J Orthop Sci (2010) 15:720–730
DOI 10.1007/s00776-010-1523-8

JOURNAL OF
ORTHOPAEDIC SCIENCE

Original article

Efficacy of perioperative halo–gravity traction for treatment of severe scoliosis (≥100°)

Kei Watanabe[1], Lawrence G. Lenke[2], Keith H. Bridwell[2], Yongjung J. Kim[4], Marsha Hensley[3], and Linda Koester[2]

[1] Department of Orthopaedic Surgery, Niigata University Medical and Dental General Hospital, Niigata, Japan
[2] Department of Orthopaedic Surgery, Washington University School of Medicine, 660 S Euclid Avenue, Campus Box 8233, St. Louis, MO 63110, USA
[3] Shriners Hospital for Children — St. Louis Unit, St. Louis, MO, USA
[4] Columbia University Medical Center, New York, NY, USA

Abstract

Background. There have been no standardized surgical options for severe scoliotic curvatures ≥100°. Halo–gravity traction is a viable option for surgical treatment of severe scoliosis. The aim of this study was to evaluate the efficacy and safety of perioperative halo–gravity traction for scoliosis curves ≥100° with respect to radiographic outcomes and clinical complications.

Methods. A total of 21 scoliosis patients with ≥100° curves (average 118.7°; range 100°–158°) with a minimum 2-year follow-up (average 41.8 months; range 24.0–97.0 months) who underwent spinal instrumented fusion using perioperative halo–gravity traction were analyzed. Diagnoses were neuromuscular scoliosis ($n = 10$), idiopathic ($n = 9$), and congenital ($n = 2$). In all, 15 patients were treated by the anterior release procedure followed by final posterior fusion and 6 patients by posterior fusion alone. Six patients had only preoperative traction preceding posterior fusion alone, 6 patients only staged traction between anterior release and final posterior fusion, and 9 patients had both preoperative traction preceding anterior release and staged traction preceding final posterior fusion. The average overall traction period in all patients was 67 days (range 10–78 days).

Results. Radiographic outcomes demonstrated 51.3% correction of the major Cobb angle, 40 mm correction of apical vertebral translation, 76 mm increase of T1-S1 length, and 20.7% increase of space available for lungs at the ultimate follow-up (all comparisons $P < 0.05$). Preoperative traction demonstrated 27.5% correction of the major curve Cobb angle, 51.5 mm increase of T1-S1 length, 14.9% increase of space available for the lungs (all comparisons $P < 0.05$). Staged traction after anterior release demonstrated 37.2% correction of the major curve Cobb angle, 26.1 mm correction of apical vertebral translation, 56.5 mm increase of T1-S1 length, 14.2% increase of space available for the lungs (all comparisons $P < 0.05$). There were only two patients with a pin-site problem, and one required débridement. There were no neurological deficits or clinical complications.

Conclusions. Scoliosis patients with ≥100° curves can be managed successfully by corrective fusion surgery concomitant with perioperative halo–gravity traction without significant complications.

Introduction

Although great technical improvements have been made in the surgical treatment of scoliosis in children, severe and rigid deformities remain a challenge to treat with spinal instrumentation. Adjunctive methods such as traction (halo–femoral, halo–pelvic) provide adequate corrective forces for such deformities but require extended periods of bed rest, and significant complications have been reported with these techniques. Stagnara[1] popularized halo–gravity traction as a safe alternative, using the weight of the body as a counterforce. The traction forces can be transferred between the patient's bed, wheelchair, and walking frame.

Although various modern instrumentation systems and surgical techniques have been developed, spinal reconstructive surgery for severe, rigid scoliosis curves ≥100° remains challenging because of the severity of the deformity, associated poor pulmonary function, potential for pseudarthrosis, and neurological complications. There have been no standardized surgical options for severe scoliotic curvatures ≥100°. To the best of our knowledge, there are no reports on the efficacy of perioperative halo–gravity traction for correction of scoliosis curves ≥100° and no data to indicate how much of the deformity halo–gravity traction can correct before definitive spinal fusion. The purpose of this study was to evaluate retrospectively the efficacy and safety of perioperative halo–gravity traction for scoliosis curves ≥100° with respect to radiographic outcomes and clinical complications.

Offprint requests to: L.G. Lenke
Received: January 3, 2009 / Accepted: June 30, 2010

Materials and methods

A total of 23 consecutive patients with severe operative scoliosis treated with preliminary halo–gravity traction were identified from a patient database. Patients with kyphosis-dominant deformities were excluded from this series. All surgeries were performed by one of the two senior authors between 1993 and 2004. Clinical and radiographic data were collected and evaluated by an independent spinal surgeon who was not involved in the surgical treatment, and the data were retrospectively analyzed after obtaining institutional review board approval.

Inclusion criteria were halo–gravity traction used during the perioperative time period (before anterior and/or posterior fusion) and the availability of standing pretreatment, traction (before anterior or posterior fusion), postoperative (each stage), and final standing radiographs. A total of 21 scoliosis patients with ≥100° curves (average 118.7°; range 100°–158°) with a minimum 2-year follow-up (average 41.8 months; range 24–97 months) were included in the study. We defined "preoperative traction" as traction prior to initial anterior release or initial posterior fusion and "staged traction" as traction between anterior release and final posterior fusion. Six patients had only preoperative traction applied preceding posterior fusion, 6 patients had only staged traction between anterior release and final posterior fusion, and 9 patients had both preoperative traction preceding anterior release and staged traction preceding final posterior fusion. The average body weight was 35.1 kg (range 19.5–53.3 kg), and the average maximum traction force was 12.7 kg (range 6.8–18.2 kg).

There were 16 female and 5 male patients, and the average age at the time of surgery was 13 years (range 7–17 years). Etiological diagnoses were neuromuscular (n = 10), idiopathic (n = 9) and congenital (n = 2) scoliosis. Altogether, 18 patients had a major thoracic curve, and 3 patients had a major thoracolumbar/lumbar curve. Of the 21 patients, 15 were treated with anterior release (average 8.8 segments; range 6–12 segments) followed by posterior instrumentation and fusion. Six patients were treated with posterior instrumentation and fusion alone. The average number of fused vertebrae was 13.9 (range 10–19). Intraoperative halo–femoral traction was used in 7 patients for correction of pelvic obliquity (6.8 kg halo traction and a mean 11.4 kg unilateral femoral traction; range 7–18 kg)[2] and 3 patients had concomitant thoracoplasty as previously described.[3] Two patients had vertebral column resection(s) (one patient at T8/9, one at T10), and one patient had multiple Smith-Petersen osteotomies in the apical levels (one patient at two segments).

