

Two-Year Computed Tomography Evaluation of Non-Union in Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis: Risk Zones and Clinical Outcomes

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Abstract

Purpose. To investigate the incidence, clinical implications, and anatomical distribution of non-union at 2 years postoperatively using computed tomography (CT).

Methods. This retrospective investigation included 108 adolescent idiopathic scoliosis (AIS) patients (1,820 fused facet joints) who underwent posterior spinal fixation (PSF) with pedicle screw (PS) instrumentation between 2008 and 2023, followed by whole-fusion-area CT at 2 years postoperatively. The primary outcome was spinal non-union, which was evaluated using a grading system based on CT images of each facet. Non-union was graded on sagittal images as Grade 0 (solid fusion), Grade 1 (indistinct bony fusion), and Grade 2 (non-union) for classification into non-union positive (Grade 2; NU+) and negative (Grade 0 or 1; NU-) groups. The spinal fusion range was divided into proximal-end, central, and distal-end zones. Surgical data, radiographic parameters, SRS-22r scores, and mechanical failure rates were all statistically compared.

Results. Grade 2 non-union was observed in 25 of 1,820 facet joints (1.4%) from 14 of 108 patients (13%). PS loosening was noted in 86% of NU+ patients. The NU+ group had significantly lower SRS-22r Satisfaction scores (3.68 vs. 4.00, $P = 0.042$). Among the Grade 2 facet joints, 72% (18 of 25) were localized between T11 and L2, with 80% (20 of 25) located within the distal-end zone of the fusion construct.

Conclusions. Postoperative 2-year CT evaluation revealed a 13% incidence of non-union in AIS patients receiving PSF with PS, most of which occurring at the distal end of the fixation range. Non-union was associated with PS loosening and significantly decreased patient satisfaction. Adequate bone grafting, especially in the distal-end zone, may help prevent non-union and improve surgical outcomes.

Introduction

Segmental pedicle screw (PS) fixation for adolescent idiopathic scoliosis (AIS) was introduced by Suk et al. in 1995 [1]. Prior to the widespread use of PS instrumentation, pseudarthrosis was considered one of the most serious complications following posterior spinal fusion (PSF) for AIS [2]. Reported pseudarthrosis rates ranged from 7.5% to 22.7% [3, 4], which accounted for 26% of reoperations in these patients [5]. With the introduction of PS constructs, however, the incidence of pseudarthrosis after PSF for AIS has markedly decreased, with recent reports indicating rates as low as 0–3% [4, 6–8].

The diagnosis of pseudarthrosis in AIS has historically relied on radiographic evaluation [3, 8–12], evidence of mechanical failure [12], or the need for revision surgery [12, 13]. Even in the absence of obvious instability or loss of correction in the short-to-medium term, non-union itself may also serve as a source of late complications. Indeed, one report described neurological impairment caused by a cyst arising at a non-union segment 22 years postoperatively [14]. Other studies on adult spinal deformity have shown that pseudarthrosis is not uncommon after PSF [15–17]. Moreover, recent evidence

suggests that the incidence of implant failure or pseudarthrosis does not decrease beyond 2 years postoperatively [18].

Asymptomatic non-union without instability in AIS patients might not manifest as a short-term problem, but could potentially result in neurological symptoms or mechanical failure over time. To the best of our knowledge, few reports have investigated the prevalence of such latent non-union following PSF in AIS. The present study therefore sought to clarify the following key features of AIS patients undergoing PSF with PS instrumentation: (1) the incidence of overt and subclinical non-union observed at 2 years postoperatively, (2) the clinical and surgical characteristics associated with non-union, (3) the surgical outcomes in patients with non-union, and (4) the specific spinal levels and zones within the fusion construct that are more susceptible to non-union.

To address the above clinical questions, we conducted a computed tomography (CT)-based evaluation of non-union at 2 years postoperatively in 1,820 facets from 108 AIS patients who had received PSF.

Materials and Methods

Patients

At our institution, CT of the spinal fusion site was routinely performed at 2 years postoperatively to monitor patient progress, evaluate the status of bony fusion, and detect any implant failure. Consecutive patients with AIS who underwent PSF using PS constructs between March 2008 and April 2023 and underwent spinal CT imaging at 2 years postoperatively were included in this study. The inclusion criteria were as follows: (1) receiving one-stage PSF using the rod rotation and direct vertebral rotation technique with PS fixation, (2) a minimum follow-up period of 2 years, and (3) undergoing spinal CT at 2 years postoperatively. Patients with other types of scoliosis, such as congenital, neuromuscular, or syndrome-related scoliosis, were excluded.

