Spine Deformity
www.spine-deformity.org

Spine Deformity 6 (2018) 250–256

Optimal Lowest Instrumented Vertebra for Thoracic Adolescent Idiopathic Scoliosis

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Received 10 August 2017; accepted 7 October 2017

Abstract

Study Design: Retrospective cohort chart review.
Objective: To determine the optimal lowest instrumented vertebra (LIV) following posterior segmental spinal instrumented fusion (PSSIF) of thoracic adolescent idiopathic scoliosis (AIS) with LIV at L2 or above.
Summary of Background Data: Few studies evaluate the optimal LIV based on rotation or center sacral vertical line (CSVL).
Methods: A radiographic assessment of 544 thoracic major AIS patients (average age 14.7 years) with minimum 2 years' follow-up (average 4.1 years) after PSSIF was performed. The LIV was divided by CSVL: stable vertebra 1 (SV-1) if the CSVL fell between the medial walls of the LIV pedicles; SV-2 if between stable vertebra 1 and 3; and SV-3 if the CSVL did not touch the LIV. LIV was divided by rotation into: neutral vertebra 0 (NV-0) if the LIV was at or distal to the neutral vertebra; NV-1 if one vertebra proximal to the NV; NV-2 if two vertebrae proximal; and NV-3 if three vertebrae proximal to the NV.
Results: The prevalence of adding-on (AO) or distal junctional kyphosis (DJK) at ultimate follow-up was 13.6%. Patients with AO or DJK had a higher rate of open triradiate cartilage, LIV not touching the CSVL, and more proximal to the NV ($p < .05$). Risk factors were SV-3 (39% vs. SV-2 14%, SV-1 9%, $p < .05$), NV-3 (35% vs. NV-2 9%, NV-1 6%, NV-0 12%, $p = .000$), open triradiate cartilage (43% vs. closed 13%, $p < .05$), lumbar C modifier (22% vs. B modifier 8%, A modifier 13%, $p < .05$), and Risser stage 0 (19% vs. 12% Risser 1-5, $p < .05$).
Conclusion: The prevalence of AO or DJK at ultimate follow-up of PSSIF for AIS with LIV at L2 or above was 13.6%. Risk factors included the CSVL outside the LIV, LIV 3 or more proximal to the NV, open triradiate cartilage, lumbar C modifier, and Risser stage 0.
Level of Evidence: Level IV.

Keywords: Adolescent idiopathic scoliosis; Spinal fusion; Selection of levels

Introduction

The surgical management of thoracic adolescent idiopathic scoliosis (AIS) has progressed through many different surgical concepts over the last century. The goals remain the same: (1) halt curve progression; (2) maintain coronal and sagittal balance including the shoulders; (3) preserve motion segments; (4) correct the deformity, including the ribs; and (5) avoid complications such as adding-on (AO), distal junctional kyphosis (DJK), proximal junctional kyphosis (PJK), and crankshaft phenomenon [1-18]. Choosing "the most proximal and stable" lowest instrumented vertebra (LIV) without increasing the risk of adding-on (AO) or distal junctional kyphosis (DJK) for patients with AIS has been a challenging process, with many theories starting from end-to-end vertebrae without rotation by Hibbs, neutral vertebra by Goldstein, stable zone by Harrington, stable vertebra by Moe, selective

Author disclosures: none.

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2212-134X/$ - see front matter
https://doi.org/10.1016/j.jspd.2017.10.002

fusion concept, side-bender flexibility, and push-prone radiography [2-4,6,8-10,19]. To our knowledge, no study has analyzed the optimal LIV based on the stable vertebra, center sacral vertical line (CSVL), and neutral vertebra simultaneously. The purpose of this study was to determine ''the most proximal and stable'' LIV without AO or DJK at ultimate follow-up after posterior segmental spinal instrumented fusion (PSSIF) for Lenke 1 and 2 AIS cases according to the preoperative CSVL and vertebral rotation.

Materials and Methods

After obtaining approval by the institutional review board at the respective institutions involved, all AIS patients who underwent PSSIF for thoracic AIS between 1990 and 2008 at four institutions were analyzed. Inclusion criteria were age at surgery ⩽25 years, AIS with Lenke type 1 or 2 curve, PSSIF with LIV at L2 or above, and minimum 2 years' follow-up with a complete set of radiographs. Of the 604 patients with Lenke type 1 or 2 curve, 60 patients were lost to follow-up, did not have a complete set of radiographs, and were thus excluded from the study.

