Original Article

AO SPINE

Global Spine Journal
2026, Vol. 16(7) 3190-3200
© The Author(s) 2026
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/21925682261426267
journals.sagepub.com/home/gsj
Sage

Comparative CT-Based Bone Density of Traditional Pedicle Screw Trajectory, Cortical Bone Trajectory, and Modified Cortical Bone Trajectory — Radiographic Analysis of 3500 Simulated Pedicle-Screw Trajectories in 1750 Lumbar Vertebrae

Sathish Muthu, MS DNB PhD[1,2], Kavya Priyadharshini Natarajan, MD[3], Vibhu Krishnan Viswanathan, MS[1,4], Dhibin Vikash Kolarpatti Ponnusamy, BS[5], Sathish Kumar Rajappan Chandra, MD[6], and Khan Sharun, PhD[7]

Abstract

Study Design: Retrospective study.

Objective: To evaluate and compare bone density along the traditional pedicle trajectory(TPT), cortical bone trajectory(CBT), and modified cortical bone trajectory(mCBT) using computed tomography(CT)-derived Hounsfield unit(HU) measurements.

Methods: CT scans of the lumbar spine (L1–L5) of adult patients undergoing CT for non-spinal indications (predominantly younger adults) were retrospectively analyzed. Three pedicle screw trajectories were virtually simulated: TPT, CBT, and mCBT. For each trajectory, CTHU values were measured in sagittal section at four anatomical points along the screw path: posterior cortex, mid-pedicle, mid-vertebral body, and anterior vertebral body cortex using multiplanar reconstruction. Mean CTHU values, maximum screw lengths were compared across trajectories, and subgroup analyses were performed for age and sex.

Results: A total of 350 patients (1750 vertebrae) were analyzed. Mean CTHU values differed significantly among trajectories: CBT (538.2 ± 73.1HU) >mCBT (472.6 ± 87.9HU) >TPT (362.8 ± 68.4HU) ($P < .001$). At the posterior cortex, density was highest for CBT (1128.9 ± 147.6 HU), followed by mCBT (962.4 ± 192.7 HU) and TPT (582.1 ± 162.3HU). Across mid-pedicle, mid-body, and anterior cortex, CBT and mCBT showed comparable values, both significantly greater than TPT. mCBT showed significantly increased length of screw compared to CBT and TPT($P < .001$). Age negatively correlated with CTHU across all trajectories, most pronounced in TPT ($r = -0.36, R^2 = 0.13$). Gender differences were significant only for TPT ($P < .05$).

Conclusion: In this radiographic anatomical study of predominantly young adults, CBT and mCBT trajectories traversed higher CT-HU than the traditional pedicle path. These observations are hypothesis-generating and require validation in DEXA-verified osteoporotic cohorts and biomechanical and clinical studies before clinical recommendations can be made.

[1] Department of Spine Surgery, Orthopaedic Research Group, Coimbatore, India
[2] Central Research Laboratory, Meenakshi Medical College Hospital and Research Institute, Meenakshi Academy of Higher Education and Research, Chennai, India
[3] Department of Radiodiagnosis, Government Medical College, Karur, India
[4] Department of Orthopaedic Surgery, University of Alabama, Birmingham, AL, USA
[5] Department of Orthopaedics, Government Medical College, Karur, India
[6] Clinical Trial & Research Unit, Interdisciplinary Institute of Indian System of Medicine (IIISM), SRM Institute of Science and Technology, Kattankulathur, India
[7] Graduate Institute of Medicine, Yuan Ze University Taoyuan, Taiwan

Corresponding Author:
Sathish Muthu, MS DNB PhD, Department of Spine Surgery, Orthopaedic Research Group, Ramananthapuram, Coimbatore 641045, India.
Email: drsathishmuthu@gmail.com

Creative Commons Non Commercial No Derivs CC BY-NC-ND: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 License (https://creativecommons.org/licenses/by-nc-nd/4.0/) which permits non-commercial use, reproduction and distribution of the work as published without adaptation or alteration, without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

Keywords
cortical bone trajectory, modified cortical bone trajectory, pedicle screw, bone mineral density, hounsfield unit

Introduction

The pedicle screw (PS) technique was initially described by Roy Camille in 1963[1] and has remained the gold standard treatment for lumbar spine stabilisation, providing excellent anchorage across the three columns of the spine.[2] However, the insertional torque and pull-out strength of traditional PS are reported to be substantially compromised in osteoporotic bones, which may lead to mechanical complications such as implant failure, pseudoarthrosis and kyphotic collapse.[3,4] This relatively poor anchorage of PS in weaker bones has been attributed to the significant loss of density within the cancellous bones (especially in the elderly), which is crucial to facilitate the bonding between the screw and the vertebral body.[3,5] With this background, in the year 2009, Santoni et al6[6] described the cortical bone trajectory (CBT), which was designed to enhance the contact between the PS and cortical bone. These screws utilise an intermediate trajectory in the caudo-cephalic direction, joining the cortical bone in the pars interarticularis and the inferior portion of the pedicle.[7] Recent studies have reported substantial advantages of CBT over traditional PS trajectory (TPT), such as greater mechanical stability, mitigated paravertebral muscular damage, reduced blood loss, and shorter hospital stay.[8] Owing to these benefits, some authors have also recommended the routine use of this screw trajectory in bariatric patients and revision procedures.[4,9]

However, studies have also highlighted certain shortcomings of CBT screws, namely inadequate engagement of the medial and inferior pedicular walls or bony cortex of the lateral edge of the superior end plate, transgression of facetal articulation or adjoining intervertebral disc (IVD), possible blow-out of screw entry point or lateral pedicular wall, and lack of reliable anatomical reference points for the screw entry. In this context, the trajectory for the modified CBT (mCBT) screw has been recently described.[10–12] Previous finite element analyses (FEA) have indicated potential biomechanical superiority of the mCBT over TPT and CBT.[5,13–15] Hounsfield Unit (HU) measurement on computerised tomography (CT) scans has been clinically correlated with the bone mineral density (BMD) on dual energy X-ray absorptiometry (DEXA) scan, and has been utilised as a surrogate marker to predict pedicle screw pullout strength and postoperative screw loosening.[16–21] An illustration of the three screw trajectories described is given in Figure 1.

In this context, our current study was planned to evaluate the bone density along 4 different points of TPT, CBT and mCBT using CTHU, to provide insights regarding the relative strengths and biomechanical robustness of the three techniques (TPT, CBT, mCBT).

Methods

This was a retrospective cross-sectional morphometric study conducted using CT scans of the lumbar spine. The study evaluated the feasibility and bone quality of the CBT, and mCBT compared with TPT screw placement. The study was conducted following the approval of the Institutional Ethics Committee with document reference number IEC/ME2/25/2-12 dated 07.02.2025. Informed consent was waived considering the anonymization of data for patient identifying information.

