Computer-assisted Hemivertebra Resection For Congenital Spinal Deformity

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Conflict of Interest Disclosure

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Abstract

Background. There has been no study reporting the osteotomies utilising a navigation system in congenital scoliosis surgery. This study aimed to evaluate the surgical outcomes for eight patients with congenital scoliosis or kyphoscoliosis due to hemivertebra treated by computer-assisted hemivertebra resection using a posterior approach only.

Methods. Eight consecutive patients (two scoliotics and six kyphoscoliotics) managed by computer-assisted hemivertebra resection using a posterior approach only with transpedicular instrumentation were investigated retrospectively. CT-based navigation system was used to confirm the position among vertebra, spinal cord and aorta in real-time when we inserted pedicle screw and conducted osteotomy. Their mean age at surgery was 18 years (range, 11-41 years). The mean follow-up was 46 months (range, 18-84 months).

Results. Before surgery, the mean kyphotic curve was 55.8 degrees (range, 26-83 degrees), and the mean scoliotic curve was 50.0 degrees (range, 36-62 degrees). At final follow-up period, the curves averaged 23.2 degrees (range, 15-40 degrees) and 31.6 degrees (range, 21-44 degrees), respectively, yielding kyphotic angle corrections of 32.7 degrees (range, 11-58 degrees) and Cobb angle correction rates of 36.8% (range, 24.1-48.3 %). Total of 72 pedicle screws were inserted with navigation system and two screws revealed perforating pedicle. No neurovascular complication occurred. Perforation rate was 2.8%.

Conclusions. Hemivertebra resection via a single posterior approach is less invasive than combined anterior and posterior approach, however, this procedure increases risk of spinal and

vascular injuries. Computer-assisted hemivertebra resection enables safe and accurate performance of a hemivertebra resection via a single posterior approach.

Introduction

Congenital scoliosis is caused by a congenital morphological abnormality of the spinal column. It is subclassified from an embryological perspective into three types[1]: type 1, failure of formation; type 2, failure of segmentation; and type 3, mixed. In type 1 scoliosis, spinal deformities caused by hemivertebra show various types of clinical progression, according to the morphology of the anomalous vertebra and level of deformity. Fully-segmented hemivertebra, in which disc space is maintained between the hemivertebra and adjacent vertebral body, is progressive as the anomalous hemivertebra maintains almost normal developmental ability, causing spinal imbalance. Posterior quarter-vertebra, presenting as a kyphotic deformity in the sagittal plane around the hemivertebra, also carry a high risk of severe spinal deformity. In general, surgical treatment is indicated for symptoms that are judged from the morphology of anomalous vertebra to be progressive, when severe spinal deformity has developed, or when there is a neurological disorder due to the spinal deformity (particularly kyphotic deformities).

Many surgical procedures for hemivertebra have been reported, including posterior fusion *in situ*[2,3] and hemivertebral resection using a combined anterior and posterior approach[4-8], and recently a single posterior approach. [9-13] Hemivertebral resections using a single posterior approach has the advantage of less surgical impact; however, the procedure carries risk, including neurovascular injury and insufficient osteotomy. To solve these problems, since 2003 we have attempted hemivertebra resections using single-stage surgery via a posterior approach alone, utilizing CT-based navigation system. The purpose of this study was to evaluate the surgical outcomes for consecutive eight patients with congenital scoliosis or kyphoscoliosis due to hemivertebra treated by computer-assisted hemivertebra resection using a posterior only approach.

Materials and Methods

After approval by the hospitals' investigational review board, eight consecutive patients (3 males and 5 females; mean age, 18±10 [mean±S.D.] years; range, 11-41 years) who underwent the procedure from March 2003 to March 2009 were included in the study. We have obtained informed consent to perform this surgical procedure from the cases**.** The mean post-operative follow-up was 46±27 months (range, 18-84 months). Two patients were diagnosed with congenital scoliosis and six patients with congenital kyphoscoliosis.

