



Derotation screws provide no advantage over polyaxial screws regarding coronal & sagittal correction in thoracic curves of AIS patients

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Abstract

Purpose We compared two techniques for thoracic apical derotation; one using conventional reduction screws (Single-Innie–SI) and one requiring special derotation screws that can be converted to monoaxial screws to enhance derotation (Dual-Innie–DI) for coronal and sagittal correction and.

Methods A total of 200 patients with thoracic AIS have been included. In the SI-Group ($n = 127$) the convex rod was applied first. Vertebral derotation was done by translation to the concave rod with the convex rod being in place and center of rotation (COR). In the DI-Group ($n = 73$) correction started with translation on the concave side as well but now followed by derotation around the concave rod using the DI-mechanism.

Results The mean rotation according to Raimondi and coronal correction was not sig. affected ($72 (\pm 12) %$ in the SI-Group versus $68 (\pm 15) %$ in the DI-Group), even when flexibility was respected (Cincinnati Correction Index CCI was $2.9 (\pm 4.9)$ versus $3.5 (\pm 4.4)$. ($p < 0.01$). The gain of kyphosis was sig greater (2.7°) in the SI-group, but not clinical relevant.

Conclusion The use of DI screws for apical derotation did not provide an advantage for coronal correction or derotation in thoracic curves. Presumably after translation is performed in the DI-group, there was too much tension and friction in the construct impeding further derotation. Simultaneous translation and derotation in the SI-group, with the convex rod being the COR, yielded similar correction with better kyphosis and was faster and more economic.

Keywords Scoliosis · Direct vertebral derotation (DVD) · Pedicle screws · Kyphosis

Introduction

Over the past years many studies addressed apical derotation and direct vertebral derotation (DVD) with different techniques leading to heterogenous results.

In 2004 Lee et al. introduced a technique with monoaxial [1, 2] pedicle screws reporting better apical rotation and coronal correction [3]. However, the effect on the sagittal profile remains controversial [4]. Some authors report a negative effect of DVD on the kyphosis while others did not [1, 5–7]. Monoaxial screws make the introduction of the contoured rod challenging [8] and might have adverse effects on the sagittal profile. In the aftermath screws were developed that combined the advantages of monoaxial screws with the easiness of polyaxial screws. In this paper we examined the Dual-Innie screws by DePuy, which can be locked after rod introduction converting them from polyaxial to monoaxial screws, so that the screw itself can be used for derotation.

Various other procedures for direct vertebral derotation have been described [1, 2, 9, 10].

In our paper two derotation techniques will be compared; one using Dual-Innie screws, as described above, and one using conventional Single-Innie (SI) polyaxial long-tab

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screws. Here derotation was achieved by rod bending and translation in a technique described below.

The aim of our study is to find out if one technique is superior and whether special derotation screws are needed.

Materials and methods

Study design & patient sample

This is a single surgeon retrospective comparative study. The data of 200 AIS patients with structural thoracic curves (Lenke I, II, III, IV) that have received thoracic spinal fusion by a single surgeon have been reviewed. The follow-up period was at least 1 year for all patients. Only patients that have received posterior spinal fusion with all-screw constructs and without additional anterior approach have been included. These were divided into two groups according to the derotation technique. In the SI-group of 127 patients common polyaxial reduction screws with a single-Innie have been used. In the DI-Group of 73 patients the screw head has a special Dual-Innie locking mechanism, allowing to convert them to monoaxial screws.

Surgical techniques

Implants

All screws were part of the ExpEDIUM system (DePuy). So, rods, tools and other equipment were the same. In both groups long-tab reduction screws were placed on the concave side and short-tab screws on the convex side of the apex. The main difference was that in the DI-group the screws had a different head and dual locking Innies. Furthermore, the screw head had a favored angle so it could move to one side more than to the other. Regarding the Dual-Innie screws, two versions have been used. Initially DIFAR screws

were used until the next generation of Dual-Innie screws, named ‘ExpEDIUM VERSE,’ were introduced in 2015. The main difference was that the head was smaller. 12 patients were operated with this later system.