Radiographic measurements

The preoperative radiographic evaluation for all patients included 36-inch posteroanterior (PA) and lateral taken with the patient standing (or sitting in the case of nonambulatory patients); supine and supine side-bending anteroposterior (AP); and a push-prone PA. Traction and postoperative radiographs consisted of standing or sitting PA and lateral. In each case, radiographs were repeated weekly while the patients were in traction. Preoperative radiographic measurements were performed on the pretraction radiograph and then on 1-week, 3-week, 6-week, and final-traction radiographs after preoperative traction. Staged radiographic measurements were performed on 1-week and final-traction radiographs after the preliminary anterior release procedure. Final radiographic measurements were performed on the 6-week and ultimate postoperative films.

Radiographic analysis of the coronal plane included the major curve Cobb angle, apical vertebra translation (AVT), global coronal imbalance [C7 plumbline deviation from the center sacral vertical line (CSVL)], T1-S1 length, and space available for lung (SAL), as described by Campbell et al.[4] on the standing/sitting PA radiograph. Radiographic analysis also included preoperative flexibility on side-bending radiographs compared to the standing or sitting PA radiograph. AVT was measured as the distance from the perpendicular line drawn from the CSVL to the center of the apical vertebral body or disc. T1-S1 length was measured as the distance from the center of the T1 vertebral body to the center of the upper border of the sacrum. For the sagittal plane, we included thoracic (T5-T12) and lumbar (T12-S1) sagittal Cobb measurements. Positive values were used to denote kyphosis and negative values to indicate lordosis. All lateral radiographic measurements were performed on preoperative, 6 weeks postoperative, and ultimate postoperative films.

Clinical complications

Traction-related complications during the traction period were investigated by reviewing the medical records. Long-term complications including pseudarthrosis, coronal or sagittal imbalance, and implant failure (e.g., implant breakage or dislodgement) were investigated on plain radiographs. Pseudarthrosis was defined as a loss of correction in the major Cobb angle of >10° with associated implant failure and confirmed by revision surgery. Perioperative and delayed postoperative neurological deficits were investigated using medical records.

Halo–gravity treatment protocols

The patient was brought to the operating room for placement of the halo device. Normally, six to eight halo pins were placed to minimize the risk of loosening and tightened to 6- to 8-inch pounds of torque depending on the size of the patient and the overall density of the skull bone. Typically, the pins were not tightened after 24–48 h unless there was evidence of loosening. Traction was usually started immediately with a low weight of 1.5–2.5 kg. Traction was gradually increased at a rate of 1.0–1.5 kg per day as tolerated. The goal was to reach a maximum traction of 33%–50% of the patient's body weight depending on how well it was tolerated. Traction was applied for a minimum of 12 h per day, with the weight lessened by 50%–75% when the patient was sleeping to avoid proximal migration in bed at night. Traction was applied while in bed, a wheelchair, or standing apparatus (Fig. 1).

Neurological checks were performed once during each 8-h shift. Daily cranial nerve and upper/lower extremity neurological examinations were performed. The duration of preoperative traction was usually 2–12 weeks depending on the overall medical condition. If an anterior release and fusion was performed, the patient was placed back in traction during the recuperative phase. Often, 2–8 weeks of staged traction was provided before definitive posterior instrumentation and fusion with ultimate curve correction. During this time, the patient continued to be ambulatory on a daily basis and underwent daily respiratory treatments to maximize pulmonary health. The length of the traction period was determined by progressive curve correction as evidenced on weekly radiographs, in addition to clinical maximization of the patient's pulmonary and nutritional status.

Statistical analysis

Statistical comparison of the radiographic measurements was performed using the parametric paired *t*-test. $P < 0.05$ was considered significant. StatView-J 5.0 (Abacus Concepts, Berkeley, CA, USA) was used for all statistical analyses.

Results

The average overall traction period for all patients was 67.0 days (range 10–78 days). The average preoperative traction period ($n = 15$) was 40.3 days (range 10–78 days), and the average staged traction period ($n = 15$) was 53.5 days (range 14–108 days).

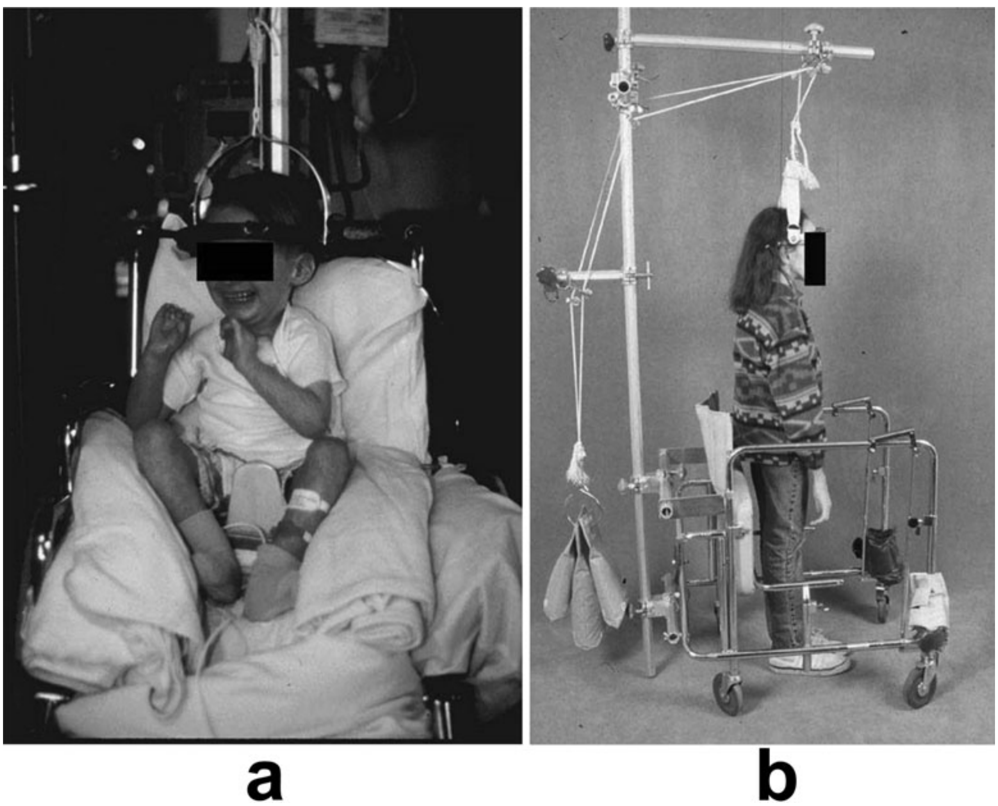


Fig. 1. Upright halo–gravity traction options. **a** Modified wheelchair. **b** Standing apparatus

