The Effects of Intersegmental Compression on the 3-D Correction of Idiopathic Scoliosis Using Thoracoscopic Surgery

Sung Kyun Oh*, Sung Soo Chung†, Chong Suh Lee‡

*Department of Orthopedic Surgery, Sanbon Hospital of Wonkwang University, Kunpo, Korea, †Department of Orthopedic Surgery, Samsung Medical Center, Sungkyunkwan University, School of Medicine, Seoul, Korea

Study Design: Retrospective study.

Purpose: To investigate whether intersegmental compression can affect the results of three-dimensional correction for idiopathic scoliosis.

Overview of Literature: Intersegmental compression is usually performed to increase the correction rate and enhance kyphosis restoration. However, it is presumed that the risk of decompensation is increased.

Methods: Twenty-seven patients with idiopathic scoliosis who were corrected thoracoscopically were divided into two groups: a compression group and a non-compression group. Thoracic and lumbar scoliotic Cobb angles were measured preoperatively, one week postoperatively, and at last follow-up. Changes in thoracic kyphosis and in sagittal and coronal balance were compared.

Results: The average correction rates for thoracic scoliotic curves were 70.3% and 58.8% in the compression and non-compression groups, respectively (p=0.023), at 1 week postoperatively. However, these changed to 62.6% and 58.1% at the final follow-up visit (p=0.381). Thoracic kyphosis increased by 37.4% in the compression group and 20.9% in the non-compression group at 1 week postoperatively (p=0.435). Finally, thoracic kyphosis increased by 59.9% and 42.6% (p=0.473), respectively, at final follow-up. Axial rotation was corrected by 45.3% and 24.7% in the compression and non-compression groups, respectively (p=0.214). There were no significant differences in postoperative changes in coronal and sagittal balance between the two groups.

Conclusions: Three-dimensional correction by intersegmental compression tended to produce better results, especially during the early postoperative period. However, at final follow-up, no significant differences were observed between the two groups in terms of three-dimensional correction. Thus, we conclude that intersegmental compression is not always necessary for thoracoscopic scoliosis correction.

Key Words: Idiopathic scoliosis, Thoracoscopy, Intersegmental compression, Three dimensional correction

Introduction

Anterior scoliosis correction has the advantage of shorter fusion, possibly due to greater correctability and greater restoration of kyphosis and rotational deformity compared to posterior surgery. However, anterior surgery requires a more extensive thoracotomy, and rod fractures have frequently been reported. The advantages of anterior surgery and minimally invasive surgery are realized with the use of video-assisted thoracoscopic surgery (VATS).

After scoliosis correction, decompensation becomes a considerable issue in King type II and III curves. The suggested causes of decompensation are: too much correction,
rod derotation, selective thoracic fusion, inadequate application of hooks, inadequate distraction or compression, thoracic curve type, and others. The Harms study group reported a decompensation incidence of 11% for anterior scoliosis correction using open thoracotomy and 17% for posterior instrumentation (p=0.25). A lower probability of decompensation was expected in anterior surgery due to the avoidance of rod derotation1. As a final step in thoracoscopic scoliosis correction, intersegmental compression is usually performed to increase the correction rate and to enhance kyphosis restoration. However, it is presumed that the risk of decompensation is increased by the higher correction rate using intersegmental compensation.

The purpose of this study was to determine if intersegmental compression can achieve greater three-dimensional correction, and how this affects coronal and sagittal balance.

**Materials and Methods**

Twenty-seven patients with idiopathic thoracic scoliosis were included in this study. All patients were treated with VATS by one surgeon (Chong Suh Lee). Patients were divided into two groups: a compression group and a non-compression group. The compression group was comprised of 14 patients who were treated using the Eclipse system (Sofamor-Danek), which has a 4.5 mm diameter rod. The non-compression group was comprised of 13 patients who were treated using the pediatric size Synergy system (Interpore Cross), which has a 4.75 mm diameter rod. All procedures were the same in both groups, with the exception of the intersegmental compression procedure.

