

How well does radiographic middle segment height loss reflect CT-defined cage–endplate penetration after zero-profile ACDF? A paired imaging study

Research Article

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Abstract

Background

Cage subsidence after anterior cervical discectomy and fusion (ACDF) is commonly monitored on lateral radiographs, whereas computed tomography (CT) directly depicts focal cage–endplate penetration. Whether radiographic middle segment height loss (Δ MSH), including the commonly used 2-mm threshold, can reliably identify CT-defined penetration remains unclear. We evaluated their relationship and the clinical limitations of threshold-based radiographic assessment after zero-profile ACDF.

Methods

This single-center retrospective paired-imaging study screened 107 consecutive patients treated with zero-profile ACDF from 2023 to 2025; 74 met the final paired-imaging criteria. The postoperative day-7 radiograph after ambulation served as the Δ MSH baseline. Follow-up CT, obtained mainly at 6 or 12 months, was paired with the nearest technically adequate lateral radiograph within 30 days. Superior and inferior CT penetration were measured separately and summed. Spearman correlation was the primary analysis; paired differences, penetration direction, and a 2-mm threshold analysis were secondary or exploratory.

Results

Median CT cumulative penetration was 2.39 mm (IQR 1.80–3.11) and Δ MSH was 1.37 mm (IQR 0.88–2.19), with a moderate-to-strong correlation ($\rho = 0.634$, 95% CI 0.456–0.770; $P < 0.001$). Δ MSH was lower than CT cumulative penetration in 68/74 patients (91.9%). Inferior penetration predominated in 63/74 patients (85.1%). For maximum single-endplate CT penetration > 2 mm, Δ MSH ≥ 2 mm had 75.0% sensitivity, 87.0% specificity, 68.2% positive predictive value, and 90.4% negative predictive value; 5/20 CT-positive patients (25.0%) were radiographically negative. Continuous Δ MSH yielded an AUC of 0.873.

Conclusions

Radiographic Δ MSH tracks the overall pattern of cage–endplate penetration but is not interchangeable with CT penetration depth. In this cohort, applying the same 2-mm threshold to radiographs missed one quarter of CT-positive cases. Serial radiographs remain appropriate for routine height surveillance, whereas CT is complementary when symptoms and radiographs are discordant or interface-level penetration requires clarification.

Background

Anterior cervical discectomy and fusion (ACDF) is widely used for degenerative cervical disorders. Cage subsidence is a common postoperative imaging finding, but reported definitions vary substantially because radiographic height loss, cage migration, and direct endplate penetration are often grouped under the same term [1]. This heterogeneity complicates interpretation of serial follow-up and comparison across studies.

Routine lateral radiographs allow longitudinal assessment of disc or fusion-segment height and cage position. Among several radiographic approaches, Zhao et al. [2] showed that changes in center middle height, disc height, and middle segment height are not interchangeable; middle segment height loss (Δ MSH) demonstrated favorable reproducibility and clinical relevance. CT addresses a different structural question by directly depicting the cage–endplate interface. Pinter et al. [3] quantified penetration separately at the cranial and caudal interfaces and observed a predominance of penetration into the superior endplate of the caudal vertebral body.

For postoperative surveillance, the practical issue is not only whether radiographic height loss correlates with local cage–endplate penetration, but also whether a commonly used radiographic threshold can safely exclude focal penetration on CT. Because radiography measures longitudinal segment-height change whereas CT measures local interface penetration, the same numerical cutoff may not represent the same structural severity across modalities. A direct paired comparison is therefore needed to define both the relationship and the clinical limits of routine radiographic assessment.

Accordingly, we performed a paired radiograph–CT study in a standardized zero-profile ACDF cohort. The primary objective was to evaluate the association between radiographic Δ MSH and CT cumulative endplate penetration. Secondary analyses examined the paired numerical difference and the directional pattern of superior and inferior penetration. The 2-mm threshold analysis was exploratory and was used to assess whether radiographic Δ MSH $\geq$ 2 mm could identify maximum single-endplate CT penetration $>$ 2 mm, with particular attention to radiographically negative CT-positive cases.

Methods

Study design and patients

This was a single-center retrospective paired imaging study. The methods and results were organized in accordance with the STROBE reporting framework for observational studies [4]. All patients were diagnosed with cervical spondylotic myelopathy or mixed cervical spondylosis. We consecutively screened 107 patients who underwent Zero-P ACDF by the same surgeon between 2023 and 2025 and were scheduled for long-term imaging follow-up under the institutional standard protocol. Thirty-one patients were excluded before paired-imaging eligibility assessment: 23 refused or missed follow-up, 2 had an interval of more than 2 months between the nearest CT and corresponding lateral radiograph, 1 underwent reoperation, and 5 had inadequate image quality. Of the remaining 76 patients, 2 were excluded because both the study CT and radiographs were obtained outside the study institution. The

final paired-imaging cohort therefore comprised 74 patients. All study levels were treated with the Zero-P system. The study flow is shown in Fig. 1.

