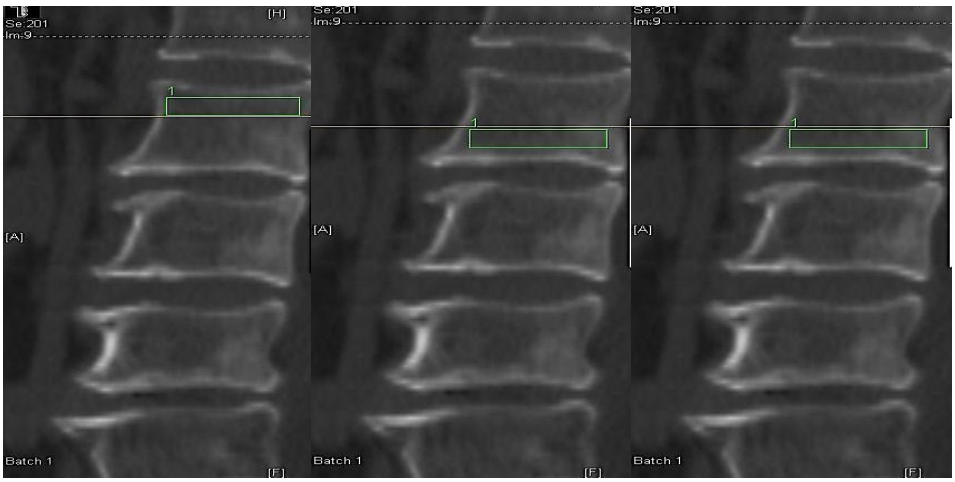
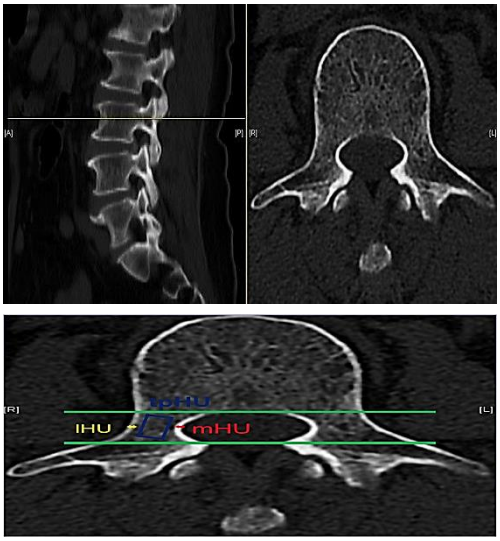



**Figure 2.** Example of CT HU value measurement in specific regions of lumbar pedical: The mean HU value of the trabecula bone area (tpHU), medial cortical bone area (mHU) and lateral cortical bone area (lHU) were measured on the mid-axial images of each vertebral pedical through PACS. The mid-axial images of the any given vertebral pedical from L1 to L4 were derived and followed by locating the sagittal images of the largest supra-inferior diameter.




## Statistical analysis

Means, Standard Deviation (SD) of the parameters and the differences in HU value amongst different lumbar pedical areas, lumbar vertebral body areas at the same level and those amongst different levels were analyzed statistically with T-test (ANOVA). The correlation between HU value and BMD, T-scores were evaluated with Pearson's correlation coefficient. SPSS version 21 was used for the statistical analysis of this study.

## RESULTS

The mean HU values of all measured regions are shown in Table 1. The result showed no significant intersexual differences in HU value of both vertebral pedical and vertebral body regions. Therefore, we were able to combine the data of male and female group (Table 1).