Surgical procedure

The patients were positioned on the operating table and underwent PSF while in a prone position. PSs were inserted with the assistance of preoperative CT-based navigation in 54 cases, intraoperative CT-based navigation in 43 cases, and a robotic-assisted system in 11 cases. After PS placement, the inferior articular processes within the instrumented levels were resected in all patients. In 75 cases, the spinous processes within the fusion area were removed, while in 33 cases they were preserved. In patients whose spinous processes were removed, the excised spinous process was crushed and used as graft material. In those with preserved spinous processes, the base of spinous process was partially decorticated using a round chisel to serve as a graft bed. Ponte osteotomy around the apical vertebra was performed in 35 patients. The mean number of intervertebral Ponte osteotomies per patient was 4.1 (range: 1–6), with none conducted on the upper instrumented vertebra (UIV) or lowest instrumented vertebra (LIV). At the thoracic level, the medial two-thirds of the transverse processes were removed.

Bone grafting was performed using local autografts, without iliac crest bone grafts or artificial bone. Decortication of the lamina was carried out using a round chisel. The articular surface of the superior articular processes was removed with a high-speed burr and utilized as a recipient bed for bone grafting. The grafted bone was packed on the dorsal surface of the superior articular process within the fixation area. The excess bone was then placed on the lamina. Postoperative thoracolumbar braces were prescribed for patients who requested them, had concerns about their immobilization strength, or were active children.

Radiological assessment

Standing long-cassette postero-anterior and lateral radiographs were evaluated by three spinal surgeons (the first and sixth authors) preoperatively, immediately after surgery, and 2 years postoperatively. The investigators reviewed the radiographs while blinded to the outcomes. Correction rate (%) was calculated from preoperative and immediately postoperative Cobb angles, and correction loss (°) was determined using immediately postoperative and 2-year postoperative Cobb angles. At our institution, it had been standard practice to suggest high-resolution CT scans of the entire fusion area at 2 years postoperatively in patients with AIS, primarily to assess PS loosening and bony non-union.

The presence of non-union at all fused facet joints in each patient was independently assessed by two blinded examiners (the first and second authors). Each facet joint was evaluated in sagittal CT images. Non-union status was graded as Grade 0 for solid fusion, Grade 1 for indistinct bony fusion (indistinct bone continuity, gap < 1 mm in width between bony surfaces, and absence of a radiolucent line), and Grade 2 for non-union (gap > 1 mm in width between bony surfaces and/or presence of a radiolucent line). If definitive evidence of bony fusion was present in any portion of the facet joint, it was classified as fused (Grade 0), even if gaps were visible in other areas. Classification as Grade 1 or Grade 2 was made only when no clear evidence of fusion was observed throughout the entire facet joint. (Fig. 1)

An intervertebral segment was considered fused if either the left or right facet was classified as Grade 0, or Grade 1 in both bilateral facet joints. If one facet was Grade 1 and the other was Grade 2, the segment was classified as non-union. Similarly, the segment was classified as non-union if both facets were Grade 2. A patient was diagnosed as having non-union if at least one intervertebral segment met the criteria for non-union.

The above assessment was performed for every segment within the instrumented spinal levels. The UIV and its caudal neighbor were defined as the proximal-end zone, the LIV and its cephalic neighbor were judged as the distal-end zone, and all other segments were considered the central zone (Fig. 2). All PSs within the fusion area were evaluated by CT for the presence of loosening, evidence of pull-out, and breakage of the screw or screw-rod interface.

Clinical assessment

Scoliosis Research Society (SRS)-22r questionnaire results were collected preoperatively and at 2 years postoperatively. Patients completed the survey in an isolated room to avoid any influence from medical staff.

Statistical analysis

Patients with one or more non-union segments were classified into the non-union positive group (NU+), while those without any non-union segments were placed into the non-union negative group (NU-). Baseline characteristics, surgical data, and pre- and immediately postoperative radiographic parameters were compared between the groups, followed next by comparisons of postoperative radiographic findings at 2 years, SRS-22r scores, the incidence of mechanical failure, and reoperation rate. The incidence of non-union segments was first analyzed for each spinal level, and then compared among the proximal-end zone, central zone, and distal-end zone (Fig. 2). Continuous data were analyzed using Welch's *t*-test, ordinal data were assessed with the Mann–Whitney U test, and nominal and ratio data were evaluated by Fisher's exact test. All analyses were performed using the Statistical Package for Social Sciences (SPSS) for Windows version 28.0 (IBM, Chicago, IL, USA). For all testing, $P < 0.05$ was considered statistically significant.