Table 1. Radiographic outcomes

Outcome	Preoperative	Ultimate follow-up	P
Coronal plane deformity			
Major curve Cobb angle (°)	119.0 ± 19.2	58.0 ± 23.4	<0.0001
Apical vertebral translation (mm)	99.0 ± 37.2	59.0 ± 22.6	<0.0005
C7 translation (mm)	33.0 ± 38.3	27.0 ± 23.8	>0.05
T1-S1 length (mm)	283.0 ± 43.5	359.0 ± 50.7	<0.0005
Available lung space (%)	77.0 ± 14.2	98.0 ± 10.3	<0.05
Sagittal plane deformity			
Thoracic kyphosis (T5–12) (°)	60.0 ± 36.6	36.0 ± 23.1	<0.05
Lumbar lordosis (T12-S1) (°)	–66.0 ± 23.9	–59.0 ± 16.1	>0.05

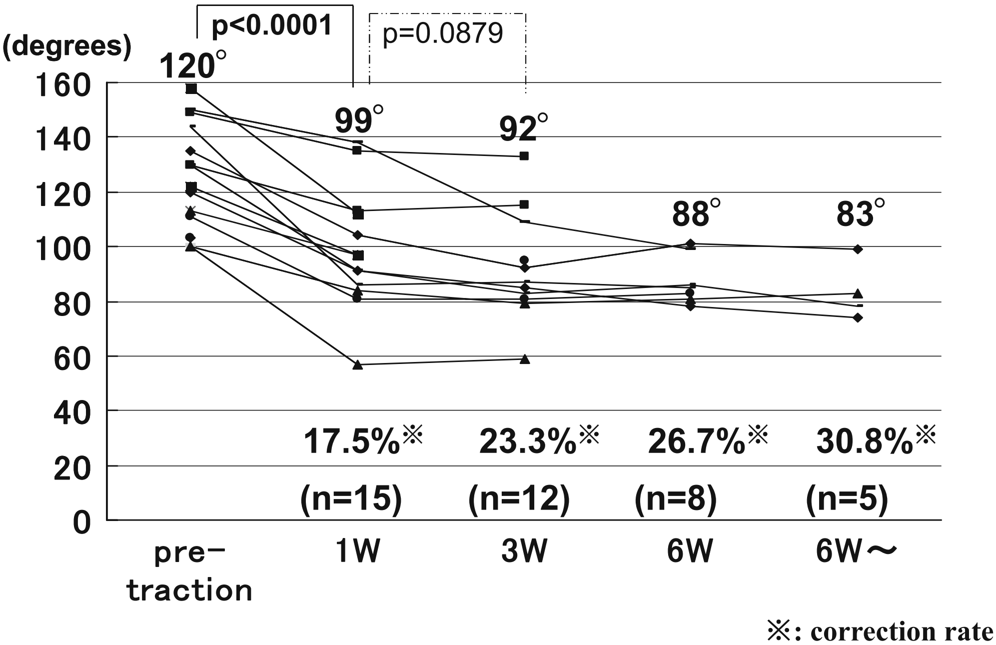


Fig. 2. Changes in the Cobb angle of the major curve during preoperative halo–gravity traction. *W*, week(s)

Final radiographic outcomes (n = 21)

The average major curve Cobb angle was corrected from 119° (curve flexibility 20.2%) before treatment to 58° (correction rate 51.3%) at ultimate follow-up ($P < 0.0001$). The average AVT was corrected from 99 mm to 59 mm ($P < 0.0005$), and the average global coronal balance was maintained from 33 mm before treatment to 27 mm at ultimate follow-up ($P > 0.05$). The average T1-S1 length was increased from 283 mm to 359 mm ($P < 0.0005$), and the average SAL was increased from 77% to 98% ($P < 0.05$). The average thoracic kyphosis was corrected from 60° to 36° ($P < 0.05$), and the average lumbar lordosis was maintained from –66° to –59° ($P > 0.05$) (Table 1).

Radiographic measurements of preoperative traction (n = 15)

The average major curve Cobb angle was corrected from 120° before traction to 99° (correction rate 17.5%) after 1 week of preoperative traction ($P < 0.0001$) and tended toward a further correction to 92° (correction rate 23.3%) after 3 weeks of preoperative traction ($P = 0.0879$) (Fig. 2). Preoperative traction ($n = 15$) demonstrated an average 27.5% correction of the major curve Cobb angle ($P < 0.05$) for all 15 patients, although the traction period varied from one patient to another. There was no significant change in average AVT for overall preoperative traction period (all comparisons $P > 0.05$) or in the average global coronal imbalance (all comparisons $P > 0.05$). The average T1-S1 length increased from 277 mm before traction to 304 mm after 1 week of preoperative traction ($P < 0.001$) and tended to further increase to 310 mm after 3 weeks of preoperative traction ($P = 0.073$) (Fig. 3). Overall, preoperative traction ($n = 15$) demonstrated a 51.5 mm increase in T1-S1 length compared with the pretreatment T1-S1 length ($P < 0.05$). The average SAL increased from 77.2% before traction to 86.5% after 1 week of preoperative traction ($P < 0.0005$) (Fig. 4). Overall, preopera-