The study population included 25 female and 2 male patients. The mean age at the time of operation of 16.5 years (range 12~23.9 years). The mean follow-up period was 16.8 months (range 6~36.8 months) overall, 15.7 months in the compression group, and 17.7 months in the non-compression group. One patient with pseudarthrosis was excluded from the study (Table 1).

The magnitude of the main thoracic and compensatory lumbar curves and of the thoracic kyphosis (T3-T12) were

| Table 1. Summary of the cases |
|-----------------------------|
| Sex | Age | King type | Curve | Cobb's angle | Fusion level | Instrumentation |
|-----|-----|-----------|-------|--------------|--------------|---------------|
| F   | 13.1| 2         | T5-T12| 57           | T5-T12       | Eclipse       |
| F   | 20.4| 2         | T5-T11| 63           | T5-T11       | Eclipse       |
| M   | 13.0| 2         | T6-T11| 53           | T6-T11       | Eclipse       |
| F   | 17.1| 3         | T5-T12| 46           | T5-T12       | Eclipse       |
| F   | 17.8| 3         | T4-L1 | 49           | T5-T12       | Eclipse       |
| F   | 17.2| 3         | T5-L1 | 52           | T5-L1        | Eclipse       |
| F   | 16.0| 3         | T6-L1 | 48           | T6-T12       | Eclipse       |
| F   | 12.1| 4         | T6-L1 | 50           | T6-L1        | Eclipse       |
| F   | 15.4| 4         | T7-L2 | 61           | T7-L2        | Eclipse       |
| F   | 17.7| 5         | T5-T12| 73           | T5-T12       | Eclipse       |
| M   | 15.9| 5         | T8-L2 | 81           | T8-L2        | Eclipse       |
| F   | 12.1| 5         | T6-T11| 55           | T6-T11       | Eclipse       |
| F   | 14.3| 5         | T7-L1 | 51           | T7-L1        | Eclipse       |

| F   | 16.3| 2         | T4-T11| 48.7         | T5-T11       | Synergy       |
| F   | 12.4| 2         | T4-T11| 61           | T5-T11       | Synergy       |
| F   | 13.3| 2         | T5-T10| 45           | T5-T10       | Synergy       |
| F   | 12.0| 2         | T5-T12| 49           | T5-T12       | Synergy       |
| F   | 18.8| 3         | T5-T12| 52           | T5-T12       | Synergy       |
| F   | 13.5| 3         | T5-T11| 50           | T5-T11       | Synergy       |
| F   | 31.6| 3         | T7-L1 | 45.4         | T7-T12       | Synergy       |
| F   | 23.9| 3         | T6-T12| 43           | T6-T12       | Synergy       |
| F   | 13.7| 4         | T6-L1 | 55           | T6-T12       | Synergy       |
| F   | 16.0| 5         | T6-L1 | 60           | T6-L1        | Synergy       |
| F   | 21.9| 5         | T6-T1 | 248          | T6-T12       | Synergy       |
| F   | 18.4| 5         | T6-L1 | 51           | T6-L1        | Synergy       |
| F   | 14.0| 5         | T6-T12| 46.6         | T6-T11       | Synergy       |
measured by Cobb’s method using 14 inch × 36 inch whole spine standing radiographs obtained preoperatively, 1 week postoperatively, and at the final follow-up visit. Coronal and sagittal balance were assessed based on the distance between a vertical line (C7 plumb line) dropped from the center of the C7 vertebral body and the center sacral line. Coronal decompensation was defined as a measurement of >10 mm in coronal plane. Sagittal balance was assessed based on the shortest distance between the C7 plumb line and the posterior superior corner of the S1 vertebral body. If this distance was more than 30 mm removed from the posterior superior corner of S1 in the sagittal plane, then the case was designated as exhibiting sagittal decompensation.

A preoperative MRI was available for all patients. However, postoperative MRIs - which were obtained at postoperative week 1 were available for only 22 of the 27 patients (13 patients in the compression group and 9 patients in the non-compression group). Axial rotation of apical vertebrae (AVR) was measured using the methods devised by Aaro and Dahlborn.