Results

Overall data

A total of 108 AIS patients met the criteria for inclusion in this study. The demographic characteristics and clinical features of the patients are summarized in Table 1. The medical records of 108 consecutive AIS patients (14 male and 94 female, mean $\pm$ standard deviation age: 15.2 ± 2.3 years [range: 11–20 years], preoperative Cobb angle: $54.5 \pm 10.3^\circ$ [range: 37.0 – 88.2°], fusion area: 9.4 ± 2.4 vertebrae [range: 4–14 vertebrae]) were reviewed. Grade 2 non-union was recorded in 14 of 108 patients (13%) and 25 of 1,820 facet joints (1.4%). The interobserver agreement for the presence or absence of Grade 2 non-union, as measured by Fleiss' kappa, was 0.69, indicating good reliability. Two patients underwent reoperation to extend the fixation range due to instability in the Grade 2 non-union segment.

Table 1
Patient characteristics (N = 108)

Age at surgery (years)	15.2 ± 2.3 (11–20)
Male / Female	14 / 94
Height (cm)	157.3 ± 7.6 (143.4–180.5)
Weight (kg)	47.4 ± 7.6 (26.4–75.7)
BMI	19.1 ± 2.4 (12.8–27.2)
Risser sign (Grade)	
0	8
1	5
2	8
3	12
4	43
5	32
Lenke classification	
1	63
2	13
3	2
4	3
5	15
6	12
Cobb angle (°)	54.5 ± 10.3 (37.0–88.2)
Interval values represent the mean ± standard deviation (minimum–maximum).	

Comparison of baseline characteristics between NU+ and NU– patients

There were 14 patients in the NU+ group and 94 patients in the NU– group (Table 2). No significant differences were noted between the groups for age, gender, height, weight, bone maturity, curve type, or preoperative or immediately postoperative radiological parameters. Moreover, we witnessed no remarkable differences in terms of the extent of fixation, intraoperative blood loss, operative time, or Ponte osteotomy. A total of 7.1% of patients in the NU+ group had their spinous process preserved,

which tended to be lower than the 34% in the NU– group ($P = 0.059$). No patient in the NU+ group underwent robot-assisted PS insertion.

Table 2
Comparison of baseline characteristics between non-union + and non-union-
patients

Variable	Non-union+ (n = 14)	Non-union- (n = 94)	P-value
Age at surgery (years) *	14.8 ± 0.6	15.3 ± 0.2	0.426
Male	14.3%	12.8%	0.876
Height (cm)	159.1 ± 3.2	157.1 ± 0.7	0.526
Weight (kg)	46.1 ± 2.0	47.6 ± 0.8	0.471
Risser sign (Grade)			0.511
0	1 (13%)	7 (87%)	
1	0	5 (100%)	
2	1 (13%)	7 (87%)	
3	1 (8.3%)	11 (92%)	
4	9 (21%)	34 (79%)	
5	2 (6.3%)	30 (94%)	
Lenke classification			0.351
1	9 (14%)	54 (86%)	
2	3 (23%)	10 (77%)	
3	0	2 (100%)	
4	1 (33%)	2 (67%)	
5	1 (6.7%)	14 (93%)	
6	0	12 (100%)	
Range of fixation (vertebrae)	9.9 ± 0.7	9.4 ± 0.3	
Surgical procedure			
Preservation of spinous process	1 (7.1%)	32 (34%)	0.059
Ponte osteotomy	4 (29%)	31 (33%)	0.999
Robot surgery	0	11 (12%)	0.353
Bleeding (g)	714 ± 217	487 ± 53	0.308
Interval values are presented as the mean ± standard error.			

Variable	Non-union+ (n = 14)	Non-union– (n = 94)	P-value
Bleeding / vertebra (g)	64 ± 16	50 ± 4	0.364
Operative time (min)	240 ± 20	247 ± 8	0.736
Preoperative			
Cobb angle of major curve (°)	55.1 ± 3.3	54.5 ± 1.0	0.860
Cobb angle with side bending (°)	29.7 ± 3.9	28.6 ± 1.4	0.780
Flexibility of major curve (%)	47.6 ± 4.5	48.6 ± 2.0	0.835
T5-12 kyphosis (°)	20.0 ± 4.1	16.8 ± 0.9	0.434
T10-L2 kyphosis (°)	0.3 ± 1.8	1.3 ± 0.8	0.594
T12-S1 lordosis (°)	55.4 ± 4.3	52.7 ± 1.5	0.555
Immediately postoperative			
Cobb angle of major curve (°)	17.4 ± 2.1	19.2 ± 0.7	0.413
T5-12 kyphosis (°)	20.4 ± 2.6	20.8 ± 0.8	0.874
T10-L2 kyphosis (°)	-0.5 ± 2.4	-4.1 ± 0.8	0.154
T12-S1 lordosis (°)	46.2 ± 2.4	48.6 ± 1.2	0.355
Interval values are presented as the mean ± standard error.			