**Table 1**. Mean HU values of specific Lumbar Spine regions. P>0.05.

| | | Female | Male | |
|---|---|---|---|---|
| Level | Parameter | Mean ± SD | Mean ± SD | p |
| L1 | tpHU | 175.3 ± 85.48 | 153.7 ± 59.19 | 0.513 |
| | mHU | 964.7 ± 328.4 | 1131.5 ± 280.6 | 0.209 |
| | lHU | 559.9 ± 161.37 | 675.7 ± 63.22 | 0.059 |
| | sHU | 118.9 ± 47.07 | 144.9 ± 68.98 | 0.266 |
| | mbHU | 136.8 ± 56.39 | 171.7 ± 69.54 | 0.188 |
| | iHU | 133.4 ± 52.36 | 182.3 ± 87.74 | 0.08 |
| L2 | tpHU | 174.6 ± 72.42 | 147.7 ± 60.86 | 0.355 |
| | mHU | 962.3 ± 297.9 | 1147.4 ± 310.9 | 0.142 |
| | lHU | 587.6 ± 182.5 | 717.3 ± 109.1 | 0.069 |
| | sHU | 111.7 ± 47.68 | 139.1 ± 68.37 | 0.244 |
| | mbHU | 129.8 ± 56.30 | 158.0 ± 89.40 | 0.327 |
| | iHU | 121.9 ± 50.10 | 171.3 ± 91.33 | 0.076 |
| L3 | tpHU | 173.9 ± 62.72 | 168.2 ± 60.44 | 0.825 |
| | mHU | 1025 ± 326.9 | 1179 ± 309.7 | 0.251 |
| | lHU | 610.9 ± 192.62 | 754.1 ± 84.00 | 0.052 |
| | sHU | 103.3 ± 47.75 | 148.9 ± 85.28 | 0.082 |
| | mbHU | 119.4 ± 59.16 | 163.1 ± 87.54 | 0.142 |
| | iHU | 120.6 ± 51.70 | 168.6 ± 90.84 | 0.088 |
| L4 | tpHU | 169.9 ± 59.87 | 172.5 ± 63.13 | 0.917 |
| | mHU | 999.5 ± 296.9 | 1109.6 ± 301.4 | 0.373 |
| | lHU | 588.1 ± 194.0 | 637.4 ± 124.0 | 0.507 |
| | sHU | 100.8 ± 37.50 | 139.2 ± 68.23 | 0.063 |
| | mbHU | 127.5 ± 51.33 | 162.9 ± 86.75 | 0.187 |
| | iHU | 127.3 ± 55.60 | 176.7 ± 106.15 | 0.111 |

### The characteristics of CT HU value in specific lumbar spine regions

In vertebral body, the value of mHU is the lowest (p<0.001) while mbHU and iHU are not significantly different. Meanwhile, the differences in the mean value of mbHU and iHU are not significant. The HU values of all vertebral

regions between different lumbar levels are not significantly different. In vertebral pedical, there's no significant differences between the left side and the right side ($p>0.05$) and the tpHU had the lowest HU value compared to mHU and lHu. mHU had significantly higher value than lHU at all levels ($p<0.001$). The tendency of mean HU value at all lumbar levels is demonstrated in Figure 3 and Figure 4.

**Figure 3.** The tendency of mean HU value in specific regions of lumbar vertebra according to lumbar level.

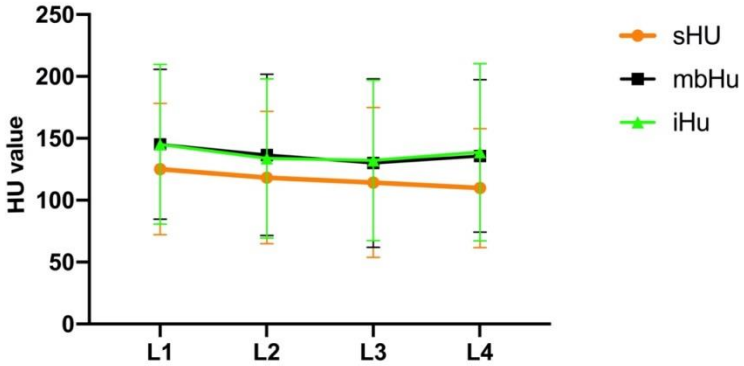
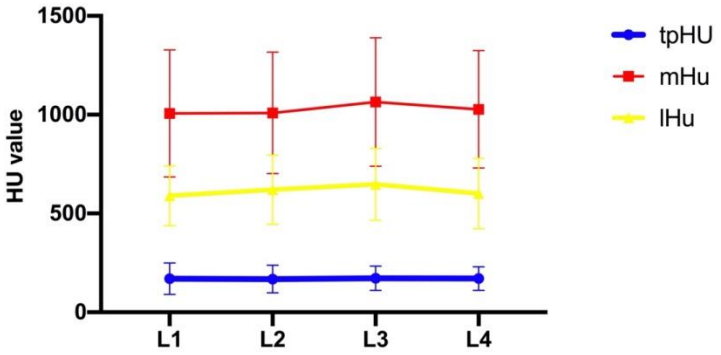