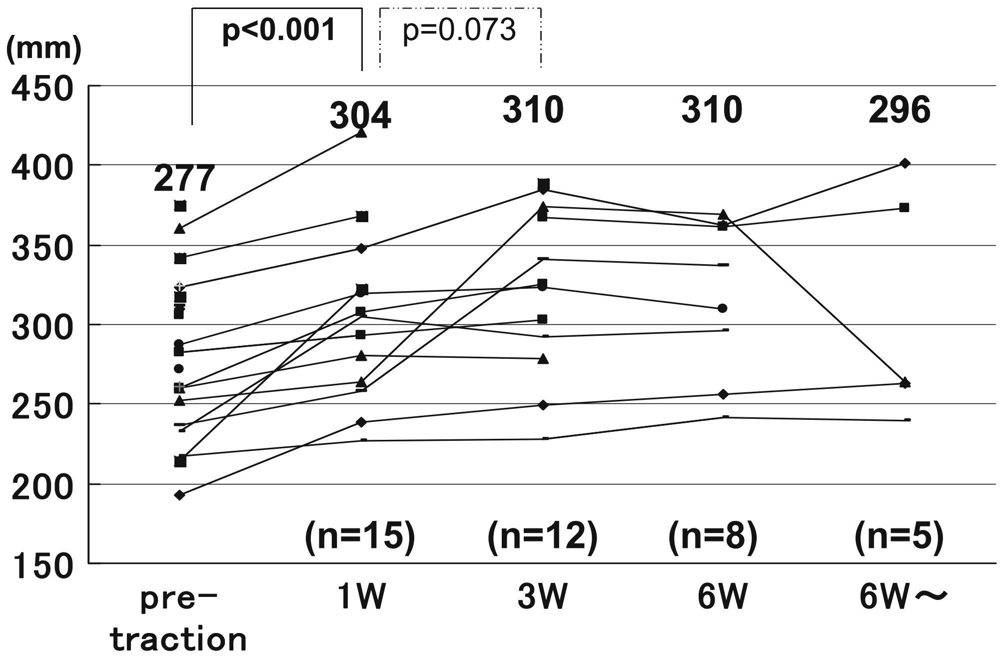


Fig. 3. Changes in the T1-S1 length during preoperative halo–gravity traction

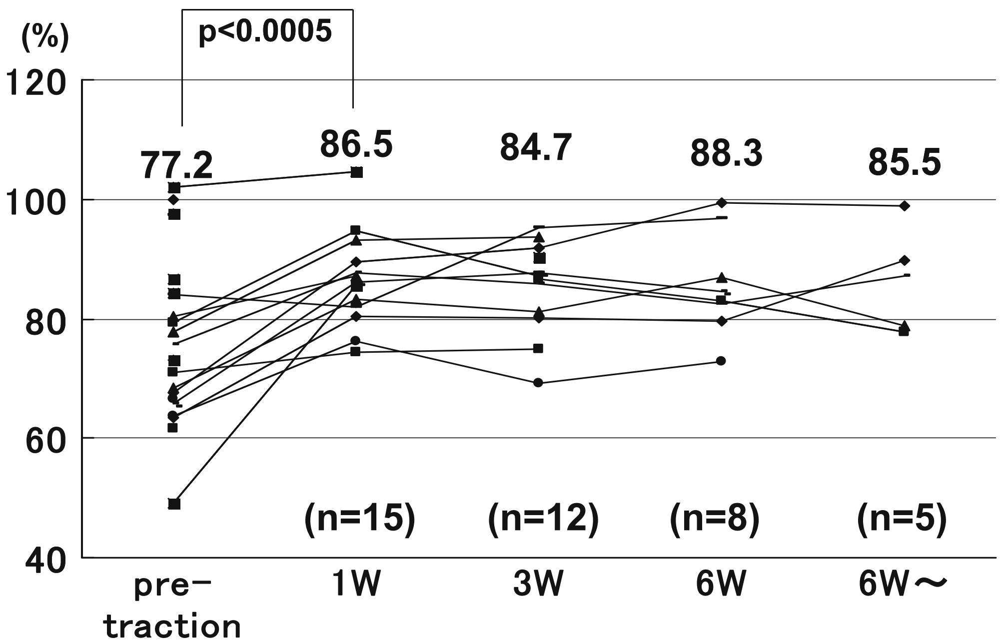
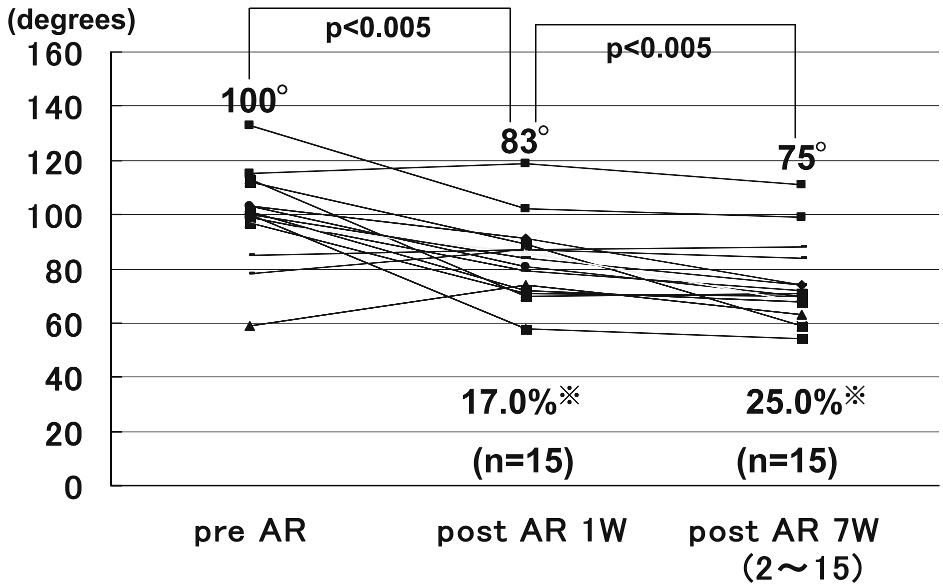


Fig. 4. Changes in the space available for the lungs during preoperative halo–gravity traction

tive traction ($n = 15$) demonstrated a 14.9% increase of SAL compared with pretreatment SAL ($P < 0.05$).

Radiographic measurements of staged traction (n = 15)

The average major curve Cobb angle was corrected from 100° just before anterior release surgery to 83° after 1 week of staged traction ($P < 0.005$) and further corrected to 75° preceding final posterior fusion ($P < 0.005$) (Fig. 5). Staged traction ($n = 15$) and immediately following anterior release with ($n = 9$) or without ($n = 6$) preoperative traction, resulted in a significant curve correction, with an average rate of 37.5% ($P < 0.05$). The average AVT was corrected from 96 mm to 83 mm after 1 week of staged traction ($P < 0.0005$) and further corrected to 73 mm preceding final posterior fusion ($P < 0.05$) (Fig. 6). Overall, staged traction ($n = 15$) demonstrated 26.1 mm correction of AVT compared with pretreatment AVT ($P < 0.05$). The average global coronal balance did not significantly change during the overall staged traction period (all comparisons $P > 0.05$). The average T1-S1 length increased from 313 mm to 331 mm



※: correction rate

Fig. 5. Changes in the Cobb angle of the major curve during staged halo–gravity traction. *AR*, anterior release surgery