Comparison of surgical outcomes at 2 years postoperatively between NU+ and NU– patients

The NU+ group displayed significantly lower Satisfaction (3.68 vs. 4.00, $P = 0.042$) and Total (4.04 vs. 4.31, $P = 0.024$) SRS-22r scores at 2 years postoperatively versus the NU– group (Table 3). Moreover, preoperative SRS-22 Function, Pain, and Subtotal scores tended to be lower in NU+ patients. In the NU+ group, 14% of patients required reoperation; the causes were PS loosening in one case and rod breakage in another, and both were associated with non-union.

Table 3
Comparison of surgical outcomes at 2 years postoperatively between non-union + and non-union- patients

Variable	Non-union+ (n = 14)	Non-union- (n = 94)	P-value
Preoperative SRS-22r			
Function	4.26 ± 0.19	4.56 ± 0.05	0.051
Pain	3.96 ± 0.26	4.32 ± 0.06	0.064
Self-image	2.77 ± 0.13	2.81 ± 0.06	0.798
Mental health	3.83 ± 0.22	4.06 ± 0.08	0.302
Subtotal	3.72 ± 0.16	3.95 ± 0.04	0.073
2-year postoperative SRS-22r			
Function	4.44 ± 0.11	4.67 ± 0.04	0.069
Pain	4.23 ± 0.19	4.50 ± 0.06	0.190
Self-image	3.64 ± 0.19	3.98 ± 0.07	0.105
Mental health	4.20 ± 0.18	4.40 ± 0.06	0.296
Subtotal	4.13 ± 0.12	4.39 ± 0.04	0.053
Satisfaction	3.68 ± 0.13	4.00 ± 0.08	0.042*
Total	4.04 ± 0.10	4.31 ± 0.04	0.024*
Change in SRS-22r			
Function	0.19 ± 0.15	0.11 ± 0.06	0.662
Pain	0.27 ± 0.25	0.16 ± 0.07	0.680
Self-image	0.87 ± 0.23	1.18 ± 0.09	0.219
Mental health	0.37 ± 0.23	0.34 ± 0.07	0.896
Subtotal	0.41 ± 0.13	0.44 ± 0.05	0.874
Mechanical complication			
Correction loss (°)	3.6 ± 2.0	1.6 ± 0.5	0.349
Correction loss > 10°	1 (7.1%)	1 (1.1%)	0.244
Interval values are presented as the mean ± standard error.			
*P < 0.05 was considered statistically significant.			

Variable	Non-union+ (n = 14)	Non-union– (n = 94)	P-value
Pedicle screw loosening	12 (86%)	25 (27%)	< 0.001*
Implant fracture or instability	2 (14%)	0	0.016*
Re-operation	2 (14%)	0	0.016*
Interval values are presented as the mean ± standard error.			
*P < 0.05 was considered statistically significant.			

Location of non-union

A total of 1,820 facet joints within the fixation range of 108 patients were evaluated on CT (Fig. 3). Grade 0 fusion was observed in 1,716 segments (94%), Grade 1 in 79 segments (4.3%), and Grade 2 in 25 segments (1.4%). Grade 2 non-union was most frequently identified at L1/2 (6.8%), T12/L1 (3.8%), and T11/12 (2.0%), with 72% (18 of 25) of all Grade 2 segments localized between T11 and L2. In contrast, no Grade 2 segments were identified in the upper thoracic region from T2 to T7.

Non-union rate by zone

The fixation range zones most susceptible to Grade 2 non-union were analyzed next (Fig. 2). Among the 25 non-union segments, 20 (80%) occurred in the distal-end zone and 4 cases (16%) were found in the proximal-end zone. In the central zone, only 1 case of Grade 2 non-union (0.072%) was observed among 1,392 facet joints.

