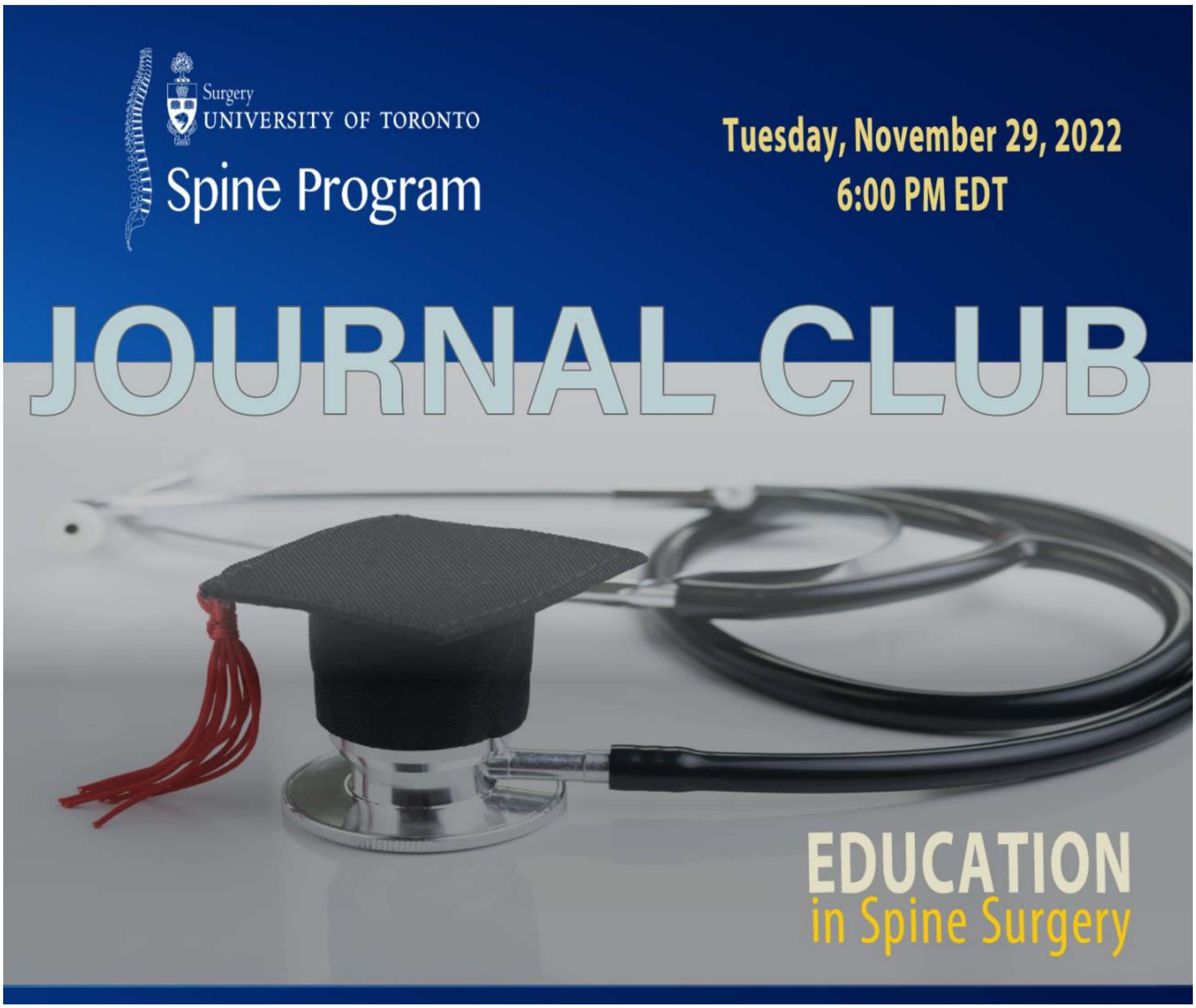
University of Toronto Spine Program

Journal Club

EDUCATION IN SPINE SURGERY

Tuesday, Nov 29, 2022

6:00 PM to 8:00 PM EST



Accreditation:

This educational event is a self-approved group learning activity (Section 1) as defined by the Maintenance of Certification Program of the Royal College of Physicians and Surgeons of Canada

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Content

Agenda

6:00 pm: Introductory Remarks
Professor Michael Fehlings & Professor Albert Yee, Co-Director, U of T Spine Program

6:05 Fellow Presentations

1. **Dr. Ahmed Cherry, Spine Fellow at Toronto Western Hospital**
   - *The importance of determining trainee perspective on procedural competencies during spine clinical fellowship (article)*
   - *The use of a Standardized Surgical Case Log to Document Operative Exposure to Procedural Competencies in a Spine Surgery Fellowship Curriculum: University Wide Initiative.*

2. **Dr. Rajesh Kumar, Spine Fellow at Sunnybrook Health Sciences Centre**
   - *Nerve transfers in the upper extremity following cervical spinal cord injury. Part 2: Preliminary results of a prospective clinical trial.*
   - *Metastatic Cholingio carcinoma C2/3 Level. (case study).*

3. **Dr. Raj Sakhrekar, Spine Fellow at Hospital for Sick Children**
   - *Five major controversial issues about fusion level selection in corrective surgery for adolescent idiopathic scoliosis: a narrative review (article)*

7:30 pm: Wrap up

Co-Chairs

Dr. Michael Fehlings is the Vice Chair Research for the Department of Surgery at the University of Toronto and a Neurosurgeon at Toronto Western Hospital, University Health Network. Dr. Fehlings is a Professor of Neurosurgery at the University of Toronto, holds the Robert Campeau Family Foundation / Dr. C.H. Tator Chair in Brain and Spinal Cord Research at UHN, is a Senior Scientist at the Krembil Brain Institute and a McLaughlin Scholar in Molecular Medicine. In the fall of 2008, Dr. Fehlings was appointed d the inaugural Director of the University of Toronto Neuroscience Program (which he held until June 2012) and is currently Co-Director of the University of Toronto Spine Program. Dr. Fehlings combines an active clinical practice in complex spinal surgery with a translationally oriented research program focused on discovering novel treatments to improve functional outcomes following spinal cord injury (SCI). He has published over 1000 peer-reviewed articles (h-index 112; cited over 49,000 times) chiefly in the area of central nervous system injury and complex spinal surgery. His seminal 1991 paper, cited over 2,000 times, outlined the severe and lasting consequences of SCI due to a cascade of secondary injury mechanisms following the initial trauma. His research on secondary injury mechanisms ultimately led to the commencement of the multicenter, international Surgical Timing in Acute Spinal Cord Injury Study (STASCIS), aimed at establishing the need for early surgical decompression to prevent the negative effects of the secondary injury cascade. His work examining the use of regenerative approaches including neural stem cells to repair the injured nervous system has led to numerous international awards and has helped lead the field toward clinical translation in this area. Dr. Fehlings has published in prominent journals such as Nature, Nature Neuroscience, Lancet Neurology, and Science Translational Medicine.

Dr. Michael Fehlings has received numerous prestigious awards including the Gold Medal in Surgery from the Royal College of Physicians and Surgeons (1996), nomination to the Who's Who list of the 1000 most influential scientists of the 21st century (2001), the Lister Award in Surgical Research (2006), the

Leon Wiltse Award from the North American Spine Society for excellence in leadership and/or clinical research in spine care (2009), the Olivecrona Award (2009) -- the top award internationally for neurosurgeons and neuroscientists awarded by the Nobel Institute at the Karolinska Institute in Stockholm for his important contributions in CNS injury repair and regeneration, the Reeve-Irvine Research Medal in Spinal Cord Injury (2012), the Golden Axon Leadership Award (2012), the Mac Keith Basic Science Lectureship Award for significant contributions to the basic science of cerebral palsy and childhood onset disabilities (2012), and was the Mayfield Lecturer (2012). In 2012, Dr. Fehlings served as the 40th President of the Cervical Spine Research Society (CSRS) -- the only Canadian to do so -- and was honoured with the CSRS Presidential Medallion for outstanding leadership and contributions to cervical spine research. In 2013, Dr. Fehlings was honoured with the Queen Elizabeth II Diamond Jubilee Medal presented to him by the Honourable Stephen Harper, the H. Richard Winn Prize from the Society of Neurological Surgeons, the Jonas Salk Award for Scientific Achievements from the March of Dimes Canada and the Henry Farfan Award from the North American Spine Society. In 2014, Dr. Fehlings was elected to the Fellowship of the Royal Society of Canada and to the Canadian Academy of Health Sciences, and in 2016 won the Royal College of Physicians and Surgeons Mentor of the Year Award. In 2019, the Right Honourable Jacinda Ardern, Prime Minister of New Zealand, presented him with the Ryman Prize for his work enhancing the quality of life for older people. He also received the Vilhelm Magnus Medal (2019) for his contributions to the neurosurgery field and the American Spinal Injury Association Apple Award (2016 & 2022) for excellence in spinal cord injury research publishing.