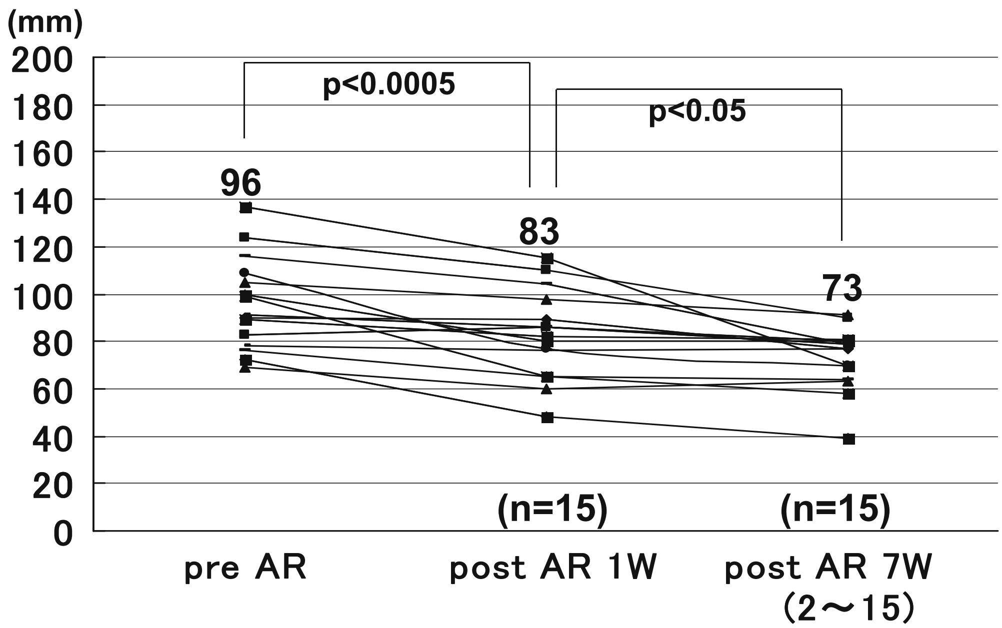


Fig. 6. Changes in apical vertebral translation during staged halo–gravity traction

after 1 week of staged traction ($P < 0.005$) (Fig. 7). Overall, staged traction ($n = 15$) demonstrated a 56.5 mm increase in T1-S1 length compared with the pretreatment T1-S1 length ($P < 0.05$). The average SAL increased from 88.0% to 95.0% after 1 week of staged traction ($P < 0.05$) (Fig. 8). Overall, staged traction ($n = 15$) demonstrated a 14.2% increase in SAL compared with pretreatment SAL ($P < 0.05$).

Traction-related complications

With regard to traction-related complications, there was one case of pin-site infection that was resolved by débridement and one case of pin-site drainage that was resolved by cleaning the site. There were no neurological deficits or long-term complications such as pseudarthrosis or implant failure.