Discussion

This study yielded four key findings on non-union following PSF for AIS as assessed by CT: (1) non-union was detectable in 25 of 1,820 facet joints (1.4%) from 14 of 108 patients (13%), (2) preservation of the spinous process tended to associate with higher fusion rates, with complete bony fusion in all 11 patients who underwent robot-assisted surgery, (3) patients with non-union exhibited PS loosening in 86% of cases and significantly lower satisfaction at 2 years postoperatively, and (4) non-union occurred most frequently in the thoracolumbar junction, with 80% of non-union cases in the distal-end zone and 16% in the proximal-end zone.

Historically, pseudarthrosis rates in AIS were as high as 22.7% before the advent of instrumentation, and have since decreased to 2–7% with modern implants [19]. Prior studies have reported pseudarthrosis rates of 3.1% with Harrington rods, 1.7% with Cotrel–Dubousset instrumentation, and even 0% with PS constructs [6]. Although our study focused solely on patients treated using PS instrumentation, our non-union rate appeared slightly higher than past reports. However, those investigations primarily defined pseudarthrosis based on radiographic findings (e.g., correction loss > 10°), the need for revision surgery,

or implant failure⁴. In patients with segmental PS instrumentation, non-union may not manifest as radiographic instability or mechanical failure; only 2 patients in our cohort showed > 10° correction loss within the fusion area, with 1 of them displaying solid fusion on CT. Only 1 patient (0.93%) required revision surgery due to non-union. These findings suggest that radiographs alone may be insufficient to detect non-union in PSF for AIS.

If radiographic instability is absent despite non-union, one may question the clinical relevance of identifying non-union. We believe it remains important for several reasons. First, long-term non-union could potentially lead to neurological complications, such as in a case of paraparesis caused by a cyst arising from a pseudarthrosis site 22 years postoperatively [14]. Second, non-union may predispose patients to future mechanical failure in adulthood. Walker et al. found that 7.4% of young adults with idiopathic scoliosis who underwent PSF required reoperation within 2 years due to mechanical failure¹⁷. Smith et al. reported implant failure/pseudarthrosis rates of 7.47% at 2–3 years, 3.57% at 3–4 years, and 2.79% at 4–5 years postoperatively in adults with symptomatic lumbar scoliosis, which highlighted the need for continued vigilance beyond 2 years [18]. AIS patients will eventually reach adulthood and older age, when latent non-union may become clinically significant. Third, non-union may be associated with subtle reductions in quality of life. In our cohort, patients with non-union had significantly lower scores in several SRS-22r domains. Although clinical signs such as back pain have limited diagnostic utility for non-union as Dawson et al. [2] have shown, this correlation warrants further consideration.

Preservation of the spinous process and the use of Ponte osteotomy were not associated with an increased risk of non-union in our study. Although past reports have advocated iliac crest grafts or bone substitutes to increase fusion mass, our approach utilized only local bone harvested from the inferior articular process, transverse process, and spinous process, similarly to the technique reported by Yataganbaba et al. [8] These findings suggest that limited graft volume may not be the primary driver of non-union, especially since patients with spinous process preservation, which has often been associated with greater local bone volume [20], showed a tendency towards lower non-union rates. Moreover, non-union was not more frequent at Ponte osteotomy levels. As this study was not designed to determine the sufficiency or necessity of local bone grafts, however, further investigation is needed to establish optimal grafting strategies.

We observed that factors indicating insufficient mechanical stability, such as PS loosening along with involvement of the thoracolumbar junction and distal-end zones, were more strongly associated with non-union. In our cohort, 80% of non-union cases occurred in the distal-end zone, and 86% of patients with non-union had adjacent PS loosening. Furthermore, when restricted to 65 patients with LIV of T12–L2, the rate of nonunion in the distal end zone was as high as 15%. Uehara et al. reported that inaccurate PS placement increased the risk of screw loosening by a factor of 17.2 [21]. These findings indicate that precise screw placement, particularly at the LIV, may be critical in achieving solid fusion.

At our institution, it has been customary to perform a single CT scan at 2 years postoperatively as part of routine follow-up after spinal fusion surgery. Although our results showed that 13% of patients harbored

radiographically occult non-union, routine CT surveillance may still not be justifiable in future patients. Simony et al. reported a 4.3% overall cancer rate in AIS patients, which was approximately five times higher than in an age-matched Danish population²². Thus, minimizing radiation exposure remains paramount. Based on the present findings, our strongest recommendation is not routine postoperative CT imaging, but rather strategies aimed at minimizing non-union risk. Given that non-union may be more likely in the distal-end zone and thoracolumbar junction, we propose three clinical strategies: (1) perform careful decortication and grafting in these zones intraoperatively; (2) ensure precise PS placement and avoid screw loosening at the LIV during correction maneuvers; and (3) during follow-up, monitor for signs of PS loosening at the LIV. When loosening is observed, targeted evaluation for non-union in the distal-end zone may be warranted.