Dr. Albert Yee is the Holland Bone and Joint Program Chief and the Head of the Division of Orthopaedic Surgery at Sunnybrook Health Sciences Centre, where he holds the Marvin Tile Chair in Orthopaedic Surgery. Dr. Yee is an Orthopaedic Spine Surgeon at Sunnybrook Health Sciences Centre, an Associate Scientist (Physical Sciences Platform) at Sunnybrook Research Institute and a Consultant in Surgical Oncology, Bone Metastasis Clinic, Odette Cancer Centre. He is a Full Professor at the University of Toronto in the Institute of Medical Sciences with a cross appointment in the Institute of Biomaterials and Biomedical Engineering. He is the Vice Chair of Research in the Division of Orthopaedic Surgery and Co-Director of the University of Toronto's Department of Surgery Spine Program. Dr. Yee is the Past President of the Canadian Orthopaedic Research Society, President of the Canadian Spine Society and Co-Chair of Bone & Joint Canada. He is the Canadian Lead for the Young Investigators Initiative (YII) of Bone & Joint Canada, and the US Bone & Joint Initiative, a grant mentorship and career development program. Dr. Yee has over

100 peer reviewed publications and has received academic honours including the American British Canadian (ABC) International Travelling Fellowship (American Orthopaedic Association / Canadian Orthopaedic Association, 2013), the Charles H. Tator Surgeon-Scientist Mentoring Award (2012), and the Canadian Orthopaedic Foundation J. Edouard Samson Award (2011). Dr. Yee's laboratory focuses on translational orthopaedic research utilizing pre-clinical surgical models to evaluate novel minimally invasive vertebral metastatic therapies (e.g. Photodynamic Therapy, Radiofrequency Ablation). His work has led to first in human clinical trials and FDA approval with commercialization of new minimally invasive spine technology. He has interest in understanding mechanisms of disease in cancer invasiveness to bone with an aim towards identifying potential new promising therapeutic targets.

Presenters

Fellow Lead: Dr. Ahmed Cherry is currently enrolled at the Toronto Western Hospital Spine Fellowship program after previously completing his Orthopaedic surgery residency at the University of Toronto. He was born in Los Angeles, California; and was raised both there and in Beirut, Lebanon. Upon arrival to Canada, Ahmed completed an undergraduate and Master's degree in Biochemistry at the University of Windsor. He subsequently attended medical school at the University of Toronto, Mississauga Academy of Medicine. His clinical focus is aimed towards degenerative spine disease and minimally invasive procedures with a personal interest in resident education.

Fellow Co-Lead: Dr Rajesh Kumar graduated as best Neurosurgery resident from the Aga Khan University Hospital, Karachi ,Pakistan. He worked as a staff physician for more than four years in Dubai, UAE and was Involved in dealing with degenerative spine and Neurotrauuma. Rajesh has Adjunct Professor appointment in Surgery at Dubai Medical College since 2018. He is currently enrolled in spine fellowship training at Sunnybrook Health Science Centre with focus on spine trauma and degenerative spine.

Dr Raj Sakhrekar (Spine Surgery Fellow at Sick Kids hospital) was born and raised in India where he completed his medical studies in Mumbai and his orthopaedic residency at Sancheti Institute of Orthopaedic and Rehabilitation, Pune- developing particular interest in spine surgery. After completing spine fellowship with Dr Ketan Khurjekar, Dr Shailesh Hadgaonkar and Dr Ajay Kothari in Sancheti Institute of Orthopaedic and Rehabilitation, he was trained in Minimally Invasive Spine Surgery and 3D CT navigation at Kokilaben Dhirubhai Ambani Hospital, Mumbai with Dr Vishal Peshattiwar. He was trained Complex deformity corrections and reconstruction with Prof. Henry Halm, Prof Marqus Quanta, Dr Ferdinand Pecsi and Dr Mark Kozgavery at Schoen klinik Neustadt Holestine in Germany. He has keen interest in research and has published and presented his research work at various international conferences and peer reviewed journals. His areas of interest are pediatric spine deformity, Minimally Invasive Spine Surgery and spinal cord injury.

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Articles

Original Article

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The Importance of Determining Trainee Perspectives on Procedural Competencies During Spine Surgery Clinical Fellowship

Antony H. Bateman, MSc, FRCS(Orth)[1,2], Jeremie Larouche, MD, FRCSC[1], Christina L. Goldstein, MD, FRCSC[3], Daniel M. Sciubba, MD[4], Theodore J. Choma, MD[3], Brandon Lawrence, MD[5], Joseph Cheng, MD[6], Michael G. Fehlings, MD, PhD, FRCSC[7], Scott J. Paquette, MD, MSc, FRCSC[8], and Albert J. M. Yee, MD, MSc, FRCSC[1,7]

Abstract

Study Design: Longitudinal survey.

Objective: It remains important to align competence-based objectives for training as deemed important by clinical fellows to those of their fellowship supervisors and program educators. The primary aim of this study was to determine trainee views on the relative importance of specific procedural training competencies. Secondarily, we aimed to evaluate self-perceived confidence in procedural performance at the commencement and completion of fellowship.

Methods: Questionnaires were administered to 68 clinical fellows enrolled in the AOSNA fellowship program during the 2015-2016 academic year. A Likert-type scale was used to quantify trainee perspectives on the relative importance of specific procedural competencies to their training base on an established curriculum including 53 general and 22 focused/advanced procedural competencies. We measured trainee self-perceived confidence in performing procedures at the commencement and completion of their program. Statistical analysis was performed on fellow demographic data and procedural responses.

Results: Our initial survey response rate was 82% (56/68) and 69% (47/68) for the follow-up survey. Although most procedural competencies were regarded of high importance, we did identify several procedures of high importance yet low confidence among fellows (ie, upper cervical, thoracic discectomy surgery), which highlights an educational opportunity. Overall procedural confidence increased from an average Likert score of 4.2 (SD = 1.3) on the initial survey to 5.4 (SD = 0.8) by follow-up survey ($P < .0001$).

Conclusions: Understanding trainee goals for clinical fellowship remains important. Identification of areas of low procedural confidence and high importance to training experience will better guide fellowship programs and supervisors in the strategic delivery of the educational experience.

Keywords

spine surgery, clinical fellowship, competencies, education, curriculum, syllabus, trainee

Introduction

Surgical education continues to evolve with increasing focus on competence-based approaches to training.[1] The establishment of the Accreditation Council for Graduate Medical Education (ACGME) marked the era of external periodic review to ensure educational standards for medical training. Dr Frank Eismont addressed this issue in his Presidential Address to the Cervical Spine Research Society published in 1996,[2] summarizing the progress and called on spinal societies to further direct the content of fellowship programs to ensure

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adequate training for future spine surgeons. Herkowitz et al[3] in 2000 suggested further specific guidelines for spinal training that included both resident- and fellowship-level considerations. Their article highlighted the need for specific objectives and a curriculum at the fellowship level to ensure that the training offered in these programs meet the needs of trainees who eventually enter independent spinal surgical practice. In 2006, Herkowitz et al[4] reported on the American Board of Orthopedic Surgery examination results for trainees completing both ACGME accredited and nonaccredited spine fellowship programs. They showed higher achievement among graduates of accredited programs and concluded that this supported the value of periodic review of programs to ensure maintenance of high-quality education.

