Eur Spine J (2012) 21 (Suppl 6):S765–S772
DOI 10.1007/s00586-012-2156-8

ORIGINAL ARTICLE

Anterior short correction in thoracic adolescent idiopathic scoliosis with mini-open thoracotomy approach: prospective clinical, radiological and pulmonary function results

Kan Min · Mathias Haefeli · Daniel Mueller · Georg Klammer · Frederik Hahn

Received: 23 May 2011 / Revised: 4 January 2012 / Accepted: 8 January 2012 / Published online: 25 January 2012

Abstract
Introduction This is a prospective study of adolescent patients in whom idiopathic thoracic scoliosis was corrected by short anterior fusion through a mini-open thoracotomy approach. Clinical, radiological and pulmonary function results of minimal 2-year (2–6) follow-up are presented.
Materials and methods Consecutive 62 patients with Lenke 1 and 2 curves, having main thoracic scoliosis of up to 75°, were prospectively included. The shoulder imbalance in Lenke 2 patients was less than 20 mm. Thoracic scoliosis was corrected by short anterior fusion. The thoracic spine was exposed by an 8-cm mini-open thoracotomy incision. The operation technique and choosing of fusion levels are thoroughly described. Complete 360° discectomies and convex side vertebral endplates osteotomies are essential for deformity corrections with short fusions. Single-rod 5.5-mm titanium implants were used. The age at the time of operation was mean 15.2 years; 56 patients had a single thoracic curve and 6 patients had a double thoracic curve. There were almost equal numbers of patients with lumbar modifier A, B or C. The average length of fusion was 5.5 (4–7) vertebrae. The average length of fusion was 3.5 (2–6) vertebrae shorter than the average curve length.
Results The instrumented thoracic curves improved by 58.3% at 6 weeks and 56.3% at the last follow-up. Apex thoracic vertebral rotation improved by 73.78% at 6 weeks and 76.24% at the last follow-up. The non-instrumented upper thoracic curve improved by 25% in double thoracic scoliosis, where the mid-thoracic curve was selectively fused, and the non-instrumented lumbar curves improved by 33.9% at the last follow-up. The radiological changes from 6 weeks to the last follow-up were statistically not significant. The clinical rib hump improved by 54% at the last follow-up. There were no significant changes in the pulmonary function. FVC% was 81.04% preoperatively, 76.41% at 6 months and 80.38% at the 2-year follow-up. The results of SRS 24 questionnaire improved from a total of 61.40 points preoperatively to 100.50 points at 6 months and 98.62 points at the 2-year follow-up. There were no neurological or thoracotomy related complications, no pseudarthrosis, no implant pullout or breakage.
Conclusion A good deformity correction without loss of correction or adding on, a good cosmetic result and good patient's satisfaction were achieved through shorter than end-to-end thoracic fusions. The radiological residual deformity is acceptable. Anterior correction of thoracic scoliosis with a short spinal fusion is recommended to keep the large part of the spine mobile. A very short fusion, small thoracotomy incision, low-profile implants and complete closure of parietal pleura are keys to prevent reduction in postoperative lung function.

Keywords Idiopathic thoracic scoliosis · Short anterior correction · Mini-thoracotomy · Pulmonary function · Single rod instrumentation

Introduction

The correction of scoliosis with instrumentation from anterior approach is associated with shorter fusions compared to correction from posterior approach [1, 2]. Anterior correction of thoracic idiopathic scoliosis can be done either through open thoracotomy or thoracoscopic-assisted approach. Results of

K. Min (✉) · M. Haefeli · D. Mueller · G. Klammer · F. Hahn
Department of Orthopaedics, Balgrist Clinic,
University of Zurich, Forchstrasse 340,
8008 Zurich, Switzerland
e-mail: Kan.Min@balgrist.ch

both have been reported in the literature [3–6]. One of the main concerns of the anterior instrumentation of thoracic spine is the possible compromise of pulmonary function [3, 7–10]. In the thoracoscopic method a complete disc removal, involving the complete removal of the posterior annulus, is technically impossible. Without the complete removal of the intervertebral discs the fusions need to be done from the upper end to lower end of the scoliosis curve [4]. Pseudarthrosis and implant failures were also reported [11, 12]. The length of standard thoracotomy exposure, the length of spinal fusion and the bulk of anterior implants may be contributing factors for the postoperative reduction of pulmonary function [13, 14]. We used a mini-thoracotomy incision for exposure and low-profile implants for the instrumentation of the thoracic spine. Very short spinal fusions were done to achieve scoliosis correction. The clinical, radiological results and changes in pulmonary function were prospectively studied. We report the results, describe the method of choosing fusion levels and technique of the surgical procedure.