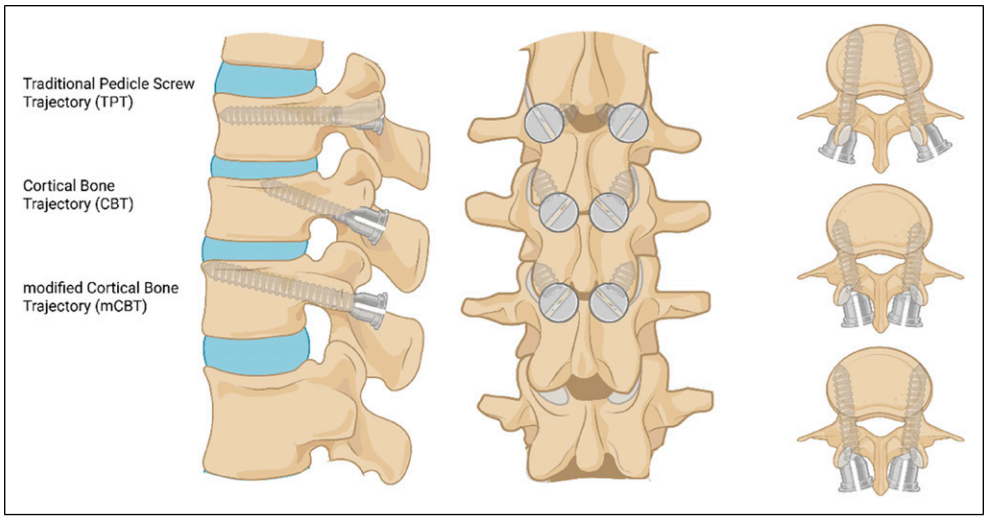


Figure 1. Illustration of the screw trajectories such as traditional pedicle screw trajectory (TPT), cortical bone trajectory (CBT) and modified cortical bone trajectory (mCBT) compared in the study

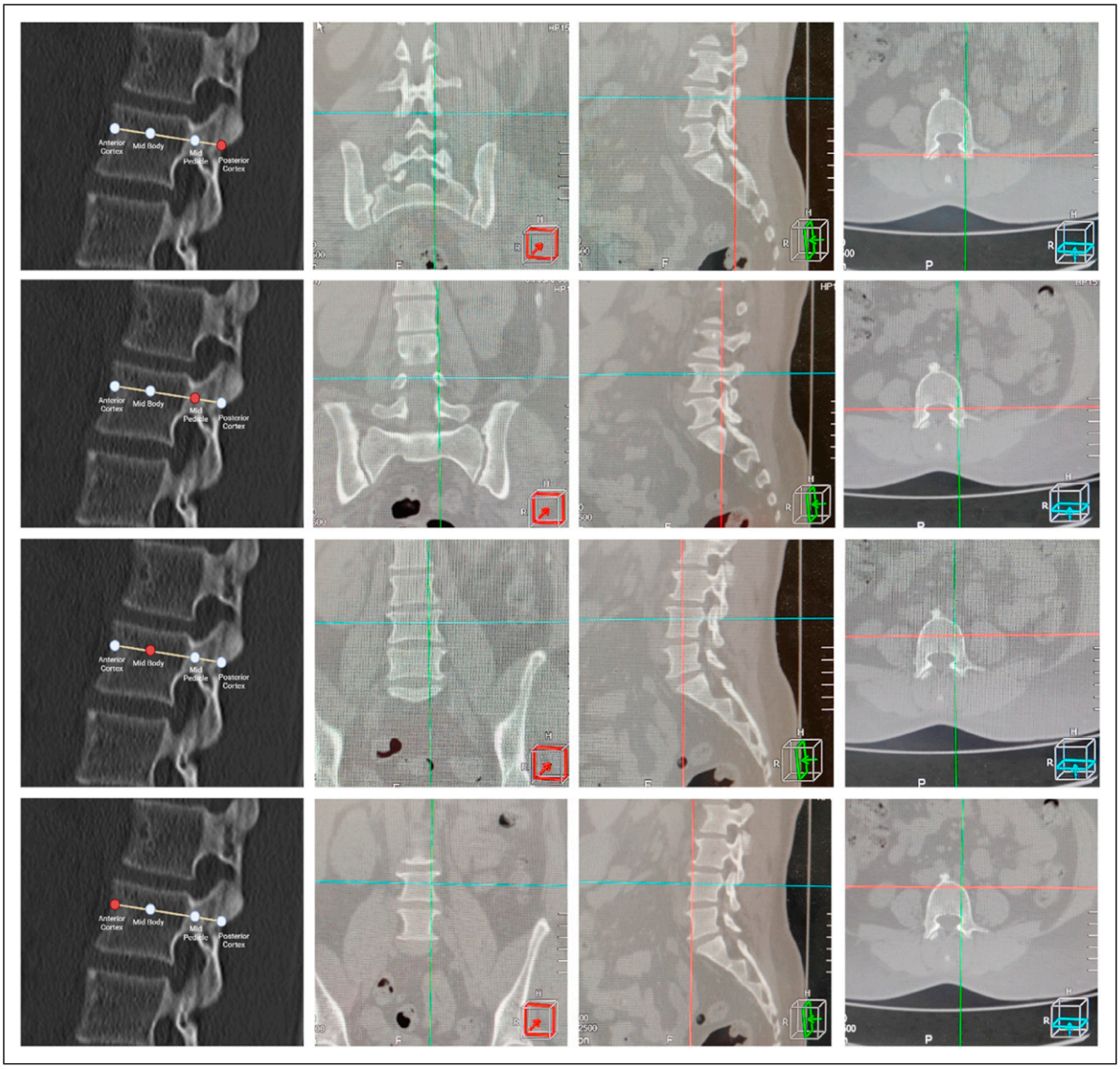


Figure 2. Multiplanar CT sections (coronal, sagittal, axial) demonstrating the plotted traditional pedicle screw trajectory (TPT). HU sampling sites (posterior cortex, mid-pedicle, mid-body, anterior cortex) are indicated

Study Population

CT scans of the lumbar spine performed between January 2024 and June 2025 were retrospectively reviewed. Consecutive scans from adult patients (≥18 years) obtained for non-spinal clinical indications (abdominal pain, renal colic, urological evaluation, trauma screening without spinal injury, oncological staging, and vascular assessment) were screened. Patients with prior lumbar surgery, congenital or acquired spinal deformity (scoliosis with Cobb angle >10°, spondylolisthesis > Grade I (Meyerding classification), congenital vertebral anomalies such as hemivertebrae, butterfly vertebrae, transitional vertebrae or rotational deformities affecting pedicle orientation), fracture, tumor, infection, or poor image quality were excluded. A total of 512 CT scans were screened; 350 met inclusion criteria (inclusion rate 68.4%).