In 2017, most spine surgeons in training around the world continue to develop their expertise through either an orthopedic or neurosurgical residency training program. The increasing number and complexity of spinal procedures means that most trainees now seek to undertake at least 1 or 2 years of spine fellowship training. Orthopedic trainees may graduate residency with less confidence in their ability to perform certain spinal procedures than their neurosurgical counterparts,[5] and there is significant variation in case numbers across different residency programs. Neurosurgical residents in the United States complete more spine cases than orthopedic residents, but orthopedic residents are often exposed to a greater numbers of spinal deformity cases.[6] European neurosurgical graduates have been shown to have self-reported incomplete competence managing the spectrum of spinal disorders.[7] Studies across Canada have shown that procedural competency expectations during residency in spine have declined, placing a greater emphasis on quality fellowship-level training.[8] With increasing emphasis being placed on fellowship-level training in spine surgery, there remains a relative paucity of literature available on this subject.[9]

A recent survey of 289 AOSpine Europe members highlighted the differences in self-reported competence between surgeons who had undertaken a year of fellowship training and those who had not. There were significant differences observed between the groups, with no significant differences observed between orthopedic and neurosurgical-trained spine surgeons. This led the authors to conclude that all spine surgeons should consider spine fellowship training and that ideally this should be guided by a formal curriculum.[10]

Against this background the Canadian Spine Society (CSS) developed a syllabus for spinal fellowship training.[11] A consensus-based syllabus of cognitive and procedural competencies were established by a national panel of fellowship educators, program directors, and academic and community surgeons including both orthopedic and neurosurgical representation. A modified-Delphi methodology was used to reach agreement on these competencies. The purpose of this study was primarily to determine the perspectives of the 2015-2016 cohort of clinical AOSpine North America (AOSNA) fellows on the relative importance of each procedure to their goals of training. Secondarily, we also determined trainee self-perceived procedural confidence in performing spinal procedures included in the syllabus at the beginning as well at end of their AOSNA fellowship year.

Table 1. Likert Scales for Importance and Confidence.

Please rank how *important* you consider each skill as a component of fellowship training. Use the following scale:
1. Extremely unimportant
2. Unimportant
3. Somewhat unimportant
4. Neither important nor unimportant
5. Somewhat important
6. Important
7. Extremely important

You will then be asked to rank your current *confidence* with the different procedural skills. Use the following scale:
1. Not at all confident to perform this task
2. Not very confident performing this task
3. Not very confident performing this task independently
4. Confident that I could perform in ideal circumstances
5. Confident that I could perform in good circumstances
6. Confident that I could perform this task in all reasonable circumstances
7. Confident that I could perform this task in all circumstances

Materials and Methods

A questionnaire was developed and ratified by a working group comprising spine surgical and education members of the AOSpine North America Executive, Fellowship Committee, Education Committee, including representatives of the CSS. The survey comprised background demographic details for each fellow and additional questions asking fellows to rank key procedural competencies from the established procedural fellowship syllabus. Fellows involved in pediatric spinal surgery fellowships were presented with additional questions relating to the specific pediatric procedural section of the syllabus. Fellows were asked at the beginning of their AOSNA fellowship to rank their confidence in performing each of the procedures using a 7-point Likert-type scale. They were also asked to rate how important they thought that competency item was to them as a component of their overall goals for fellowship training (Table 1). A repeat questionnaire ranking procedural confidence was administered toward the end of their fellowship year.

This study consisted of 68 eligible fellows enrolled in the AOSpine North America fellowship for 2015-2016. This is a competitive fellowship with currently 26 AOSpine fellowship sites across North America, each program as selected through a peer-review process as assessed against published criteria.[12] The questionnaire (Appendix 1, available in the online version of the journal) was administered using SurveyMonkey and was sent out with a covering message from the AOSpine North America Fellowship Committee in August 2015. The follow-up questionnaire was administered in June 2016. Two weeks after the initial survey request a reminder was issued to fellows who had not yet completed the survey. A final reminder was then issued at 4 weeks. Survey questions included pediatric procedures (for those completing fellowships with exposure to pediatric spinal disorders), general spine procedures, cervical spine procedures, thoracic spine procedures, lumbosacral spine procedures, and oncology and other advanced focused spine procedures. These procedural competencies matched those described by Larouche et al.[11] More broadly, the syllabus contained a list of more general spine procedural competencies (n = 53) as well as more advanced/focused procedural competencies (n = 22).

Results were analyzed and summarized using statistical methods by a biostatistical expert. Analyses were performed using SAS 9.3 (SAS Institute, Cary NC). Based on clinical relevance, importance and confidence scores were dichotomized into high versus low importance (Likert scale 6 or 7 vs 1 through 5) and high versus low confidence (Likert scale 4 through 7 vs 1 through 3; Table 1). Questions with high importance but low confidence were tested for by determining whether low confidence was significantly different from expected by comparing 95% confidence interval of likelihood of low confidence to random chance of 50%.

Differences by specialty (Neurosurgery vs Orthopedic Surgery) were compared for importance and confidence by testing whether the difference of percentage of high importance and high confidence between Neurosurgical versus Orthopedic residency training was significantly different from zero.

The effect of length of spine training during residency on procedural confidence results was also examined by dichotomizing residency spine training time into less than or equal to 6 months and more than 6 months. We then tested confidence scores between the groups using parametric Student's *t* tests. Mean confidence scores for general syllabus procedural questions versus advanced syllabus questions were compared using parametric paired Student's *t* tests, since the same fellow scored both general and advanced questions.

Questions from both the general and advanced syllabi were grouped into dimensions based on region (eg, cervical spine) or disease (eg, oncology). The importance and confidence scores were then compared using the χ^2 test. When 25% of the cells had expected counts of less than 5, the Fisher's exact test was used.

Finally, overall initial confidence was compared with confidence at follow-up using the nonparametric Wilcoxon 2-sample test.

Results

Our initial survey of 68 AOSpine North America fellows for the year of 2015-2016 achieved an 82% response rate (56/68) with 70% completing all required questions. The response rate for the follow-up survey was 69% (47/68). The mean age of the fellows respondents was 32.9 years (range = 28-50). Fifty-two respondents were males and 2 were females. Forty fellows had completed residency in the United States, 4 in Canada, and 12 outside North America. Forty-three (77%) of the fellows came from orthopedic residency programs, and 13 (23%) were from neurosurgical residency programs. Forty-eight (86%) respondents were entering their first year of spine fellowship training, 6 (10%) were starting their second year of fellowship training, and 2 (4%) had already completed at least 2 years. The subspecialty interests are reported in Table 2. Fifty percent of respondents anticipated practice that would involve pediatric spine with 24 (43%) of fellows involved in fellowships focusing on both adult and pediatric spine training. No fellowships were focused solely on pediatric spine and 32 (57%) focused purely on adult spine training. Forty-seven (84%) of fellows reported a significant research focus as part of their fellowship.

Table 2. Subspecialty Interests of the Clinical Fellows.

What Are Your Subspecialty Interests?	Response (%)	Response (n)
Degenerative	82.1	46
Trauma	67.9	38
Neoplastic/metastatic	37.5	21
Adult deformity	71.4	40
Pediatric deformity	28.6	16
None	3.6	2
Other (please specify)		5
Total responses		56

In general, good concordance was noted between syllabus items and fellow's perceived importance with more variable replies in some focused or advanced areas (eg, spinal injections). Procedural confidence had a greater spread over the possible scale. We were able to summarize values for importance and confidence based on our 7-point Likert-type scales. The data for each question is presented in Appendix 2 (available in the online version of the journal). Most items were considered of high importance.

Several procedures were identified as being of high importance (Likert scale 6 or 7) and low confidence (1 through 3) among fellows. These items are presented in Table 3. These skills include pediatric procedures such as fusion for spondylolisthesis, surgical management of congenital anomalies, and traumatic conditions of the pediatric spine. General procedures include upper cervical instrumentation, including sublaminar wiring techniques, odontoid screw fixation, and revision decompression of the cervical spine and thoracic discectomy, were considered important with low experience.

Significant differences were observed in importance responses comparing orthopedic and neurosurgical residency-trained fellows. A higher importance rating among neurosurgical trainees for use of intraoperative navigation systems ($P = .0001$), primary extradural tumor management ($P = .0001$), primary intradural tumor management ($P < .0001$), and management of syringomyelia ($P < .0001$) was observed.