The student’s t-test was used to compare angular values obtained from MRIs and plain radiographs. Statistical significance was set at p<0.05.

Results

1. Coronal correction (Table 2)

Preoperatively, the average Cobb angle measurement for the thoracic curve was 56.4 degrees in the compression group and 50.4 degrees in the non-compression group. Postoperatively, the average Cobb angle measurement was 17.2 degrees in the compression group and 20.6 degrees in the non-compression group. The average correction rates for the thoracic curves were 70.3% and 58.8% in the compression and non-compression groups, respectively (p=0.023).

At final follow-up examination, the average Cobb angle measurements for the thoracic curves were 21.7 degrees in the compression group and 20.9 degrees in the non-compression group. The average thoracic curve correction rate was 62.6% in the compression group and 58.1% in the non-compression group, with no significant difference between the two groups (p=0.381).

Preoperatively, the average Cobb angle for the lumbar compensatory curve was 23.2 degrees in the compression group and 20.1 degrees in the non-compression group. Postoperatively, it was 9.8 degrees in the compression group and 12.5 degrees in the non-compression group, which corresponded with average correction rates of 61.6% and 37.5%, respectively. At final follow-up examination, the average Cobb angle for the lumbar compensatory curve was 12.6 degrees in the compression group and 12.4 degrees in the non-compression group. These numbers corresponded to average correction rates of 50.3% in the compression group and 44.7% in the non-compression group. The correction rates of lumbar curve were significantly different for two groups at post operative 1 week (p=0.02), but not at final follow-up (p=0.522). At final follow-up, a loss of tho-

Table 2. Results of the 3 D-correction

|                                | Preoperative | Postoperative 1 week | Final  |
|--------------------------------|--------------|----------------------|-------|
| Coronal correction of T-curve (mean±SD) | Comp (+) (N=14) | 56.4±10.0° | 17.2±9.21° | 21.7±11.0° |
|                                | Comp (-) (N=13) | 50.4±5.5° | 20.6±5.68° | 20.9±5.73° |
| Coronal correction of L-curve (mean±SD) | Comp (+) (N=14) | 23.2±11.4° | 9.8±7.78° | 12.6±9.72° |
|                                | Comp (-) (N=13) | 20.1±9.66° | 12.5±7.96° | 12.4±7.11° |
| Increase of sagittal kyphosis (mean±SD) | Comp (+) (N=14) | 20.1±7.6° | 25.2±7.61° | 30.5±9.76° |
|                                | Comp (-) (N=13) | 22.1±8.8° | 22.8±5.10° | 26.8±5.38° |
| Apical vertebral correction (mean±SD) | Comp (+) (N=13) | 15.5±7.0° | 8±4.23° | 12.3±3.76° |
|                                | Comp (-) (N= 9) | 12.3±3.76° | 7±3.69° | |
racic curve correction of more than 5 degrees was observed in 6 patients in the compression group (in 1 patient it was more than 10 degrees), but in only 1 patient in the non-compression group.

2. Sagittal correction (Table 2)

Preoperative thoracic kyphotic angles were 20.1 degrees and 22.1 degrees in the compression and non-compression groups, respectively, and 25.2 degrees and 22.8 degrees, respectively, at postoperative week 1. At final follow-up, the thoracic kyphotic angle was 30.5 degrees in the compression group and 26.8 degrees in the non-compression group.

Thoracic kyphosis was elevated by 37.4% at postoperative week 1 and by 59.9% at final follow-up in the compression group; it was elevated by 20.9% at postoperative week 1 and by 42.6% at final follow-up in the non-compression group. No statistically significant difference was observed between the two groups, either postoperatively or at final follow-up (p=0.435, p=0.473). Thoracic kyphosis was divided into hypokyphosis (T3–T12, <20 degrees), normokyphosis (T3–T12, 20–40 degrees), and hyperkyphosis (T3–T12, >40 degrees). In the compression group, 7 patients were hypokyphotic, and the others were all within normokyphotic limits, preoperatively. In the postoperative period, 6 of the 7 hypokyphotic patients converted to normokyphosis, and 2 normokyphotic patients converted to hyperkyphosis. In the non-compression group, 6 patients were hypokyphotic, and the other 7 patients were normokyphotic, preoperatively. In the postoperative period, 5 of the 6 hypokyphotic patients converted to the normal range, but no hyperkyphotic correction occurred.