The standardized postoperative imaging protocol included lateral radiographs on postoperative day 7 after ambulation and at 1, 3, 6, and 12 months. CT was scheduled at 6 and 12 months to evaluate cage subsidence and the cage–endplate interface. All study CT examinations were derived from this routine follow-up protocol, although actual examination dates could vary slightly because of routine clinic scheduling.

Radiograph–CT pairing

Follow-up time was calculated from the date of surgery, and the interval from surgery to the study CT was recorded as the postoperative imaging follow-up time. The postoperative day-7 lateral radiograph obtained after ambulation was used as the baseline for Δ MSH. The follow-up lateral radiograph closest in date to the study CT and of adequate projection quality was selected. All final CT–radiograph pairs were obtained within 30 days. When both 6- and 12-month CT examinations met the study criteria, the 12-month CT was preferentially selected as the study CT. For the remaining patients, an eligible CT from routine follow-up was selected and paired with the nearest technically adequate lateral radiograph.

Imaging measurements

All measurements were performed on the institutional picture archiving and communication system (PACS). The primary radiographic measure was middle segment height (MSH), with measurement endpoints standardized according to the method of Zhao et al. [2]. Δ MSH was defined as MSH on the postoperative day-7 lateral radiograph after ambulation minus MSH on the follow-up radiograph; a larger value indicated greater loss of middle fusion-segment height.

All CT examinations were noncontrast multidetector CT scans acquired on a Philips Incisive CT system (Philips Healthcare). The protocol used 120 kVp, automatic exposure control, a pitch of 0.8, single-section collimation of 0.63 mm, and total collimation of 40 mm. Axial images were reconstructed at 1-mm slice thickness with sagittal multiplanar reconstructions. Penetration of the cage into the inferior endplate of the cranial vertebral body and the superior endplate of the caudal vertebral body was measured separately. CT cumulative endplate penetration was defined as the sum of superior and inferior penetration. Pinter et al. [3] similarly used the sum of superior and inferior penetration to describe cumulative subsidence. Maximum single-endplate CT penetration was also recorded solely for the exploratory > 2-mm stratification.

Although Δ MSH and CT cumulative penetration are both expressed in millimeters, they do not represent the same physical quantity. Δ MSH reflects overall longitudinal height change from the postoperative day-7 baseline to follow-up, whereas CT cumulative penetration is the sum of the local penetration depths at the two cage–endplate interfaces at the follow-up CT time point. We therefore evaluated their

association and paired numerical difference rather than treating them as interchangeable repeated measurements. A representative paired radiographic and CT measurement example is shown in Fig. 4.

Measurement reliability

The same observer repeated the MSH and CT penetration measurements in a predefined retest sample after an interval of approximately 2 weeks. Intraobserver intraclass correlation coefficients (ICCs) were 0.91 for MSH and 0.73 for CT penetration.

Statistical analysis

Continuous variables were summarized as mean $\pm$ standard deviation or median with interquartile range, according to their distributions. The primary analysis used Spearman rank correlation to evaluate the relationship between CT cumulative endplate penetration and Δ MSH. As a secondary numerical comparison, CT cumulative penetration minus Δ MSH was calculated for each patient, and the paired difference was assessed using the Wilcoxon signed-rank test. Superior and inferior penetration were each correlated with Δ MSH, and the paired difference between superior and inferior penetration was also tested. The proportion of patients with predominant inferior penetration was assessed using an exact binomial test. Concordance at the 2-mm threshold and receiver operating characteristic (ROC) analysis were exploratory. For clinical interpretation of this threshold analysis, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and the proportion of CT-positive cases missed by radiography were calculated with Wilson 95% confidence intervals. Because the threshold analysis was exploratory and cohort-derived, no new clinical cutoff was proposed. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

Results

Cohort characteristics and follow-up

Seventy-four patients were included in the primary analysis: 34 men and 40 women, with a mean age of 60.6 ± 11.3 years and a mean body mass index of 22.3 ± 1.5 kg/m². Seventy-two patients (97.3%) underwent single-level ACDF and 2 underwent multilevel surgery. The study level was most commonly C5/6 (48/74, 64.9%), followed by C4/5 (15/74, 20.3%), C3/4 (7/74, 9.5%), and C6/7 (4/74, 5.4%). Median Zero-P height was 6 mm (IQR 5–6). The study CT was obtained mainly within the planned 6- and 12-month follow-up windows, with a median postoperative follow-up time of 12 months. All 74 study CT examinations were paired with a follow-up lateral radiograph obtained within 30 days (Table 1).