Significant differences in confidence were also identified between orthopedic and neurosurgical residency-trained fellows. These included increased confidence among neurosurgical trainees for multilevel anterior cervical corpectomies ($P < .0001$), revision cervical spine decompression ($P < .0001$), posterior and lateral thoracic spine approaches ($P < .0001$), primary extradural tumor management ($P = .002$), primary intradural tumor management ($P < .0001$), management of syringomyelia ($P < .0001$), and dorsal column stimulator placement ($P = .0001$).

Table 3. List of Procedures With High Importance and Low Confidence.

Procedures with 50% or more rating high importance (6-7) and 50% or more rating low confidence (1-3)
Pediatric syllabus
Q13 2.5.2 Demonstrate proficiency in posterior spinal decompression and fusion in a pediatric patient with spondylolysis/spondylolisthesis.
Q14 2.5.3 Demonstrate proficiency in the surgical management of congenital anomalies and developmental disorders of the spine in a pediatric patient, such as congenital scoliosis, congenital kyphosis, Klippel-Feil syndrome, Scheurmann's disease, neuromuscular scoliosis, and idiopathic scoliosis.
Q19 2.5.8 Demonstrate proficiency in the surgical management of traumatic conditions of the pediatric spine
General syllabus
Q32 2.2.3 Demonstrate the ability to properly place upper cervical sublaminar wires
Q36 2.2.7 Demonstrate the ability to perform upper cervical instrumented stabilization procedures, including the ability to insert C2 pars screws, C1-2 (Magerl) transarticular C1-2 screws, and the Harms/Goel (ie, C1 lateral mass and C2 pars/pedicle screw/rod) technique for the management of upper cervical spine disorders.
Q44 2.2.15 Demonstrate the ability to perform common instrumented techniques for performing C1-2 arthrodesis.
Q46 2.2.17 Demonstrate the ability to perform a cervical odontoid screw fixation.
Q47 2.2.18 Demonstrate proficiency in revision decompression of the cervical spine.
Q52 2.3.4 Demonstrate proficiency in performing a posterolateral thoracic discectomy.
Advanced syllabus
Q83 2.2.3 Demonstrate the ability to perform a cervical extension osteotomy.
Q86 2.4.2 Demonstrate the ability to perform slip or angular reduction for spondylolisthesis and spondyloptosis.
Q87 2.5.1 Demonstrate proficiency in the surgical treatment of primary extradural spinal tumors.

Procedures with 50% or more rating high importance (6-7) and 40% or more rating low confidence (1-3)
Pediatric syllabus
Q18 2.5.7 Demonstrate proficiency in the application of a spinal cast for early onset scoliosis.
Q20 2.5.9 Demonstrate proficiency in the surgical management of infectious conditions of the pediatric spine.
General syllabus
Q34 2.2.3 Demonstrate the ability to implant cervical translaminar screws for cervical stabilization procedures.
Q38 2.2.9 Demonstrate the ability to perform multilevel anterior cervical corpectomies.
Q43 2.2.14 Demonstrate proficiency in performing an occipito-cervical instrumented fusion, including the ability to properly place occipital plates (midline or off midline).
Q48 2.2.19 Demonstrate proficiency in revision instrumented fusion of the cervical spine.
Q49 2.2.19 Demonstrate proficiency in performing posterior/posterolateral transpedicular, costo-transversectomy, and lateral extra-cavitary approaches to the thoracic spine.
Q53 2.3.5 Demonstrate proficiency in performing anterior thoracic discectomy.
Q54 2.3.6 Demonstrate proficiency in performing an anterior thoracic vertebrectomy with reconstruction.
Advanced syllabus
Q91 2.5.5 Demonstrate the ability to perform a XLIF (extreme lateral interbody) and DLIF (direct lateral interbody) in spinal disease.
Q91 2.5.6 Demonstrate proficiency in spinal osteotomies, including Smith-Peterson, pedicle subtraction osteotomies, and vertebral column resection osteotomies.

Low importance responses (Likert scale 1-5) were compared by dimension (question groups) and significant differences were seen comparing orthopedic and neurosurgical trainees in the areas of the thoracic spine ($P = .044$), spine oncology ($P < .001$), and Questions 90 to 97 (Appendix 1, $P = .048$). There was also a significant difference in low importance ratings in spine oncology ($P < .001$) when comparing the number of months of spine training during residency. There were no other significant differences in "low importance" (Table 4).

Greater residency exposure to spine was associated with greater general procedural confidence. Twenty-six fellows had less than or equal to 6 months of residency experience in spine surgery, and 24 fellows had more than 6 months of residency experience in spine surgery. The overall average confidence score for all competency questions (Questions 12 to 97; Appendix 1) was 3.6 ($\pm$1.1) for fellows with up to 6 months of spine training compared with 4.8 ($\pm$1.1) for fellows with more than 6 months of spine training. The difference of overall confidence score was statistically significant with p value = .0002 (Table 5).

Statistically significant differences in "low confidence" responses (Likert ratings 1-3) were observed between neurosurgical and orthopedic trainees in the cervical spine, thoracic spine, and spine oncology dimensions. The number of months spent in spine training during residency also produced significant differences in low confidence ratings across almost all dimensions (Table 5).

The overall self-perceived confidence score increased significantly from an average of 4.2 (SD = 1.3) in the initial survey to 5.4 (SD = 0.8) in the follow-up survey ($P < .0001$).

Discussion

This study was motivated by the desire to improve fellowship education for spinal surgeons and examines spine fellows' perceptions regarding their own procedural competence and the importance of specific procedures. With the development of a fellowship-level syllabus of competency-based objectives for spinal surgeons in training by the CSS,[11] we have now determined the views of fellows on the importance of various elements. We measured their confidence at the commencement of their AOSpine North America fellowship year performing

Table 4. Low Importance Dimensions[a,b].

	Percentage Reporting "Low Importance"		
Dimension (Questions)	Q5: Neurosurgical vs Orthopedic, *P* Value	Q6: ≤6 vs 7-12 vs >12 Months, *P* Value	Q7: Year 1 vs Years ≥2, *P* Value
General skills (21 to 29)	0.0% (0/12) vs 13.5% (5/37), *P* = .315	8.0% (2/25) vs 18.2% (2/11) vs 7.7% (1/13), *P* = .693	11.9% (5/42) vs 0% (0/7), *P* = 1.000
C-Spine (30 to 48)	8.3% (1/12) vs 13.5% (5/37), *P* = 1.000	8.0% (2/25) vs 18.2% (2/11) vs 15.4% (2/13), *P* = .638	14.3% (6/42) vs 0.0% (0/7), *P* = .574
T-Spine (49 to 58)	0.0% (0/11) vs 31.4% (11/35), ***P* = .044**	31.8% (7/22) vs 27.3% (3/11) vs 7.7% (1/13), *P* = .259	27.5% (11/40) vs 0.0% (0/6), *P* = .311
Lumbosacral-Spine (59 to 70)	9.1% (1/11) vs 8.6% (3/35), *P* = 1.000	4.6% (1/22) vs 18.2% (2/11) vs 7.7% (1/13), *P* = .419	10.0% (4/40) vs 0.0% (0/6), *P* = 1.000
Spine oncology (71 to 72)	0.0% (0/11) vs 25.7% (9/35), *P* = .089	18.2% (4/22) vs 27.3% (3/11) vs 15.4% (2/13), *P* = .746	20.0% (8/40) vs 16.7% (1/6), *P* = 1.000
Others (73 to 75)	27.3% (3/11) vs 48.6% (17/35), *P* = .302	54.6% (12/22) vs 36.4% (4/11) vs 30.8% (4/13), *P* = .337	47.5% (19/40) vs 16.7% (1/6), *P* = .212
Focused skills (76 to 80)	81.8% (9/11) vs 82.4% (28/34), *P* = 1.000	80.9% (17/21) vs 81.8% (9/11) vs 84.6% (11/13), *P* = .963	82.1% (32/39) vs 83.3% (5/6), *P* = 1.000
C-Spine (81 to 83)	45.5% (5/11) vs 76.5% (26/34), *P* ≤ .071	76.2% (16/21) vs 72.7% (8/11) vs 53.9% (7/13), *P* = .373	69.2% (27/39) vs 66.7% (4/6), *P* = 1.000
T-Spine (84)	0.0% (0/11) vs 17.7% (6/34), *P* = .311	14.3% (3/21) vs 9.1% (1/11) vs 15.4% (2/13), *P* = .889	15.4% (6/39) vs 0.0% (0/6), *P* = .576
Lumbosacral-Spine (85 to 86)	63.6% (7/11) vs 67.7% (23/34), *P* = 1.000	66.7% (14/21) vs 63.6% (7/11) vs 69.2% (9/13), *P* = .959	66.7% (26/39) vs 66.7% (4/6), *P* = 1.000
Spine oncology (87 to 89)	0.00% (0/11) vs 79.4% (27/34), ***P* < .001**	85.7% (18/21) vs 63.6% (7/11) vs 15.4% (2/13), ***P* < .001**	58.9% (23/39) vs 66.7% (4/6), *P* = 1.000
Others (90 to 97)	54.6% (6/11) vs 85.3% (29/34), ***P* = .048**	85.7% (18/21) vs 81.8% (9/11) vs 61.5% (8/13), *P* = .240	76.9% (30/39) vs 83.3% (5/6), *P* = 1.000