**Figure 4.** The tendency of mean HU value in specific regions of lumbar pedicle according to lumbar level.




## The correlation between CT HU values and the corresponding DEXA's BMD score, T-score in specific lumbar spine regions

In vertebral pedical, the value of mHU and lHU is found correlated with T-scores ($p<0.01$) at all lumbar levels. There's close correlation between mHU value and T-scores, BMD($r>0.6$, $p<0.01$) while the correlation between lHU value and T-scores is not remarkable ($0.4<r<0.6$, $p<0.01$). There's no correlation found between lHU value and BMD. The value of tpHU is not correlated with either T-scores or BMD ($p>0.05$). The HU values of all vertebral body regions at all lumbar levels (sHU,mbHU,iHU) correlate strongly with T-scores and BMD($r>0.6$, $p<0.01$). The correlation of HU value in measured regions and DEXA T-scores, DEXA BMD are demonstrated in Figures 5-7.

**Figure 5.** The correlation between mHU, lHU and corresponding DEXA T-score. There's close correlation between mHU value and T-scores ($r>0.6$, $p<0.01$) while the correlation between lHU value and T-scores is not remarkable ($0.4<r<0.6$, $p<0.01$).

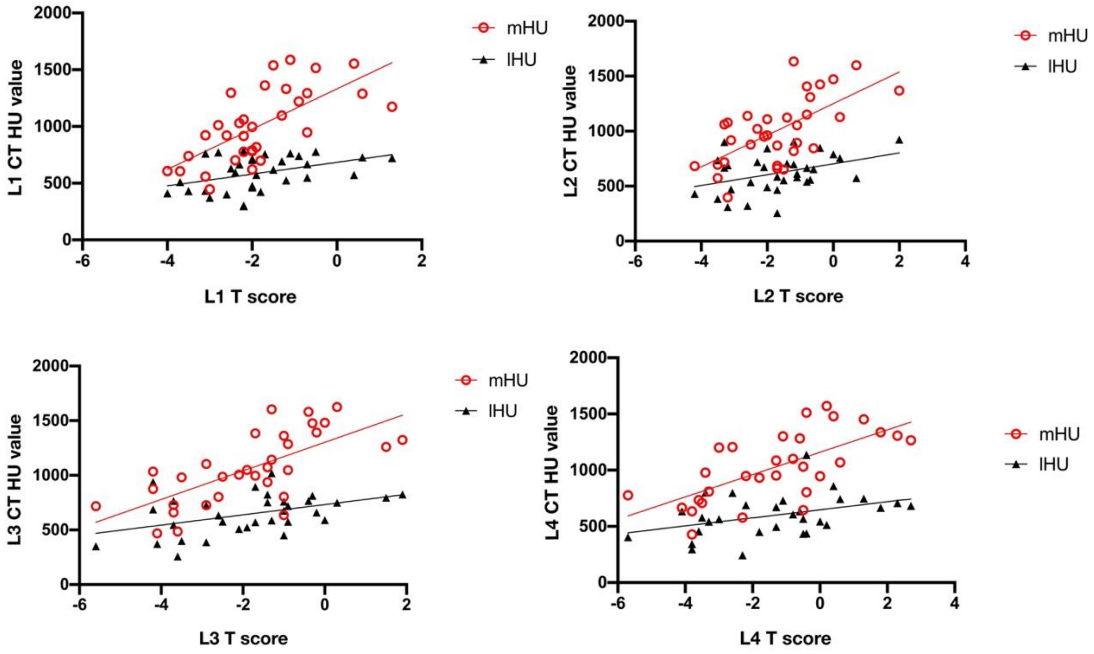



**Figure 6.** The correlation between sHU, mbHU, iHU and corresponding DEXA T-score. The HU values of sHU, mbHU, iHU correlate strongly with DEXA T-scores at all lumbar levels (r>0.6, p<0.01).