Radiographic measurements

Measurements were made on standing 14 × 36-inch long-cassette anteroposterior (AP) and lateral radiographs of the spine. All radiographic measurements were done by one senior author independent of the operative team. Complete radiographic follow-up consisted of preoperative, 8 weeks postoperative, and final follow-up AP and lateral radiographs. Patients were asked to stand naturally with their arms forward approximately 30° to 45° so that their vertebral bodies could be visualized on the lateral radiograph. The radiographic measurements included curve magnitude and flexibility, lumbar modifier, LIV to CSVL distance, and coronal disc angle below the LIV. Sagittal measurements included thoracic kyphosis (T5–T12), lumbar lordosis (T12–S1), and distal junctional angle below the LIV. Risser sign and tri-radiate cartilage (TRC) were also analyzed.

Radiographic measurements also included determination of the gravity stability and rotational stability of the LIV. Gravity stability was determined by the location of the CSVL to the LIV. The stable vertebra (SV) is the vertebra most closely bisected by the CSVL defined by King et al. [10]. Subclassification of the SV was added: SV-1 if the CSVL fell between the medial borders of the pedicles of the vertebra selected as the LIV; SV-2 when the CSVL was lateral to the medial border of the pedicle but still touching the LIV; and SV-3 if the CSVL was outside of the LIV. The relationship between the LIV and the neutral vertebra (NV) [20] was also determined and subclassified: NV-0 if the LIV and NV are the same; NV-1 if the LIV is one vertebra proximal to the neutral vertebra; NV-2 if the LIV is two vertebrae proximal; and NV-3 if three vertebrae proximal to the neutral vertebra. The combination of gravity and rotational stability is termed Total Stability (TS). The TS amount is the total from the stable grade and the neutral grade. Total stability ranges from TS-1 (NV-0 + SV-1) to TS-6 (NV-3 + SV-3).

Poor radiographic outcome (PX) was defined if AO or DJK was present at ultimate follow-up as these are early signs of curve progression and distal disc degeneration. AO is defined as ⩾3 cm of radiographic progression of the LIV to CSVL distance or ⩾10° increase in the coronal disc angle below the LIV. DJK is defined as radiographic progression of ⩾10° in the sagittal disc angle below the LIV [9-12]. All criteria are in relation to the immediate postoperative radiographs.

The radiographic measurements were performed by the senior author. The intraobserver reliability for CSVL and stable vertebra was 0.95. The intraobserver reliability for the neutral vertebra was 0.9.

Selection of the LIV

There were four criteria used by the five spine surgeons in selection of the LIV. These criteria included (1) stable vertebra touched by the CSVL; (2) neutral rotation; (3) CSVL outside the walls of the LIV if the curve was very flexible on side-bending films; or (4) the LIV bisected by the CSVL on push-prone films. Each surgeon used these criteria as guides in determining the LIV, along with individual patient characteristics.

Table 1
Summary of patient demographic data at ultimate follow-up.

Factor	Average/percentage
Average age at surgery, years	14.7
Average follow-up, years	4.1
Gender, % (n)	
Women	78 (425)
Men	22 (119)
Lenke classification, % (n)	
Type 1	73 (399)
Type 2	27 (145)
Lumbar modifier, % (n)	
A	49 (269)
B	27 (146)
C	24 (129)
Thoracic kyphosis, % (n)	
Normal	75 (407)
Hyperkyphosis	11 (58)
Hypokyphosis	14 (79)
Construct, % (n)	
Hooks	40 (212)
Pedicle screws	35 (195)
Hybrid	25 (137)
Vertebral levels,[a] M ± SD (range)	
Lower end vertebra (LEV)	12.0 ± 1.1 (T9–L4)
Neutral vertebra (NV)	12.9 ± 1.9 (T10–S1)
Lowest instrumented vertebra (LIV)	13.1 ± 0.8 (T11–L2)
Stable vertebra (SV)	13.4 ± 1.8 (T11–S1)

[a] T9 = 9; T10 = 10; T11 = 11; T12 = 12; L1 = 13; L2 = 14.