Table 1
Cohort characteristics and follow-up framework

Characteristic	Value
Patients	74
Age (yr)	60.6 ± 11.3
Male/female	34/40
BMI (kg/m ²)	22.3 ± 1.5
Single-level/multilevel ACDF	72 (97.3%)/2 (2.7%)
Study level: C3/4	7 (9.5%)
Study level: C4/5	15 (20.3%)
Study level: C5/6	48 (64.9%)
Study level: C6/7	4 (5.4%)
Zero-P height (mm)	6 [5–6]
Postoperative follow-up at study CT (mo), median	12.0
Final CT–radiograph interval ≤ 30 days	74 (100%)

Data are presented as mean ± standard deviation, median [interquartile range], or n (%), as appropriate. ACDF, anterior cervical discectomy and fusion; BMI, body mass index; CT, computed tomography.

Association between CT cumulative penetration and ΔMSH

Median CT cumulative endplate penetration was 2.39 mm (IQR 1.80–3.11), and median ΔMSH was 1.37 mm (IQR 0.88–2.19). The two measures showed a moderate-to-strong positive correlation (Spearman ρ = 0.634, 95% CI 0.456–0.770; P < 0.001; Fig. 2). In the secondary paired numerical comparison, ΔMSH was lower than CT cumulative penetration in 68 of 74 patients (91.9%). The median paired difference (CT cumulative penetration – ΔMSH) was 0.83 mm (IQR 0.50–1.17; Wilcoxon P < 0.001; Fig. 3). The primary imaging measurements and associations are summarized in Table 2.

Table 2
Primary imaging measurements and associations

Measure	Estimate
Superior CT penetration (mm)	0.88 [0.50–1.10]
Inferior CT penetration (mm)	1.52 [1.14–2.11]
CT cumulative penetration (mm)	2.39 [1.80–3.11]
Postoperative day-7 MSH (mm)	36.18 [34.68–38.05]
Follow-up MSH (mm)	34.61 [32.75–36.03]
Δ MSH (mm)	1.37 [0.88–2.19]
CT cumulative penetration vs Δ MSH	$\rho = 0.634$ (95% CI 0.456–0.770), $P < 0.001$
Inferior penetration vs Δ MSH	$\rho = 0.640$, $P < 0.001$
Superior penetration vs Δ MSH	$\rho = 0.205$, $P = 0.079$
Inferior > superior penetration	63/74 (85.1%), $P < 0.001$
Δ MSH lower than CT cumulative penetration	68/74 (91.9%)
CT cumulative penetration – Δ MSH (mm)	0.83 [0.50–1.17], $P < 0.001$

Values are median [interquartile range] unless otherwise indicated. CI, confidence interval; CT, computed tomography; MSH, middle segment height.

Directional pattern of endplate penetration

Median inferior penetration was 1.52 mm (IQR 1.14–2.11), which was greater than median superior penetration of 0.88 mm (IQR 0.50–1.10; $P < 0.001$). Inferior penetration predominated in 63 of 74 patients (85.1%; $P < 0.001$). Δ MSH showed a moderate-to-strong correlation with inferior penetration ($\rho = 0.640$, $P < 0.001$) but only a weak correlation with superior penetration ($\rho = 0.205$, $P = 0.079$).

Exploratory threshold analysis

In the exploratory analysis, 20 patients (27.0%) had maximum single-endplate CT penetration > 2 mm, whereas 22 (29.7%) had Δ MSH ≥ 2 mm. Fifteen patients were positive by both criteria, 47 were negative by both, 7 were radiograph-positive/CT-negative, and 5 were CT-positive/radiograph-negative. Thus, the radiographic 2-mm threshold had 75.0% sensitivity, 87.0% specificity, 68.2% PPV (95% CI 47.3%–83.6%), and 90.4% NPV (95% CI 79.4%–95.8%). Importantly, 5 of 20 CT-positive patients (25.0%; 95% CI 11.2%–46.9%) would have been missed if Δ MSH < 2 mm were used to exclude > 2-mm focal endplate penetration. Patient-level threshold concordance was $\kappa = 0.601$. The area under the ROC curve for continuous Δ MSH to identify maximum single-endplate CT penetration > 2 mm was 0.873 (95% CI 0.765–0.959). The exploratory threshold metrics are summarized in Table 3.