[a]"Low Importance" = importance score ranges from 1 to 5.
Q5 = What residency program have you completed?
Q6 = How many months of spine training did you undertake during residency?
Q7 = In what year of spinal fellowship training are you?
[b]Statistical significance is based on 2-sided test with *P* value ≤.05, which is in boldface. When χ^2 test may not be a valid test with 25% of the cells having expected counts less than 5, Fisher's exact test is used.

various procedures. This study identified gaps in confidence among both neurosurgical and orthopedic residency-trained surgeons as they began their fellowship year but did support an overall increase in confidence through fellowship training. These gaps may direct the educational opportunities offered by spine fellowship programs. More important, this study highlighted several key procedural skills that trainees have low confidence in performing but regard as important skills to acquire (Table 3). If these procedures are ones not commonly encountered at a fellowship training site, this list may provide a useful guide for spine fellowship program directors when planning educational opportunities that may include attending Instructional Course Lectures, cadaveric workshops, and other simulation-related courses. Reading programs have also been shown to be beneficial[13] and could potentially be guided by these key items.

This study achieved an acceptable initial and follow-up response rates. We did note that all but 2 of the respondents were male and do recognize the ongoing opportunity to better capture gender considerations specific to training objectives. Both neurosurgical and orthopedic fellows were included in the survey group with the majority (75%) of fellows having completed orthopedic residency training. We also recognize this other potential bias in related data capture and evaluation. Most (80%) of the fellows had completed residency training in North America as part of the AOSNA fellowship opportunity, although 20% were graduates of various international residency programs. This supports the international nature of fellowship training and suggests a role for future international discussions on standards, curricula, and opportunities in spine fellowship education.

The majority (85%) of fellows were starting their first year of spine fellowship training and so the self-reported confidence is likely to represent the level at graduation from residency rather than that of individuals with subspecialty training. This survey also provides us useful insight into the difference in confidence between neurosurgical and orthopedic residency graduates. More than 40% of fellows had exposure to pediatric spinal disorders through their fellowship, giving a meaningful sample group for pediatric procedural competency questions.

As anticipated, enhanced residency exposure to spine training reflected in a greater self-perceived procedural capability at the commencement of fellowship training. This is educationally interesting in that further reviewing spine case numbers for graduating

Table 5. Low Confidence Dimensions[a,b].

	Percentage Reporting "Low Confidence"		
Dimension (Questions)	Q5: Neurosurgical vs Orthopedic, *P* Value	Q6: ≤6 vs 7-12 vs >12 Months, *P* Value	Q7: Year 1 vs Years ≥2, *P* Value
General skills (21 to 29)	8.3% (1/12) vs 5.4% (2/37), *P* = 1.000	12.0% (3/25) vs 0% (0/11) vs 0% (0/13), *P* = .216	7.1% (3/42) vs 0% (0/7), *P* = 1.000
C-Spine (30 to 48)	16.7% (2/12) vs 56.8% (21/37), ***P* = .016**	76.0% (19/25) vs 27.3% (3/11) vs 7.7% (1/13), ***P* < .001**	50.0% (21/42) vs 28.6% (2/7), *P* = .293
T-Spine (49 to 58)	9.1% (1/11) vs 60.0% (21/35), ***P* = .003**	72.7% (16/22) vs 36.4% (4/11) vs 15.4% (2/13), ***P* = .003**	50.0% (20/40) vs 33.3% (2/6), *P* = .667
Lumbosacral-Spine (59 to 70)	9.1% (1/11) vs 37.1% (13/35), *P* = .133	50.0% (11/22) vs 18.2% (2/11) vs 7.7% (1/13), ***P* = .019**	32.5% (13/40) vs 16.7% (1/6), *P* = .651
Spine oncology (71 to 72)	9.1% (1/11) vs 54.3% (19/35), ***P* = .013**	63.6% (14/22) vs 36.4% (4/11) vs 15.4% (2/13), ***P* = .018**	47.5% (19/40) vs 16.7% (1/6), *P* = .212
Others (73 to 75)	9.1% (1/11) vs 31.4% (11/35), *P* = .242	36.4% (8/22) vs 18.2% (2/11) vs 15.4% (2/13), *P* = .311	27.5% (11/40) vs 16.7% (1/6), *P* = 1.000
Focused skills (76 to 80)	63.6% (7/11) vs 76.5% (26/34), *P* = .448	90.5% (19/21) vs 54.6% (6/11) vs 61.5% (8/13), ***P* = .048**	69.2% (27/39) vs 100.0% (6/6), *P* = .171
C-Spine (81 to 83)	27.3% (3/11) vs 85.3% (29/34), ***P* < .001**	90.5% (19/21) vs 72.7% (8/11) vs 38.5% (5/13), ***P* = .005**	69.2% (27/39) vs 83.3% (5/6), *P* = .656
T-Spine (84)	9.1% (1/11) vs 47.1% (16/34), ***P* = .033**	61.9% (13/21) vs 27.3% (3/11) vs 7.7% (1/13), ***P* = .005**	38.5% (15/39) vs 33.3% (2/6), *P* = 1.000
Lumbosacral-Spine (85 to 86)	27.3% (3/11) vs 76.5% (26/34), ***P* = .009**	80.9% (17/21) vs 63.6% (7/11) vs 38.5% (5/13), ***P* = .042**	64.1% (25/39) vs 66.7% (4/6), *P* = 1.000
Spine oncology (87 to 89)	18.2% (2/11) vs 88.2% (30/34), ***P* < .001**	90.5% (19/21) vs 72.7% (8/11) vs 38.5% (5/13), ***P* = .005**	66.7% (26/39) vs 100.0% (6/6), *P* = .160
Others (90 to 97)	18.2% (2/11) vs 91.2% (31/34), ***P* < .001**	95.2% (20/21) vs 81.8% (9/11) vs 30.8% (4/13), ***P* < .001**	69.2% (27/39) vs 100.0% (6/6), *P* = .171

[a]"Low Confidence" = confidence score ranges from 1 to 3.
Q5 = What residency program have you completed?
Q6 = How many months of spine training did you undertake during residency?
Q7 = In what year of spinal fellowship training are you?
[b]Statistical significance is based on 2-sided test with $P \leq .05$, which is in boldface. When χ^2 test may not be a valid test with 25% of the cells having expected counts less than 5, Fisher's exact test is used.

residents[6] may further explain some of the differences observed in studies comparing neurosurgical and orthopedic resident confidence with spinal procedures.[5] Despite higher caseloads, a recent survey of members of the American Association of Neurological Surgeons demonstrated learning needs around adult spinal deformity even among some practicing surgeons.[14] What remains somewhat less clear in the spine field is the number of surgical cases required to be "competent, "versus that required to be "proficient," or to be considered an "expert." Many residency programs focus on basic competency at the end of training. Proficiency and expertise clearly also needs to be considered during fellowship and transition into independent surgical practice. This motivates ongoing research relating to this learning curve.

Limitations of this study include a relatively small sample group although a good response rate with longitudinal follow-up makes the results more meaningful. In this study, we utilized established fellowship procedural competencies from a Canadian (CSS) developed syllabus, and recognized that there is some variation in clinical practice and fellowship training between different countries regionally, nationally, and internationally. In the CSS syllabus development, materials were derived an environmental scan from a number of international sources, including fellowship-level educational materials from AOSpine International. Finally, self-perceived confidence in the performance of procedures as determined by trainees may potentially differ from independently measured procedural performance. Understanding trainee goals for clinical fellowship education remains important. Identification of areas of low procedural confidence and high importance to training experience will better guide fellowship programs and supervisors in the strategic delivery of the educational experience. Residency exposure to spine surgery appears to enhance self-perceived procedural competence at the commencement of fellowship and there does appear to be some differences comparing background residency specialty training, which needs to be considered in the ongoing learning needs of clinical fellows.