Hemivertebral level was T8:1, T9:1, T11:1, T12: 1, L1:1, L2:1, L3:1, and L4:1. CT-based navigation system (Stealth Station and Stealth Station TREON^{TM}; Medtronic, Sofamor Danek, Memphis, TN, USA) was used in all eight patients to confirm the position of vertebra, spinal cord and aorta in real-time when we inserted pedicle screw and conducted osteotomy (Figure 1).

Osteotomy procedure was as follows: hemivertebra was transpedicularly excavated in an egg-shell shape preserving periosteum, and disc of both cranial and caudal side of hemivertebra were removed. Endplate cartilage of the cranial vertebra was also removed, to facilitate the bony fusion. The gaps were packed with local bone graft, and the bones were cantilevered by fixing the convex side rod to the pedicle screws. Compression force was also added.

Variables included surgical time, blood loss, Cobb angle and kyphotic angle before operation, post operation, and at the final follow-up, and kyphotic angle correction and Cobb angle correction rate. Furthermore, screw position was evaluated one week after operation using an axial CT scan at each screw axis. Following the scheme of Rao *et al* [14], the evaluation of screw malposition was classified as grade 0 (no apparent violation of the pedicle), grade 1 (<2 mm perforation of the pedicle, with 1 screw thread out of the pedicle), grade 2 (between 2 and 4 mm of perforation of the pedicle, with half of the diameter of the screw outside of the pedicle), grade 3 (>4 mm or complete perforation of the pedicle), with grades 2 and 3 representing ‘‘violation.’’ On the basis of this grading system, screw misplacement rates were determined. The medial or lateral perforation of the pedicle wall was also evaluated.

Results

Mean surgical time was 386±101 min. (range, 242-577 min.) with mean blood loss of 600 ±428 g (range, 200-1500 g). Cobb angle before operation, after operation and at the final follow-up was 49.9±9.8 degrees (36-62 degrees), 29.6±8.4 degrees (18-42 degrees), and 31.6 ±8.0 degrees (21-44 degrees), respectively, with mean correction rate of 41.1±8.6% (27.6-51.7%) and 36.8±7.5% (24.1-48.3%), respectively. Kyphotic angle before operation, after operation and at the final follow-up was 55.8±22.9 degrees (26-83 degrees), 21.3±8.4 degrees (14-37 degrees), and 23.2±8.9 degrees (15-40 degrees), respectively, with mean kyphotic angle correction of 34.3±17.8 degrees (12-59 degrees) and 32.7±18.0 degrees (11-58 degrees), respectively (Table 1, Figure 2, 3).

Of the 72 pedicle screws, 56 (77.8%) were categorized as grade 0, 14 (19.4%) were grade 1, 0 (0%) were grade 2, and 2 (2.8%) was grade 3. Two grade 3 screw was seen, in a left T7 and right T8 pedicle. These screws were perforated laterally. Pedicle violation was observed in 2.8% of inserted screws. Medial perforation was observed in five pedicles and lateral perforation in 11 pedicles. No intra-operative complications such as neurovascular injury or adverse clinical consequences occurred as a result of pedicle perforation. Right T10 pedicle screw was broken at 12 months after surgery in case 8. Wound infection and pseudoarthrosis have not occurred at mean 46 months follow up.

Case Reports

Case 6. A 41-year-old female patient presented to our hospital with congenital kyphoscoliosis for a T11 posterior hemivertebra. She complained of back pain from January 2007 and visited our hospital in April 2007. Scoliosis ending at T10 and T12 was observed, with Cobb angles of 42 degrees. Kyphosis ending at T9 and T12 was observed, with kyphotic angles of 51 degrees (Figure 4). Surgery was performed in November 2007. Using the CT-based navigation system, pedicle screw holes were made on the three vertebrae above and below the anomalous vertebra, and osteotomy of the effected T11 hemivertebra was performed using a surgical flame fixed at the T12 spinous process. Resection of the discs above and below the effected hemivertebra and curettage of cartilage end plate were sufficiently performed. Complete osteotomy just adjacent to spinal cord was achieved. The bone tip was packed at the bone defect and a region from T8 to L2 was corrected slowly with a cantilever. A sufficient amount of bone graft was implanted into the posterior vertebra. Surgical time was 382 min. with blood loss of approximately 200 g. Her back pain was reduced postoperatively. At final follow-up (post-operative 2 years) Cobb and kyphotic angles were corrected from 42 degrees to 29 degrees (13 degrees correction) and from 51 degrees to 20 degrees (correction rate 60.8%), respectively (Fig. 5). CT image showed correct screw insertion except for right T8 pedicel screw at 2 year post-surgery.