Correction using the ‘Derotation Screws’ (Fig. 1)

Here the rod is applied in the Dual-Innie screws on the concave side, after being bend to the aspired sagittal profile and spinal alignment. Correction will then be performed by firstly translating the spine to the concave rod. The apical concave screws will then be locked, converting them into monoaxial screws. Hence the vertebral derotation is performed around the concave rod, being the center of rotation. The more flattened convex rod is then applied on the convex side, where a cantilever maneuver can be performed to support the vertebral derotation. The derotation screws will be finally locked by tightening the inner setscrews. Fine-tuning can be performed by distraction on the concave and compression on the convex side.

Correction using the ‘Single-Innie long-arm screws’ (Fig. 2)

Again, the rod is introduced in the long-arm Single-Innie screws on the concave side, followed by derotation of the rod and initial translating the spine to the concave rod. The flatter convex rod is then applied and a cantilever maneuver is done to correct the rib hump. By translation to the overcontoured concave rod the vertebra rotates around the convex rod, which thus is the center of rotation. Distraction on the concave and compression on the convex side can be done if needed.

The main difference between the two techniques, is that in the DI-Group the whole correction is done from the concave side. In the SI-Group vertebral derotation will be performed around the convex rod. Derotation and translation are done

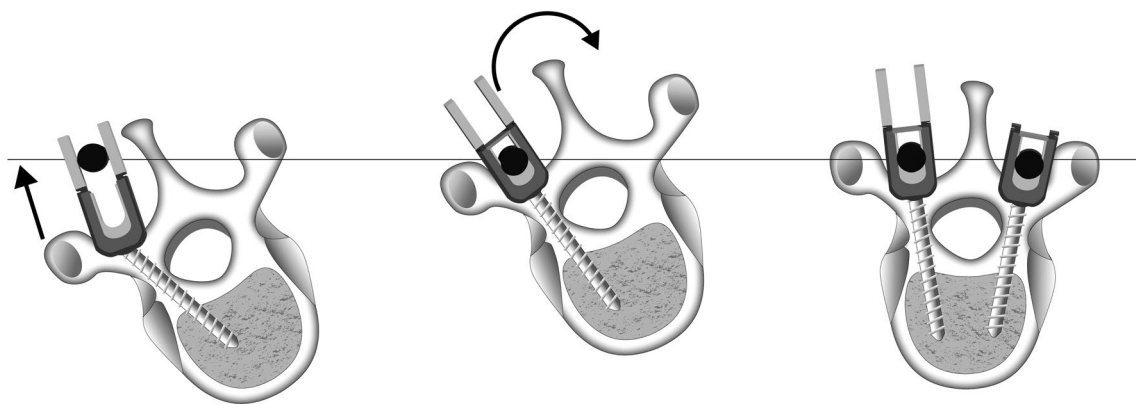


Fig. 1 Correction with Dual-Innie screws by concave translation and derotation around the concave rod

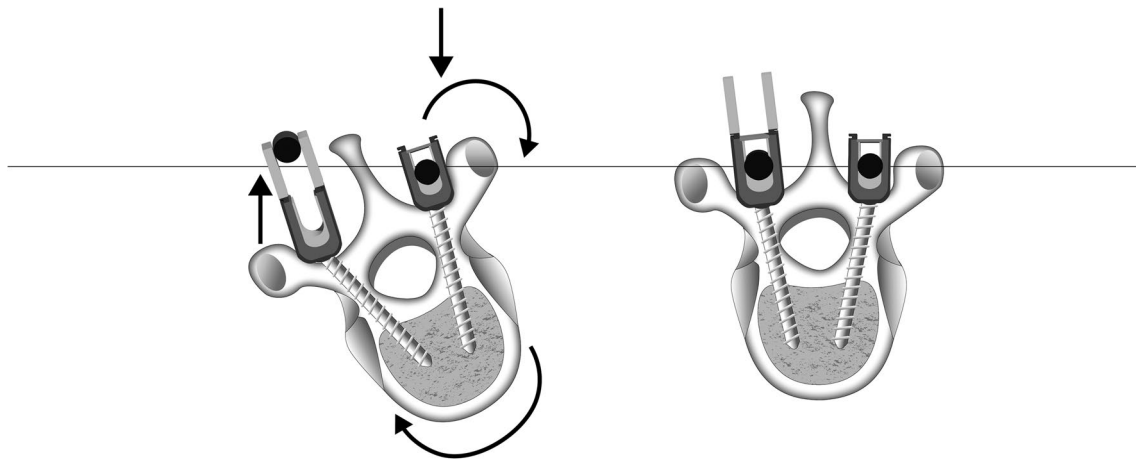


Fig. 2 Correction with polyaxial screws by simultaneous concave translation and derotation around the convex rod

simultaneously and the corrective forces are distributed on both sides.