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Supplemental Material

The supplemental material is available in the online version of the article.

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Review Article

Five major controversial issues about fusion level selection in corrective surgery for adolescent idiopathic scoliosis: a narrative review

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Abstract

BACKGROUND CONTEXT: Shoulder imbalance, coronal decompensation, and adding-on phenomenon following corrective surgery in patients with adolescent idiopathic scoliosis are known to be related to the fusion level selected. Although many studies have assessed the appropriate selection of the proximal and distal fusion level, no definite conclusions have been drawn thus far.

PURPOSE: We aimed to assess the problems with fusion level selection for corrective surgery in patients with adolescent idiopathic scoliosis, and to enhance understanding about these problems.

STUDY DESIGN: This study is a narrative review.

METHODS: We conducted a literature search of fusion level selection in corrective surgery for adolescent idiopathic scoliosis. Accordingly, we selected and reviewed five debatable topics related to fusion level selection: (1) selective thoracic fusion; (2) selective thoracolumbar-lumbar (TL-L) fusion; (3) adding-on phenomenon; (4) distal fusion level selection for major TL-L curves; and (5) proximal fusion level selection and shoulder imbalance.

RESULTS: Selective fusion can be chosen in specific curve types, although there is a risk of coronal decompensation or adding-on phenomenon. Generally, wider indications for selective fusions are usually associated with more frequent complications. Despite the determination of several indications for selective fusion to avoid such complications, no clear guidelines have been established. Although authors have suggested various criteria to prevent the adding-on phenomenon, no consensus has been reached on the appropriate selection of lower instrumented vertebra. The fusion level selection for major TL-L curves primarily focuses on whether distal fusion can terminate at L3, a topic that remains unclear. Furthermore, because of the presence of several related factors and complications, proximal level selection and shoulder imbalance has been constantly debated and remains controversial from its etiology to its prevention.

CONCLUSIONS: Although several difficult problems in the diagnosis and treatment of adolescent idiopathic scoliosis have been resolved by understanding its mechanism and via technical advancement, no definite guideline for fusion level selection has been established. A review of five major controversial issues about fusion level selection could provide better understanding of adolescent idiopathic scoliosis. We believe that a thorough validation study of the abovementioned controversial issues can help address them.

Keywords: Adding-on; Adolescent idiopathic scoliosis; Coronal decompensation; Fusion level; Shoulder imbalance; Surgical treatment

Introduction

Two major advances in the management of idiopathic scoliosis over the past 30 years include the development of modern instrumentation techniques and the enhanced understanding of the nature of curvature. After several trials and errors, strong and secure instrumentation systems have been developed, which have led to marked improvements in postoperative

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patient care and in the amount of correction. However, adverse effects of modern instrumentation, such as coronal decompensation [1,2] or adding-on phenomenon [3], have also been observed. These unexpected complications primarily result from the incorrect determination of the fusion level.

To standardize the fusion level, several curve classification systems have been proposed by previous reports. The two most widely used classifications are those by King et al. and Lenke et al. [4,5]. Although the King classification is easy to use, it considers only the thoracic curve and coronal plane deformity. In contrast, the Lenke classification includes the lumbar curve and sagittal plane profile, and exhibits good interobserver and intraobserver reliability; however, the limitations include its complexity and the lack of consideration of rotational deformity [6].

With the advent of modern instrumentation systems involving segmental pedicle screw insertion, the fusion level to be selected now differs from that used in the traditional Harrington era. Nevertheless, the principles of fusion established by Moe remain valid [7]. A maximal amount of curve correction should be achieved to obtain a stable and balanced spine. Similarly, efforts should be made to save mobile segments, particularly in the lumbar spine. The prevention of postoperative shoulder imbalance is another controversial issue. In fact, there are many debatable issues related to fusion level selection. Among these, we selected five major issues and have reviewed the problems with appropriate examples and literature.

Selective thoracic fusion

Selective thoracic fusion (STF) remains the most debatable issue during the selection of fusion level. The STF concept was introduced for the correction of main thoracic (MT) curves and minor lumbar curves, including King type 2 or Lenke type 1B, 1C, or 3B (Fig. 1) [8,9].

In thoracic and lumbar double curves, the level of correction and fusion could involve either both the curves or only the thoracic curve. If both curves are included for fusion, a larger amount of correction is achieved, without any risk of persistence or progression of the lumbar curve. However, the inclusion of both curves also diminishes the number of mobile segments, which can become a large burden for patients in the long term. Selective thoracic fusion ensures the correction and fusion of only the thoracic curve, and hence, a greater number of mobile lumbar segments can be saved with a shorter incision. However, there is also a risk of decompensation, which can lead to persistence of the lumbar curve and consequently to deviation of the trunk. The fusion of both curves (or nonselective fusion) and STF can be divided by the distal level of the fusion for convenience: STF for L1 or above, and nonselective fusion for L2 or below.

Selective thoracic fusion is defined as the fusion of the major thoracic curve, where the minor lumbar curve is left unfused. By definition, a minor curve must have completely deviated from the midline (central sacral vertical line [CSVL]),

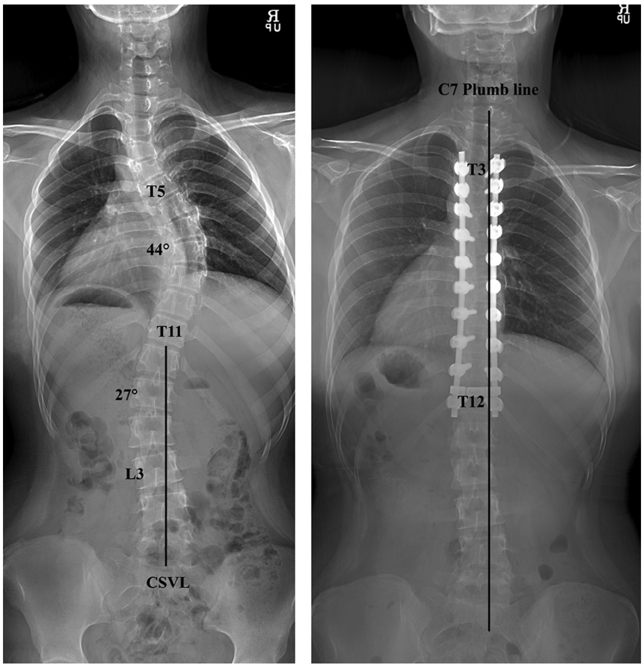

Fig. 1. Selective thoracic fusion (STF) in a 15-year-old female patient with AIS. (Left) A whole-spine anteriopposterior radiograph showed a Lenke type 1B curve. (Right) Coronal balance was well maintained following STF at 4 years postoperatively.

which suggests that STF is indicated only for King type 2 or Lenke type 1B or 1C [8]. In certain articles, STF was more broadly applied for most curve types; however, it should be confined to King type 2 [10]. It was reported that spontaneous lumbar curve correction can be achieved via STF in carefully selected cases [11]. Moreover, spinal balance and correction of the lumbar curve remained stable for 20 years following STF in Lenke 1B, 1C, or 3C curves [12]. A retrospective review showed that a 36% thoracic correction was closely matched by a 34% lumbar correction at the latest follow-up, whereas preoperative coronal imbalance was a risk factor for postoperative coronal imbalance (p=.04) in lumbar "C" modifier curves [13]. Thus, the outcomes of STF have been described in many studies (Table 1) [9,12,14–19].

However, the use of STF in double curves with thoracic and lumbar curves could lead to postoperative coronal decompensation, which is a frequently observed complication. The two most plausible causes of decompensation, excluding technical problems, are overcorrection of the thoracic curve and incorrect identification of the lumbar curve.

