European Spine Journal (2019) 28:1314–1321
https://doi.org/10.1007/s00586-019-05921-6

ORIGINAL ARTICLE

Check for updates

Can posterior implant removal prevent device-related vertebral osteopenia after posterior fusion in adolescent idiopathic scoliosis? A mean 29-year follow-up study

Kei Watanabe[1] · Masayuki Ohashi[1] · Toru Hirano[1] · Keiichi Katsumi[2] · Hirokazu Shoji[1] · Tatsuki Mizouchi[1] · Yuya Ishikawa[1] · Kazuhiro Hasegawa[3] · Naoto Endo[1] · Hideaki E. Takahashi[4]

Received: 24 August 2018 / Revised: 9 February 2019 / Accepted: 12 February 2019 / Published online: 19 February 2019

Abstract

Purpose To determine whether posterior implant removal prevents stress-shielding-induced vertebral osteopenia within the posterior fusion area in surgically treated patients with adolescent idiopathic scoliosis (AIS).

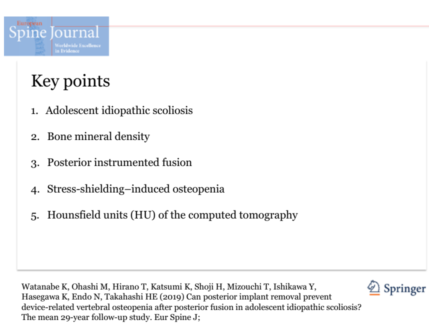
Methods Eighteen patients with major thoracic AIS (mean age, 43.3 years; range, 32–56 years; mean follow-up, 28.8 years, range, 20–39 years) who underwent posterior spinal fusion (PSF) alone between 1973 and 1994 were included. Participants were divided into implant removal (group R, $n=10$, mean interval until implant removal, 50 months) and implant non-removal groups (group NR, $n=8$). Bone mineral density was evaluated using the Hounsfield units (HU) of the computed tomography image of the full spine. The HU values of the UIV−1 (one level below the uppermost instrumented vertebra), apex, LIV+1 (one level above the lowermost instrumented vertebra), and LIV−1 (one level below the lowermost instrumented vertebra; as a standard value) were obtained. Stress-shielding-induced osteopenia was assessed as the UIV−1/LIV−1, apex/LIV−1, and LIV+1/LIV−1 HU ratios (×100).

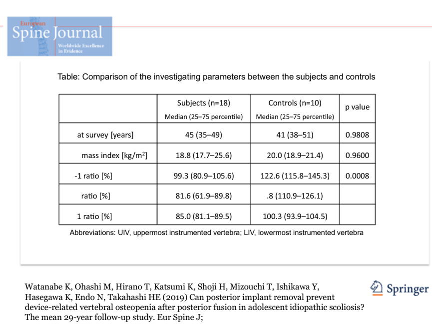
Results Overall (median, 25th–75th percentile), the apex (144.7, 108.6–176.0) and LIV+1 (159.4, 129.7–172.3) demonstrated lower HU values than LIV−1 (180.3, 149.2–200.2) (both comparisons, $p<.05$). Comparison of groups R and NR showed no significant differences in the scoliosis correction rate, bone mineral density of the proximal femur, the HU absolute values of all investigated vertebrae, or in the HU ratios of the investigated vertebrae to LIV−1.

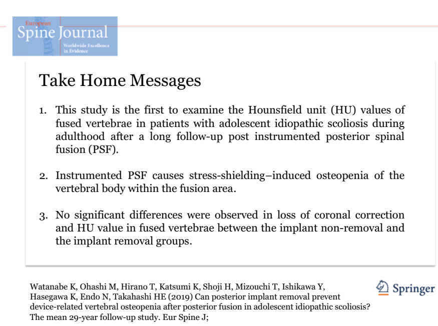
Conclusion Instrumented PSF causes stress-shielding-induced osteopenia of the vertebral body within the fusion area in adulthood, which cannot be prevented by posterior implant removal, probably due to firm fusion mass formation.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-05921-6) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Keywords Bone mineral density · Adolescent idiopathic scoliosis · Spinal fusion · Spinal instrumentation · Surgery · Long-term follow-up · Body mass index · Body weight · Bone metabolism · Osteopenia · Osteoporosis

Introduction

Adolescent idiopathic scoliosis (AIS) is a multifactorial disease with an unclear primary etiology. Several investigators have reported that 27% to 59% of patients with AIS have osteopenia during the peripubertal period [1–3]. Therefore, AIS patients should be carefully evaluated for early-onset osteoporosis during adulthood. Moreover, experimental studies revealed that surgically fused vertebrae stabilized with rigid spinal instrumentation might develop device-related vertebral osteoporosis, which might further increase the possibility of developing vertebral fractures or negatively affect the quality of life [4, 5]. Therefore, we hypothesized that posterior implant removal could prevent device-related vertebral osteopenia after posterior instrumented fusion for AIS during adulthood.