Radiographic measures

The radiographic outcome measures were thoracic and lumbar Cobb angle, thoracic kyphosis, apical vertebral translation (AVT), apical vertebral rotation according to Raimondi [11], and coronal imbalance with truncal shift defined as the lateral deviation of the C7 plumbline from the central sacral vertical line (CSVL), in millimeters. All these measures were done pre- and postoperatively by an independent observer. Percentage postoperative correction (POC), preoperative flexibility (PF) and the Cincinnati Correction Index (CCI) which is the percentage of correction in relation to the flexibility [5] were calculated.

Implant and surgical details

The types of screws (Single- or Dual-Innie), the material of the rods, number of fused segments, the UIV and LIV have been recorded. Intraoperative Neuromonitoring (IOM) with motor evoked potentials (MEP), was used in all cases to control neurological function. All patients received postoperative epidural anesthesia.

Complications

Surgery related complications were recorded. These included perioperative and late wound infections, wound healing disturbances, instrumentation-related complications such as screw loosening, and rod breakage.

Statistical methods

Data were statistically described in terms of mean \pm standard deviation (\pm SD), median and range, or frequencies (number of cases) and percentage when appropriate. Numerical data were tested for normal assumption using Kolmogorov Smirnov test. Comparison of numerical variables between the study groups was done using Student *t* test for independent samples. For comparing categorical data, Chi-square (χ^2) test was performed. Exact test was used instead when the expected frequency is less than 5. Two-sided *p* values less than 0.05 was considered statistically significant. All statistical calculations were done using computer program IBM SPSS (Statistical Package for the Social Science; IBM Corp, Armonk, NY, USA) release 22 for Microsoft windows.

Results

Demographic data and curve patterns

200 patients were included in the study. Regarding the perioperative data including age, gender, length of operation, length of hospital stay, Lenke classification [12], including lumbar & sagittal modifiers, Risser score [13] and curve patterns no significant differences between the two groups were found. The data are presented in Tables 1 and 2.

There were slightly more kyphotic and less lordotic patients in the DI-group, without reaching significance.

Radiographic measures

Coronal correction

The mean postoperative correction (POC) was 71% (\pm 13%), and the mean CCI was 3.1 (\pm 4.7) for all patients.

Table 1 Demographic data and curve patterns

	Number of cases	Mean \pm SD	DI-Group (N=73)	SI-Group (N=127)	P value
OP-Age		15.8 \pm 3.9	15.9 \pm 3.5	15.7 \pm 4.15	0.667
LOS		10.1 \pm 2.5	10.3 \pm 2.5	10.0 \pm 2.5	0.321
OP-time		148 \pm -51	190 \pm 52	141.4 \pm -50.1	0.005*
<i>Lenke</i>					
I	113 (56.5%)		35 (47.9%)	78 (61.4%)	
I	23 (11.5%)		9 (12.3%)	14 (11.0%)	
III	37 (18.5%)		14 (19.2%)	23 (18.1%)	
IV	5 (2.5%)		4 (5.48%)	1 (0.79%)	
VI	22 (11%)		11 (15.1%)	11 (8.7%)	
<i>Risser</i>					
0	23 (11.5)		7 (9.6%)	16 (12.6%)	
I	13 (6.5%)		2 (2.7%)	11 (8.7%)	
II	14 (7%)		5 (6.8%)	9 (7.1%)	
III	21 (10.5%)		7 (9.6%)	14 (11.0%)	
IV	58 (29%)		23 (31.5%)	35 (27.6%)	
V	71 (35.5%)		29 (39.7%)	42 (33.1%)	
<i>Gender</i>					
Females	179	89.5%	65 (89.0%)	114 (89.8%)	0.872
Males	21	10.5%	8 (11.0%)	13 (10.2%)	
<i>Lumber spine modifier</i>					
A		29.1%	28.8%	29.4%	0.564
B		20.1%	16.4%	22.2%	
C		50.8%	54.8%	48.4%	
<i>Sagittal thoracic modifier</i>					
(-)ve		9.4%	6.9%	10.8%	0.022*
N	150	78.1%	72.2%	81.7%	
(+)ve	24	12.5%	20.8%	7.5%	
<i>Convex Pre</i>					
Lt	19	9.5%	10 (13.7%)	9 (7.1%)	0.125
Rt	181	90.5%	63 (86.3%)	118 (92.9%)	
Length of fusion		9.1 \pm 1.9	9.4 \pm 2.1	9.0 \pm 1.8	0.087