Discussion

The natural history of congenital scoliosis has been comprehensively described by Winter et al.[3] ,and MacMaster and Ohtuka.[15] Prophylactic treatment of congenital scoliosis by hemivertebral resection via open surgery is recommended before establishment of a solid constructive deformity progresses from compensatory scoliosis.[16,17] However, definitive judgment of the progressive nature of a deformity is difficult in early childhood and a surgical indication decision, including most appropriate timing to attempt growth arrest by posterior fusion *in situ*[2,3] and hemi-epiphyseodesis[18,19] , can sometimes be very difficult. Furthermore, maintenance of a correction effect from growth arrest until the end of growth cannot be guaranteed, therefore it is necessary for some patients to undergo further surgery. To resolve these problems, deformity correction using spinal osteotomy can be effective for achieving radical correction for congenital scoliosis types that are primarily based on deformed vertebra. Congenital scoliosis treatment via hemivertebra resection was initially reported by Royle[20] in 1928. A combined anterior and posterior approach was reported by Holte[4], Bradford[5], Leatherman[6], and Bollini[8] with a single posterior approach presented by Ruf[9], Shono[12], Nakamura[10], Shimode[11] and Polly[13]. Kokubun[21] indicated that corrections of 40 degrees or greater require a combined anterior and posterior approach.

Though the single posterior approach for anomalous vertebra osteotomy has the advantage of less surgical stress, it also has disadvantages that include risk of insufficient osteotomy, vascular injury, spinal cord compression resulting from surgery and greater technical difficulties associated with surgery. To resolve these problems, utility of osteotomy for anomalous vertebra was studied using a navigation system StealthStation™ introduced in 1996.

With this accumulated clinical experience, this group studied the feasibility of anomalous vertebra resection using the same navigation system. Although Mikles et al.[22] have reported use of this navigation system in preoperative selection of osteotomy levels and placement of pedicle screws, this is the first report of osteotomies utilising a navigation system in congenital scoliosis surgery. This navigation system has the advantage of allowing preoperative determination of osteotomy levels as 3D-CT images on the navigation screen that can be moved in any direction. This procedure is characterized by the following four points: low surgical stress due to minimal invasion from the posterior alone, capability of complete anomalous vertebra resection using a single posterior approach, ability for accurate screw insertion into narrow pedicles in children and a sufficient correction rate.

Correction rate of scoliosis is reported from 35.2% to 70%[4-6,9-12,23], whereas correction rate of kyphosis is from 54.2% to 67.4%[9-12]. Our cases were in no way inferior to these reports which showed 36.8% and 55.5%, respectively. Correction of kyphosis was superior to that of scoliosis. The relatively inferior correction rate compared to the previous reports might have been caused by remaining periosteum after removing hemivertebra in egg-shell shape using speed drill, preventing sufficient correction. Meanwhile, the blood loss in this procedure might be less than those of the previous reports. The age at the final follow-up was under 17 years in case 2, 4, 7, and 8 and long time follow-up is needed in these immature cases.

There is a paucity of reports in the literature on the accuracy of pedicle screw placement in scoliosis surgery. In a report by Suk *et al* [24], the perforation rate of pedicle screw inserted by free hand in AIS posterior fusion was 1.5%; however, only 10% of cases were evaluated by CT, and thus this reported rate is not highly reliable. In report by Kim *et al* [25], the perforation rate by free hand technique was 7.9%. The reported perforation rate by Halm *et al* [26] was as high as 18.3% and the rate by Lilijenqvist *et al* [27] who employed fluoroscopy, was also as high as 25%. In contrast, the perforation rates of reports of surgeries that employed navigation system[28-30] were between 1.8 and 11.4%. In the present report, the rate was as low as 2.8%. In the evaluation of screw placement, more than 2 mm of penetration was defined as pedicle violation, for the reason that up to a 2 mm breach was considered a well-positioned screw since there are slight scatter effects seen on CT scans, even for titanium implants[31].