The usefulness of Hounsfield unit (HU) assessment using computed tomography (CT) has been recently established [6]. The studies showed a correlation between HU values and bone mineral density (BMD) [6–8], an ability to predict subsequent adjacent vertebral fracture risk [9], implant stability [10], and fusion success after spinal fusion surgery [11]. Moreover, the threshold HU values for distinguishing osteoporosis (110–120 HU) have been clarified [6–8].

However, to the best of our knowledge, no study has assessed whether device-related osteoporosis in fused vertebrae develops in patients with AIS who undergo posterior instrumented fusion surgery. The purpose of this study was to prove our working hypothesis and the preventive effect of implant removal against device-related osteoporosis at a minimum of 20 years after spinal instrumented fusion for AIS.

Methods

Data from 25 consecutive female AIS patients who underwent posterior spinal fusion (PSF) alone with instrumentation at a single institution between 1973 and 1994 were collected from medical charts and standing X-ray films. Of the 25 patients asked to join the current study and undergo clinical and radiological examinations, 18 (72%) consented. Their scoliosis curves, according to the Lenke classification [12], were type 1 in seven patients, type 2 in eight, type 3 in one, and type 4 in two. Among the participants, nine patients were treated with Harrington instrumentation, three with combined Harrington and Luque segmental spinal instrumentation (SSI), one with Luque SSI, and five with Cotrel–Dubousset instrumentation.

After providing written informed consent, each participant completed clinical and radiological examinations, which included anthropometric measurements, full-standing radiographs, whole-spine CT, BMD, and bone metabolism assessments. The loss in body height (BH) resulting from the spinal deformity was calculated using the equation by Ylikoski [13] (height loss [cm] $= 0.0062{*}\chi + 0.0024{*}\chi^2$, where χ is the major + minor curve magnitude [°]) and was used to compute the corrected BH (cBH). The body mass index (BMI) was calculated by dividing body weight (BW; kg) by the cBH squared (m^2).

For quantitative CT, patients underwent whole-spine CT with calibrating phantoms using a 320-detector scanner (Aquilion ONE; Toshiba Medical System, Tochigi-ken, Japan; CT scanning parameters: 0.5 mm section thickness, 120 kV, 150 mA, 0.5 s/rotation) or a 64-detector scanner (Ingenuity Elite; Royal Philips, Amsterdam, Netherlands; CT scanning parameters: 0.625 mm section thickness, 120 kV, 150 mA, 0.5 s/rotation). A McKesson Picture Archiving and Communication System (McKesson, San Francisco, CA, USA) was used to calculate the average HU value by placing an elliptical region of interest that was confined to the medullary space of the vertebral body to reduce the potential for beam hardening and volume averaging from the adjacent cortical bone. Regions of interest were measured on the sagittal images at one level below the uppermost instrumented vertebra (UIV−1), at the apex, at one level above the lowermost instrumented vertebra (LIV+1), and at one level below the LIV (LIV−1) as a standard value. An elliptical region confined to the trabecular bone in the vertebral body was used in three distinct sagittal cuts: immediately medial to the lateral borders of the vertebral body and in the middle of the vertebral body. The average of these three values was used as the mean HU value of the vertebra; measurements were performed twice, with the mean value used for the analysis (Fig. 1). To decrease bias caused by differences in age and BMD across patients, the HU value for each vertebra was normalized as the investigated vertebra/LIV−1 HU ratio (× 100), specifically the HU of the individual vertebra divided by the HU of the LIV−1. In addition, an intraclass correlation coefficient (ICC) was calculated to determine the within-examiner consistency for HU value measurements on CT images.

Because the spinal instruments had remained in the lumbar vertebrae at the final follow-up in about half of the participants, the BMD of the left hip was assessed using dual-energy X-ray absorptiometry (Hologic Discovery QDR