3. Axial rotational correction (Table 2)

Average preoperative apical axial rotational angles were 15.5 degrees and 12.3 degrees in the compression and non-compression groups, respectively. Average postoperative angles were 8 degrees and 7 degrees, respectively, whereas average correction angles were 7.5 degrees (range, -1.7–20 degrees) and 5.3 degrees (range, -11–9.2 degrees), respectively. Apical axial rotation was corrected by 45.3% in the compression group and by 24.7% in the non-compression group (p=0.214).

4. Coronal balance (Tables 3 and 4)

We defined coronal decompensation as greater than 10 mm of displacement of the plumb line from the central sacral line. “Worse” was defined as a plumb line displacement >10 mm from the center sacral line when compared to the preoperative state. Analysis was performed to determine whether the differences between the two groups were significant. Coronal decompensation was observed in 9 of 14 patients in the compression group, and in 6 of 13 patients in the non-compression group, at final follow-up exam. Conversion to decompensation occurred in 6 patients in the

| Table 3. Value of coronal balance |
|----------------------------------|
| **Group** | **Mean value** | **>10 mm** | **>20 mm** |
| Preoperative | Comp (+) | -3.2 mm | 7 case | 2 case |
| | Comp (-) | -1.8 mm | 6 case | 2 case |
| Postoperative 1 week | Comp (+) | -6.8 mm | 9 case | 3 case |
| | Comp (-) | -10.9 mm | 8 case | 2 case |
| Final | Comp (+) | -3.6 mm | 9 case | 1 case |
| | Comp (-) | -7.6 mm | 6 case | 2 case |

| Table 4. Change of coronal balance |
|----------------------------------|
| **Group** | **>10 mm “worse”** | **>15 mm “worse”** |
| Postoperative 1 week | Comp (+) | 5 case | 2 case |
| | Comp (-) | 3 case | 2 case |
| Final | Comp (+) | 1 case | 0 case |
| | Comp (-) | 1 case | 1 case |

“worse” if the plumb line was displaced far from center sacral line.
compression group and in 4 patients in the non-compression group. In the compression group, 5 patients were “worse” at 1 week postoperatively, and 1 was worse at final follow-up; in the non-compression group, 3 patients were worse at 1 week postoperatively, and 1 patient was worse at the final follow-up.

5. Sagittal balance (Tables 5 and 6)

Changes in sagittal balance varied markedly, both anteriorly and posteriorly with respect to the sacrum (range, -49~45 mm). Anterior and posterior displacements were assigned positive or negative values, respectively, but aver-

| Table 5. Value of sagittal balance |
|-----------------------------------|
| Group | Mean value | > ± 15 mm | > ± 30 mm |
|-------|------------|-----------|-----------|
| Preoperative Comp (+)            | -7.2 mm    | 6 case    | 0 case    |
| Comp (-)                          | -22.4 mm   | 8 case    | 7 case    |
| Postoperative 1 week Comp (+)    | -6.0 mm    | 7 case    | 3 case    |
| Comp (-)                          | -20.5 mm   | 7 case    | 5 case    |
| Final Comp (+)                    | -9.7 mm    | 6 case    | 3 case    |
| Comp (-)                          | -24.2 mm   | 10 case   | 6 case    |

| Table 6. Change of sagittal balance |
|------------------------------------|
| Group | Mean value | > 15 mm | >30 mm |
|-------|------------|---------|--------|
| Postoperative 1 week Comp (+)     | 1.2 mm    | 5 case  | 3 case |
| Comp (-)                           | 1.9 mm    | 6 case  | 1 case |
| Final Comp (+)                     | -2.5 mm   | 5 case  | 3 case |
| Comp (-)                           | -1.8 mm   | 7 case  | 1 case |