* = $p < 0.05$ **Table 2** Pre- & postoperative coronal parameters

	Mean \pm SD	DI-Group (N=73)	SI-Group (N=127)	P value
Preop. Cobb	54.8 \pm 11.9	55.2 \pm 13.8	54.5 \pm 10.7	0.692
PF	37.4 \pm 20.5	33.2 \pm 22.1	38.4 \pm 19.0	0.083
Preop. AVT Rt.	37.1 \pm 18.7	35.5 \pm 21.312	38.0 \pm 17.2	0.404
Preop. AVT Lt.	27.6 \pm 18.7	25.972 \pm 16.0	29.4 \pm 21.7	0.632
Deviation from CSVL Rt Pre	14.2 \pm 10.0	15.5 \pm 10.4	12.7 \pm 9.6	0.173
Deviation from CSVL Lt Pre	15.6 \pm 10.4	13.5 \pm 10.6	16.13 \pm 10.4	0.360
Postop. Cobb	16.5 \pm 8.7	18.2 \pm 10.3	15.6 \pm 7.4	0.060
POC	70.5 \pm 13.1	67.9 \pm 14.9	71.9 \pm 11.7	0.050
CCI	3.1 \pm 4.7	3.5 \pm 4.4	2.9 \pm 4.9	0.411
Postop. AVT Rt.	12.6 \pm 8.8	13.3 \pm 10.2	12.1 \pm 8.0	0.529
Postop. AVT Lt.	12.7 \pm 8.4	11.1 \pm 8.4	13.5 \pm 8.3	0.166
Deviation from CSVL Rt. Postop.	16.4 \pm 10.9	17.0 \pm 12.2	15.6 \pm 9.3	0.552
Deviation from CSVL Lt. Postop.	16.8 \pm 12.6	13.1 \pm 12.1	17.9 \pm 12.6	0.092

* = $p < 0.05$

No sig. difference was found in preoperative flexibility between the SI-Group ($38 \pm 19\%$) and the DI-Group ($33 \pm 22\%$). The postoperative correction (POC) was slightly higher in the SI-Group ($72\% \pm 12\%$) than in the DI-Group ($68 \pm 15\%$). In order to compare the correction in correlation to the flexibility the CCI was calculated. It was $2.9 (\pm 4.9)$ in the SI-Group and $3.5 (\pm 4.4)$ in the DI-Group. The postoperative change in rotation in relation to the preoperative value was nearly similar in both groups (11 ± 8 in the SI-group, 10 ± 8 in the DI-group) The differences between the 2 groups in all the preoperative and postoperative coronal parameters were statistically insignificant (Table 3).

Sagittal correction

Sagittal kyphosis was lower in the SI-group preoperatively, but was restored to similar postoperative values (Table 3). While the kyphosis did not change postoperatively in the DI-group (-0.4), it increased in the SI-group by 2.3° . The difference was statistically significant ($p=0.013$), however, so small that it was of no clinical relevance.

Implant and surgical details

Thoracoplasty for rib hump correction was not performed, but a release of the costotransversal joints in curves exceeding 60° was done. The mean length of fusion was $9.1 (\pm 1.9)$ segments. The differences between the 2 groups regarding length of fusion, the use of connectors and the need for rib head release were not statistically significant.

Complications

17 out of the 200 patients had one complication. This included 3 wound infection, 4 wound healing disturbances, 9 screw loosening and 1 case of rod breakage. No major complications have been observed. The differences in complications' rate between the two groups was not statistically significant.

Discussion

The aim of scoliosis surgery is to correct not only the sagittal plane, but to restore the thoracic kyphosis and derotate the apex. A technique for apical derotation was first introduced

by Lee et al. [3] Since then, a variety of techniques for apical derotation was described using monoaxial, uniplanar or poliaxial screws with special derotators [1, 4, 14–17].