Overcorrection of the thoracic curve in STF

With the advent of modern strong instrumentation devices, it has become easy to correct spinal deformity, particularly in adolescent cases with flexible spines. However, if the degree of correction in the thoracic curve is excessive, it cannot be matched by the lumbar spine, which then results in decompensation [20,21]. Therefore, it is strongly recommended to not overcorrect the thoracic curve, and ensure that the lumbar

Table 1
Outcomes of selective thoracic fusion in patients with AIS

Authors	No. of patients	Curve type	Follow-up (y)	Conclusions
Dobbs et al. [14]	66	Lumbar modifier C	Min. 2	STF with pedicle screws (n=32) allowed for better thoracic correction and less postoperative decompensation as compared with hooks (n=34).
Takahashi et al. [15]	172	Lenke type 1B, 1C, 3C	2	The greatest correction of the main thoracic and compensatory lumbar curves was achieved when the LIV was at least one level below the EV, without any increased risk of truncal imbalance.
Ishikawa et al. [16]	24	Lenke type 1C, 2C	—	The final Cobb angle of the lumbar curve was correlated with the immediate postoperative Cobb angle of the thoracic curve and tilt of the LIV. A more distal fixation to the SV resulted in the shifting of coronal balance to the left side.
Demura et al. [17]	71	Lenke type 1C	2	Patients with Lenke 1C tended to be decompensated to the left preoperatively. After STF, the majority (57%) continued to have coronal imbalance.
Wang et al. [18]	44	Lenke type 1C	2	A postoperative trunk shift occurred less frequently when the LEV was selected as the LIV and the ratio of MT to TL-L was ≥1.2.
Larson et al. [12]	28	Lenke type 1B, 1C, 3C	20	Spinal balance and correction of the lumbar curve remained stable during the 20-year follow-up after STF.
McCance et al. [19]	67	King II	2	Frontal plane balance analysis showed that 47 of the 67 patients had the T1 plumb line located within <2 cm of the midline.
Newton et al. [9]	203	Lenke type 1B, 1C (King II)	—	The rate of STF was 92% for the 1B type, as compared with 68% for the 1C type.

Min., minimum; STF, selective thoracic fusion; LIV, lowest instrumented vertebra; SV, stable vertebra; LEV, lower end vertebra; MT, mid-thoracic; TL-L, thoracolumbar-lumbar.

spine can match the amount of correction of the thoracic curve. The precise correction of the lumbar curve can reportedly be predicted by a push-prone side-bending radiograph [22]; the authors proposed that the lumbar curve can be corrected to the predicted amount by using this technique. Some other authors also suggested that the supine and post-anesthesia radiographs were helpful for predicting the degree of correction [23]. Based on that study, the end vertebra (EV) and neutral vertebra (NV) tend to vary in terms of position and anesthesia, which may result in confusion during fusion level selection. Hence, the careful selection of fusion level by using various useful tools should be considered when planning STF.

Inadequate identification of the lumbar curve

If STF is attempted for large and stiff lumbar curves, decompensation is inevitable. It is believed that STF should be avoided in cases of lumbar curves with an angle of >40°–45°. Some authors have proposed certain criteria for STF. In particular, it was proposed that King type 2 should be subclassified as 2A and 2B, based on the magnitude of the lumbar curves. These classes correspond to lumbar modifier B and C in the Lenke classification [24]. It was recommended that STF should be considered only for type 2A. Some authors previously analyzed the frequency of STF in Lenke 1B and 1C curves [9]. The overall rate of STF was 83%, and the rate was 92% in 1B and 68% in 1C. Lenke et al. carefully extended the indication of STF for 2C or 3C curves as well [8]. However, it should be noted that the risk of decompensation may be increased if this technique is used.

In summary, STF can be attempted for thoracic major and lumbar minor double curves (King type 2 or Lenke classification 1B or 1C) while preserving the mobile segments in the lumbar spine. However, the risk of decompensation should be carefully considered. To avoid decompensation, overcorrection of the thoracic curve, either by excessive derotation or by distraction-compression maneuvers, should be avoided. Furthermore, the careful assessment of curve character is important for determining the indications for STF. Selective thoracic fusion is usually indicated for King type 2 or Lenke classification 1B or 1C. However, it could be extended carefully to large lumbar curves (3B or 3C), although the risk of decompensation also increases.

Selective thoracolumbar or lumbar fusion

Correction and fusion can be limited to the thoracolumbar or lumbar (TL-L) curves in Lenke 5C or 6C curves. In fact, a satisfactory result was predicted in cases with a TL-L-to-T Cobb ratio of ≥1.25, in cases where the thoracic curve was bent to ≤20°, or in cases with closure of triradiate cartilages [25]. This suggests that selective thoracolumbar or lumbar fusion should be applied only when the thoracic curve is flexible and the patient is close to the end of maturity. Otherwise, the thoracic curve would persist and progress, and cause adverse effects on the adjacent inferior segment of the lowest instrumented vertebra (LIV) (Fig. 2). However, earlier studies have shown that higher flexibility and better immediate spontaneous correction did not ensure better results. In contrast, cases with more flexible thoracic curves were likely to progress during follow-up [26]. Despite this controversial issue, several authors have proposed the effectiveness of selective TL-L fusion for cases of adolescent idiopathic scoliosis (AIS) with Lenke 5C curves (Table 2) [26–29]. In a previous report, maximal correction instead of undercorrection was suggested, as it did not influence coronal imbalance [29].

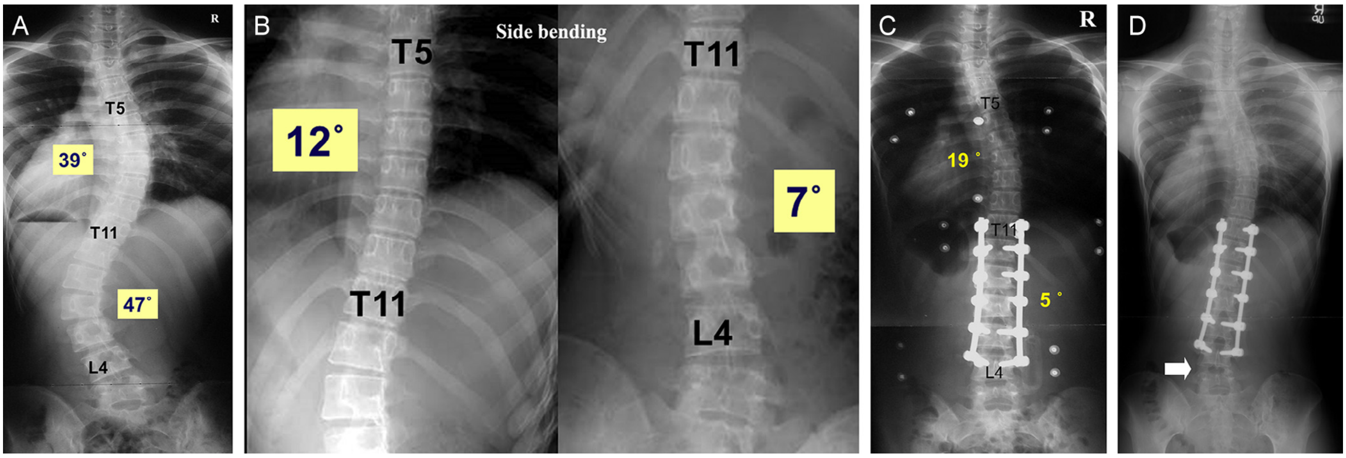

Fig. 2. Selective thoracolumbar fusion in a 16-year-old female patient with AIS. (A) A whole-spine anterioposterior radiograph showed double thoracic and TL-L curves. (B) The thoracic curve was found to be flexible on a bending radiograph. (C) A well-balanced spine was noted in the coronal plane in the immediate postoperative period following selective thoracolumbar fusion (T11–L4). (D) However, asymmetrical disc wedging was also observed just inferior to the lowest instrumented vertebra at 1.5 years postoperatively (arrow).

In fact, none of the published studies have suggested undercorrection of TL-L curves for the maintenance of coronal balance.