Conclusion

A sufficient correction rate for congenital spinal deformities with anomalous vertebra was achieved using surgery via a posterior approach alone utilising a CT-based navigation system. In all eight cases, safe osteotomies and accurate pedicle screw insertions were performed.

Conflict of Interest Disclosure

None of the authors of this manuscript has received any type of support, benefits, or funding from commercial party related directly or indirectly to the subject of this article.

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Figure Legends

Figure 1. Navigation image obtained during osteotomy of anomalous vertebra. Upper left: sagittal plane, lower left: axial plane, upper right: coronal plane, lower right: 3D-image. The area pointed by the navigation probe could be clearly observed in each image.

Figure 2. Pre-operative and post-operative standing PA and lateral X-ray from case 1 to 4.

Figure 3. Pre-operative and post-operative standing PA and lateral X-ray from case 5 to 8.

Figure 4. A 41-year-old female patient presented to our hospital with congenital kyphoscoliosis for a T11 posterior hemivertebra.

Figure 5. At final follow-up (post-operative 2 years) Cobb and kyphotic angles were corrected from 42 degrees to 29 degrees (13 degrees correction) and from 51 degrees to 20 degrees (correction rate 60.8%), respectively.

Table 1. Clinical Data on 7 patients

Case	Gender	Age(y)	Operation time (min)	Blood loss (g)	Follow up (m)	Hemivertebrae level
1	F	16	440	600	84	T8
2	F	11	420	600	77	L2
3	F	17	577	1500	72	L4
4	M	13	352	300	36	T9
5	F	22	383	850	36	L3
6	F	41	382	200	24	T11
7	M	11	242	550	24	L1
8	M	13	292	200	18	T12

Case	Preoperative Cobb angle (degrees)	Postoperative Cobb angle (degrees)	Final follow-up Cobb angle (degrees)	Preoperative kyphotic angle (degrees)	Postoperative kyphotic angle (degrees)	Final follow-up kyphotic angle (degrees)
1	36	18	21	35	19	21
2	58	42	44	83	24	25
3	39	23	24			
4	49	28	30	26	14	15
5	58	28	30			
6	42	27	29	51	16	20
7	55	29	33	62	18	18
8	62	42	42	78	37	40