Table 3
Exploratory concordance of the 2-mm thresholds

Metric	Result
CT maximum penetration > 2 mm	20/74 (27.0%)
Δ MSH $\geq$ 2 mm	22/74 (29.7%)
Both positive	15
Both negative	47
Radiograph positive/CT negative	7
CT positive/radiograph negative	5
Sensitivity	75.0% (95% CI 53.1%–88.8%)
Specificity	87.0% (95% CI 75.6%–93.6%)
Positive predictive value	68.2% (15/22; 95% CI 47.3%–83.6%)
Negative predictive value	90.4% (47/52; 95% CI 79.4%–95.8%)
CT-positive cases missed by radiography	25.0% (5/20; 95% CI 11.2%–46.9%)
Cohen κ	0.601
AUC	0.873 (95% CI 0.765–0.959)

CT-positive was defined as maximum single-endplate penetration > 2 mm; radiograph-positive was defined as Δ MSH $\geq$ 2 mm. AUC, area under the receiver operating characteristic curve; CI, confidence interval; CT, computed tomography; NPV, negative predictive value; PPV, positive predictive value. Confidence intervals for threshold proportions were calculated using the Wilson method.

Discussion

For clinicians following patients after zero-profile ACDF, the principal finding is that radiographic Δ MSH and CT cumulative cage–endplate penetration describe related but non-equivalent postoperative changes. The moderate-to-strong correlation ($\rho = 0.634$) indicates that greater longitudinal segment-height loss generally accompanies greater local endplate penetration. However, Δ MSH was lower than CT cumulative penetration in 91.9% of patients, with a median difference of 0.83 mm. The clinically important consequence is that a small radiographic height-loss value should not be interpreted either as a direct estimate of CT penetration depth or as proof that focal endplate penetration is absent.

This distinction helps reconcile the heterogeneous definitions used in the ACDF subsidence literature. Previous studies have variously defined subsidence by disc-height loss, fusion-segment height loss, cage migration, or direct endplate penetration [1–3]. Radiographic Δ MSH is a longitudinal change measured at the middle of a two-dimensional lateral projection from an early postoperative baseline,

whereas CT cumulative penetration is the sum of the deepest local penetrations at two interfaces on a follow-up examination. The deepest superior and inferior penetration points need not lie at the same sagittal location, and differences in positioning, magnification, and projection geometry can further separate the two measurements [16–20]. A meaningful correlation can therefore coexist with a systematic difference in absolute values.

The directional findings provide an additional structural explanation for the radiographic change. Penetration into the superior endplate of the caudal vertebral body predominated in 85.1% of patients and correlated more strongly with Δ MSH than penetration into the cranial vertebral body ($p = 0.640$ vs 0.205). Pinter et al. [3] likewise reported a predominance of inferior penetration on CT. Local bone-bearing capacity, endplate preservation, cage contact area, construct configuration, and distraction can influence interface loading [5–15]. Because the present study did not directly measure endplate bone quality or contact area, these data support a directional imaging association rather than a specific biomechanical mechanism.

The exploratory 2-mm analysis makes this limitation clinically tangible. Continuous Δ MSH showed good discrimination for maximum single-endplate CT penetration > 2 mm (AUC 0.873), yet applying a 2-mm cutoff to radiographs yielded only 75.0% sensitivity. Five of 20 CT-positive patients (25.0%) had Δ MSH < 2 mm, despite focal CT penetration exceeding 2 mm; the corresponding NPV was 90.4%. Thus, a sub-2-mm radiographic height loss reduced but did not eliminate the possibility of focal interface penetration. This distinction is important because ACDF studies have used 2-mm, 3-mm, or height-based criteria to define subsidence [1–3, 21, 22]. A threshold developed for longitudinal radiographic height loss should therefore not be assumed to represent an equivalent depth of local CT penetration.

The clinical implication is complementary use rather than replacement of one modality by the other. Serial lateral radiographs remain appropriate as the first-line method for tracking progressive fusion-segment height loss because they are practical for repeated follow-up. CT is not justified routinely on the basis of the present data, but it becomes more informative when symptoms are discordant with apparently minor radiographic change, when the depth or direction of cage–endplate penetration must be localized, or when a structural explanation is required before further management. In this framework, the 2-mm radiographic criterion is better viewed as a modality-specific definition of visible height loss than as a rule-out test for focal CT penetration. Prospective studies should determine whether combining radiographic change with symptoms, bone quality, or construct-related factors can identify the subgroup that benefits most from confirmatory CT.