Patients and methods

Sixty-two consecutive adolescent patients with idiopathic thoracic scoliosis were studied. It was a prospective series of patients, data were collected prospectively, and analysed at the end of 2-year follow-up. All adolescent patients with idiopathic scoliosis of Lenke 1 and 2 type curves having main thoracic curve of equal to or less than 75° were prospectively and consecutively included in the study. In Lenke type 2 patients the shoulder imbalance should be not more than 20 mm.

Anterior correction and instrumentation by mini-open thoracotomy approach was done in these patients. SRS questionnaire and lung function test were carried out preoperatively and at regular intervals postoperatively. The age at the time of operation was 15.2 (SD 2.5) years. The mean Cobb angle of scoliosis was 56° (45°–75°). 19 patients were at Risser stage 0, 4 patients were at Risser stage 1, 6 patients were at Risser stage 2, 5 patients were Risser at stage 3 and 26 patients were at Risser stage 4. 56 patients had a single thoracic curve (King type 3, Lenke type 1) and 6 patients had double thoracic curves (King type 5, Lenke type 2). Lumbar modifier of the lumbar curve was A in 26 patients, B in 17 patients and C in 19 patients. The length of follow-up was average 36 months (24–72 months).

Surgical technique

Choosing of fusion levels (Figs. 1, 2)

In the supine side-bending radiograph the first caudal disc that opens in the concavity of the main thoracic curve is not included in the fusion. The distal last instrumented vertebra (LIV) is the one that is immediately proximal to the opening disc in supine bending radiograph. This distal LIV is then counted from the apex of the scoliosis curve in the standing anteroposterior radiograph of the whole spine. The apex can be either a vertebra or a disc. The same numbers of vertebrae proximal to the apex are then chosen as the proximal arm of instrumentation (Fig. 1). The number of vertebrae in the distal arm must be at least two from the apex. If the vertebra proximal to the opening disc is one vertebra below the apex, the vertebra distal to the opening disc must be taken as distal LIV (Fig. 2). The proximal arm of instrumentation is then counted as mentioned above.

The double thoracic curves can also be operated using the same rule by instrumenting only the larger mid-thoracic curve, if the upper thoracic curve is less than 45° in standing, and the preoperative shoulder balance is acceptable, which should not be more than 20 mm in clinical shoulder level. The supine bending radiographs of the upper thoracic curve are not useful for the surgical planning.

Operation technique

After single lung intubation the patient is positioned on the side. A lateral thoracotomy incision of 8 cm is made directly on the rib of the most proximal vertebra to be instrumented. A piece of the rib is excised. With small thoracotomy incision of 8 cm, a collapsed right lung is very helpful for surgical exposure the thoracic spine. Otherwise the safety could be compromised, like injury to lung tissue during screw insertion and correction manoeuvre with the rod**.** Parietal pleura is incised longitudinally medial to the ribs on the lateral surface of vertebrae, the segmental vessels are coagulated and cut. After blunt dissection medial and lateral pleural flaps are raised and held with holding sutures.

360° discectomies were done. The discs are completely removed, including the part of annulus fibrosis on the concave side as well as the posterior part. It is very important to remove the part of annulus on the concave lateral side of the disc and the part in front of posterior longitudinal ligament, to make the spine mobile enough. Spinal canal is opened after removal of posterior annulus.