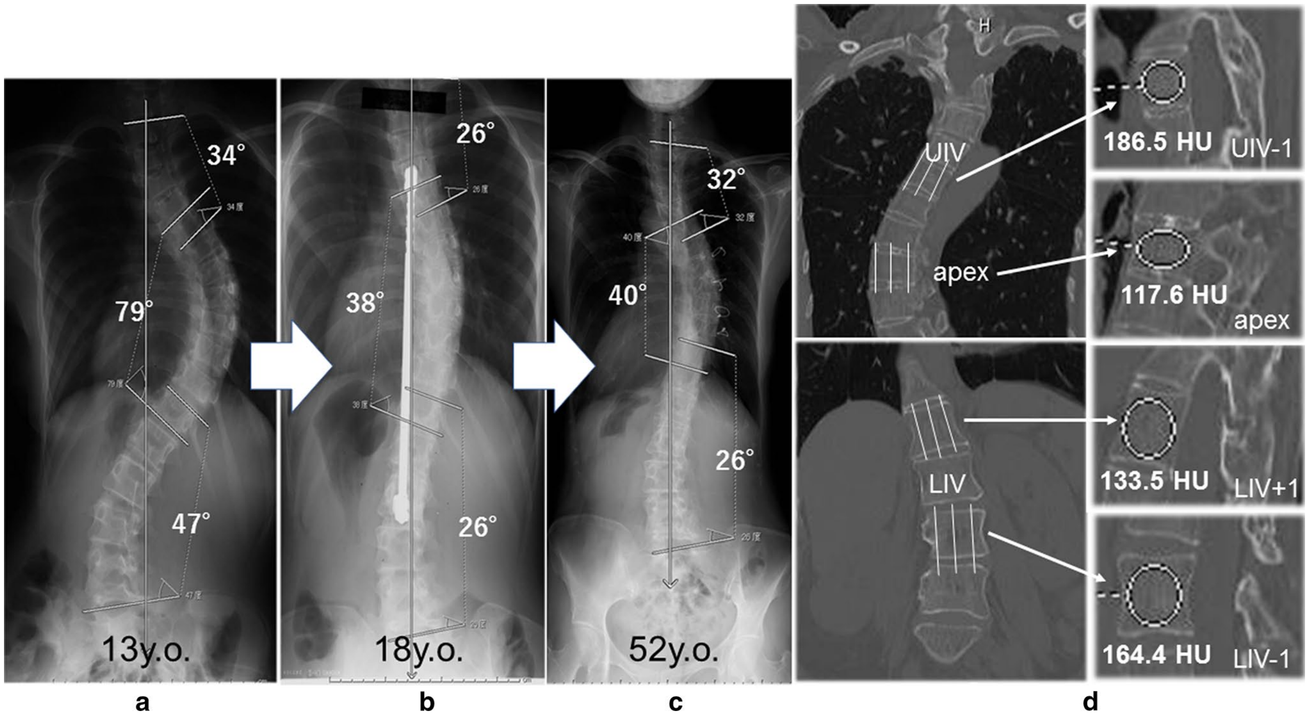


Fig. 1 **a** Radiograph of a 13-year-old girl with Lenke type 2 adolescent idiopathic scoliosis before surgery. **b** Radiograph 5 years after posterior spinal fusion using Harrington instrumentation from T4 to L2. **c** Radiograph 34 years after implant removal, demonstrating acceptable correction. **d** CT scans showing the determination of the HU value using an elliptical region-of-interest function: (left) sagittal planes of interest on the coronal slices of the whole-spine CT scan; (right) HU values at the UIV−1, apex, LIV+1, and LIV−1 levels generated by the McKesson Picture Archiving and Communication System. HU, Hounsfield units; CT, computed tomography; UIV−1, one level below the uppermost instrumented vertebra; LIV+1, one level above the lowermost instrumented vertebra; LIV−1, one level below the lowermost instrumented vertebra

Series Densitometer; Hologic Inc., Bedford, MA, USA). The BMD of the total proximal femur and femoral neck was measured, and the site of the lesser BMD T-score was utilized to represent the BMD and T-score of the left hip. The T-score was defined as the number of standard deviations from the mean BMD for healthy young adults. To assess bone metabolism, serum levels of procollagen type I N-propeptide and tartrate-resistant acid phosphatase 5b were measured, which are bone formation and resorption markers, respectively.

In the early phase, mainly from 1973 to 1990, we performed initial PSF followed by planned implant removal after confirming bony union according to our hypothesis regarding device-related vertebral osteopenia. In the late phase, mainly from 1991 to 1994, we stopped removing implants, according to the surgeons' preference. Based on whether or not the implant was removed, the participants were divided into two groups. The implant non-removal group (group NR) included individuals who did not undergo implant removal, and the implant removal group (group R) underwent removal at an average of 50 months (range, 32–110 months) after initial PSF (9 patients with Harrington instrumentation and 1 with Luque SSI).

Ten adult age-matched female patients who had been diagnosed with idiopathic scoliosis during adolescence and did not undergo surgical treatment were recruited as the control group (mean age, 43.4 years; range, 32–61 years; mean upper thoracic Cobb angle, 23.5°; range, 5°–40°; main thoracic Cobb angle, 52.4°; range, 40°–68°; thoracolumbar Cobb angle, 56.4°; range, 29°–72°). For the control group, CT evaluation was conducted at T5 (corresponding to UIV−1), T9 (corresponding to apex), L2 (corresponding to LIV+1), and L4 (corresponding to LIV−1), and their results were compared with the study groups.

Statistical analyses

Statistical analyses were performed using StatView-J version 5.0 (Abacus Concepts, Berkeley, CA, USA). Continuous data are expressed as median (25th–75th percentile). Statistical comparisons between groups NR and R were performed using Mann–Whitney *U* tests for continuous variables. Differences between the values before and after surgery were evaluated using Wilcoxon signed-rank tests. A p value $< .05$ was considered statistically significant.

Results

The demographic data of the 18 female participants are shown in Table 1. The average age at the survey and the average follow-up period was 43.3 years (range, 32–56 years) and 28.8 years (20–39 years), respectively. There were no significant differences between the two groups in the presurvey characteristics. In terms of the characteristics at the time of the survey, there were no significant differences in BMI, BMD, serum level of procollagen type I N-propeptide, and amount of scoliosis correction, whereas significant differences were found in the follow-up period and in the serum level of tartrate-resistant acid phosphatase 5b.