The senior author of this paper started early with derotation techniques [8] hoping that this would solve the problem of the three-dimensional correction. As this technique which needed special derotation screws was more expensive and some publications suggested that derotation around the concave rod would cause a flattening of the thoracic kyphosis [4], it was abandoned after several years. An alternative approach with conventional polyaxial reduction screws and a different correction strategy was established in which rotation was done around the convex rod with simultaneous translation to the concave side. In a preliminary series [18] we found more kyphosis than by rotating around the concave rod with the DI screws. As conflicting publications about the pros and cons of direct vertebral derotation exist, we now compare these two groups in a larger series which were otherwise comparable and were all operated by the same surgeon.

We found no significant difference in coronal correction when using the special Dual-Innie screws compared to the long-tab polyaxial screws. The postoperative coronal correction (POC) was $68 (\pm 15)\%$ in the DI-Group and $72 (\pm 12)\%$ in the SI-Group. These results were comparable to those of Vallespir et al. [9] who reported coronal correction of 73.3% and Qiu et al. [19] who reported coronal correction of 71.8% .

As the amount of correction depends on the preoperative stiffness of the curve, the Cincinnati Index (CCI) was used. It compares the percentage of correction related to the preoperative flexibility with a higher CCI indicating more relative correction. It was $3.5 (\pm 4.4)$ in the DI-Group compared to $2.9 (\pm 4.9)$ in the SI-Group, with the difference not being statistically significant.

Few studies address the amount of derotation achieved as pre- and postoperative CT scans are hard to justify for research issues. Especially, as Ruchton and Greivitt [20] who examined clinical factors found no effect on rib hump correction or patient satisfaction. We therefore measured the rotation of the apex according to Raimondi [11] and could not find a difference in the two groups but are aware that this is not as exact as a CT scan would have been. Di Silvestre et al. [2] performed rod derotation followed by DVD around the concave rod as done in our DI-group and measured rotation with pre- and postoperative CTs. They observed a better

Table 3 Pre- & postoperative sagittal parameters

	Mean \pm SD	DI-Group (N=73)	SI-Group (N=127)	P value
Preoperative thoracic kyphosis	29.0 ± 13.5	32.3 ± 16.2	27.1 ± 11.3	0.01*
Postoperative thoracic kyphosis	30.3 ± 9.7	31.9 ± 9.9	29.4 ± 9.5	0.087
Postop. kyphosis–Preop. kyphosis	1.3 ± 11.1	-0.4 ± 11.5	$+2.3 \pm 10.7$	0.013*

* $=p<0.05$

coronal correction and derotation with DVD compared to correction by concave rod rotation alone. However, worsening of thoracic kyphosis was seen.

As other authors indicate that derotation will lead to a flattening of the spine as well [7, 21], we looked for the sagittal plane in our patients. Here a minimal decrease in thoracic kyphosis in the DI-Group, from 32.3 (± 16) preoperatively to 31.9 (± 10) postoperatively; and a small increase in thoracic kyphosis in the SI-Group from 27° (± 11) preoperatively to 29° (± 10) degrees postoperatively, was seen. The difference was statistically significant, but is not clinically relevant and within the margin of error. The results were superior to those provided by Kim et al. [21] who reported 14 degrees decrease in thoracic kyphosis and Lowenstein et al. [7] who reported 10 degrees decrease in thoracic kyphosis. Watanabe et al. [15] also showed that vertebral derotation caused hypokyphosis of the thoracic spine. This was partly attributed to the wedge deformity of the vertebral bodies, being taller on the convex side and taller ventrally; resulting in shifting the taller convex wall and the taller anterior wall ventrally during the vertebral derotation, thus elongating the anterior column and decreasing the thoracic kyphosis [15]. On the other hand, Urbanski and colleagues [15] showed contradicting results with en-block DVD maintaining, or even improving, the thoracic kyphosis [22]. We believe that this heterogeneity can be explained by different techniques used to perform DVD. Tsirikos et al. [23] for example describes a technique with DI reduction screws, only on the convex side, for both thoracic and lumbar curves, without using screws on the concave side of the apex. He reported a thoracic coronal correction of approximately 71% with an increase in kyphosis of 13°.