The upper and lower end plates of the apical vertebrae are osteotomised on the convex side using an ordinary straight osteotome to remodel the trapezoidal shaped apical vertebrae having a broader base on the convex side. In the apical region rib heads are partially resected by removing the part of the rib head covering postero-lateral corner of the disc. This allows the direct visualisation of postero-lateral corner of annulus fibrosus, which is removed

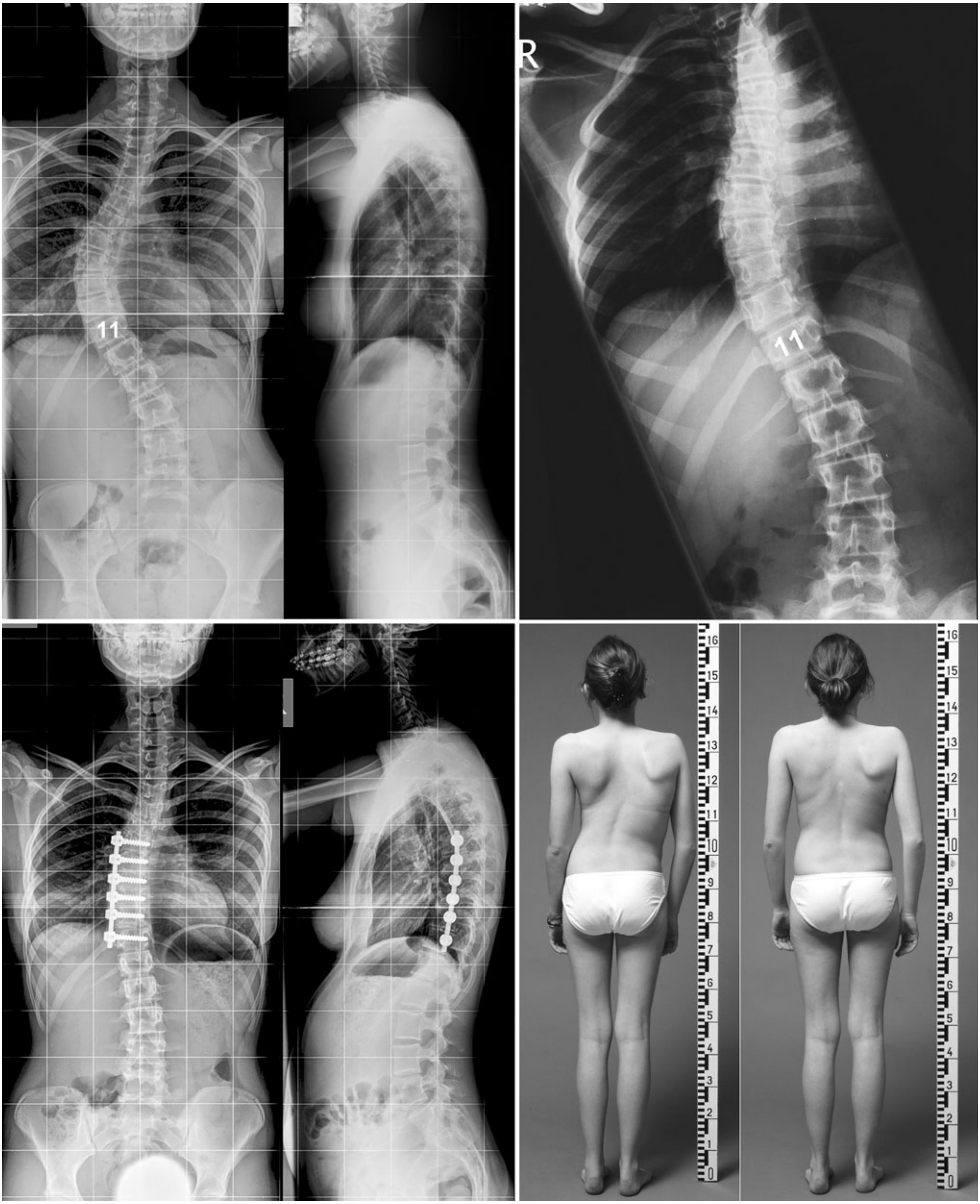

Fig. 1 A single thoracic curve. Disc T11/T12 opens in supine bending. T11 is distal LIV. In anteroposterior standing radiograph the apex is disc T8/T9. There are three vertebrae (T9, T10, T11) distal to the apex and therefore three proximal vertebrae (T6, T7, and T8) need to be included in the proximal arm. Radiographs and clinical pictures preoperatively and at 5-year follow-up