The sample size of 350 patients (1750 vertebrae; 3500 trajectories) was chosen to ensure adequate representation across age and sex strata. Post-hoc power analysis indicated that with this sample size, the study had >90% power to detect a mean HU difference of 50 units between trajectories at $\alpha = 0.05$. All scans were anonymized prior to analysis. We did not selectively recruit elderly or DEXA-verified osteoporotic patients, therefore the sample predominantly represents younger adults. DEXA data were not routinely available in this dataset. To explore age-related trends within our available data we performed exploratory, post-hoc age-

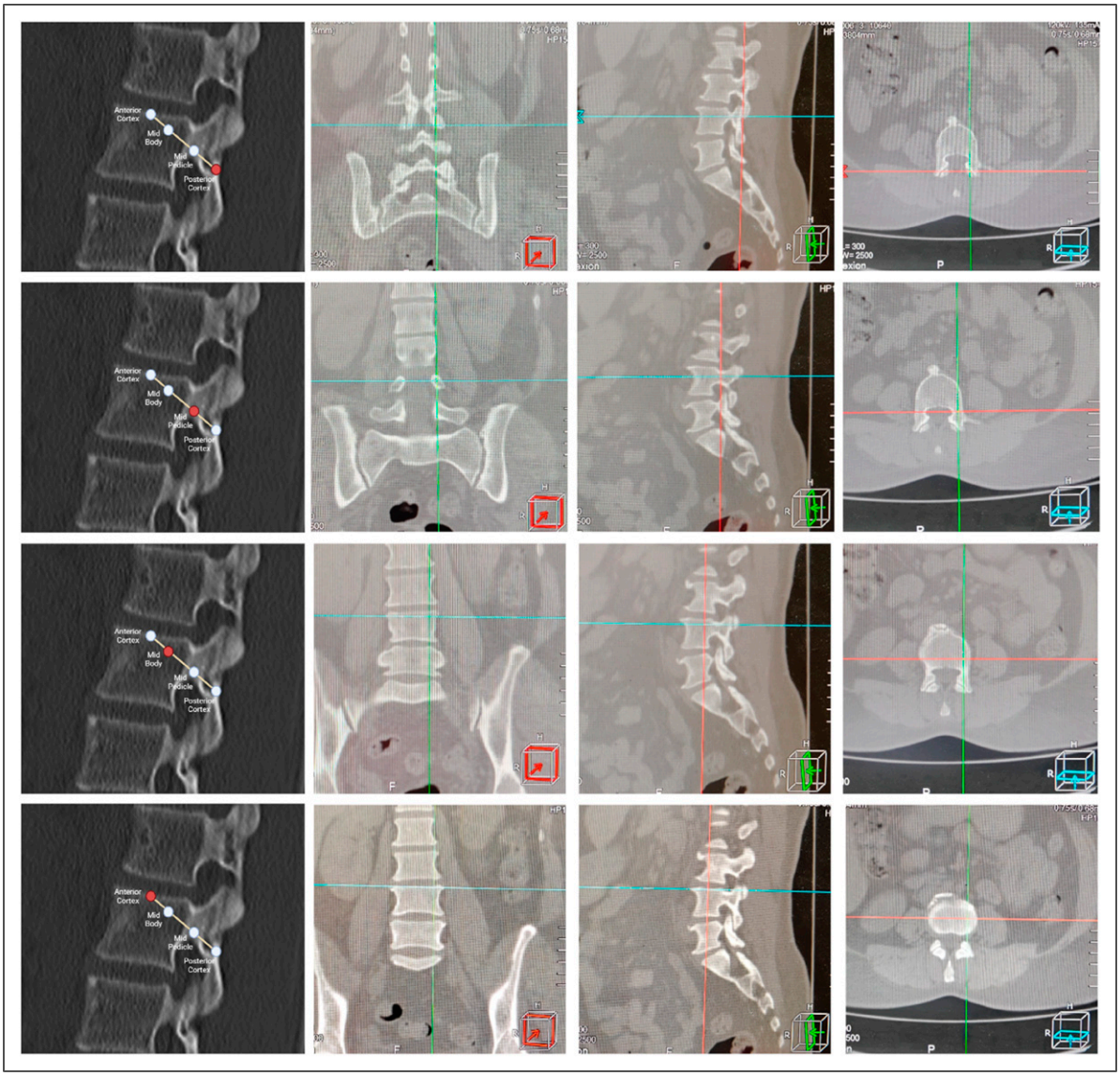


Figure 3. Multiplanar CT sections (coronal, sagittal, axial) demonstrating the plotted cortical bone trajectory (CBT) pedicle screw. HU sampling sites (posterior cortex, mid-pedicle, mid-body, anterior cortex) are indicated

stratified analyses comparing subjects <50 years and ≥50 years, and an exploratory CT-HU–based categorization.

Imaging Protocol

All CT scans were performed using a 16-row Aquilion Lightning 110 CT scanner (Canon Medical Systems, Otawara, Japan). Images were reconstructed in axial and sagittal planes using Picture Archiving and Communication System (PACS) workstation. Three pedicle screw trajectories (TPT, CBT, mCBT) were defined according to published anatomical descriptions. Using the PACS workstation (Canon Medical Systems, Otawara, Japan), multiplanar reconstructions (axial, sagittal, coronal) were employed to plot each trajectory with appropriate cranio-caudal and mediolateral angulations.

TPT (Figure 2): Directed along the neutral mid-pedicle axis, starting at the junction of the superior articular process and transverse process, traversing the pedicle into the vertebral body without significant cranial or lateral angulation.

CBT (Figure 3): Initiated at the pars interarticularis near the medial border of the transverse process and inferior pedicle. Directed 25-30° cranially and 8-15° laterally to reach the cranial endplate in the midaxis of the vertebral body.

mCBT (Figure 4): Entry point located caudal and lateral to the junction of the lamina and superior articular process. Directed 15-20° cranially and 8-10° laterally to reach the cranial endplate in the anterior vertebral body line, allowing deeper screw placement and longer trajectory.