The mean ICCs (95% confidence interval) of inter-rater reliabilities for HU value measurement of the investigated vertebrae (UIV−1, apex, LIV+1, and LIV−1) were 0.990 (0.974–0.996), 0.983 (0.956–0.993), 0.987 (0.966–0.995), and 0.952 (0.880–0.982), respectively.

With regard to the HU value at the overall corresponding levels, the apex and LIV+1 demonstrated lower HU values compared with the standard value at LIV−1 (both comparisons, $p < .05$), whereas UIV−1 did not demonstrate a significant difference (Fig. 2). Comparison between groups NR and R showed no significant differences in the HU ratio in any of the corresponding levels (Table 2) ("Appendix" Figs. 3, 4).

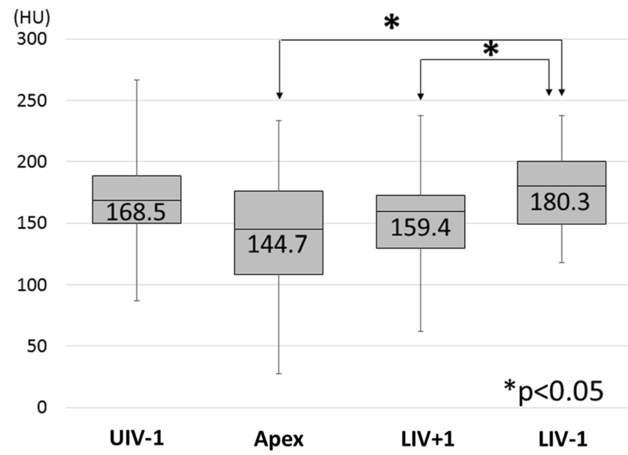


Fig. 2 Comparison of the HU values between the investigated vertebrae and LIV−1 (standard value) using Wilcoxon signed-rank tests (*$p < .05$). HU, Hounsfield units; UIV−1, one level below the uppermost instrumented vertebra; LIV+1, one level above the lowermost instrumented vertebra; LIV−1, one level below the lowermost instrumented vertebra

In comparison with the control group, the subjects showed lower HU ratios at the overall corresponding levels (all comparisons, $p < .001$) (Table 3).

Table 1 Comparison of the demographic and investigating parameters between groups NR and R

	Group NR ($n = 8$) Median (25–75th percentile)	Group R ($n = 10$) Median (25–75th percentile)	*p* value
Age at operation (years)	13.0 (12.0–16.0)	13.5 (13–17)	.5570
Number of fused segments (n)	10.5 (9.0–11.0)	10.0 (9–10)	.3034
Follow-up period (year)	21.0 (20.5–22.0)	35 (34–36)	.0005
BMI (m^2/kg)	24.8 (18.3–27.2)	18.5 (17.5–20.4)	.0833
BMD (femur) (g/cm^2)	0.825 (0.748–0.882)	0.742 (0.692–0.796)	.2076
T-score	− 0.35 (− 1.05–0.15)	− 1.20 (− 1.55–0.80)	.1719
Bone metabolic marker P1NP (ng/mL)	40.4 (35.7–45.5)	48.7 (39.5–69.2)	.1551
TRAP-5b (mU/dL)	204.0 (178.5–234.5)	350.5 (203–412)	.0410
Upper thoracic Cobb angle (°)			
Preoperative	30.5 (23.0–53.0)	37.0 (35.3–45.5)	.3114
Final follow-up	53.0 (22.5–50.5)	34.0 (29.0–37.0)	.5930
Correction loss	2.0 (− 2.5–8.5)	5.0 (1.0–9.0)	.6233
Main thoracic Cobb angle (°)			
Preoperative	71.5 (64.5–78.5)	70.5 (55.0–77.0)	.7219
Final follow-up	53.0 (38.0–60.0)	56.5 (45.0–68.0)	.3976
Correction loss	6.5 (2.0–7.0)	3.5 (0.0–7.0)	.6220
Thoracolumbar Cobb angle (°)			
Preoperative	45.5 (36.5–54.5)	36.0 (32.3–45.3)	.0603
Final follow-up	29.5 (25.5–47.5)	21.0 (14.0–38.0)	.1549
Correction loss	0.5 (− 3.5–10.0)	4.0 (− 5.0–7.0)	.9290

SD standard deviation, *BMI* body mass index and *BMD* bone mineral density

Table 2 Comparison of the computed tomography evaluation between groups NR and R

	Group NR ($n = 8$) Median (25–75th percentile)	Group R ($n = 10$) Median (25–75th percentile)	p value
UIV−1 absolute value (HU)	176.6 (157.5–215.9)	162.3 (146.6–188.3)	.4772
Apex absolute value (HU)	159.3 (141.2–177.9)	125.5 (102.1–156.9)	.2135
LIV+1 absolute value (HU)	168.8 (135.8–187.7)	150.0 (129.7–178.1)	.2481
LIV−1 absolute value (HU)	198.1 (167.1–214.7)	175.0 (144.8–194.4)	.2481
UIV−1 ratio (%)	92.6 (81.1–108.9)	100.8 (80.9–102.2)	.7898
Apex ratio (%)	84.6 (71.4–93.6)	78.4 (58.8–87.7)	.4239
LIV+1 ratio (%)	84.6 (77.1–92.0)	85.7 (81.1–89.5)	> .9999