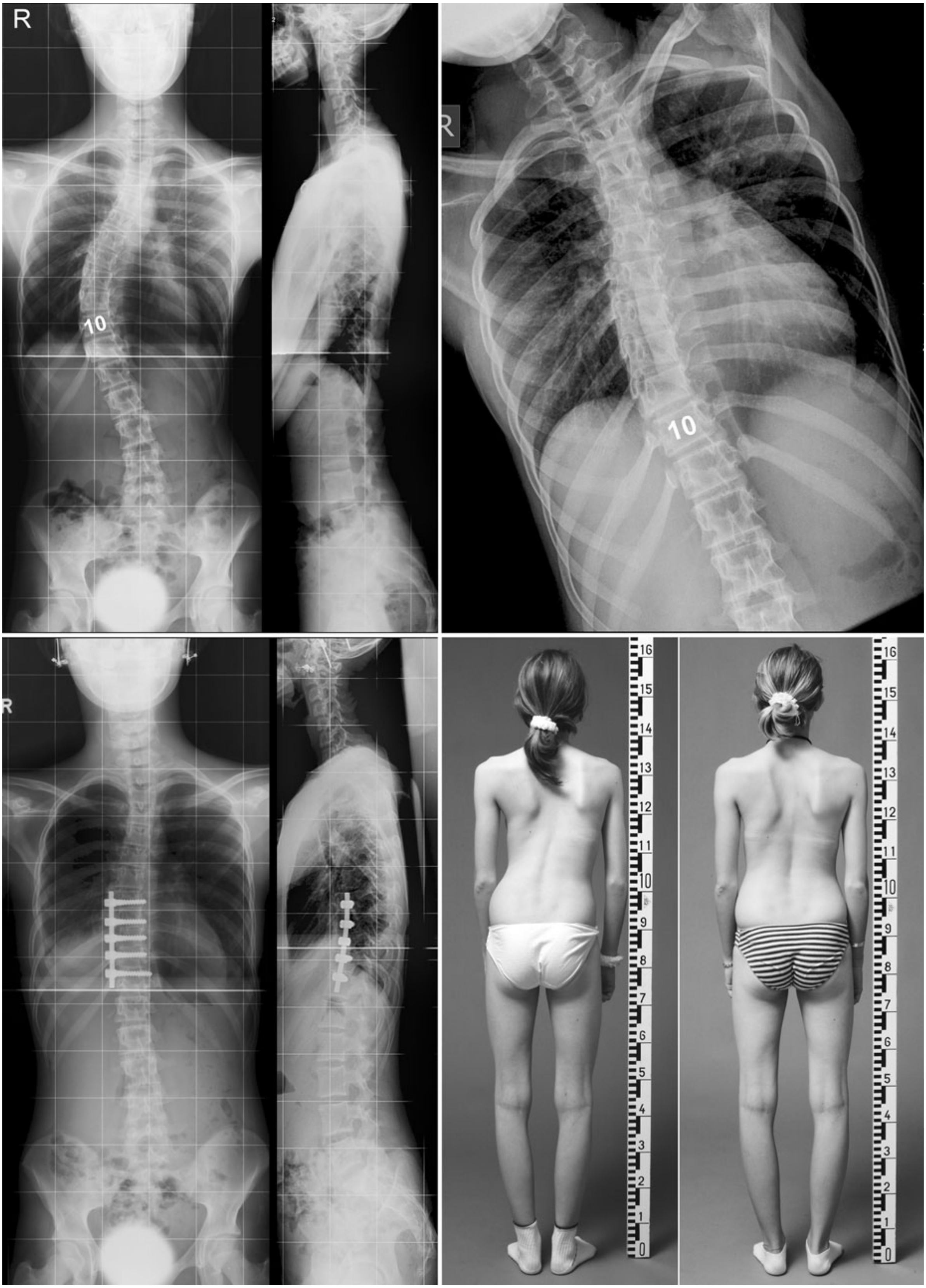

Fig. 2 Opening disc in supine bending is T10/T11. The vertebra above the opening disc is T10 which is the first vertebra below the apex T9. In such a case the vertebra below the opening disc T11 is chosen as the distal LIV. Two vertebrae (T7, T8) proximal to the apex are then included in the fusion. Radiographs and clinical pictures preoperatively and at 3-year follow-up

stepwise using a bone rongeur. Every vertebra is instrumented with a single titanium vertebra screw. The tip of the screw is placed into the contralateral cortex of the vertebra to achieve bicortical purchase. Screws are inserted using anatomical landmarks without the use of a C-Arm: after complete removal of the disc the posterior margin of each vertebra body is visible and the screws are inserted along the posterior cortex of the vertebra body in a safe distance away from the spinal canal under direct visualisation. If the instrumentation is more than five vertebrae, the distal-most screw is inserted through a small separate distally placed 1 cm incision, which was later used for insertion of the chest tube. We intentionally avoid placing washers under the screws to keep the profile of the implant as low as possible. This also allows turning in of the screw deeper into the vertebra body with good bicortical purchase.