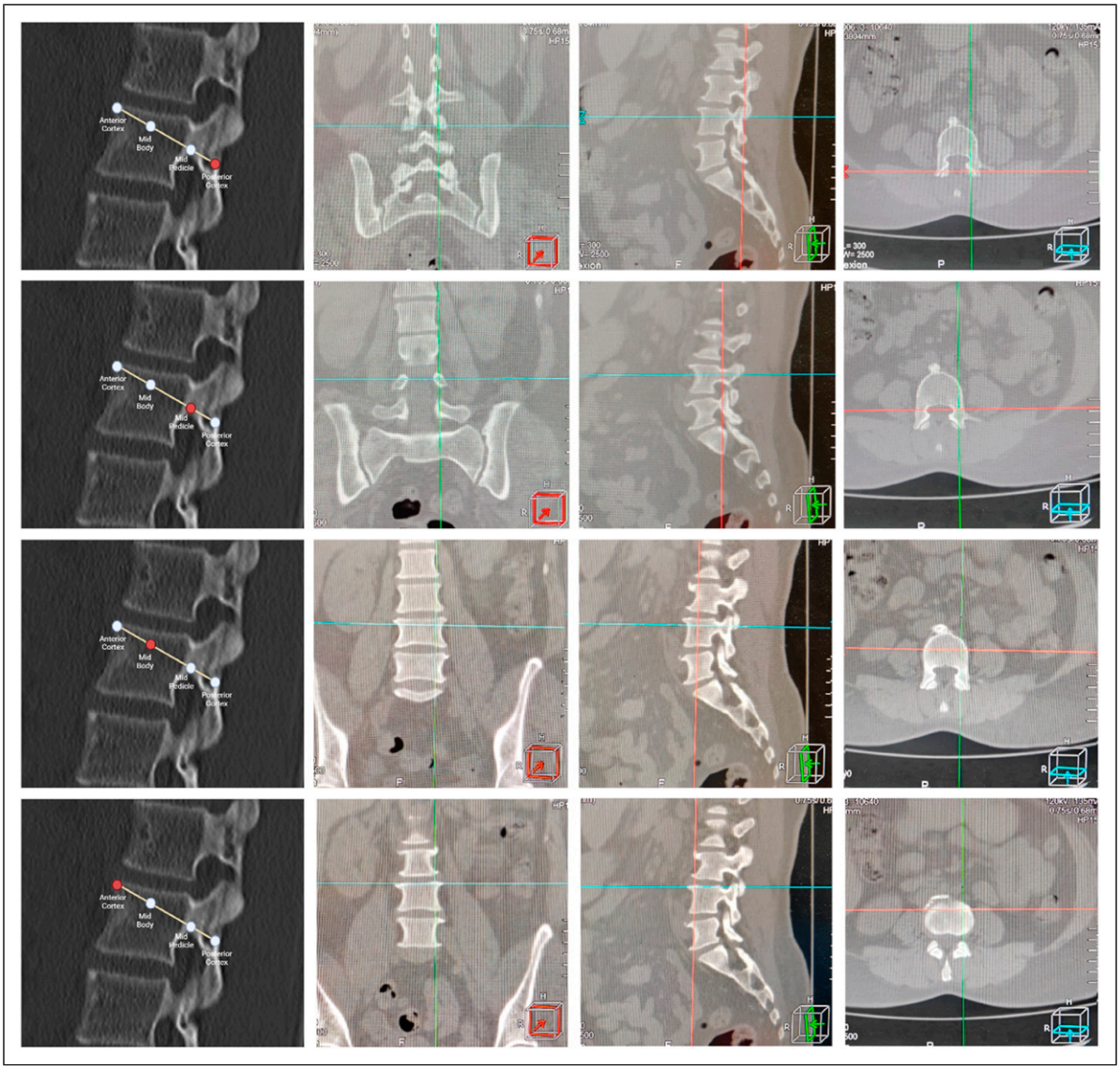


Figure 4. Multiplanar CT sections (coronal, sagittal, axial) demonstrating the plotted modified cortical bone trajectory (mCBT) pedicle screw. HU sampling sites (posterior cortex, mid-pedicle, mid-body, anterior cortex) are indicated

For each trajectory, HU values were sampled at four standardized anatomical landmarks: posterior cortex (PC), mid-pedicle (MP), mid-vertebral body (MB), and anterior cortex (AC). This approach provided reproducible point-based HU comparisons across trajectories. We did not perform continuous HU mapping along the entire screw path; therefore, results represent discrete anatomical sampling rather than full 3-D density profiling. Mean HU values were calculated for each trajectory, and the maximum feasible screw length was recorded.

Interobserver Reliability Assessment

To assess reproducibility, two independent observers (each with >5 years of spine imaging experience) performed HU measurements for all four anatomical landmarks (posterior cortex, mid-pedicle, mid-vertebral body, anterior cortex) across 50 randomly selected vertebrae (250 measurements per observer). Prior to formal data collection, a training phase was conducted on 10 vertebrae to standardize landmark identification and measurement technique. Intraclass correlation coefficients (ICC, two-way random effects, absolute agreement) were calculated for each landmark and trajectory. In cases of discrepancy >10 HU between observers, values were jointly reviewed and consensus reached; the consensus value was used for analysis.

Statistical Analysis

Continuous variables were expressed as mean ± standard deviation (SD). Comparisons across trajectories were

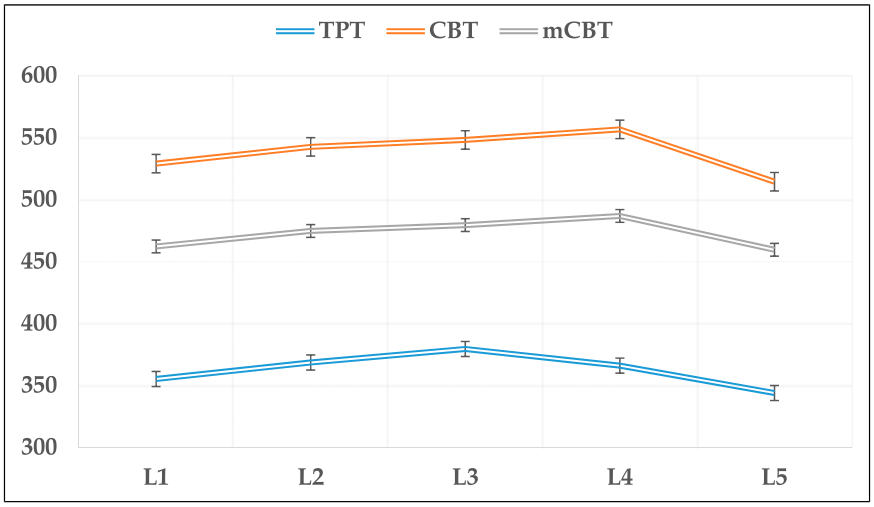


Figure 5. Mean HU values at individual vertebrae for TPT, CBT, and mCBT trajectories

performed using one-way analysis of variance (ANOVA) with post-hoc Tukey test. The effects of age and sex were evaluated using independent-sample t-tests and linear regression. Correlation analysis was conducted with Pearson's correlation coefficient (r) along with adjusted R^2 values. Interobserver reliability was assessed using ICC, which were interpreted as poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), or excellent (>0.9). A *P*-value of less than .05 was considered statistically significant. As DEXA was not available, we used exploratory CT-HU–based categories as a surrogate for low bone density for within-cohort comparisons. Vertebral trabecular HU categories were defined for exploratory purposes as: HU <110 (suggestive of low BMD), 110-150 (indeterminate/osteopenia range), and >150 (higher trabecular density). These thresholds were applied only as an internal, hypothesis-generating categorization and results interpreted cautiously. All statistical analyses were performed using Stata statistical software: Release 17 (StataCorp LLC, College Station, TX).