UIV uppermost instrumented vertebra and *LIV* lowermost instrumented vertebra

Table 3 Comparison of the investigating parameters between the subjects and controls

	Subjects ($n = 18$) Median (25–75 percentile)	Controls ($n = 10$) Median (25–75 percentile)	p value
Age at survey (years)	45 (35–49)	41 (38–51)	.9808
Body mass index (kg/m^2)	18.8 (17.7–25.6)	20.0 (18.9–21.4)	.9600
UIV−1 absolute value (HU)	168.5 (149.9–188.3)	233.5 (208.1–243.0)	.0016
Apex absolute value (HU)	144.7 (108.6–176.0)	218.8 (175.6–236.4)	.0007
LIV+1 absolute value (HU)	159.4 (129.7–172.3)	166.6 (156.4–200.0)	.1136
LIV−1 absolute value (HU)	180.3 (149.2–200.2)	175.3 (155.0–203.0)	.9618
UIV−1 ratio (%)	99.3 (80.9–105.6)	122.6 (115.8–145.3)	.0008
Apex ratio (%)	81.6 (61.9–89.8)	116.8 (110.9–126.1)	< .0001
LIV+1 ratio (%)	85.0 (81.1–89.5)	100.3 (93.9–104.5)	< .0001

UIV uppermost instrumented vertebra and *LIV* lowermost instrumented vertebra

Discussion

The current study is the first to examine the HU values of fused vertebrae in patients with AIS during adulthood at a mean follow-up of 29 years after instrumented PSF. The present study showed no significant difference in loss of coronal correction between the two groups or adverse effects related to scoliosis correction by planned implant removal. Overall, device-related osteopenia existed in fused vertebrae, except in the cranial portion during adulthood. However, there were no significant differences in the HU ratio at the UIV−1, apex, and LIV+1 between groups NR and R, and our working hypothesis could not be supported.

Osteoporosis, which is a widespread metabolic bone disease manifested by decreased BMD and poor bone quality, is a major public health problem in the elderly. Although AIS is a multifactorial disease and its primary etiology remains unclear, several investigators have reported that 27% to 59% of patients with AIS have osteopenia during the peripubertal period [1–3]. Ohashi et al. [14] conducted a long-term follow-up survey of BMD at a minimum of 20 years after surgery for AIS, and reported the average BMD (0.69 g/cm^2) and T-score (− 1.1) of the left hip. They found that more than half of the participants had osteopenia [14]. Based on previous reports [1–3, 14], AIS patients with low BMD at surgery are at risk of osteoporosis in adulthood. According to another point of view, bone mineral status might be influenced by BMI rather than scoliotic deformity [15], which was comparable between groups NR and R in the present study. Thus, the prevention of osteoporosis, which involves maximizing nutritional status and maturational gains in bone density or peak bone mass and minimizing post-maturity losses, is crucial. Although modern rigid spinal instrumentation could provide increased stability and higher fusion success rates in complex spinal disorders, device-related osteoporosis in fused vertebrae, probably caused by the stress-shielding effect, has been demonstrated in experimental studies [4, 5]. In the clinical setting, Zagra et al. [16, 17] used axial CT images to compare the evolving fusion mass in idiopathic scoliosis patients treated by PSF with or without posterior instrumentation. Use of instrumentation slowed fusion mass formation and lead to asymmetric bone formation with an area of central resorption, in accordance with Wolf's law in which remodeling of bone occurs in response to stress-shielding. Furthermore, Demir et al. [18] reported a decrease in the bone density of the stabilized vertebrae after lumbar posterior fusion. Several papers demonstrated pedicular stress fractures associated with long instrumented fusions, which have been theorized to be related to stress shielding [19–21]. The lower HU values at apex and LIV+1 than those at LIV−1 observed in this study were compatible with the above-mentioned reports. We speculated that preservation of HU values at UIV−1, which was located below the non-instrumented mobile segments, was caused by the lesser influence of posterior instrumentation on weight-bearing. In the present study, there were significant differences in bone resorption markers between the two groups, which may have been caused by the age differences at the time of the survey. Bone resorption makers are widely used for predicting future decreases in bone mass or BMD, evaluating fragility fracture risk, and monitoring therapeutic effects [22, 23]. Since bone markers have limited accuracy in predicting bone mineral status or rate of decrease in bone mass in individual patients [23], further longitudinal studies are needed to clarify their utility in secondary osteopenia related to posterior instrumentation. Osteoporosis/osteopenia is a multifactorial disease, and its etiology includes, in addition to aging, physical activity, the age of menarche, the onset of menopause, history of pregnancy, and comorbidities. Since establishing exactly equivalent groups of patients with osteoporosis/osteopenia was difficult, we established the HU ratio of the vertebrae being investigated to decrease bias caused by the various confounding factors.