This study has several limitations. First, it was retrospective in nature. This study has several limitations. First, it was retrospective in nature. Although postoperative CT was routinely performed at our institution 2 years after surgery, not all patients underwent CT evaluation. Therefore, the possibility of selection bias cannot be excluded. Second, most patients did not undergo CT immediately after surgery, making it difficult to determine whether PS loosening preceded non-union, or vice versa. Third, the follow-up period was limited to 2 years. As mechanical failure can occur beyond this period, longer follow-up is needed to clarify the clinical implications of CT-detected non-union.

Conclusion

In a cohort of patients with AIS who underwent PSF with PS constructs, CT at 2 years postoperatively identified non-union in 1.4% of fused facet joints and 13% of patients. PS loosening was observed in 86% of patients with non-union, who also reported significantly lower postoperative satisfaction scores. Non-union cases were primarily located at the thoracolumbar junction and distal-end zone. These findings highlight that accurate PS placement and meticulous bone grafting, particularly at the level of the LIV, are critical to achieving solid bone fusion in PSF for AIS.

Declarations

Author Contribution

Hiroki Oba wrote and prepared the manuscript. All authors contributed to the study design, data acquisition, data analysis, and manuscript revision. All authors read and approved the final version of the manuscript.

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Figures

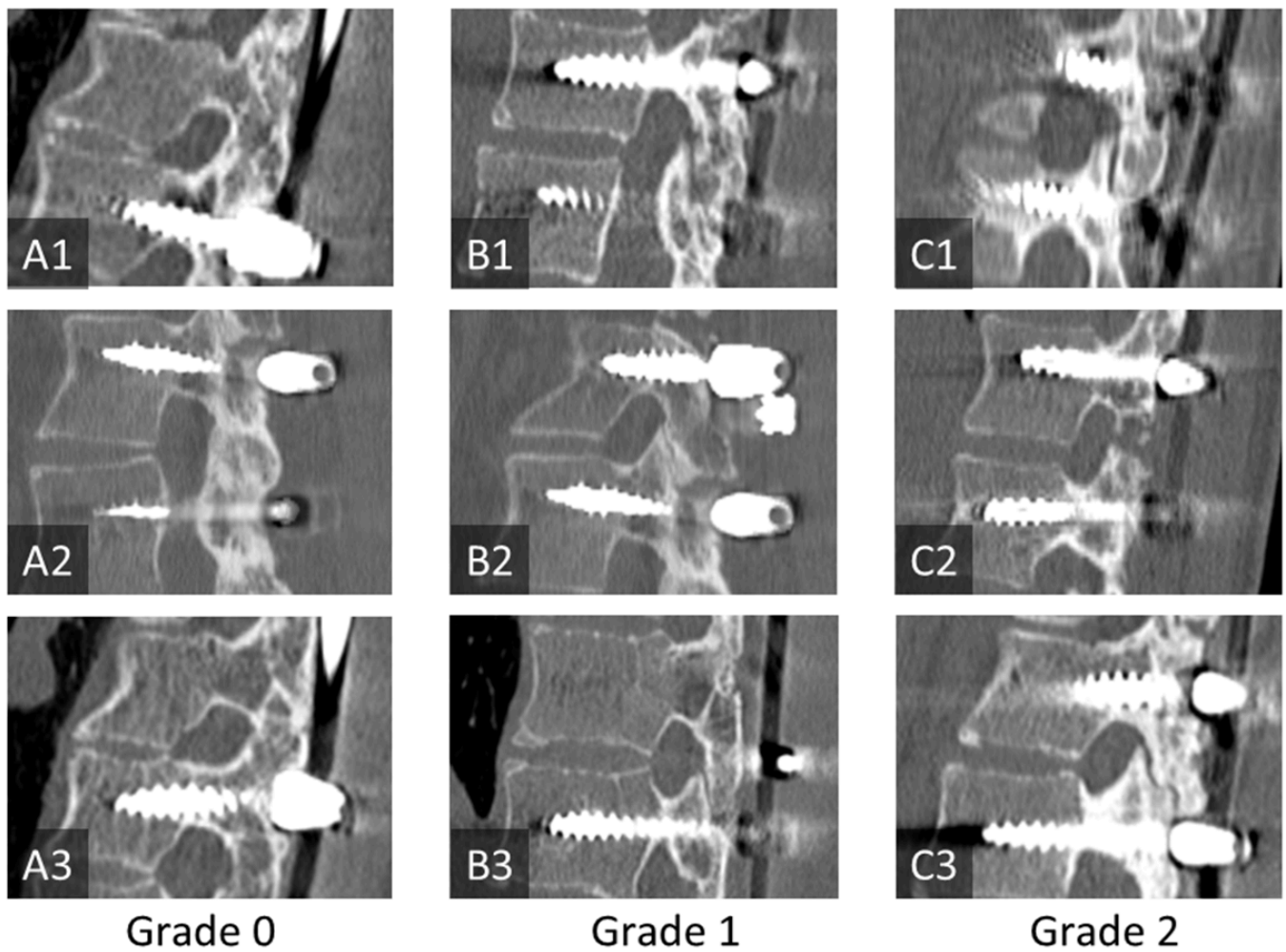


Figure 1

Grading system for spinal non-union based on sagittal computed tomography (CT) images

Grade 0: solid fusion (A1-3). Grade 1: indistinct bony fusion characterized by indistinct bone continuity, gap <1 mm in width between bony surfaces, and absence of a radiolucent line (B1-3). Grade 2: non-union defined as gap >1 mm in width between bony surfaces and/or presence of a radiolucent line (C1-3). Each facet joint was evaluated in sagittal CT images.