Results

Of 512 CT scans screened during the study period, 350 met inclusion criteria and were analyzed (inclusion rate 68.4%). Reasons for exclusion included prior spinal surgery (n = 42), congenital or acquired deformity (n = 15), fracture/tumor/infection (n = 85), and poor image quality (n = 20). The final cohort comprised 232 males (66%) and 118 females (34%), mean age 34.4 ± 11.7 years. The number of patients aged ≥50-59 years and ≥60 years corresponded to 23.4% (n = 82) and 18.3% (n = 64) respectively. Because the cohort is skewed to younger adults, subgroup samples in older age-bands were limited and analyses are exploratory.

We calculated the HU values at different measurement sites for TPT, CBT, and mCBT in 3500 simulated trajectories in 1750 vertebrae. Inter-observer agreement for HU measurements across all trajectories and anatomical points was excellent, with ICC ranging from 0.87 to 0.94 (95% CI: 0.84-0.96). This indicates high reproducibility of the morphometric measurements between the two observers. The mean bone density as assessed by the CTHU along the screw trajectories for 3 different pedicle screw techniques were (from highest to lowest) 538.2 ± 73.1 HU for CBT, 472.6 ± 87.9 HU for mCBT, and 362.8 ± 68.4 HU for TPT as shown per vertebral level in Figure 5. Thus, based on our analysis, while the mean CTHU values along the mCBT screw trajectory were 30.3% higher than TPT; the values were 12.2% lower than for standard CBT screws. These differences were statistically significant (One-way ANOVA: $P < .001$) as shown in Table 1.

Table 1. Mean Hounsfield Unit (HU) Values at Different Measurement Sites and Maximum Screw Length for TPT, CBT, and mCBT Trajectories

Measurement site/Parameter	TPT (mean ± SD)	CBT (mean ± SD)	mCBT (mean ± SD)	*P*-value
Overall mean HU	362.8 ± 68.4	538.2 ± 73.1	472.6 ± 87.9	<.001
Posterior cortex	582.1 ± 162.3	1128.9 ± 147.6	962.4 ± 192.7	<.001
Mid-pedicle	348.7 ± 74.5	521.6 ± 81.2	468.9 ± 85.7	<.001
Mid-vertebral body	336.2 ± 69.8	507.4 ± 77.9	455.1 ± 82.3	<.001
Anterior cortex	384.5 ± 72.1	495.8 ± 80.6	471.2 ± 83.5	<.001
Maximum screw length (mm)	38.6 ± 3.2	36.9 ± 2.8	44.7 ± 3.5	<.001

Table 2. Post-hoc Age-Stratified HU Means by Trajectory and Anatomical Site (Patients <50 years: *n* = 204; Patients ≥50 years: *n* = 146)

Measurement site/Parameter	<50 years mean ± SD (*n* = 204)	≥50 years mean ± SD (*n* = 146)
Overall mean HU — TPT	382.0 ± 63.5	335.0 ± 66.2
Overall mean HU — CBT	562.0 ± 69.1	505.0 ± 70.8
Overall mean HU — mCBT	492.0 ± 82.0	445.0 ± 88.5
Posterior cortex — TPT	600.0 ± 155.0	560.0 ± 164.0
Posterior cortex — CBT	1160.0 ± 140.0	1080.0 ± 152.0
Posterior cortex — mCBT	990.0 ± 185.0	920.0 ± 197.0
Mid-pedicle — TPT	365.0 ± 70.0	325.0 ± 76.0
Mid-pedicle — CBT	540.0 ± 78.0	490.0 ± 82.0
Mid-pedicle — mCBT	490.0 ± 82.0	435.0 ± 88.5
Mid-vertebral body — TPT	355.0 ± 66.0	305.0 ± 70.0
Mid-vertebral body — CBT	525.0 ± 74.0	475.0 ± 77.0
Mid-vertebral body — mCBT	475.0 ± 79.0	425.0 ± 85.0
Anterior cortex — TPT	405.0 ± 68.0	355.0 ± 73.0
Anterior cortex — CBT	515.0 ± 78.0	465.0 ± 82.0
Anterior cortex — mCBT	490.0 ± 81.0	445.0 ± 86.0
Maximum screw length (mm) — TPT	38.9 ± 3.0	38.1 ± 3.5
Maximum screw length (mm) — CBT	37.4 ± 2.6	36.2 ± 3.1
Maximum screw length (mm) — mCBT	45.2 ± 3.2	44.0 ± 3.9

We had measured the CTHU values at 4 different anatomical points along each screw trajectory, ie, PC, MP, MB, and AC. For all the 4 screw types, the CTHU values were the highest at the level of posterior cortical entry. Again, the CTHU values were significantly highest for the CBT, and lowest for the TPT noted as CBT (1128.9 ± 147.6 HU)> mCBT (962.4 ± 192.7 HU)> TPT (582.1 ± 162.3 HU). Thus, while the density of the PC region corresponding to the entry point of mCBT was 65.3% greater than for TPT; it was 14.7% lower than that of standard CBT. At the other 3 measured regions of the vertebrae (MP, MB, AC), while the bone density was fairly similar between CBT and mCBT; the values for TPT were significantly lower. The maximum screw length was significantly greater in the mCBT trajectory (44.7 ± 3.5 mm) compared with TPT (38.6 ± 3.2 mm) and CBT (36.9 ± 2.8 mm) ($P < .001$) as shown in Table 1.

Impact of Age & Gender

Univariate linear regression demonstrated a negative correlation between age and CTHU across all trajectories: TPT: r = −0.36, adjusted $R^2 = 0.130$; mCBT: r = −0.21, adjusted $R^2 = 0.045$; CBT: r = −0.19, adjusted $R^2 = 0.038$ indicating age explains a modest proportion of variance. The decline in bone density with age was most pronounced in TPT, suggesting greater vulnerability of trabecular-rich zones. Associations for CBT and mCBT were smaller, consistent with partial cortical engagement. These correlations are modest and should be interpreted cautiously. Based on our analysis, while patients aged 60 years or older exhibited significantly greater reduction in CTHU (approximately 17.8%) as compared to their younger counterparts; the age-related difference was substantially lower for both the cortical-based trajectories (6.9% and 4.2% in mCBT and CBT, respectively).