We hypothesized that posterior implant removal could prevent the device-related vertebral osteopenia after instrumented PSF for AIS during adulthood. The removal was performed at an average of 50 months (range, 32–110 months) after the initial surgery. However, posterior implant removal did not prevent device-related vertebral osteopenia in this study, probably due to the formation of a firm fusion mass that created a stress-shielding effect with or without the retained instrumentation. Although previous studies reported loss of coronal correction after instrumentation removal in AIS, surgical site infection or implant-related pain (possibility of nonunion) resulted in unplanned implant removal in most cases [24, 25]. In the present study, planned implant removal after checking for surgical site infection and nonunion led to no significant differences in loss of coronal correction or BMD in the fused vertebrae. Thus, removal might cause no adverse consequences and removal of artificial prominent implants may be considered in young patients after bony union within the instrumented segments. However, the question of whether posterior implant should be removed to maximize quality of life in adulthood remains controversial.

Limitations exist in the current study. First, the study involved a relatively small number of participants due to the difficulty of long-term follow-up of young female patients. Therefore, further studies utilizing larger sample sizes are needed to confirm the effects of implant removal after PSF. Second, no data regarding bone mineral status at surgery were obtained; thus, the extent of bone mineral status changes between surgery and survey is unclear. Third, the participants underwent PSF using various instrumentation systems, which might affect the stress-shielding effect on the fused vertebral body. Modern segmental fixation devices might promote secondary vertebral osteopenia due to the higher stability of the constructs, and this should be investigated further. Therefore, prospective studies utilizing larger sample sizes and including control subjects are needed to clarify these issues.

Conclusion

Instrumented PSF caused long-term stress-shielding-induced osteopenia of the vertebral body within the fusion area in AIS patients. However, the preventive effect of posterior implant removal could not be proven in the present study.

Funding No funds were received in support of this work, and no relevant financial activities outside the submitted work exist.

Compliance with ethical standards

Conflict of interest Kei Watanabe, Masayuki Ohashi, Toru Hirano, Keiichi Katsumi, Hirokazu Shoji, Tatsuki Mizouchi, Kazuhiro Hasegawa, Naoto Endo, and Hideaki E. Takahashi declare that they have no conflict of interest.

Ethical approval The study was approved by the ethics committee of the Niigata University Graduate School of Medical and Dental Sciences. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix

See Figs. 3 and 4.