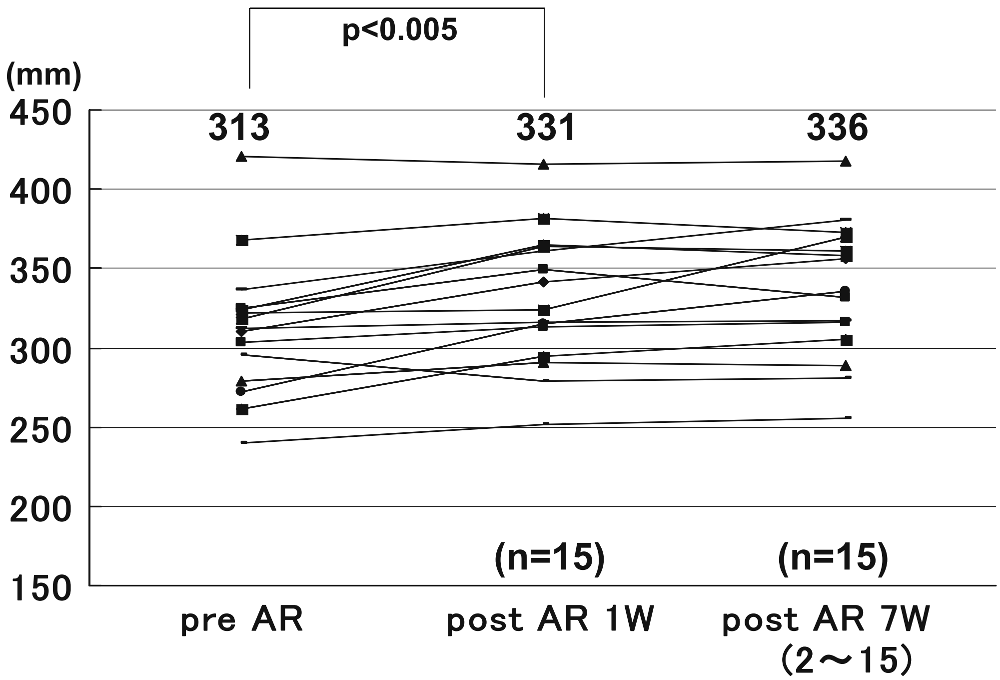


Fig. 7. Changes in the T1-S1 length during staged halo–gravity traction

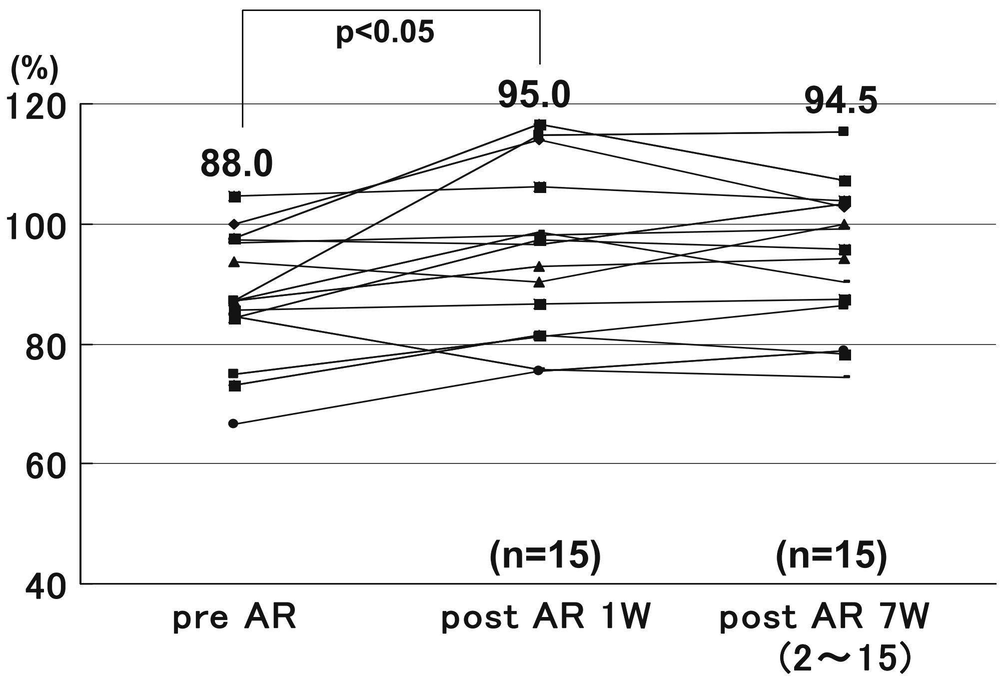


Fig. 8. Changes in the space available for the lungs during staged halo–gravity traction

Discussion

Development of the halo revolutionized spinal traction during the late 1950s and allowed skeletal traction of spinal deformities with halo–femoral, halo–tibial and halo–pelvic traction.[5] The use of halo–pelvic and halo–femoral traction for preoperative correction and in staged procedures in both adults and children is well documented in the literature. However, many complications such as cranial nerve palsy,[6,7] traction-related paraplegia,[8] cervical spondylosis,[9–12] and loss of bone mineral density[13] due to the high traction force or long periods of bed rest have been reported. In contrast, halo–gravity traction required relatively lower traction force without bed rest to improve coronal or sagittal plane deformity, trunk decompensation, pulmonary function, and nutritional status before final corrective surgery[14,15]; moreover, because bed rest is not required, it seems to be better tolerated, especially by young patients.

Few studies have described the usefulness of halo–gravity traction in the surgical treatment of severe scoliosis in detail. Sink et al.[14] reported 19 scoliosis patients who underwent corrective surgery using perioperative halo–gravity traction (traction period 6–21 weeks). The major curve Cobb angle improved 35% from an average of 84° to 55° preceding fusion; global coronal imbalance improved 60% from 3.0 cm to 1.2 cm; and trunk height increased 5.3 cm after traction. Our experience was similar. In the present study, preoperative halo–gravity traction permitted correction of the scoliotic deformity an average of 23.3%, which is equivalent to curve flexibility by side bending radiographs (20.2%) for the first 3 weeks; however, it was limited in correcting AVT and global imbalance in the coronal plane. In addition, preoperative halo–gravity traction allowed an increase in trunk height (51.5 mm) and SAL (14.9%) for the overall period. Staged halo–gravity traction allowed correction of the scoliotic deformity an average of 37.2%, which was more than curve flexibility and AVT (26.1 mm); however, it was limited in correcting global coronal imbalance. In addition, staged halo–gravity traction allowed an increase in trunk height and SAL further after an anterior release (Fig. 9). The reason halo–gravity traction did not affect global coronal imbalance is that the imbalance was minimal (average 33 ± 38.3 mm) before initial treatment. Perioperative traction permits most of the correction of the coronal deformity within the first week and should be applied for at least 3 weeks to obtain maximum deformity correction before definitive spinal fusion. In our series, the average traction period was prolonged to more than 60 days by pin-site problems, various curve flexibility, and optimizing the general condition of the patients including nutritional status preceding these major surgical interventions. We concluded that perioperative halo–gravity traction improves coronal deformity, trunk height, and lung volume by expanding the thoracic cage in patients with severe scoliotic deformity.

Many complications related to halo traction have been reported. Several authors have reported pin loosening and superficial pin-site infections.[10,16] For the most part, infections were limited by cleaning the site regularly and occasionally removing the pin and débriding the site as necessary.[17] Several authors have noted deep intracranial lesions related to halo pins,[18] in addition to reports of cranial osteomyelitis and intradural and extradural infections.[19] With regard to neurological complications, several have been reported, such as paraplegia,[8] cranial nerve complications[6,7] and brachial plexus palsy.[20] The cranial nerve symptoms were most frequent in the sixth cranial nerve, occurring less frequently in the ninth, tenth and twelfth cranial nerves. These neurological symptoms usually disappeared once the traction force was released. Several authors reported loss of cervical lordosis in this form of traction, often with associated degenerative changes of the cervical apophyseal joints related to high traction forces or prolonged traction periods.[9–12]

In our series, overdistraction was monitored by visualizing the cervical spine on weekly radiographs. In general, traction did not exceed 50% of the patient's body weight, a force much lower than that associated with halo–pelvic traction. Furthermore, the release of traction for up to 12 h per day, as well as allowing for changes in position, removes many of the problems associated with constant high traction. In the present study, there were only two cases of pin-site problems and no neurological complications. The reason for the small number of complications might be that the subjects did not have severe kyphosis deformity or intraspinal lesions such as diastematomyelia and tethered cord syndrome, which have a potential for spinal cord impairment with halo traction.

Anterior discectomy and bone graft followed by posterior segmental spinal instrumentation and fusion have been the general treatment for large idiopathic thoracic (≥90°) and stiff (≥70° residual side-bending) curves or those with significant lordotic or hyperkyphotic sagittal thoracic malalignment. Following long-term usage of pedicle screws in the lumbar spine, the use of segmental pedicle screw constructs have been popular even for severe scoliosis, and we reported better correction rates and successful outcomes compared with other conventional constructs.[21–23] One-stage posterior correction and fusion using segmental pedicle screw constructs demonstrated similar deformity correction rates, and a tendency toward lower complications compared with preliminary anterior release followed by posterior fusion for scoliosis curves ≥100°.[24] We have used this technique in all patients with severe scoliosis since 2004. Although the frequency of indication for perioperative halo–gravity traction has been decreasing since the introduction of segmental pedicle screw constructs, we utilize preoperative halo–gravity traction to achieve gradual and safe correction of severe spinal deformities and to optimize the overall health and general condition of these often debilitated patients with rigid curves >100° (usually <20% flexibility). Although anterior release followed by staged halo–gravity traction is an effective treatment for achieving maximum scoliosis correction before definitive posterior spinal fusion. Physicians have to consider the negative impact of anterior procedures through an open thoracotomy on pulmonary function in these patients.[25,26]

One of the limitations of the present study is that there was no control group to validate the efficacy and