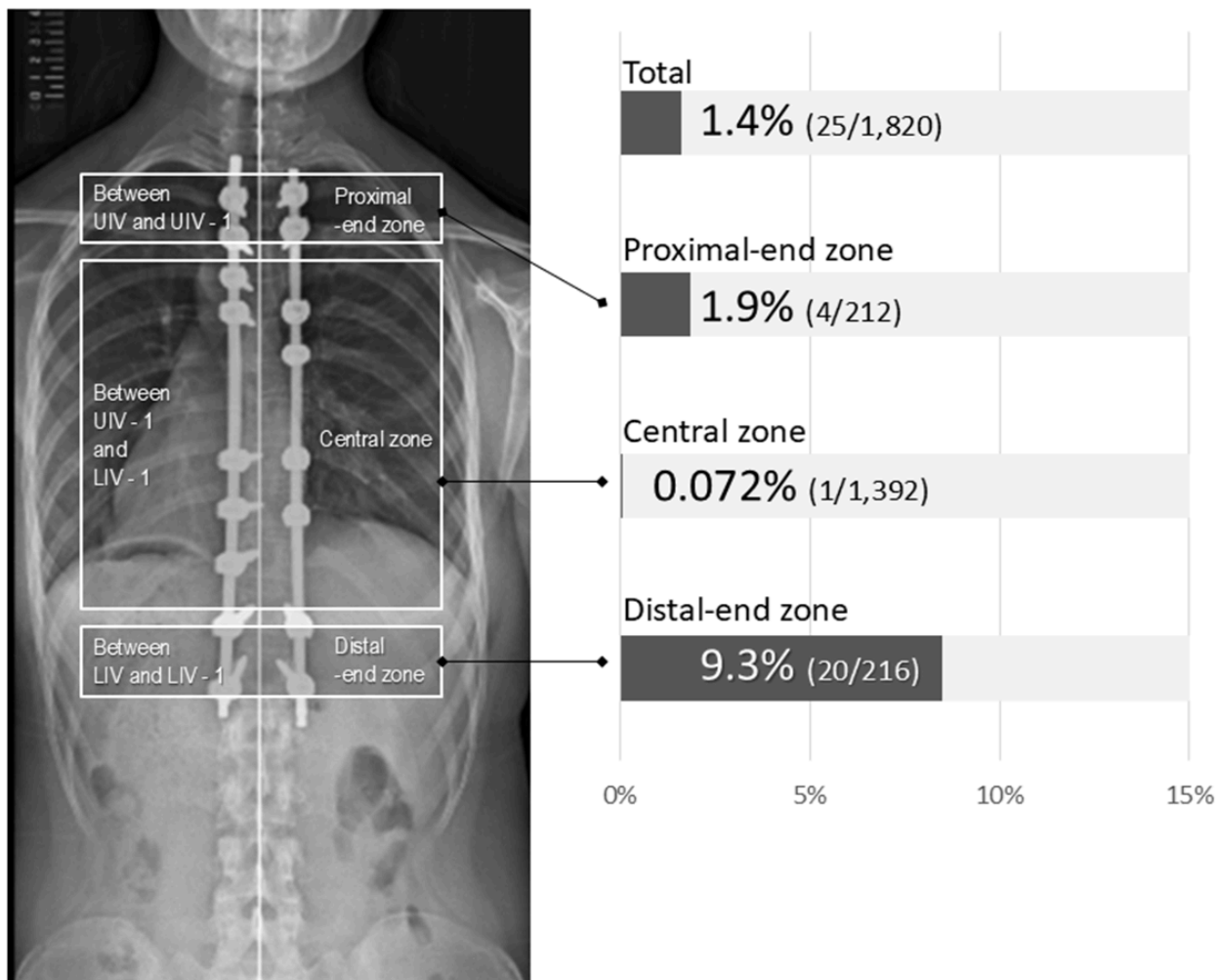


Figure 2

Incidence of non-union in each zone within the instrumented fusion area

Grade 2 was defined as non-union. The proximal-end zone included the upper instrumented vertebra and its caudal neighbor. The