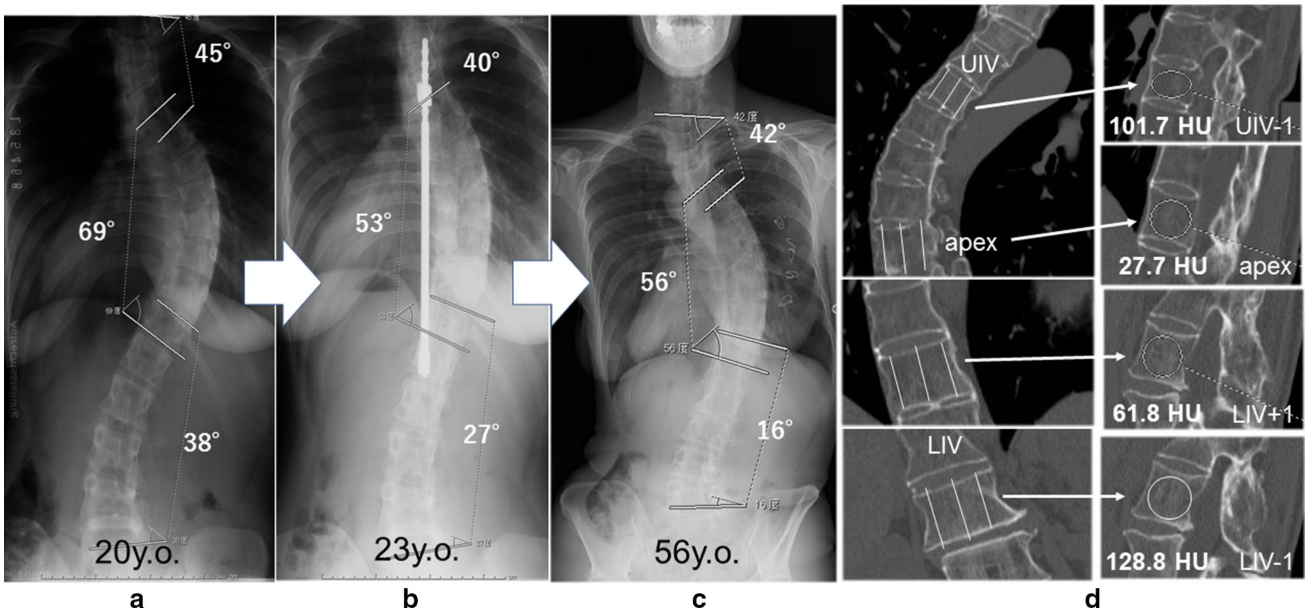


Fig. 3 **a** Radiograph of a 20-year-old girl (group R) with Lenke type 2 adolescent idiopathic scoliosis before surgery. **b** Radiograph 3 years after posterior spinal fusion using Harrington instrumentation from T4 to L1. **c** Radiograph 33 years after implant removal, demonstrating acceptable correction. **d** HU values of CT at the UIV−1, apex, LIV+1, and LIV−1 levels showing 101.7, 27.7, 61.8, and 128.8 HU, respectively. HU, Hounsfield units; CT, computed tomography; UIV−1, one level below the uppermost instrumented vertebra; LIV+1, one level above the lowermost instrumented vertebra; LIV−1, one level below the lowermost instrumented vertebra

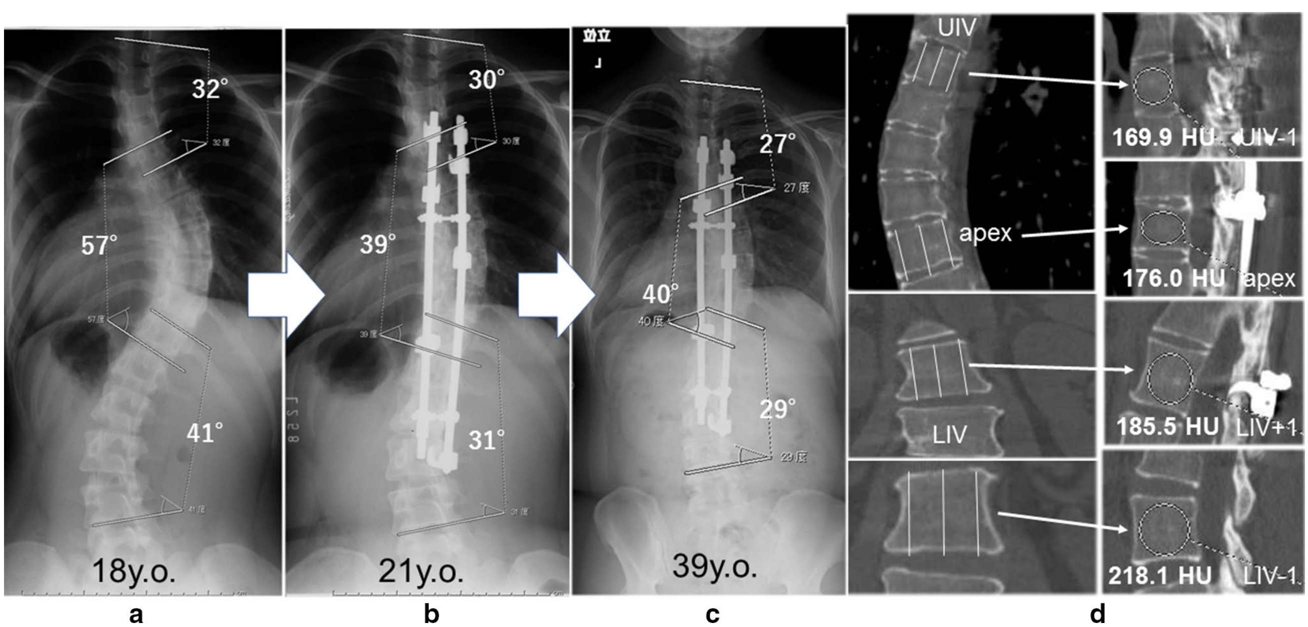


Fig. 4 **a** Radiograph of an 18-year-old girl (group NR) with Lenke type 1 adolescent idiopathic scoliosis before surgery. **b** Radiograph 2 years after posterior spinal fusion using Cotrel–Dubousset instrumentation from T5 to L2. **c** Radiograph 21 years after initial surgery, demonstrating acceptable correction. **d** HU values of CT at the UIV−1, apex, LIV+1, and LIV−1 levels showing 169.9, 176.0, 185.5, and 218.1 HU, respectively. HU, Hounsfield units; CT, computed tomography; UIV−1, one level below the uppermost instrumented vertebra; LIV+1, one level above the lowermost instrumented vertebra; LIV−1, one level below the lowermost instrumented vertebra