The 5.5 mm titanium unit rod is contoured in slight kyphosis. As anterior scoliosis correction is kyphogenic, contouring the rod to physiological kyphosis is not necessary. Contouring the rod to less than physiological kyphosis avoids hyperkyphosis after correction. The rod is first fixed to the most proximal screw, and then reduced stepwise to the distal screws. Manual derotating pressure on the rib cage is helpful in reducing the rod without force. Stepwise compression using compression forceps completes the procedure of correction. The incised pleura is sutured back to cover the implant completely. This prevents the lung from lying in direct contact with metal implant. Thoracotomy is closed over a single chest tube.

All the operations were under spinal cord neuromonitoring with SEP and MEP. Average operation time was 180 min and estimated blood loss was 220 ml. The patients were observed for 24 h in the surgical intermediate care unit and the ambulation of the patient began on the first postoperative day. The thorax drain was removed on the second or third day. Respiratory physiotherapy was started on the operation day till the patient is discharged from the hospital. The patients were discharged on the fifth to seventh postoperative day. Patients could resume swimming and cycling after 6 weeks, skiing, tennis and other sports after 3 months.

Subjective assessment with SRS-24 questionnaire and pulmonary function tests were done preoperatively, 6 and 24 months postoperatively. Clinical and radiological data were assessed from the preoperative, 6 weeks postoperative and the last follow-up examinations.

All operations were performed by a single surgeon. Data collection and analysis were carried out by four orthopaedic surgeons not involved in the care of the patients (M.H., G.K., D.M., F.H.). Paired samples *t* tests were used to compare changes within the parameters. Linear regression analysis was performed to identify predictors for outcome. SPSS™ 11.5 was used for statistical analyses. The level of significance was set at 0.05, two-tailed.

Fusion length

The average length of fusion was 5.5 (min. 4 to max. 7) vertebrae.

The distal end of fusion was T10 in 19 patients, T11 in 32 patients, T12 in 8 patients, L1 in 2 patients and L2 in 1 patient.

On average the length of fusion was 3.5 (min. 2 to max. 6) vertebrae shorter than the length of the scoliosis curve. The last instrumented distal vertebra (LIV) was on average 2.3 (min. 1–max. 4) vertebrae proximal to the lower end vertebra of the scoliosis curve.

Results

Scoliosis correction (Table 1)

Instrumented thoracic curve

The flexibility of the thoracic curves was average 46% (SD 8.24). The improvement of Cobb angle was from mean 56° (SD 7.59) preoperative to 24° (SD 8.42) at 6 weeks, and to 28° (SD 8.42) at the last follow-up. This resulted in a

Table 1 Summary of radiographic measurements

	Mean	SD	Min–max
Thoracic curve Cobb angle (°)			
Preoperative	56	7.59	45–75
Postoperative	24	8.42	9–45
Follow-up	28	8.42	11–43
Apical vertebral rotation (°)			
Preoperative	20.33	5.92	10–35
Postoperative	5.46	5.67	0–30
Follow-up	4.83	5.01	0–25
Apical vertebral translation (mm)			
Preoperative	42.46	12.13	6–80
Postoperative	10.71	7.79	0–31
Follow-up	14.08	7.70	0–27
Lumbar curve Cobb angle (°)			
Preoperative	36.92	8.04	19–52
Postoperative	22.93	7.93	8–40
Follow-up	23.74	6.84	8–37
Thoracic kyphosis (T1–T12) (°)			
Preoperative	27.30	12.52	2–55
Postoperative	33.19	12.21	10–56
Follow-up	36.42	11.51	14–59
Lumbar lordosis (L1–S1) (°)			
Preoperative	54.1	11.84	30–85
Postoperative	53.57	11.02	26–83
Follow-up	58.8	11.54	38–89

correction of Cobb angle of 58.3% at 6 weeks and 56.3% at the last follow-up.