The first rod applied will be the center of rotation (COR). If the COR is the concave rod, a derotation will lead to a decrease in kyphosis. A derotation around the convex rod can increase kyphosis as shown in our patients. Furthermore, the sequence of correction steps is important. In the DI-group we started with translation to create kyphosis and correct the coronal curve and then locked the screws to perform derotation afterward. However, after translation is performed, there is a lot of tension on the construct making any further derotation, difficult; thus, minimizing the effect of vertebral derotation that could be obtained. In the SI-group the convex rod was established as COR with concave translation and convex derotation being performed simultaneously. By connecting both rods with cross links the stiffness of the whole construct was increased before the final correction started. Thus, a slightly better sagittal correction could be achieved.

Although it was disappointing that our initial technique was not as superior as we hoped, it helped us to achieve a better understanding. It must be emphasized that this study not only compares different screw designs but also two

correction strategies, as the DI design allows derotation only after the rod was fixed with the first set screw. The same DI mechanism might help in lumbar curves where lordosis has to be increased.

The main limitations of the study would be the retrospective design, and the lack of clinical correlation with the radiographic outcomes (e.g., with SRS-30 and SF-36 questionnaires). The strengths are the number of patients with similar curves and that all surgeries were done by a single surgeon and the same system so that other variables did not influence the results.

Conclusion

According to our experience, segmental apical derotation with Dual-Innie screws does not provide any advantage, regarding coronal or sagittal correction, when correcting thoracic curves in AIS patients. Similar results could be achieved with regular reduction screws using a different technique, which was faster and easier. A possible explanation is that after translation is performed in the DI-group, there is so much tension and friction in the construct that further derotation was impeded.

When performing DVD, a technique in which derotation is done before applying translation could result in better rotational correction.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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References