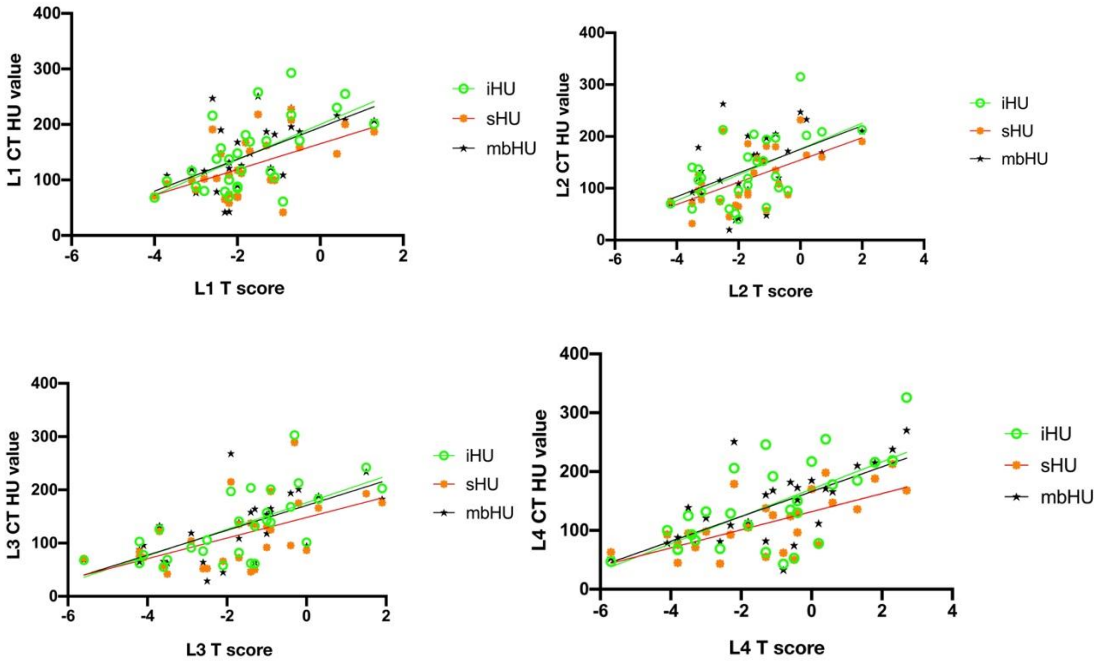
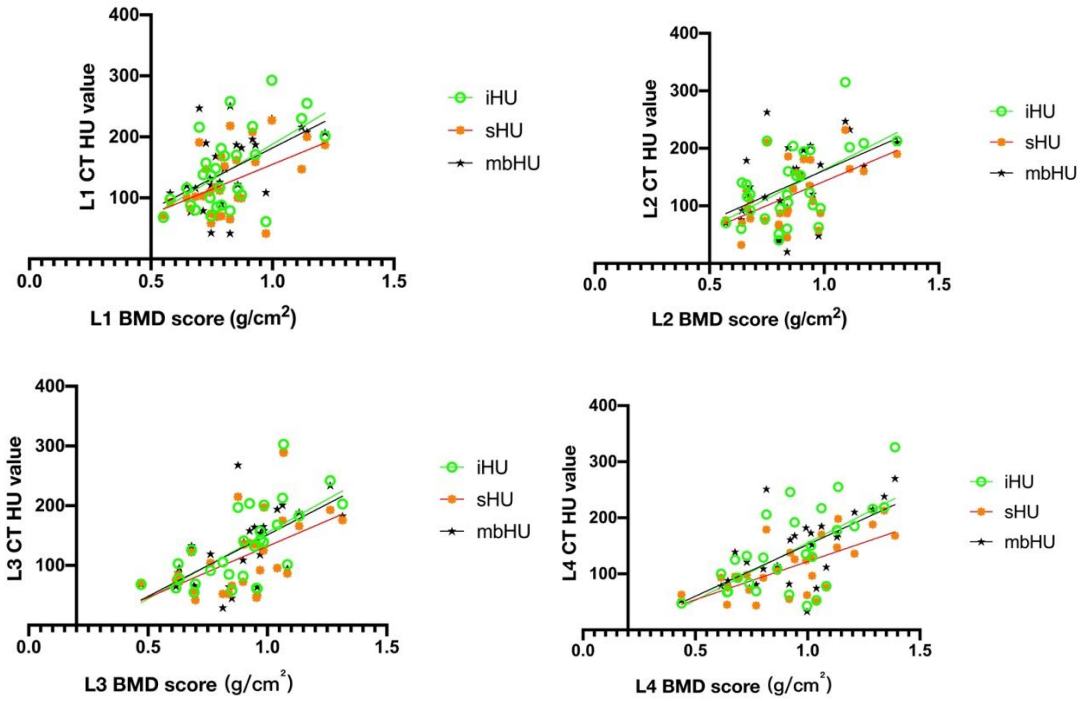