Post-hoc age-stratified analyses divided the cohort into patients aged <50 years (*n* = 204) and ≥50 years (*n* = 146). Table 2 shows mean CT-HU values by trajectory and measurement site for these age bands. The primary directional relationship observed in the full cohort (CBT > mCBT > TPT) is preserved within both age bands; absolute HU values decline in the ≥50 years group across all trajectories and sites. Table 3 shows pooled exploratory results using internal CT-HU bands (HU <110; 110-150; >150) as a radiographic surrogate for lower bone density; trajectory HU declines across HU categories, with CBT and mCBT maintaining higher mean HU than TPT within each category. These

Table 3. Exploratory CT-HU Category Based Subgroup Analysis

CT-HU category (trabecular HU)	*n* (patients)	TPT mean HU ± SD	CBT mean HU ± SD	mCBT Mean HU ± SD
HU <110 (suggestive low BMD)	30	220 ± 40	390 ± 65	330 ± 72
HU 110-150 (indeterminate/osteopenia range)	70	320 ± 45	480 ± 60	420 ± 75
HU >150 (higher trabecular density)	250	420 ± 50	610 ± 68	540 ± 80

subgroup and HU-category analyses are post-hoc and descriptive, the study lacked DEXA data and was not prospectively powered for definitive subgroup inference.

The gender-based differences in CTHU were statistically significant in TPT (male: 358.4 ± 61.2 HU; female: 368.7 ± 75.1 HU; $P < .05$). However, the effect size is small and may reflect cohort composition and localized trabecular variability rather than systemic BMD differences; this finding requires confirmation in DEXA-verified samples. The difference was not statistically significant for both the cortical-based trajectories (CBT and mCBT).

Discussion

Our results (CBT > mCBT > TPT) are consistent with the findings of Parajuli et al,2[22] who reported higher HU values for CBT compared with mCBT and TPT in a similar CT-based analysis. However, they contrast with Liu et al,8[8] who observed mCBT > CBT > TPT in their study of 60 patients. Several methodological and anatomical factors likely account for this discrepancy. First, HU sampling strategy differs: our four landmark approach emphasizes posterior cortical density—an area where CBT excels—whereas deeper, anterior-weighted or continuous sampling can favor mCBT due to its longer path and multi-cortical engagement. Second, vertebral levels matter; we observed level-specific variation (L4 > L3 > L2 > L1 > L5), with L4's robust posterior cortex accentuating CBT's advantage, while L5's cancellous predominance may benefit longer mCBT paths. Third, trajectory angulations and targets vary subtly between studies; our definitions (CBT 25-30° cranial, 8-15° lateral to cranial endplate midaxis; mCBT 15-20° cranial, 8-10° lateral to cranial endplate along the anterior body line; TPT neutral) prioritize different cortical contacts. Finally, scanner protocols and cohort composition (predominantly young, non-DEXA-verified) influence HU contrasts and generalizability. Collectively, these factors suggest that trajectory rankings are sensitive to the balance between posterior cortical purchase (favoring CBT) and anterior multi-cortical engagement with longer screws (favoring mCBT). Standardized, continuous 3D HU profiling across all lumbar levels, coupled with biomechanical validation, is needed to reconcile these differences.

Clinical Implications of Density vs Screw Length

The trade-off between bone density and screw length is central to the choice of trajectory. CBT demonstrated the highest HU values, particularly at the posterior cortex (1128.9 ± 147.6 HU), reflecting robust cortical engagement. This suggests superior pull-out strength and insertional torque, consistent with prior biomechanical studies.[7,23] However, CBT screws are typically shorter (30-35 mm), which may limit three-column anchorage. In contrast, mCBT allowed significantly longer screws (44.7 ± 3.5 mm), engaging both cortical and cancellous regions. Although its posterior cortical density was lower than CBT, the increased length may confer biomechanical advantages in multi-level constructs or revision scenarios, as suggested by finite element analyses.[14] Thus, CBT may be optimal for maximizing cortical purchase in short constructs, while mCBT may provide a balance of cortical engagement and screw length in situations requiring deeper anchorage.

Inter-Level Variation

An interesting finding in our study was the inter-level variation in HU values, with L4 demonstrating the highest density, followed by L3, L2, L1, and L5. This pattern has not been widely discussed in prior literature. Anatomically, L4 serves as a transitional vertebra between the highly mobile upper lumbar spine and the sacrum, bearing significant mechanical loads. The higher cortical density at L4 may reflect adaptive remodeling to these stresses. Conversely, L5's lower HU values may be attributable to its proximity to the sacrum, greater trabecular content, and higher incidence of degenerative changes. These inter-level differences suggest that trajectory choice may need to be tailored by vertebral level, with CBT favored at L4 for maximal cortical purchase and mCBT potentially advantageous at L5 for longer screw anchorage.

Age and Gender Effects

We observed a negative correlation between age and HU across all trajectories, most pronounced in TPT ($r = -0.36$, $R^2 = 0.13$). This indicates that trabecular-rich trajectories are more vulnerable to age-related bone loss, consistent with prior reports.1[16,24,25,26] However, the correlation explained only 13% of variance, underscoring that age alone is not a strong predictor of HU. Interestingly, females demonstrated slightly higher HU values than males in TPT, which is counterintuitive given the higher prevalence of osteoporosis in women. This may reflect sampling bias in our cohort, which was predominantly young and male, or differences in trabecular distribution. Importantly, cortical-based trajectories (CBT and mCBT) showed minimal gender differences, supporting their relative robustness across sexes. These findings reinforce the potential utility of cortical trajectories in mitigating age- and sex-related variability, though definitive conclusions require validation in elderly, osteoporotic populations.

Anatomical Feasibility

Trajectory feasibility is a critical consideration. In our cohort, CBT and mCBT were feasible in >95% of vertebrae, with exclusions primarily due to narrow pedicles or transitional anatomy. This aligns with prior anatomical studies,1[10,11,12] which emphasized the reproducibility of mCBT entry points and angulations. The ability of mCBT to accommodate longer screws without extensive lateral exposure may enhance feasibility in minimally invasive or revision settings. However,

both CBT and mCBT can be technically demanding at proximal thoracic levels or in patients with severe deformity. Our findings suggest that while cortical trajectories are broadly feasible, careful preoperative imaging is essential to identify anatomical constraints.

Integration With Biomechanical Evidence

Biomechanical studies have consistently demonstrated superior pull-out strength and insertional torque for CBT compared with TPT.3[3,5,7,27] mCBT has been proposed to combine cortical purchase with longer screw length, potentially enhancing stability.1[14] Our radiographic findings support these biomechanical observations: CBT traverses denser bone, while mCBT allows longer screws. However, radiographic HU values cannot directly predict mechanical performance. Finite element analyses1[13,14] and experimental studies2[27] suggest that cortical contact layers are critical for stability, with at least three cortical engagements desirable. Our data show that CBT maximizes posterior cortical density, while mCBT engages multiple cortices along a longer path. Together, these findings suggest complementary roles for CBT and mCBT, depending on clinical context.