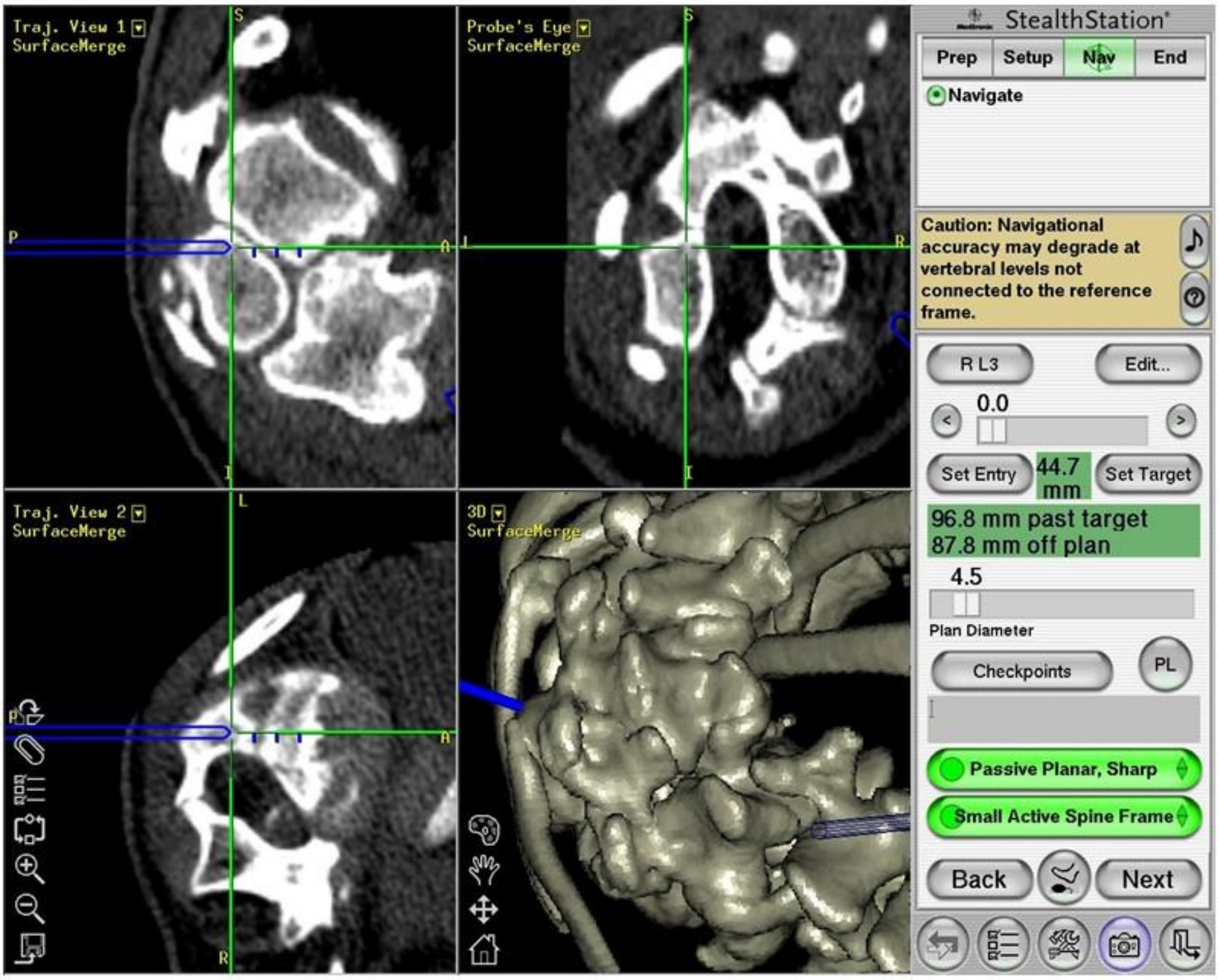
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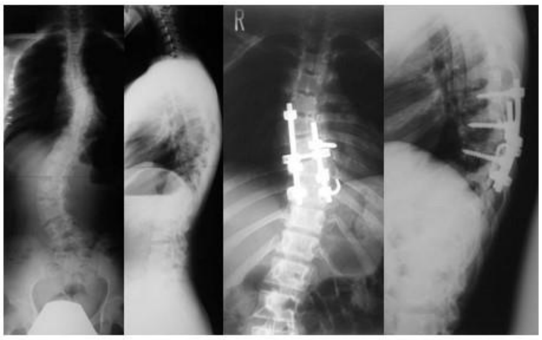
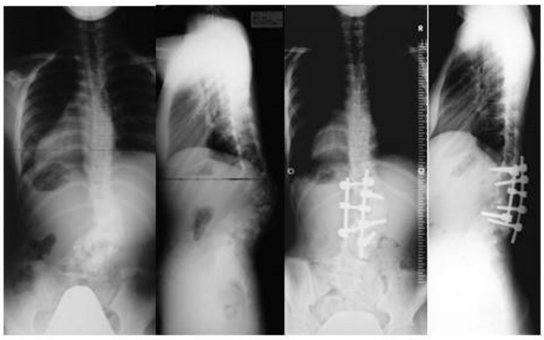
Figure 1.