**Figure 7.**The correlation between sHU, mbHU, iHU and corresponding DEXA T-score. The HU values of sHU, mbHU, iHU correlate strongly with DEXA BMD at all lumbar levels (r>0.6, p<0.01).




## DISCUSSION

Researchers have revealed that The BMD scores and T-scores provided by DEXA are increased causing the bone quality overestimation of the lumbar spine in people with degenerative changes [17,18]. Besides, Quantitative Computed Tomography (QCT) has been studied and proved highly effective for detecting different vertebral regions. But since it is not a conventional examination for people requiring lumbar surgery, it brings extra cost and demands specialized technicians to process. Furthermore, since HU values derived from Computed Tomography (CT) have been proved to be a reliable indicators for regional bone quality [19,20], in this study, we collected the data from CT to assess the bone quality in different regions of the vertebral body (sHU,mbHU,iHU), the vertebral pedical (mHU, tpHU, lHU) and evaluate the correlation of CT HU values in these specific regions with the corresponding T-scores, BMD in people that have Grade I or Grade II osteophytes in L1-L4 vertebral body. We found that the HU values of most regions in L1-L4 including vertebra and pedical correlate with T scores and BMD measured by DEXA. With this result, we have verified the feasibility and the availability of CT to determine local bone quality in lumbar spine. While the HU values of all vertebral body regions and medial cortical bone of the pedical have strong correlation with T-scores and BMD at L1-L4($r>0.6$, $p<0.01$), those of the trabecula bone areas in lumbar pedical do not. This means BMD provided by is not a suitable indicator for trabecula bone quality of the lumbar pedical. The Traditional Pedical Screw (TPS) technique has been the most common surgical method for patient requiring posterior lumbar fusion. With this technique, the pedical screws are placed transverse to the anatomical axis of lumbar pedical in axial plane and parallel to the superior end plate in the sagittal plane. Therefore, trabecular, bone in both lumbar pedical and vertebra play an important role in providing the stabilization of pedical screw fixation following traditional trajectory. Consequently, is not a reliable tool in measuring regional bone quality of the lumbar spine to aid spinal surgeons with the surgical decision making for osteoporotic patients? Additionally, with CT HU measurement's precision of assessing regional bone quality, it has become a reliable substitute of for pre-operative bone quality assessment and further testing, especially for people with osteoporosis.

The mean Hu values of sHU are higher than mbHU and iHU at all lumbar vertebral bodies while there are no differences between mbHU and iHU. This result demonstrated that the superior portion of the lumbar vertebra at L1-L4 is thinner and have lower bone quality than other portions. This may support the morphometric mechanism of the clinical finding that in most people diagnosed with Osteoporotic Vertebral Compression Fracture (OVCF), the fracture mostly happened in the mid-portion and superior portion of the vertebra. The bone mineral density directly affects the pullout strength and the insertional torque in lumbar fixation so it's essential to assess local bone quality in purpose of enhancing the surgical stabilization. Clinically, spinal surgeons are recommended to angulate the insertion towards the subchondral bone near the end plate to achieve stronger fixation in osteoporotic patients [21,22]. In addition to this surgical recommendation we suggest surgeons to aim for the lower endplate as with this

insertion angle, the screw trajectory will avoid the top portion of the vertebra to penetrate the stronger regions of it, resulting in optimal pull out strength and better screw fixation[23,26]. Meanwhile, previous studies have revealed that pedical screw insertion with medial angle in a triangular configuration with a transverse connector can enhance the screw length to improve pullout strength [27-29]. Therefore, we believe that medially, inferiorly angulated insertion is recommended for osteoporotic patients undergoing pedical screw fixation with traditional trajectory technique to achieve better pull-out strength.