References

1. Cheng JC, Guo X, Sher AH (1999) Persistent osteopenia in adolescent idiopathic scoliosis. A longitudinal follow up study. Spine 24:1218–1222
2. Hung VW, Qin L, Cheung CS et al (2005) Osteopenia: a new prognostic factor of curve progression in adolescent idiopathic scoliosis. J Bone Joint Surg Am 87:2709–2716
3. Ishida K, Aota Y, Mitsugi N et al (2015) Relationship between bone density and bone metabolism in adolescent idiopathic scoliosis. Scoliosis 10:19
4. McAfee PC, Farey ID, Sutterlin CE et al (1989) Device-related osteoporosis with spinal instrumentation. Spine 14:919–926
5. Ito M, Fay LA, Ito Y et al (1997) The effect of pulsed electromagnetic fields on instrumented posterolateral spinal fusion and device-related stress shielding. Spine 22:382–388
6. Schreiber JJ, Anderson PA, Rosas HG et al (2011) Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. J Bone Joint Surg Am 93:1057–1063
7. Pervaiz K, Cabezas A, Downes K et al (2013) Osteoporosis and shoulder osteoarthritis: incidence, risk factors, and surgical implications. J Shoulder Elbow Surg 22:e1–e8
8. Pickhardt PJ, Pooler BD, Lauder T et al (2013) Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. Ann Intern Med 158:588–595
9. Meredith DS, Schreiber JJ, Taher F et al (2013) Lower preoperative Hounsfield unit measurements are associated with adjacent segment fracture after spinal fusion. Spine 38:415–418
10. Krappinger D, Bizzotto N, Riedmann S et al (2011) Predicting failure after surgical fixation of proximal humerus fractures. Injury 42:1283–1288
11. Schreiber JJ, Hughes AP, Taher F et al (2014) An association can be found between Hounsfield units and success of lumbar spine fusion. HSS J 10:25–29
12. Lenke LG, Betz RR, Harms J et al (2001) Adolescent idiopathic scoliosis. A new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am 83-A:1169–1181
13. Ylikoski M (2003) Height of girls with adolescent idiopathic scoliosis. Eur Spine J 12:288–291
14. Ohashi M, Hirano T, Watanabe K et al (2018) Bone Mineral density after spinal fusion surgery for adolescent idiopathic scoliosis at a minimum 20-year follow-up. Spine Deform 6:170–176
15. Szalay EA, Bosch P, Schwend RM et al (2008) Adolescents with idiopathic scoliosis are not osteoporotic. Spine 33:802–806
16. Zagra A, Lamartina C, Pace A et al (1988) Posterior spinal fusion in scoliosis: computer-assisted tomography and biomechanics of the fusion mass. Spine 13:155–161
17. Zagra A, Lamartina C, Pace A et al (1990) Computer-assisted tomography of scoliosis operated with or without Harrington's rod. Biomechanics aspects of the fusion. Spine 15:796–802
18. Demir Ö, Öksüz E, Deniz FE et al (2017) Assessing the effects of lumbar posterior stabilization and fusion to vertebral bone density in stabilized and adjacent segments by using Hounsfield unit. J Spine Surg 3:548–553
19. Obid P, Richter A, Ubeyli H et al (2012) Spontaneous bilateral pedicle fracture 30 years after Harrington instrumentation for idiopathic scoliosis: a case report. J Med Case Rep 6:29
20. Tribus CB, Bradford DS (1993) Bilateral pedicular stress fractures after successful posterior spinal fusion for adult idiopathic scoliosis. Spine 18:1222e5
21. Knight RQ, Chan DP (1992) Idiopathic scoliosis with unusual stress fracture of the pedicle within solid fusion mass: a case report. Spine 17:849e51
22. Chaki O, Yoshikata I, Kikuchi R et al (2000) The predictive value of biomechanical markers of bone turnover for bone mineral density in postmenopausal Japanese women. J Bone Miner Res 15:1537–1544
23. Bergmann P, Body JJ, Boonen S et al (2009) Evidence-based guidelines for the use of biochemical markers of bone turnover in the selection and monitoring of bisphosphonate treatment in osteoporosis: a consensus document of the Belgian Bone Club. Int J Clin Pract 63:19–26
24. Potter BK, Kirk KL, Shah SA et al (2006) Loss of coronal correction following instrumentation removal in adolescent idiopathic scoliosis. Spine 31:67–72
25. Farshad M, Sdzuy C, Min K (2013) Late implant removal after posterior correction of AIS with pedicle screw instrumentation—a matched case control study with 10-year follow-up. Spine Deform 1:68–71

Affiliations

Kei Watanabe[1] · Masayuki Ohashi[1] · Toru Hirano[1] · Keiichi Katsumi[2] · Hirokazu Shoji[1] · Tatsuki Mizouchi[1] · Yuya Ishikawa[1] · Kazuhiro Hasegawa[3] · Naoto Endo[1] · Hideaki E. Takahashi[4]

✉ Kei Watanabe
keiwatanabe_39jp@live.jp

[1] Division of Orthopedic Surgery, Department of Regenerative and Transplant Medicine, Niigata University Graduate School of Medical and Dental Sciences, 1-757 Asahimachi Dori, Chuo-ku, Niigata City 951-8510, Niigata, Japan

[2] Department of Orthopedic Surgery, Uonuma Kikan Hospital, 4132 Urasa, Minami-Uonuma City 949-7302, Niigata, Japan

[3] Niigata Spine Surgery Center, 2-5-22 Nishimachi, Konanku, Niigata City 950-0165, Niigata, Japan

[4] Niigata Bone Science Institute, 761 Kizaki, Kitaku, Niigata City 950-3304, Niigata, Japan