Limitations

This study has several limitations. Its single-center retrospective design and the requirement for eligible CT–radiograph pairs may have introduced follow-up selection bias. The absence of CT at the postoperative day-7 baseline prevented separation of early cage seating or endplate embedding from subsequent progressive penetration. Although all final CT and radiographic examinations were obtained

within 30 days of each other, unavoidable differences in positioning and radiographic magnification remained. Reliability assessment was limited to intraobserver measurements, and the ICC for CT penetration was 0.73, indicating that further standardization of local interface quantification is needed. The threshold analysis was exploratory, included only 20 CT-positive patients, and was not externally validated; PPV and NPV are also prevalence-dependent. Patient-reported outcomes were not systematically available, so the present study cannot determine whether CT-only penetration predicts symptoms or subsequent clinical deterioration. Prospective studies with matched early and later imaging, standardized projection conditions, multiobserver measurements, and clinical endpoints are needed to confirm these findings.

Conclusions

Radiographic Δ MSH showed a moderate-to-strong association with CT cumulative cage–endplate penetration after zero-profile ACDF, but the two measurements were not interchangeable. In this cohort, the commonly used 2-mm radiographic threshold missed 25% of patients with > 2-mm focal CT penetration, indicating that minor radiographic height loss cannot completely exclude local cage–endplate penetration. Serial radiographs remain appropriate for routine longitudinal surveillance, whereas CT should be regarded as a complementary problem-solving modality when clinical findings and radiographs are discordant or interface-level localization is required.

Abbreviations

ACDF, anterior cervical discectomy and fusion; AUC, area under the receiver operating characteristic curve; BMI, body mass index; CI, confidence interval; CT, computed tomography; ICC, intraclass correlation coefficient; IQR, interquartile range; MSH, middle segment height; NPV, negative predictive value; PACS, picture archiving and communication system; PPV, positive predictive value; ROC, receiver operating characteristic

Declarations

Ethics approval and consent to participate

This study was reviewed and approved by the Scientific Research Ethics Committee of Wuxi People's Hospital (Approval No. KY25078; review date: April 15, 2025) and was conducted in accordance with the Declaration of Helsinki. The approved study documents included a waiver of informed consent; accordingly, the requirement for written informed consent was waived by the ethics committee.

Clinical trial number: Not applicable.

Consent for publication

The requirement for individual informed consent was waived by the Scientific Research Ethics Committee of Wuxi People's Hospital under the approved waiver of informed consent (Approval No. KY25078). All clinical and imaging data, including the representative radiographs and CT images, were fully deidentified before inclusion in this manuscript, and no participant is identifiable.

Availability of data and materials

Deidentified data may be made available by the corresponding author on reasonable request, subject to institutional and ethics approval.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SY: data curation, imaging measurements, visualization, formal analysis, and writing - original draft. BW: conceptualization, methodology, formal analysis, and writing - review and editing. YW: data organization, imaging measurements, and manuscript review. SZ: imaging data verification, clinical interpretation, and manuscript review. AG: supervision, resources, project administration, and critical revision of the manuscript. SY and BW contributed equally to this work and share first authorship; SY is listed first among the co-first authors. All authors reviewed and approved the final manuscript.

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Not applicable.