Clinical Translation and Future Directions

Clinically, cortical trajectories may be particularly valuable in osteoporotic spines, where traditional pedicle screws are prone to loosening.[4,9,28,29] CBT offers strong cortical purchase with minimal muscle dissection, while mCBT provides longer screws and potentially greater stability in multi-level constructs. Since the standard CBT screw insertion relies upon the subjective surgeon experience, classical reference angles determining the screw orientation and intraoperative radiographs[10–12]; the patients' position, posture and screw insertion point have a substantial impact on the angle of screw placement. CBT prioritizes cortical engagement but often requires a steeper medial angulation and more aggressive screw trajectory, which can be technically demanding and may risk medial breach or facet violation. On the other hand, mCBT, by modifying the entry point and angulation, achieves substantial cortical purchase while maintaining a safer and more reproducible path, especially in patients with anatomical variability or lower bone quality. The mCBT relies more upon constant anatomical landmarks; and therefore, is less liable to screw misplacements.

As against the standard CBT,[10–12] where the entire inferior border of TP adjacent to intervertebral foramen is exposed in order to identify the *x*-axis 1mm inferior to the inferior border of TP; the lateral exposure of TP is not necessary for mCBT screw placement, which can minimize the extent of paraspinal muscle dissection, blood loss and soft tissue injury. In addition, the important anatomical landmarks for the modified screw trajectory are tangential points on bilateral isthmus, which are typically symmetrical and consistent even in a highly degenerated spine (which makes them a more viable option in the aged individuals).

In the real-world practice, mCBT may therefore, offer a middle ground since it utilises the benefits of engaging the cortical bone (especially in osteoporotic spines); while at the same time, potentially enhances the ease of insertion, facilitates insertion of longer or larger diameter screws (with 3-column engagement); as well as mitigates complications associated with standard CBT. These advantages are especially realised in minimally-invasive or revision surgeries, especially in resource-limited or high-volume settings. Both these cortical trajectory screws can be technical demanding (with a small margin of error) at the proximal thoracic levels (small pedicles), and in patients with severe spinal deformities or pedicle anomalies. Nevertheless, the evidence available on mCBT is still limited to a few biomechanical and radiological studies. Large-scale, prospective, multi-centered, randomised controlled, trials are necessary to clearly evaluate the clinical, radiological and functional outcome; as well as determine the role of the MCBT screws in diverse clinical settings.

This study has several important limitations. It is retrospective and radiographic in design, relying on CT-HU as a surrogate for bone mineral density; HU values are influenced by scanner model, acquisition and reconstruction parameters and cannot replace DEXA. The cohort is predominantly young (mean 34.4 years) and male, so generalizability to elderly, DEXA-verified osteoporotic patients is limited. Post-hoc age-stratified and HU-category analyses are exploratory and underpowered. Further, our methodology relied on point-based HU sampling at four anatomical landmarks along predefined screw paths using multiplanar sections. Continuous HU mapping along the entire 3-D trajectory was not performed, and virtual simulation cannot fully replicate intraoperative screw placement or mechanical performance. This limitation may affect the precision of trajectory comparisons and requires validation with biomechanical testing and intraoperative imaging and clinical outcome data (insertional torque, pull-out strength, fusion, implant survival). Although consecutive CTs were screened to minimize selection bias, the cohort reflects patients imaged for non-spinal indications (abdominal/urological/oncological/vascular), which may introduce heterogeneity. Certain systemic conditions (renal disease, endocrine disorders) can affect bone density; while such patients were included, we did not stratify by comorbidity. This may limit generalizability.

Despite limitations, our study has several strengths. It is the largest CT-based analysis to date, including 350 patients and 3500 trajectories across all lumbar levels. Measurements were performed independently by two experienced observers with excellent interobserver reliability (ICC 0.87-0.94). Standardized sampling at four anatomical landmarks allowed reproducible comparisons across trajectories. The inclusion of age- and sex-stratified analyses, as well as inter-level variation, provides novel insights into anatomical density patterns.

Conclusion

This study provides a descriptive radiographic analysis of lumbar pedicle screw trajectories in a cohort of relatively young adults. Using standardized CT-HU sampling, we found that CBT consistently traverses denser bone than the TPT, while the mCBT permits longer screw length with intermediate density values. These findings highlight anatomical differences between trajectories and generate hypotheses about their biomechanical potential. However, the study population was young and not DEXA-verified for osteoporosis, and the methodology relied on virtual CT reconstructions rather than intraoperative or biomechanical validation. Accordingly, these results should be interpreted as anatomical observations rather than clinical recommendations. Validation in elderly and osteoporotic populations, together with biomechanical and clinical outcome studies, is required before extrapolating these findings to surgical practice.

ORCID iDs

Sathish Muthu https://orcid.org/0000-0002-7143-4354
Vibhu Krishnan Viswanathan https://orcid.org/0000-0002-3804-1698
Dhibin Vikash Kolarpatti Ponnusamy https://orcid.org/0000-0003-1071-0084
Khan Sharun https://orcid.org/0000-0003-1040-3746

Ethical Considerations

Institutional ethical committee approval was obtained with the document no IEC/ME2/25/2-12 dated 07.02.2025.

Author Contributors

Dr S Muthu and Dr VKV contributed to the conceptualization and design of the research goals and aims. Dr S Muthu developed the methodology and statistical framework. Dr KPN carried out the data collection. Data validation and ensuring the accuracy of results were undertaken by Dr S Muthu, Dr SKR Chandra and Dr VKV. Dr S Muthu secured the necessary resources for the study, and Dr DVKP curated and organized the study data. Writing the original draft of the manuscript was managed by Dr S Muthu, Dr SK with other authors providing critical revisions and editing. Visualization and creation of figures were executed by Dr S Muthu. Supervision and coordination of the project were led by Dr S Muthu.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

Data generated in the study will be made available upon reasonable request to the authors.