Case 1



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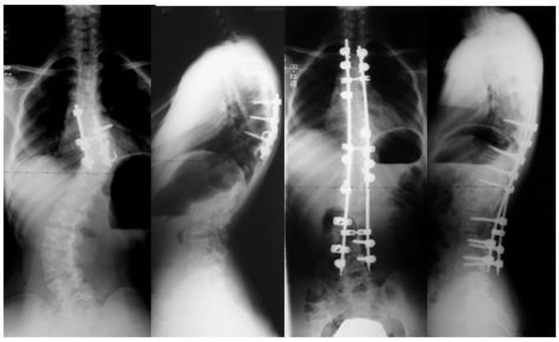
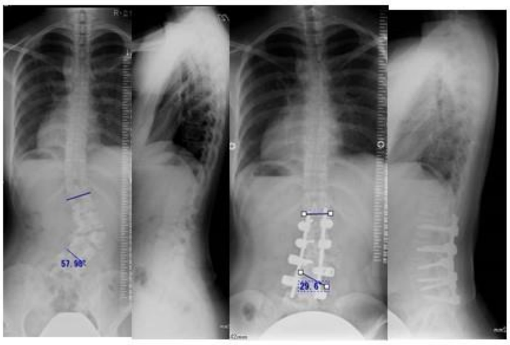


Case 3

Case 4

Figure 2.



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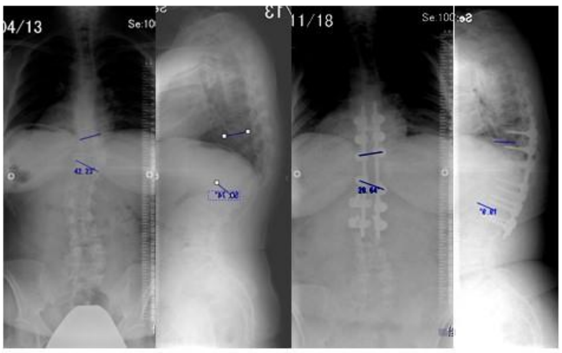

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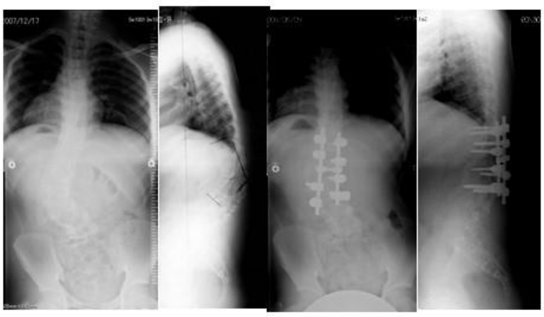

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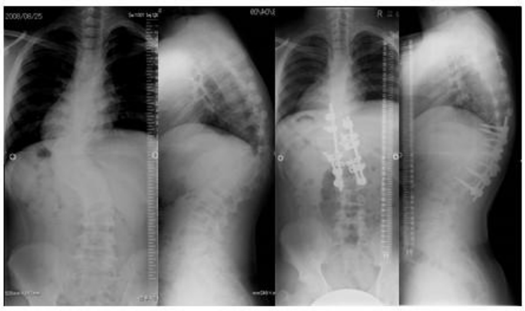

Case 8

Figure 3.