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Figures

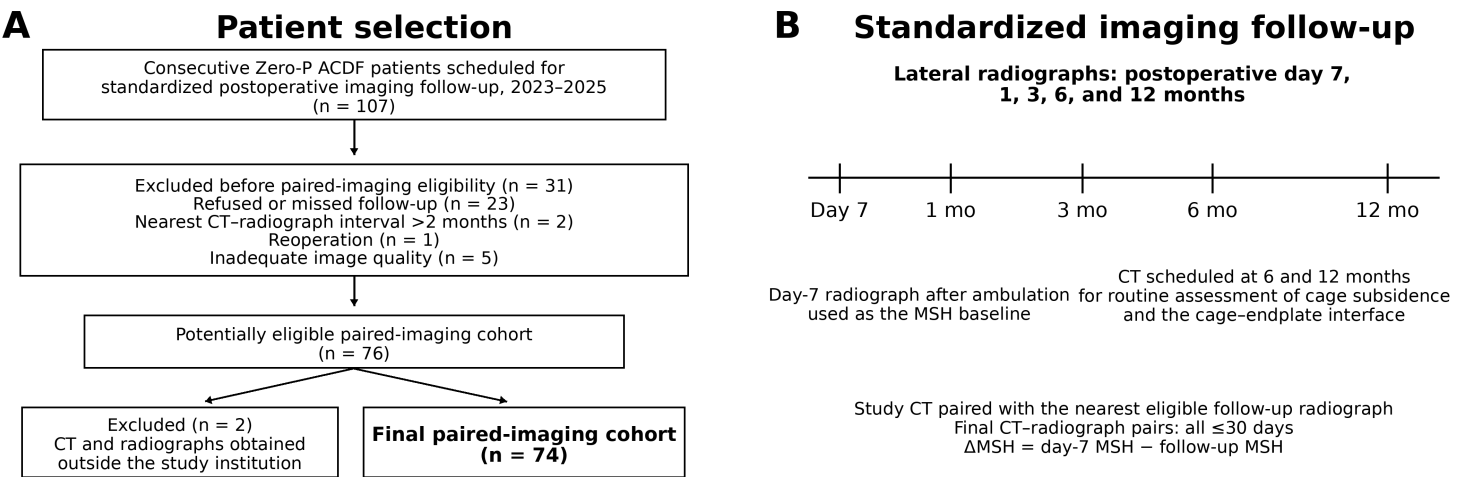


Figure 1

Study flow and standardized imaging follow-up. A total of 107 consecutive Zero-P ACDF patients treated by the same surgeon during 2023–2025 and scheduled for standardized postoperative imaging follow-up were screened. Thirty-one were excluded before paired-imaging eligibility: refused or missed follow-

up (n=23), nearest CT–radiograph interval >2 months (n=2), reoperation (n=1), or inadequate image quality (n=5). Of the remaining 76 patients, 2 with both CT and radiographs obtained outside the study institution were excluded, leaving 74 for analysis. Routine lateral radiographs were scheduled at postoperative day 7 and 1, 3, 6, and 12 months; CT was scheduled at 6 and 12 months to assess cage subsidence and the cage–endplate interface. All final study CT–radiograph pairs were obtained within 30 days

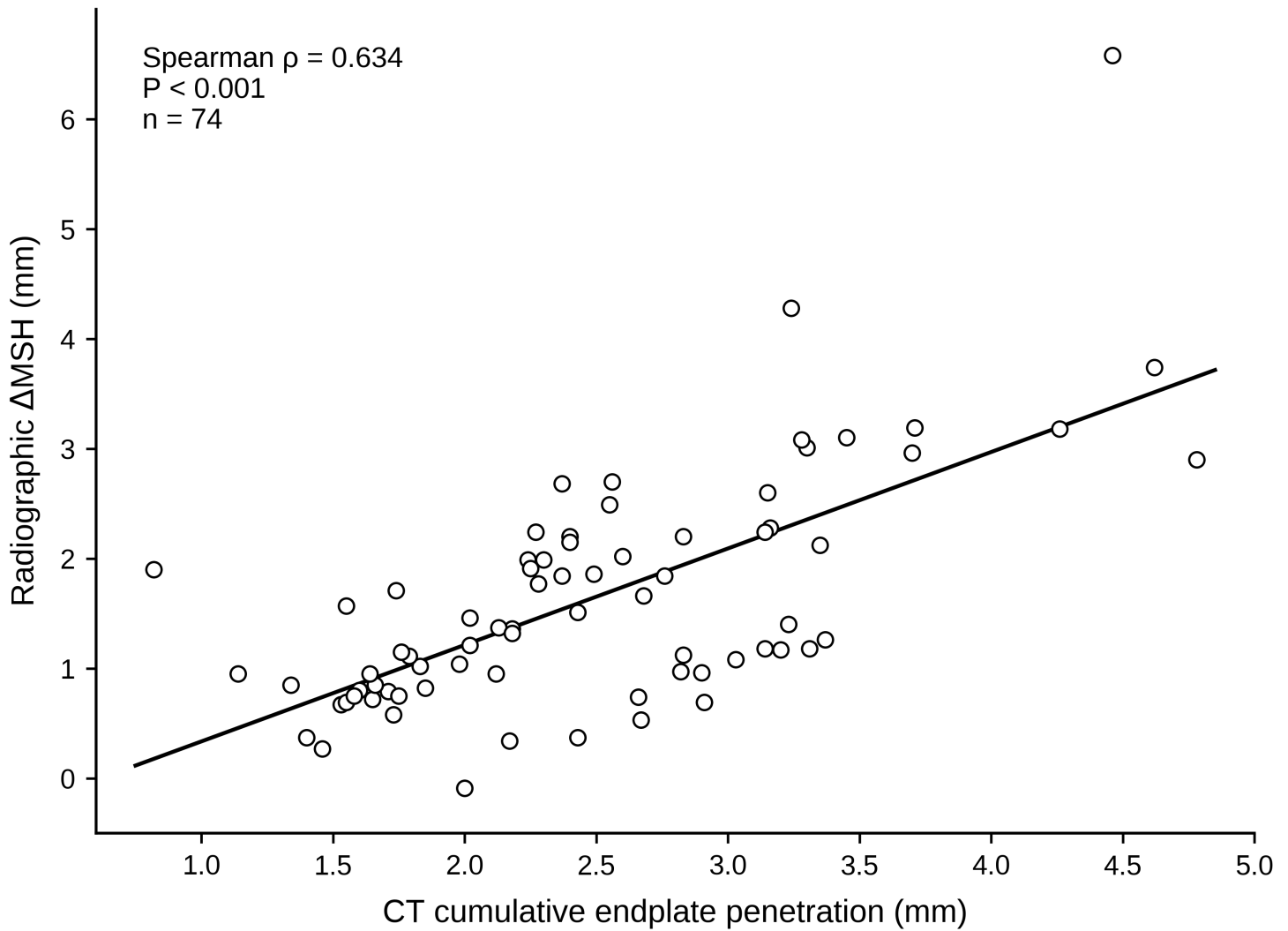


Figure 2

Relationship between CT cumulative endplate penetration and radiographic Δ MSH. The solid line shows the fitted linear trend for visualization. The primary association was assessed using Spearman rank correlation