distal-end zone included the lowest instrumented vertebra and its cephalic neighbor. The central zone comprised all other segments.

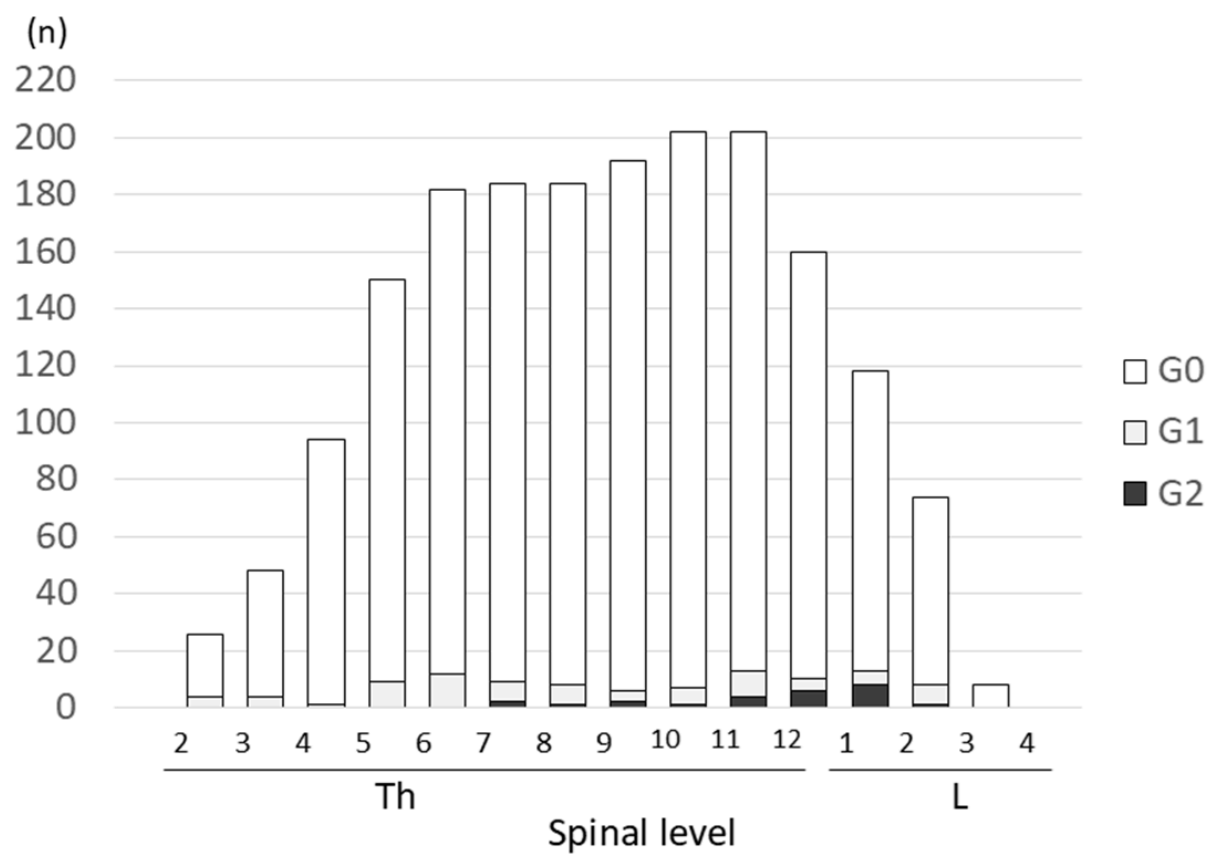


Figure 3

Location of non-union

Abbreviations: Th, thoracic; L, lumbar; G, grade