The improvement of apical vertebral rotation was from mean 20.33° (SD 5.92) preoperative to 5.46° (SD 5.67) at 6 weeks and to 4.83° (SD 5.01) at the last follow-up, which resulted in a rotational correction of 73.78% at 6 weeks and 76.24% at the last follow-up.

The apical vertebral translation was 42.46 mm (SD 12.13) preoperative, 10.71 mm (SD 7.79) at 6 weeks postoperative and was 14.08 mm (SD 7.70) at the last follow-up. The changes between the results at 6 week and at the last follow-up were statistically not significant.

The non-instrumented lumbar curve

The flexibility of the lumbar curve was average 77% (SD 6.8). The lumbar curves improved from 36.92° (SD 8.04) preoperative to 22.93° (SD 7.93) at 6 weeks to 23.74° (SD 6.84) at the last follow-up, which resulted in 33.9% spontaneous correction of the lumbar curve at the last follow-up. The changes between the 6 weeks and last follow-up were statistically not significant.

The translation of the apical lumbar vertebra did not change significantly. It was 16.03 mm (SD 8.95) preoperatively, 18.53 mm (SD 10.81) ($p = 0.57$) at 6 weeks and 17.95 mm (SD 9.62) ($p = 0.08$) at the last follow-up.

The non-instrumented upper thoracic curve

In 6 patients with double thoracic curves there was mean 25% improvement of the non-instrumented upper thoracic curves. The upper thoracic curves were rigid on bending with a mean flexibility of less than 20%. The average size of the curves were 40° (32°–45°) preoperatively and 30° (24°–40°) at 6 weeks and remained unchanged to the last follow-up.

Rib hump

The clinical rib hump improved mean 54% from 15.02° (SD 3.84) preoperative to 8.21° (SD 2.88) at the last follow-up. Clinical rib hump at 6 weeks follow-up was not measured.

Shoulder level

The difference in clinical shoulder height was 11.56 mm (SD 8.30) preoperative to 2.39 mm (SD 4.83) at 6 weeks to 1.46 mm (SD 3.22) at the last follow-up. These changes were statistically significant. No patient had a worsening of shoulder balance.

Coronal spinal balance

The C7 offset changed from an average of 11.33 mm before the surgery to 10.63 mm at 6 weeks postoperatively ($p = 0.62$) and to 10.28 mm at the last follow-up ($p = 0.68$), both changes being statistically not significant.

Sagittal spinal profile

The thoracic kyphosis, measured T1–T12, increased from mean 27.30° (SD 12.52) preoperative to 33.19° (SD 12.21) at 6 weeks and this increased further to 36.42° (SD 11.51) ($p = 0.0014$) at the last follow-up.

The mean lumbar lordosis, measured L1–S1, did not change in the first 6 weeks. It was 54.1° (SD 11.84) preoperatively and 53.57° (SD 11.02) at 6 weeks ($p = 0.71$). But the lumbar lordosis increased slightly to 58.8° (SD 11.54) ($p = 0.0001$) at the last follow-up.

Pulmonary function

The expected percent of forced vital capacity (FVC%) did not change significantly. The preoperative FCV% was mean 81.04% (SD 16.47), and was 76.41% (SD 10.21) at 6 months and 80.38% (SD 11.95) at the last follow-up. The absolute values of forced vital capacity (FVC) were 2,842 ml (SD 660) preoperatively; 2,777 ml (SD 414) at 6 months and 2,812 ml (SD 421) at the last follow-up. All the changes in the pulmonary function were statistically not significant.

SRS questionnaire

The results of SRS-24 questionnaire improved from the preoperative mean of 61.40 (SD 11.08) total points to 100.50 (SD 6.58) total points at 6 months and 98.62 (SD 9.62) total points at the last follow-up. The changes between 6 months and 2 years follow-up were not significant. The subscale 'self image/appearance' improved significantly from 17.6 (13–21) points to 22.0 (18–25) points at latest follow-up ($p = 0.001$).

Complications

There were no neurological complications, no thoracotomy-related complications, no pseudarthrosis, no implant loosening nor breakage in this group. Segmental pulmonary atelectasis, which needed intensive non-invasive respiratory physiotherapy was seen in two patients. Both recovered uneventfully. There were no other pulmonary complications.