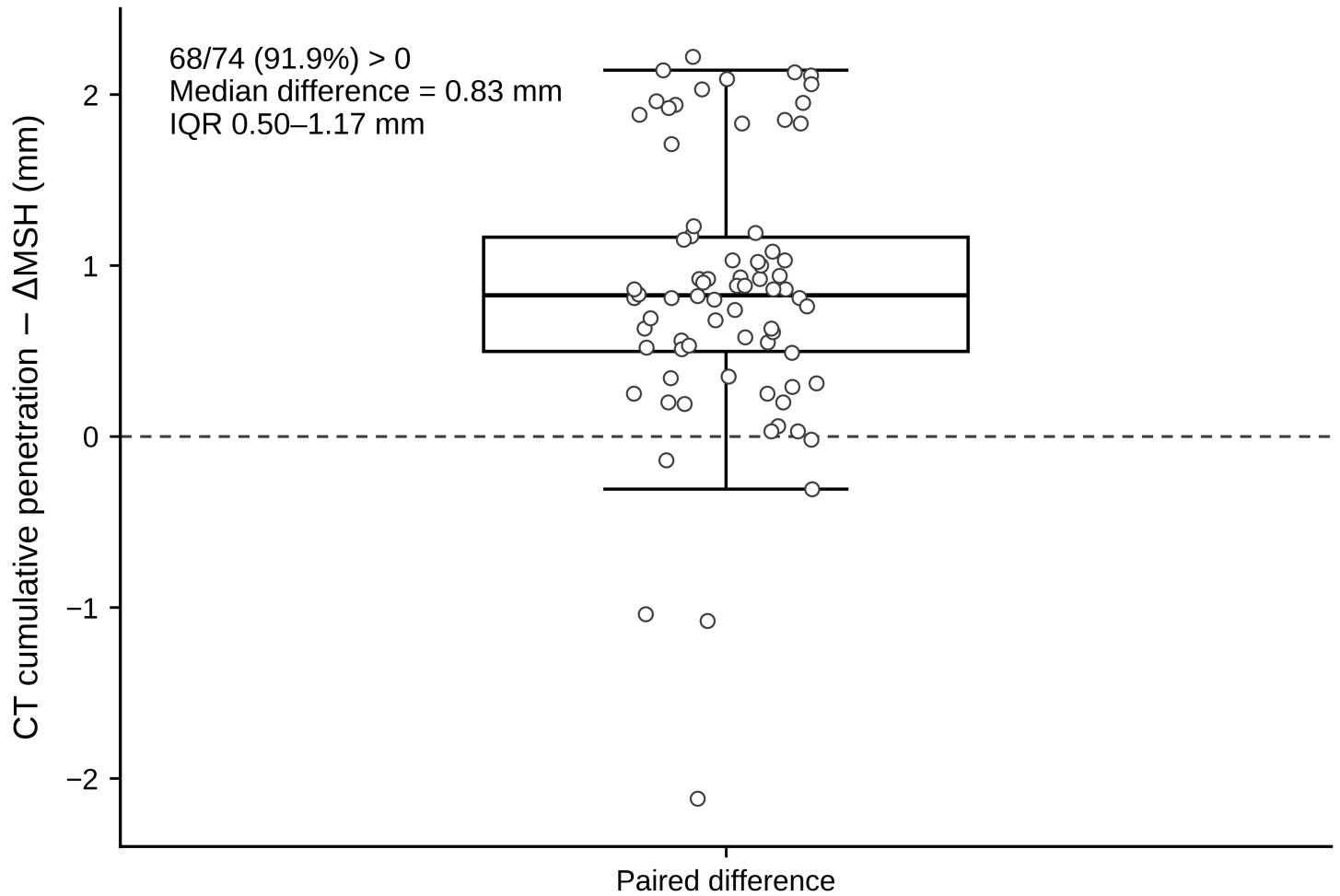


Figure 3

Secondary paired numerical comparison between CT cumulative endplate penetration and radiographic Δ MSH. Positive values indicate a larger CT cumulative penetration value. Δ MSH was smaller in 68 of 74 patients (91.9%)