1. Tambe AD, Panikkar SJ, Millner PA, Tsirikos AI (2018) Current concepts in the surgical management of adolescent idiopathic scoliosis. *Bone Joint J* 100-B(4):415–424. <https://doi.org/10.1302/0301-620X.100B4.BJJ-2017-0846.R2>
2. Di Silvestre M, Lolli F, Bakaloudis G, Maredi E, Vommaro F, Pastorelli F (2013) Apical vertebral derotation in the posterior treatment of adolescent idiopathic scoliosis: myth or reality? *Eur Spine J* 22(2):313–323. <https://doi.org/10.1007/s00586-012-2372-2>
3. Lee SM, Suk SI, Chung ER (2004) Direct vertebral rotation: a new technique of three-dimensional deformity correction with segmental pedicle screw fixation in adolescent idiopathic scoliosis. *Spine(Phila Pa 1976)* 29(3):343–349. <https://doi.org/10.1097/01.brs.0000109991.88149.19>
4. Mladenov KV, Vaeterlein C, Stuecker R (2011) Selective posterior thoracic fusion by means of direct vertebral derotation in adolescent idiopathic scoliosis: effects on the sagittal alignment. *Eur Spine J* 20(7):1114–1117. <https://doi.org/10.1007/s00586-011-1740-7>
5. Vora V, Crawford A, Babekhir N et al (2007) A pedicle screw construct gives an enhanced posterior correction of adolescent idiopathic scoliosis when compared with other constructs: myth or reality. *Spine(Phila Pa 1976)* 32(17):1869–1874. <https://doi.org/10.1097/BRS.0b013e318108b912>
6. Hwang SW, Samdani AF, Lonner B et al (2012) Impact of direct vertebral body derotation on rib prominence: are preoperative factors predictive of changes in rib prominence? *Spine(Phila Pa 1976)* 37(2):E86–E89. <https://doi.org/10.1097/BRS.0b013e31821fd379>
7. Lowenstein JE, Matsumoto H, Vitale MG et al (2007) Coronal and sagittal plane correction in adolescent idiopathic scoliosis: a comparison between all pedicle screw versus hybrid thoracic hook lumbar screw constructs. *Spine(Phila Pa 1976)* 32(4):448–452
8. Geiger F (2009) More options in scoliosis patients with the dual innie vavored angle reduction tab screw (DI FAR screw). *ArgoSpine News J* 21:102–105. <https://doi.org/10.1007/s12240-009-0020-4>
9. Vallespir GP, Flores JB, Trigueros IS et al (2008) Vertebral coplanar alignment: a standardized technique for three dimensional correction in scoliosis surgery: technical description and preliminary results in Lenke type 1 curves. *Spine(Phila Pa 1976)* 33(14):1588–1597
10. Chang M, Lenke L (2009) Vertebral Derotation in adolescent idiopathic scoliosis. *Oper Tech Orthop* 19:19–23. <https://doi.org/10.1053/j.oto.2009.04.001>
11. Weiss HR (1995) Measurement of vertebral rotation: Perdriolle versus Raimondi. *Eur Spine J* 4:34–38. <https://doi.org/10.1007/BF00298416>
12. Lenke LG, Betz RR, Harms J et al (2001) Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am* 83(8):1169–1181
13. Risser JC (1958) The Iliac apophysis; an invaluable sign in the management of scoliosis. *Clin Orthop*. 11:111–119
14. Suk SI (2011) Pedicle screw instrumentation for adolescent idiopathic scoliosis: the insertion technique, the fusion levels and direct vertebral rotation. *Clin Orthop Surg* 3(2):89–100. <https://doi.org/10.4055/cios.2011.3.2.89>
15. Watanabe K, Nakamura T, Iwanami A, Hosogane N, Tsuji T, Ishii K, Nakamura M, Toyama Y, Chiba K, Matsumoto M (2012) Vertebral derotation in adolescent idiopathic scoliosis causes hypokyphosis of the thoracic spine. *BMC Musculoskelet Disord* 12(13):99. <https://doi.org/10.1186/1471-2474-13-99> (PMID:22691717;PMCID:PMC3441743)
16. Kuklo TR, Potter BK, Polly DW Jr, Lenke LG (2005) Monaxial versus multiaxial thoracic pedicle screws in the correction of adolescent idiopathic scoliosis. *Spine(Phila Pa 1976)* 30(18):2113–20. <https://doi.org/10.1097/01.brs.0000179260.73267.f4> (PMID:16166904)
17. Dalal A, Upasani VV, Bastrom TP, Yaszay B, Shah SA, Shufflerbarger HL, Newton PO (2011) Apical vertebral rotation in adolescent idiopathic scoliosis: comparison of uniplanar and polyaxial pedicle screws. *J Spinal Disord Tech* 24(4):251–257. <https://doi.org/10.1097/BSD.0b013e3181edebe4> (PMID: 20844450)
18. Geiger F, Hilber T, Rauschmann M (2014) P 18 The Influence of derotation and translation on coronal and sagittal correction of AIS*. *Eur Spine J* 23:2473–2569
19. Qiu Y, Zhu F, Wang B et al (2011) Comparison of surgical outcomes of lenke type 1 idiopathic scoliosis: vertebral coplanar alignment versus derotation technique. *J Spinal Disord Tech* 24(8):492–499. <https://doi.org/10.1097/BSD.0b013e3182060337>
20. Rushton PR, Grevitt MP (2013) What is the effect of surgery on the quality of life of the adolescent with adolescent idiopathic scoliosis? A review and statistical analysis of the literature. *Spine(Phila Pa 1976)* 38(9):786–94. <https://doi.org/10.1097/BRS.0b013e3182837c95> (PMID: 24477054)
21. Kim YJ, Lenke LG, Cho SK, Bridwell KH, Sides B, Blanke K (2004) Comparative analysis of pedicle screw versus hook instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. *Spine(Phila Pa 1976)* 29(18):2040–2048. <https://doi.org/10.1097/01.brs.0000138268.12324.1a>
22. Urbanski W, Wolanczyk MJ, Jurasz W, Kulej M, Morasiewicz P, Dragan SL, Sasiadek M, Dragan SF (2017) The impact of direct vertebral rotation (DVR) on radiographic outcome in surgical correction of idiopathic scoliosis. *Arch Orthop Trauma Surg* 137(7):879–885. <https://doi.org/10.1007/s00402-017-2700-4> (Epub 2017 Apr 24. PMID: 28439703; PMCID: PMC5486624)
23. Tsirikos AI, Mataliotakis G, Bounakis N (2017) Posterior spinal fusion for adolescent idiopathic scoliosis using a convex pedicle screw technique: a novel concept of deformity correction. *Bone Joint J* 99-B(8):1080–1087. <https://doi.org/10.1302/0301-620X.99B8.BJJ-2016-1351.R1> (PMID: 28768786)

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