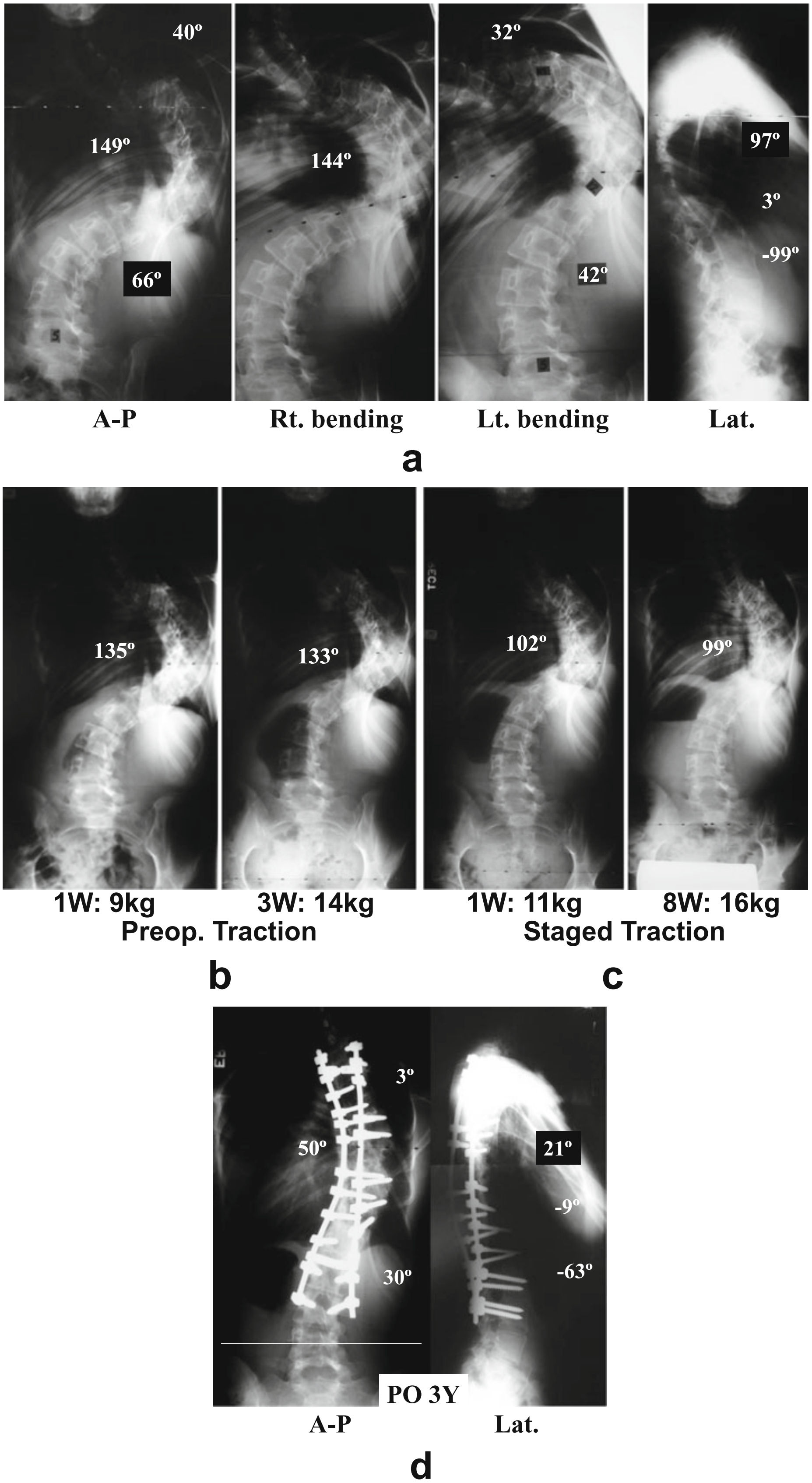


Fig. 9. A 15-year-old girl had severe progressive idiopathic scoliosis. **a** Preoperative standing radiographs demonstrate a 149° major curve; side-bending radiographs demonstrate 3.4% flexibility. *A-P*, anteroposterior; *Rt*, right; *Lt.*, left; *Lat.*, lateral. **b** Posteroanterior (PA) radiographs 3 weeks after preoperative halo–gravity traction demonstrate 10.7% correction of the major curve. **c** PA radiographs 8 weeks after anterior release (eight segments) and staged halo–gravity traction demonstrate 33.6% correction of the major curve. **d** PA radiographs 3 years after final posterior fusion from T2 to L3 with T8/9 VCR demonstrate 66.4% correction of the major curve to 50°

safety of perioperative halo–gravity traction for scoliotic curves >100°. It is challenging to obtain a comparable control group of these severe types of spinal deformities. Seller et al.[27] analyzed two groups of severe neuromuscular spinal deformity patients: one group ($n = 8$) with preoperative halo–gravity traction and one ($n = 17$) without. After surgery, the average main Cobb angle decreased 57% (33°–77°) in the non-halo-traction group and 61% (33°–85°) in the halo-traction group, respectively. The difference was not significant ($P > 0.05$). Therefore, they concluded that unless there are specific indications for halo traction it is not needed as a standard procedure for neuromuscular deformities. Sponseller et al.[28] reported a similar comparative multicenter study. They analyzed two groups of severe spinal deformity patients: one group ($n = 30$) with preoperative halo–gravity traction and one ($n = 23$) without. There were no statistically significant differences in the main coronal curve correction rate (62% vs. 59%), operating time, blood loss, or total complication rate (27% vs. 52%). However, the nontraction group underwent vertebral column resection more often (30% vs. 3%, $P < 0.05$). The traction group had a statistically significant increase in average hospital stay (36 vs. 14 days) ($P < 0.05$). Therefore, it might be possible to avoid more invasive procedures, such as an anterior release or osteotomy, by using halo–gravity traction. These studies were, however, limited by their small sample size and retrospective nature.

Conclusion

Perioperative halo–gravity traction is effective in improving coronal plane deformity, trunk height, and lung volume by expanding the thoracic cage in patients with severe rigid scoliosis. In addition, staged halo–gravity traction after an anterior release procedure is more effective for scoliosis correction compared with preoperative halo–gravity traction alone. Perioperative traction permits most of the correction of the coronal deformity within the first week, and should be applied for at least 3 weeks to obtain maximum deformity correction before definitive spinal fusion is performed. In addition, halo–gravity traction is better tolerated overall, especially by young patients, and does not require prolonged bed rest or the high forces of halo–skeletal traction. Needless to say, surgeons must be aware of the complications related to halo traction and should monitor the patient's neurological status; furthermore, whole spine radiographs should be obtained regularly during the traction period.