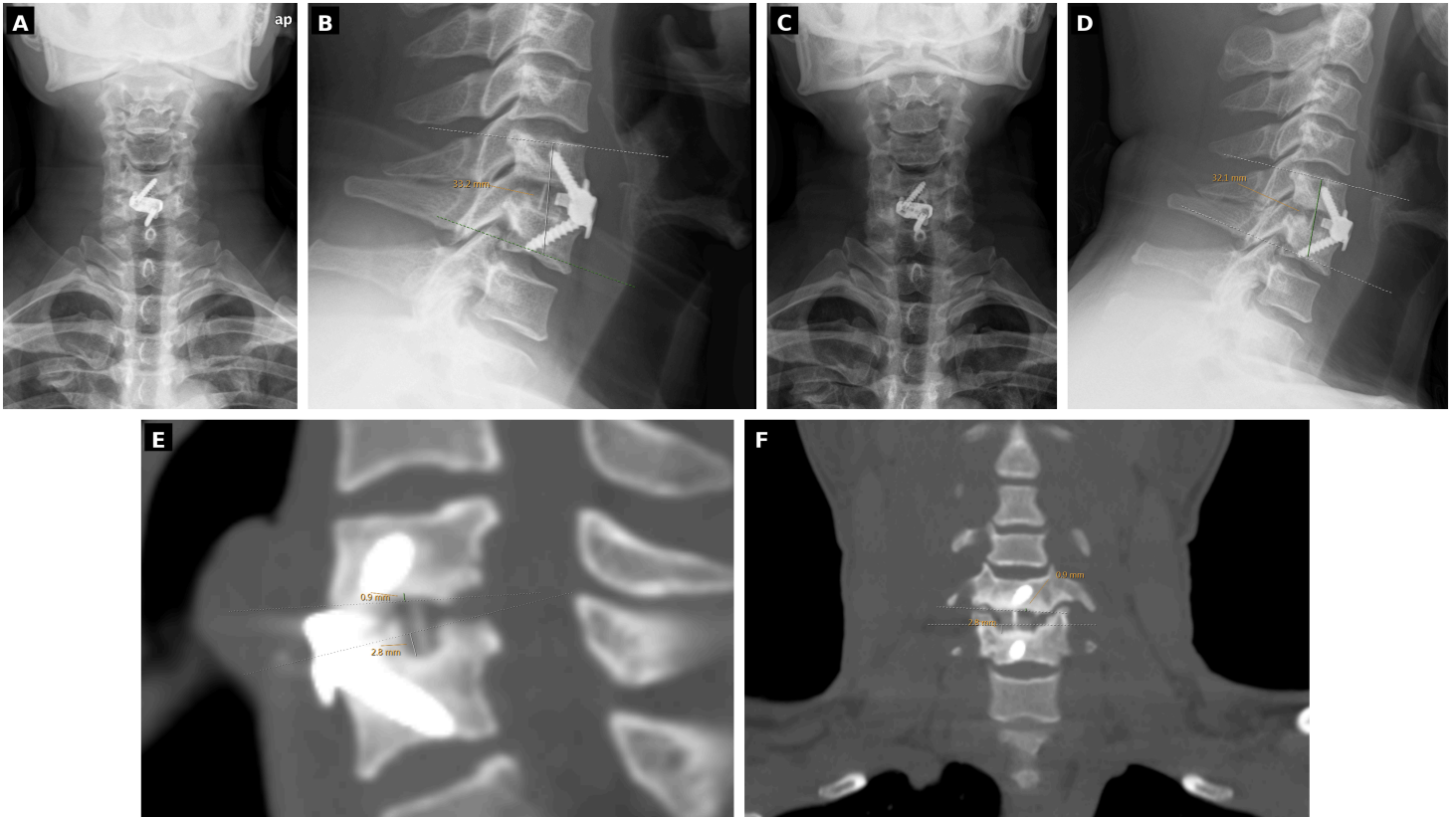


Figure 4

Representative radiographic and CT measurements after Zero-P ACDF. (A, B) Anteroposterior and lateral radiographs obtained on postoperative day 7 after ambulation; the lateral radiograph shows a middle segment height (MSH) of 33.2 mm. (C, D) Anteroposterior and lateral radiographs obtained at postoperative month 12; the lateral radiograph shows an MSH of 32.1 mm, corresponding to a Δ MSH of 1.1 mm from the day-7 baseline. (E, F) Follow-up sagittal and coronal CT reconstructions showing superior and inferior endplate penetration of 0.9 mm and 2.8 mm, respectively; cumulative CT penetration was 3.7 mm. MSH, middle segment height