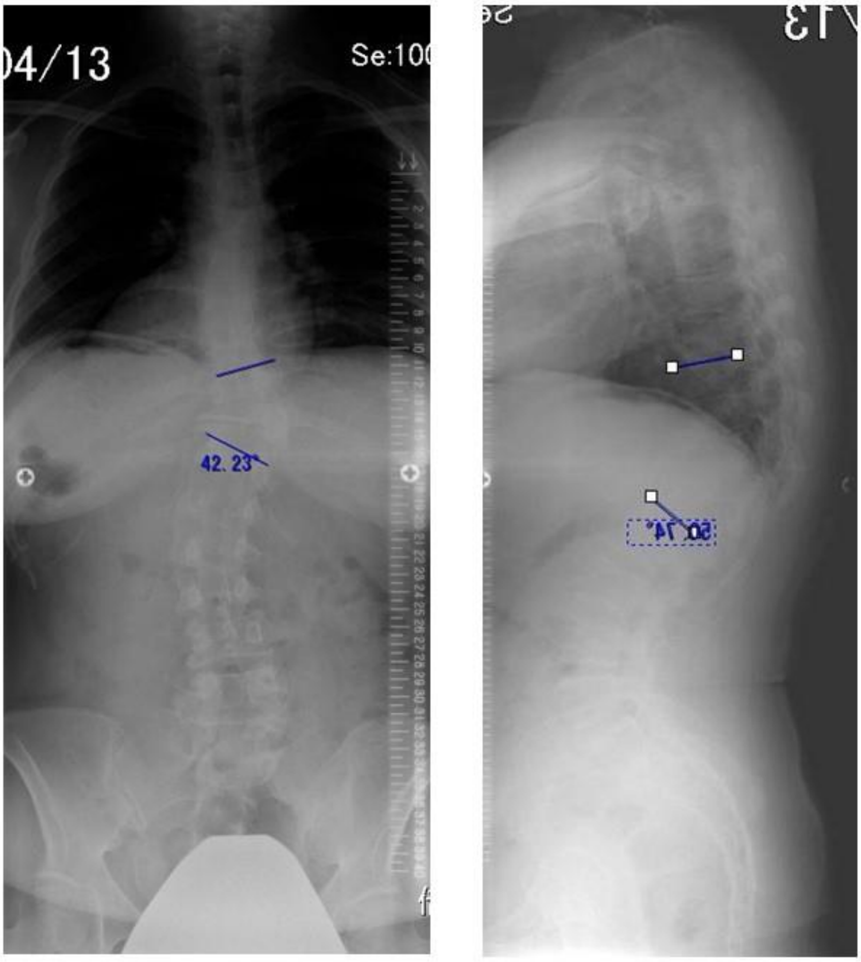

Figure 4.

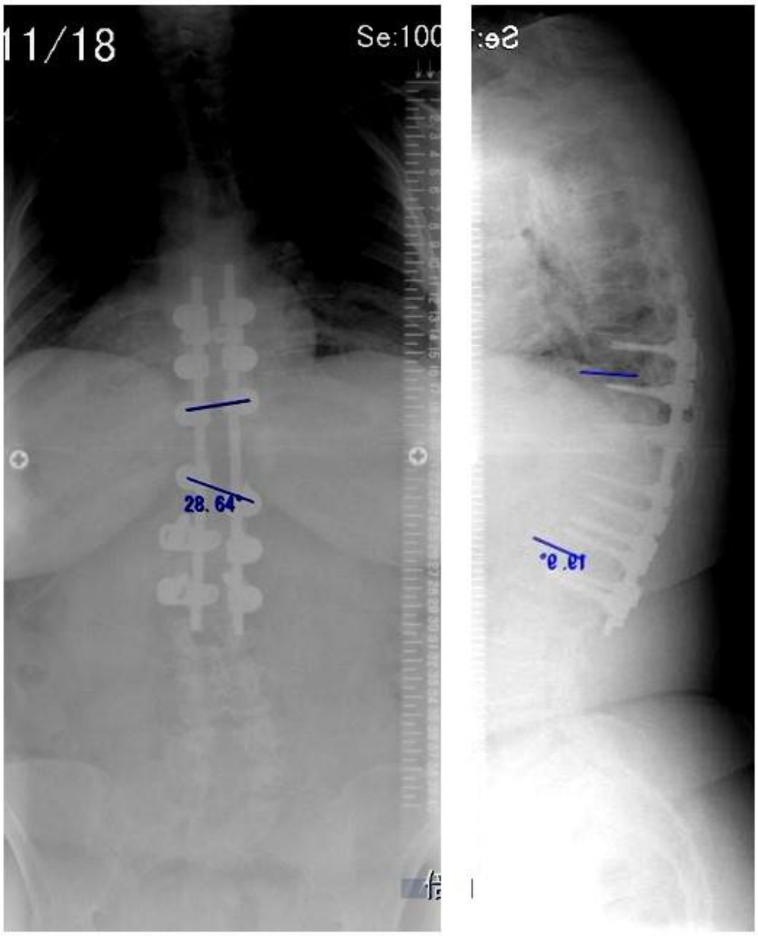

Figure 5.