The authors did not receive any outside funding or grants in support of their research for or preparation of this work. The authors did not received funding from any agency that requires deposit of copies of articles in a public access database. Two of the authors received from a commercial entity, payments or pecuniary, in kind, or other professional or personal benefits including stock, honoraria, or royalties (collectively, "Benefits") or any commitment or agreement to provide such Benefits.

References

1. Stagnara P. [Cranial traction using the "Halo" of Rancho Los Amigos.] Rev Chir Orthop Reparatrice Appar Mot 1971;57:287–300 (in French).
2. Takeshita K, Lenke LG, Bridwell KH, Kim YJ, Sides B, Hensley M. Analysis of patients with nonambulatory neuromuscular scoliosis surgically treated to the pelvis with intraoperative halo-femoral traction. Spine 2006;31:2381–5.
3. Lenke LG, Bridwell KH, Blanke K, Baldus C. Analysis of pulmonary function and chest cage dimension changes after thoracoplasty in idiopathic scoliosis. Spine 1995;20:1343–50.
4. Campbell RM Jr, Smith MD, Mayes TC, Mangos JA, Willey-Courand DB, Kose N, et al. The characteristics of thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis. J Bone Joint Surg Am 2003;85:399–408.
5. Dewald RL, Ray RD. Skeletal traction for the treatment of severe scoliosis: the University of Illinois halo-hoop apparatus. J Bone Joint Surg Am 1970;52:233–8.
6. Ginsburg GM, Bassett GS. Hypoglossal nerve injury caused by halo-suspension traction: a case report. Spine 1998;23:1490–3.
7. Wilkins C, MacEwen GD. Cranial nerve injury from halo traction. Clin Orthop 1977;126:106–10.
8. MacEwen GD, Bunnell WP, Sriram K. Acute neurological complications in the treatment of scoliosis: a report of the Scoliosis Research Society. J Bone Joint Surg Am 1975;57:404–8.
9. Dove J, Hsu LC, Yau AC. The cervical spine after halo-pelvic traction: an analysis of the complications of 83 patients. J Bone Joint Surg Br 1980;62:158–61.
10. Kalamchi A, Yau AC, O'Brien JP, Hodgson AR. Halo-pelvic distraction apparatus: an analysis of one hundred and fifty consecutive patients. J Bone Joint Surg Am 1976;58:1119–25.
11. Ransford AO, Manning CW. Complications of halo-pelvic distraction for scoliosis. J Bone Joint Surg Br 1975;57:131–7.
12. Tredwell SJ, O'Brien JP. Apophyseal joint degeneration in the cervical spine following halo-pelvic distraction. Spine 1980;5:497–501.
13. Abu Salim F, Zielke K. [Osteoporosis and halo traction in scoliosis patients (author's translation).] Z Orthop Ihre Grenzgeb 1982;120:330–2 (in German).
14. Sink EL, Karol LA, Sanders J, Birch JG, Johnston CE, Herring JA. Efficacy of perioperative halo-gravity traction in the treatment of severe scoliosis in children. J Pediatr Orthop 2001;21:519–24.
15. Rinella A, Lenke L, Whitaker C, Kim Y, Park SS, Peelle M, et al. Perioperative halo-gravity traction in the treatment of severe scoliosis and kyphosis. Spine 2005;30:475–82.
16. O'Brien JP. The management of severe spinal deformities with the halo-pelvic apparatus; pitfalls and guidelines in its use. (Proceedings and Reports of Universities, Colleges, Councils and Associations). J Bone Joint Surg Br 1977;59:117–8.
17. Garfin SR, Botte MJ, Waters RL, Nickel VL. Complications in the use of halo fixation device. J Bone Joint Surg Am 1986;68:320–5.
18. Goodman ML, Nelson PB. Brain abscess complicating the use of a halo orthosis. Neurosurgery 1987;20:27–30.
19. Letts RM, Palakar G, Bobecko WP. Preoperative skeletal traction in scoliosis. J Bone Joint Surg Am 1975;57:616–9.

20. Bang-ping Q, Yong Q, Bin W, Yang Y, Ze-zhang Z. Brachial plexus palsy caused by halo traction before posterior correction in patients with severe scoliosis. Chin J Traumatol 2007;10: 294–8.
21. Dobbs MB, Lenke LG, Kim YJ, Luhmann SJ, Bridwell KH. Anterior/posterior spinal instrumentation versus posterior instrumentation alone for the treatment of adolescent idiopathic scoliotic curves more than 90 degrees. Spine 2006;31:2386–91.
22. Kuklo TR, Lenke LG, O'Brien MF, Lehman RA Jr, Polly DW Jr, Schroeder TM. Accuracy and efficacy of thoracic pedicle screws in curves more than 90 degrees. Spine 2005;30:222–6.
23. Watanabe K, Lenke LG, Bridwell KH, Kim YJ, Watanabe K, Kim YW, et al. Comparison of radiographic outcomes for the treatment of scoliotic curves greater than 100 degrees: wires versus hooks versus screws. Spine 2008;33:1084–92.
24. Watanabe K, Lenke LG, Bridwell KH, Kim YJ, Watanabe K, Kim YW, et al. Comparison of radiographic outcomes between anterior/posterior combined fusion and posterior fusion alone for scoliosis curves ≥100 degrees: is anterior release necessary? Spine (in process).
25. Lenke LG, Newton PO, Marks MC, Blanke KM, Sides B, Kim YJ, Bridwell KH. Prospective pulmonary function comparison of open versus endoscopic anterior fusion combined with posterior fusion in adolescent idiopathic scoliosis. Spine 2004;29:2055–60.
26. Kim YJ, Lenke LG, Bridwell KH, Kim KL, Steger-May K. Pulmonary function in adolescent idiopathic scoliosis relative to the surgical procedure. J Bone Joint Surg Am 2005;87:1534–41.
27. Seller K, Haas S, Raab P, Krauspe R, Wild A. [Preoperative halo-traction in severe paralytic scoliosis.] Z Orthop Ihre Grenzgeb 2005;143:539–43 (in German).
28. Sponseller PD, Takenaga RK, Newton P, Boachie O, Flynn J, Letko L, et al. The use of traction in the treatment of severe spinal deformity. Spine 2008;33:2305–9.