Discussion

This is the only prospective study on clinical, radiological and pulmonary function results of thoracic scoliosis correction with mini-open thoracotomy approach reported up to now. Through this approach we achieved a scoliosis correction comparable to other reports on anterior instrumentation but with a significantly shorter fusion. Most reports on the anterior thoracic instrumentation used end-to-end fusions, in which length of the fusion was the same as the curve length [2, 4–6, 9, 11, 14]. Liljenqvist et al. [14] reported anterior fusion with dual rod instrumentation and end-to-end fusions, with a thoracic curve correction of 57.5%. Brodner et al. [15] reported on short fusions using dual rod instrumentation in single thoracic curves but the prospective pulmonary function results were not available. They reported correction of thoracic curve to 51.4%. Our Cobb angle correction thoracic curve was 56.3% at the last follow-up, which is comparable to Liljenqvist et al., but with significantly shorter fusion lengths. We used very short fusions for the correction of thoracic scoliosis, on average 3.5 vertebrae (2.5 discs) less than the length of the curve. In our opinion the complete removal of the intervertebral discs and remodelling osteotomies in the vertebral end plate are essential steps to achieve correction with very short fusions. Our results showed that end-to-end fusions from anterior approach are not necessary. Pseudarthrosis and implant failures were reported in thoracoscopic-assisted technique with end-to-end fusions [4, 11, 12]. Complete disc removal, end plate osteotomies and compression of the osteotomised vertebral endplates promoted rapid fusion which was the reason why we did not have any pseudarthrosis nor implant breakage in our series. We also believe that our correction technique using a very short instrumentation, complete removal of intervertebral discs, osteotomy of the endplates to remodel the shape of vertebral bodies on the convex side and bicortical vertebral screw fixation prevents pulling out of cranial construct, which is a known problem in anterior instrumentation techniques, even without the use of underlying washers. In our experience, the use of underlying washers to the vertebral screws is not necessary. We did not see any significant loss of correction and adding-on not only in instrumented thoracic curves, but also in non-instrumented lumbar curves. We believe that a slight overcorrection in the instrumented segment of the spine which resulted from the combined effect of complete discectomies and endplate convex osteotomies helps to avoid loss of correction and adding-on up to the last follow-up. Even though a significant overcorrection like in anterior correction of lumbar spine is not possible due to anatomical constraints in the thoracic spine, a minimal overcorrection is usually seen as a result of the above-mentioned techniques.

The Cobb angle correction of the instrumented thoracic curves was less than the result from the posterior approach with segmental pedicle screw fixation [16] but present results from anterior approach were superior in correction of vertebral rotation and improvement of clinical rib hump. There was a good spontaneous correction 33.9% of the non-instrumented lumbar curves in our series which was less than in the series of Brodner et al. [15], the reason of which may be that a third of the patients in our series had a lumbar C modifier.

In patients with double thoracic curves, the non-instrumented thoracic curves improved 25%. Our results showed that patients with a double thoracic curve can be treated from the anterior approach by selective instrumented fusion of the larger mid-thoracic curve. The short fusions leave the whole spine mobile enough to compensate for the residual deformity in the upper thoracic spine so that the shoulder balance is maintained. In all patients with double thoracic curves there was no worsening of the preoperative shoulder balance. Our results showed that patients with double thoracic curves with an acceptable preoperative clinical shoulder imbalance of up to 20 mm can be treated successfully with this method. The patients should be informed in advance that the shoulder imbalance will not be corrected completely.

Lonner et al. [8] reported in a multicenter study comparing various methods of anterior approach in correction of idiopathic scoliosis. Their result showed a slight reduction in pulmonary function in open thoracotomy group. The length of spinal fusions was not described. Other authors also reported on reduction in pulmonary function at 2 year post-surgery after open thoracotomy approach [9, 10]. Our results were not in agreement with them. We did not have any reduction in pulmonary function either at 6 months or at 2-year follow-up. We are convinced that the reasons for the favourable pulmonary function in our series were threefold. Most importantly, the volume of the lungs taken up by the implants was very small, on one hand due to the very short length of fusion and on the other hand the use of low-profile single rod implants. This combination resulted in less metal volume left behind in the thorax. Small thoracotomy incision was another reason in preventing worsening of lung function. The third reason was the complete coverage of the implant with parietal pleura after spinal instrumentation, which prevents the development of adhesions between the lung and the implant.