References

1. Boucher HH. A method of spinal fusion. *J Bone Joint Surg Br*. 1959;41-B:248-259. doi:10.1302/0301-620X.41B2.248
2. Perna F, Borghi R, Pilla F, Stefanini N, Mazzotti A, Chehrassan M. Pedicle screw insertion techniques: an update and review of the literature. *Musculoskelet Surg*. 2016;100:165-169. doi:10.1007/s12306-016-0438-8
3. Matsukawa K, Yato Y, Kato T, Imabayashi H, Asazuma T, Nemoto K. In vivo analysis of insertional torque during pedicle screwing using cortical bone trajectory technique. *Spine*. 2014;39:E240-E245. doi:10.1097/BRS.0000000000000116
4. Rosinski AA, Mittal A, Odeh K, et al. Alternatives to traditional pedicle screws for posterior fixation of the degenerative lumbar spine. *JBJS Rev* 2021;9(7). doi:10.2106/JBJS.RVW.20.00177
5. Matsukawa K, Yato Y, Imabayashi H, Hosogane N, Asazuma T, Chiba K. Biomechanical evaluation of lumbar pedicle screws in spondylolytic vertebrae: comparison of fixation strength between the traditional trajectory and a cortical bone trajectory. *J Neurosurg Spine*. 2016;24:910-915. doi:10.3171/2015.11.SPINE15926
6. Santoni BG, Hynes RA, McGilvray KC, et al. Cortical bone trajectory for lumbar pedicle screws. *Spine J*. 2009;9:366-373. doi:10.1016/j.spinee.2008.07.008
7. Delgado-Fernandez J, García-Pallero MÁ, Blasco G, Pulido-Rivas P, Sola RG. Review of cortical bone trajectory: evidence of a new technique. *Asian Spine J*. 2017;11:817-831. doi:10.4184/asj.2017.11.5.817
8. Liu D, Kahaer A, Wang Y, et al. Comparison of CT values in traditional trajectory, traditional cortical bone trajectory, and modified cortical bone trajectory. *BMC Surg*. 2022;22:441. doi:10.1186/s12893-022-01893-5
9. Arzoglou V, Vial I, Hussain M, et al. Lumbar fixation using the cortical bone trajectory fixation: a single surgeon's experience with 3-Year Follow-up. *Oper Neurosurg*. 2022;22:87-100. doi:10.1227/ONS.0000000000000042
10. Rexiti P, Abudurexiti T, Abuduwali N, Wang S, Sheng W. Measurement of lumbar isthmus parameters for novel starting points for cortical bone trajectory screws using computed radiography. *Am J Transl Res*. 2018;10:2413-2423.
11. Rexiti P, Aierken A, Sadeer A, et al. Anatomy and imaging studies on cortical bone screw freehand placement applying anatomical targeting technology. *Orthop Surg*. 2020;12:1954-1962. doi:10.1111/os.12775
12. Rexiti P, Aierken G, Wang S, et al. Anatomical research on strength of screw track fixation in novel cortical bone trajectory for osteoporosis lumbar spine. *Am J Transl Res*. 2019;11:6850-6859.
13. Campbell GM, Glüer C-C. Skeletal assessment with finite element analysis: relevance, pitfalls and interpretation. *Curr Opin Rheumatol*. 2017;29:402-409. doi:10.1097/BOR.0000000000000405

14. Kahaer A, Maimaiti X, Maitirouzi J, et al. Biomechanical investigation of the hybrid modified cortical bone screw-pedicle screw fixation technique: finite-element analysis. *Front Surg*. 2022;9:911742. doi:10.3389/fsurg.2022.911742
15. Maitirouzi J, Luo H, Zhou Z, Ren H, Rexiti P. Finite element analysis of human lumbar vertebrae in internal fixation system model with different bone density trajectories. *Int J Artif Organs*. 2022;45:478-487. doi:10.1177/03913988221088613
16. Berger-Groch J, Thiesen DM, Ntalos D, Hennes F, Hartel MJ. Assessment of bone quality at the lumbar and sacral spine using CT scans: a retrospective feasibility study in 50 comparing CT and DXA data. *Eur Spine J*. 2020;29:1098-1104. doi:10.1007/s00586-020-06292-z
17. Ikeura A, Kushida T, Oe K, et al. Correlation between the computed tomography values of the screw path and pedicle screw pullout strength: an experimental study in porcine vertebrae. *Asian Spine J*. 2020;14:265-272. doi:10.31616/asj.2019.0170
18. Pinto EM, Neves JR, Teixeira A, et al. Efficacy of hounsfield units measured by lumbar computer tomography on bone density assessment: a systematic review. *Spine*. 2022;47:702-710. doi:10.1097/BRS.0000000000004211
19. Zou D, Sun Z, Zhou S, Zhong W, Li W. Hounsfield units value is a better predictor of pedicle screw loosening than the T-score of DXA in patients with lumbar degenerative diseases. *Eur Spine J*. 2020;29:1105-1111. doi:10.1007/s00586-020-06386-8
20. Viswanathan VK, Shetty AP, Rai N, Sindhiya N, Subramanian S, Rajasekaran S. What is the role of CT-based hounsfield unit assessment in the evaluation of bone mineral density in patients undergoing 1- or 2-level lumbar spinal fusion for degenerative spinal pathologies? A prospective study. *Spine J*. 2023;23:1427-1434. doi:10.1016/j.spinee.2023.05.015
21. Kurra S, Farhadi HF, Metkar U, et al. CT based bone mineral density as a predictor of proximal junctional fractures. *N Am Spine Soc J*. 2022;11:100130. doi:10.1016/j.xnsj.2022.100130
22. Parajuli B, Shrestha D, Abumi K, et al. Bone density comparison between the normal pedicle trajectory, cortical bone trajectory, and modified cortical bone trajectory using computed tomography: a cross-sectional study. *Asian Spine J*. 2025;19:372-379. doi:10.31616/asj.2024.0377
23. Marie-Hardy L, Pascal-Moussellard H, Barnaba A, Bonaccorsi R, Scemama C. Screw loosening in posterior spine fusion: prevalence and risk factors. *Glob Spine J*. 2020;10:598-602. doi:10.1177/2192568219864341
24. Kanno H, Onoda Y, Hashimoto K, Aizawa T, Ozawa H. Innovation of surgical techniques for screw fixation in patients with osteoporotic spine. *J Clin Med*. 2022;11:2577. doi:10.3390/jcm11092577
25. Soldozy S, Montgomery SR, Sarathy D, et al. Diagnostic, surgical, and technical considerations for lumbar interbody fusion in patients with osteopenia and osteoporosis: a systematic review. *Brain Sci*. 2021;11:241. doi:10.3390/brainsci11020241
26. Singh V, Mahajan R, Das K, Chhabra HS, Rustagi T. Surgical trend analysis for use of cement augmented pedicle screws in osteoporosis of spine: a systematic review (2000-2017). *Glob Spine J*. 2019;9:783-795. doi:10.1177/2192568218801570
27. Wu C, Long H, Fu Y, He Z, Liu J, Xu Z. Finite element analysis of cortical bone trajectory screw resistance to pullout during exposure to different cortical layers based on AbaqusCEA software. *Indian J Orthop*. 2023;57:1329-1337. doi:10.1007/s43465-023-00944-0
28. Ding H, Hai Y, Liu Y, et al. Cortical trajectory fixation versus traditional pedicle-screw fixation in the treatment of lumbar degenerative patients with osteoporosis: a prospective randomized controlled trial. *Clin Interv Aging*. 2022;17:175-184. doi:10.2147/CIA.S349533
29. Chang C-C, Chang H-K, Ko C-C, et al. Comparison of cortical bone trajectory to pedicle-based dynamic stabilization: an analysis of 291 patients. *Neurospine*. 2023;20:308-316. doi:10.14245/ns.2244888.444