In the vertebral pedical, we found that the HU value of the trabecula bone area is lower than the medial cortical bone and the lateral cortical bone. This result indicated that trabecula bone areas are much thinner and weaker than cortical bone areas at all lumbar levels from L1 to L4. In the last decade, Cortical Bone Trajectory (CBT) technique has been developed to enhance the screw purchase in osteoporotic spine [24]. In 2009, Cortical Bone Trajectory (CBT) was introduced for the first time by Santoni et al.[30] and since then many morphometric and biomechanical studies have been proceeded and shown the advantages of CBT over tradition trajectory in providing better stabilization and fixation, especially for people with osteoporosis. The insertion of CBT is on the medial side of the pars interarticularis, and the screw path is medial-to-lateral in axial plane and caudocephalad in the sagittal plane through the pedical. For this reason, the CBT covers 4 cortical bone areas: the dorsal, posteromedial, and anterolateral sides of the pedicle, and the lateral region of the vertebra which means in comparison with TT, CBT provides greater engagement between the screw and the cortical bone of lumbar pedical. Besides, it has been revealed that the trabecula bone of the vertebra changes most rapidly due to osteoporosis compared to other regions and total bone quality of the lumbar spine [31]. Therefore, the results of our study are consistent with previous biomechanical and morphometric findings about CBT technique's predominant stabilization over TT, especially in osteoporotic patients. Additionally, present study revealed that medial cortical bone area had the highest HU values in comparison to other portions of the lumbar pedical. This result demonstrated that the medial zone of the pedical not only had thicker cortical bone, but had higher HU values and bone density than the lateral cortical bone of the lumbar pedicle. Understandably, CBT technique took advantage of this portion of higher bone density in the lumbar pedical.

However, the present study has several limitations that should be acknowledged. Firstly, HU value is not a definite reflection of the strength of bone. Although HU value has been studied and proved to be a reliable indicator of regional bone quality, there are many biomechanical factors that directly influence the bone strength. That's why further biomechanical studies should be conducted to measure the real penetrating force of specific regions of lumbar spine and evaluate the correlation between it and HU value to provide surgeons a better pre-operative assessment about region bone quality. Second, we didn't investigate the osteoporosis criteria of trabecula bone area of the lumbar pedical. Zou D et al. [18] suggested an osteoporosis criterion of lumbar vertebra based on CT HU values in people with lumbar degenerative diseases. Therefore, it'd be convenient and meaningful to have similar criteria for trabecula bone in lumbar pedical so surgeons can optimize surgical plans, especially for patients with osteoporosis and lumbar degenerative changes. Third, even though we excluded patients with obvious calcification of abdominal aorta from this study, mild calcification of the vascular and ligament ossification structure still can influence BMD causing possible low liability of the results.

## CONCLUSION

Although DEXA is still the first choice for general bone density, CT HU value has been proved to be a reliable indicator for regional bone quality, especially in people with lumbar degenerative changes. The superior portion of the lumbar vertebra is the weakest portion in comparison with other regions of the vertebra at L1-L4. Medially, inferiorly angulated insertion may enhance pull-out strength in osteoporotic patients undergoing pedical screw fixation with traditional trajectory technique. In lumbar pedical, the medial lateral cortical bone area had higher bone density than the lateral cortical bone and trabecula bone area supporting the advantages of cortical bone trajectory in providing pedical screw stabilisation over traditional pedicle screw trajectory.

## Data Availability

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

## Conflicts of Interest

All authors declare that they have no conflicts of interest.

## Authors' Contributions

Viet Anh Nguyen, Chi Sun, and Haocheng Xu contributed equally to this work and should be considered as the co-first authors.

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