The small thoracotomy incision not only helps in preserving the lung function, but also is very important for the cosmetic result in young women. They can cover the small incision scar under the underwear or in bathing suits. The subjective results of SRS-24 questionnaire showed that the patients were highly satisfied with the cosmetic appearance. The results were better than those from the posterior series where correction was done with pedicle crew instrumentation and also where thoracoplasty was performed additionally [16]. The improvement of rotational deformity of more than 70% was also superior to posterior techniques [16]. This contributed to the 54% improvement of clinical rib hump, which together with a favourable scar produced better cosmetic results. A slight residual radiological deformity does not affect the cosmetic results.

Based on this prospective study we conclude that short anterior fusion through mini-open thoracotomy is a novel method for correction of thoracic idiopathic scoliosis with good radiological, clinical and cosmetic results in patients with moderately severe thoracic scoliosis of up to 75°. The pulmonary function is not affected. It is recommendable to accept a residual radiological deformity to keep a large length of the spine mobile, rather than aiming for full radiological correction by means of long fusions at the cost of the mobility of the spine.

Conflict of interest None.

References

1. Min K, Hahn F, Ziebarth K (2007) Short anterior correction of the thoracolumbar/lumbar curve in King 1 idiopathic scoliosis: the behaviour of the instrumented and non-instrumented curves and the trunk balance. Eur Spine J 16(1):65–72
2. Lowe TG, Betz R, Lenke L et al (2003) Anterior single-rod instrumentation of the thoracic and lumbar spine: saving levels. Spine 28(20):208–216
3. Newton PO, Perry A, Bastrom MA et al (2007) Predictors of change in postoperative pulmonary function in adolescent idiopathic scoliosis. Spine 32(17):1875–1882
4. Lonner BS, Kondrachov D, Siddiqui F et al (2006) Thoracoscopic spinal fusion compared with posterior spinal fusion for the treatment of thoracic adolescent idiopathic scoliosis. JBJS 88(A):1022–1034
5. Tis JE, O‘Brien MF, Newton PO et al (2009) Adolescent idiopathic scoliosis treated with open instrumented anterior spinal fusion. Spine 35(1):64–70
6. Wong HK, Hee HT, Yu Z (2004) Results of thoracoscopic instrumented fusion vs. conventional posterior instrumented fusion in adolescent idiopathic scoliosis undergoing selective thoracic fusion. Spine 29(18):2031–2038
7. Kishan S, Bastrom T, Betz RR (2007) Thoracoscopic scoliosis surgery affects pulmonary function less than thoracotomy at 2 years postsurgery. Spine(23):453–457
8. Lonner BS, Auerbach JD, Estreicher MB et al (2009) Pulmonary function changes after various anterior approaches in the treatment of adolescent idiopathic scoliosis. J Spinal Disord Tech 22(8):551–558
9. Kim YJ, Lenke LG, Lowe T et al (2005) Pulmonary function in adolescent idiopathic scoliosis relative to the surgical procedure. JBJS 87(A):1534–1541
10. Kisan S, Bastrom T, Betz R et al (2007) Thoracoscopic scoliosis surgery affects pulmonary function less than thoracotomy at 2 years postsurgery. Spine 32(4):453–458
11. Picetti GD, Pang D, Bueff HU (2002) Thoracoscopic techniques for the treatment of scoliosis: early results in procedure development. Neurosurgery 51:978–984
12. Reddi V, Clarke DV, Arlet V (2008) Anterior thoracoscopic instrumentation in adolescent idiopathic scoliosis. A systematic review. Spine 33(18):1986–1994
13. Brodner W, Mun YW, Möller HB et al (2003) Short segment bone-on-bone instrumentation for single curve idiopathic scoliosis. Spine 28(20):224–233
14. Liljenqvist UR, Bullmann V, Schulte TL et al (2006) Anterior dual rod instrumentation in idiopathic thoracic scoliosis. Eur Spine J 15:1118–1127
15. Brodner W, Mun Yue W, Möller HB et al (2003) Short segment bone-on-bone instrumentation for single curve idiopathic scoliosis. Spine 28(20):S224–S233
16. Min K, Waelchli B, Hahn F (2005) Pedicle screw instrumentation and primary thoracoplastic in thoracic idiopathic scoliosis. Eur Spine J 14(8):777–782