Fig. 1. A case of decompensation in the segmental compression group. A 12-year-old female patient with King type II was in a balanced state preoperatively, but she converted to a decompensated state postoperatively. (A) Preoperative whole spine standing P/A view. (B) One-week postoperative whole spine standing P/A view. (C) Fifteen-month postoperative whole spine standing P/A view.
age values in the two groups were minimally different. In the compression group, the average sagittal balance changed from 1.2 mm (range, -49~45 mm) at 1 week postoperatively to -2.5 mm (range, -41~33 mm) at final follow-up. In the non-compression group, the average sagittal balance changed from 1.9 mm (range, -24~36 mm) at 1 week postoperative and -1.8 mm (range, -41~23 mm) at final follow-up. The sagittal balances of 3 patients in the compression group and of 1 patient in the non-compression group changed more than 30 mm anteriorly or posteriorly at 1 week postoperatively and at final follow-up.

Discussion

Idiopathic scoliosis is a complex three-dimensional deformity in the coronal, sagittal, and axial planes. To our knowledge, reports addressing the magnitude of three-dimensional correction by thoracoscopic scoliosis correction are rare. Moreover, no report is available concerning the effects of intersegmental compression on three-dimensional correction.

We initiated this study after encountering two patients who exhibited severe negative balance postoperatively, and several cases of coronal decompensation (Figs. 1 and 2). We presumed that intersegmental compression might have some role in inducing severe balance changes by causing overcorrection.

We found that intersegmental compression could correct the main thoracic and compensatory lumbar curves to a greater extent than the non-compression group at 1 week postoperatively. The degrees of correction achieved by intersegmental compression were 70.3% and 61.6% in the main and lumbar curves, respectively, which appear to be better correction rates than those reported for posterior correction using a multiple hook system. The figures are similar to the correction quoted for the segmental pedicle screw system. However, a loss of correction was observed over time, and the final correction rates were 62.6% and 50.3% for the main and compensatory curves, respectively. It is not surprising that some loss of correction occurs in anterior scoliosis correction when a flexible 4.5 mm diameter rod is...
used, because the fixation point is not as rigid as a pedicle.

Although immediate corrections of the main and compensatory curves were no greater in the non-compression group, no loss of main curve correction (some cases even showed a gain in correction) was observed in the lumbar compensatory curve during follow-up. It is difficult to explain this lack of correction loss in the non-compression group. We believe it may be due to the fact that the diameter of the rod used in the non-compression group was larger than that used in the compression group (4.75 mm vs. 4.5 mm). This point appears to be a limitation of the present study. Another reason for lack of correction loss may be that intersegmental compression pre-stresses the rod and the fixation points of screws to the vertebral body in a permanent manner. The reason for more correction in the lumbar compensatory curve is also difficult to explain, although it could be argued that initial correction without intersegmental compression leaves more room for the compensation of main curve correction.

It is thought that a loss of main curve correction in the compression group and a gain of compensatory curve correction in the non-compression group could provide some benefit in achieving compensation during follow-up.

Preoperatively, coronal decompensation occurred in 7 and 6 cases in compression and non-compression group, in 9 and 8 cases at 1 week postoperatively, and in 9 and 6 cases at the final follow up, respectively (Table 3).

During the follow-up period, 6 cases in the compression group and 5 cases in the non-compression group achieved compensation.

There appear to be no fixed rules concerning sagittal balance changes. There were 2 cases of positive balance of >40 mm in the compression group and 1 case of positive balance in the non-compression group. There were 4 cases of negative balance of >40 mm in the compression group and 1 case of negative balance in the non-compression group.

During the follow-up period, an increase in thoracic kyphosis was observed in both groups, which led to greater sagittal correction than posterior scoliosis correction. However, this increase in thoracic kyphosis seems to be one of the reasons for the severe negative balance observed in the compression group.

Conclusions

Intersegmental compression showed a tendency to produce better three-dimensional correction, especially during the immediate postoperative period. However, at final follow-up, no significant differences were noted between the compression and non-compression groups with respect to three-dimensional correction. We conclude that it is doubtful whether intersegmental compression is always necessary in thoracoscopic scoliosis correction.

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