The differences in the outcome based on the surgical approach are an interesting topic for selective TL-L fusion. Selective thoracolumbar or lumbar fusion can be performed by the anterior approach [25]. Dong et al. showed that the spontaneous correction of the unfused thoracic curve was comparable between anterior and posterior selective fusion during 4 years postoperatively [30]. However, it was reported that greater correction of the TL curve could be achieved via an anterior approach, when controlling for the distal fusion level [31]. In contrast, better clinical and radiological outcomes were obtained when treatment was performed with pedicle screw instrumented fusion via posterior release, as compared with anterior fusion [32]. A recent meta-analysis of seven case-control studies revealed that both approaches yielded comparable coronal correction. In particular, one more fusion segment could be saved by the anterior approach, whereas a larger lumbar lordosis could be obtained by the posterior approach [33]. Thus, no definite conclusion has been drawn regarding the better surgical approach in the treatment of Lenke 5C curves, although there has been a trend for posterior-only surgery following the advent of instrumentation.

In summary, if thoracic rigidity is suspected on bending radiographs in Lenke 5C curves, it may be better to extend the fusion into the thoracic curve. The effectiveness and safety of selective TL-L fusion has been described by many authors thus far. However, the criteria for undergoing selective TL-L fusion, as well as the appropriate approach, remain unclear.

How to prevent adding-on phenomenon?

Although correction appears to be easy in single thoracic curves (King type 3 or Lenke type 1A) and double thoracic curves (King type 4 or Lenke type 2A), there is a major complication: the "adding-on phenomenon" [3]. This is characterized by a progressive loss of correction by either vertebral deviation of the lumbar spine or disc angulation below the LIV. The manner in which adding-on phenomenon develops has been illustrated in Fig. 3. If unsatisfactory outcomes are derived as a result of the adding-on phenomenon, revision surgery is required to obtain a balanced spine. This complication has been considered to be very important, par-

Table 2
Outcomes of selective lumbar fusion in patients with AIS

Authors	No. of patients	Curve type	Follow-up (y)	Conclusions
Ilgenfritz et al. [27]	21	Lenke type 5C	5	The uninstrumented thoracic curves were corrected by a mean of 30% at 5 years. The curves do not seem to progress between 1 and 5 years postoperatively.
Senkoylu et al. [28]	28	Lenke type 5C	2	Selective anterior fusion of the TL-L curves was an effective method. The minor thoracic curves did not progress over a minimum of 2 years' follow-up.
Wang et al. [29]	34	Lenke type 5C	2	Spontaneous correction of the thoracic curve is a reflection of the TL-L curve correction, and supine side-bending radiographs can be used to predict the spontaneous correction of thoracic curves.
Zhang et al. [26]	45	Lenke type 5C	3	Maximal correction was recommended for moderate Lenke 5C curves. It allows for spontaneous thoracic correction and maintains coronal balance.

E.V. → Most tilted vertebra
N.V. → Vert. c̄ neutral rotⁿ
S.V. → Most prox. vert. distal to EV that is nearly bisected by CSVL

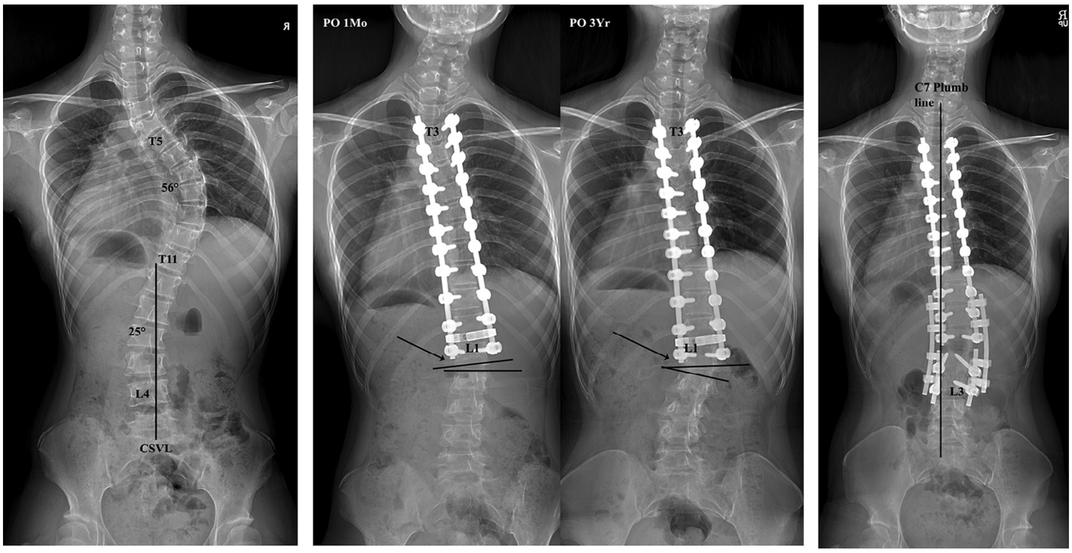

Fig. 3. Distal adding-on phenomenon. (Left) A 13-year-old female patient with a Lenke type 1B curve; (Middle) "adding-on" was observed postoperatively. (Right) Revision corrective surgery was performed after 5 years postoperatively, and a well-balanced shoulder was observed thereafter.

ticularly after the advent of powerful instruments such as pedicle screws. In fact, the distal fusion level (or LIV) is considered to be an important factor in the development of the adding-on phenomenon [3]. The incidence of adding-on increased when the preoperative LIV+1 deviation from CSVL >10 mm.

Suk et al. identified three distinctive index vertebrae at the distal end of the single thoracic curve: EV, NV, and stable vertebra (SV), from the proximal to the distal end. The EV is defined as the most tilted vertebra at the distal end of the structural curve. The NV is defined as the vertebra with apparently neutral rotation confirmed by radiographic pedicle symmetry at the distal structural curve. The SV is the most proximal vertebra distal to the EV of the distal structural curve that is most nearly bisected by the CSVL. An average of 2.2 vertebral body (VB) differences was found between EV and NV, whereas an average of 1.1 VB differences was noted between NV and SV [34]. In single thoracic curves, when preoperative NV and EV show ≤2-level gap differences, the curve should be fused down to the NV. However, when the gap spans >2 levels, then fusion down to NV-1 is satisfactory, and one or two motion segments can be saved. However, fusion down to NV-2 or 3 exhibits unsatisfactory results and can lead to the adding-on phenomenon [34]. The cases to enhance understanding are presented in Fig. 4. In another study, the direction of rotation was considered an important parameter. If the rotation of the first vertebra just below the EV is in the same direction as the thoracic curve, and if the SV and EV show >2 level differences, then distal fusion to L2 or L3 is recommended. However, if the rotation of the first vertebra just below the EV is in the opposite direction, and if SV and EV show ≤2 level differences, then the LIV can be selected as SV-2 or SV-3 [35].

To prevent the adding-on phenomenon, effective methods to choose the distal fusion level have been suggested. In one prospective study, ≥1 motion segment could be saved in 86.9% of patients by using side-bending radiographs [36]. In another study, the selection of LIV by analyzing the coronal and sagittal range of motion helped prevent the development of the adding-on phenomenon [37]. The adding-on index (DnfS; number of vertebra from the first non-fused vertebra to the L5 vertebra) and the postoperative lumbar curves were proposed for predicting the adding-on phenomenon in Lenke type 1 and 2 AIS [38]. The early detection of the adding-on phenomenon has also been proposed. It was suggested that distal adding-on could be detected based on an LIV-CSVL of >10 mm during the postoperative period [39]. In fact, previous studies attempted to classify Lenke 1A curves into 1A-L (left) and 1A-R (right) based on the direction of the L4 tilt, and this classification was helpful in preventing the adding-on phenomenon postoperatively [40,41]. In 1A-R curves, it is recommended to extend the distal fusion to NV-1, SV-1, or SV-2. However, in 1A-L curves, younger age and skeletal immaturity are related to the adding-on phenomenon [41]. Another study indicated that the selection of the last touched vertebra as the LIV in Lenke 1 or 2 curves with A-R lumbar modifier could decrease the risk of the distal adding-on phenomenon [42].

In summary, various methods to select the distal fusion level in Lenke 1 or 2 curves to prevent the adding-on phenomenon have been proposed. However, no definitive conclusion has been drawn regarding the selection of LIV to prevent the adding-on phenomenon in Lenke 1A curves. Further comparative study on various criteria is required to elucidate this problem.

Distal fusion level selection in major lumbar-thoracolumbar curves, L3 or L4?

In large lumbar curves and thoracic curves such as King type 1 or Lenke type 3C, 4C, 5C, or 6C, the selection of the distal fusion level is a debatable issue. The pain intensity is

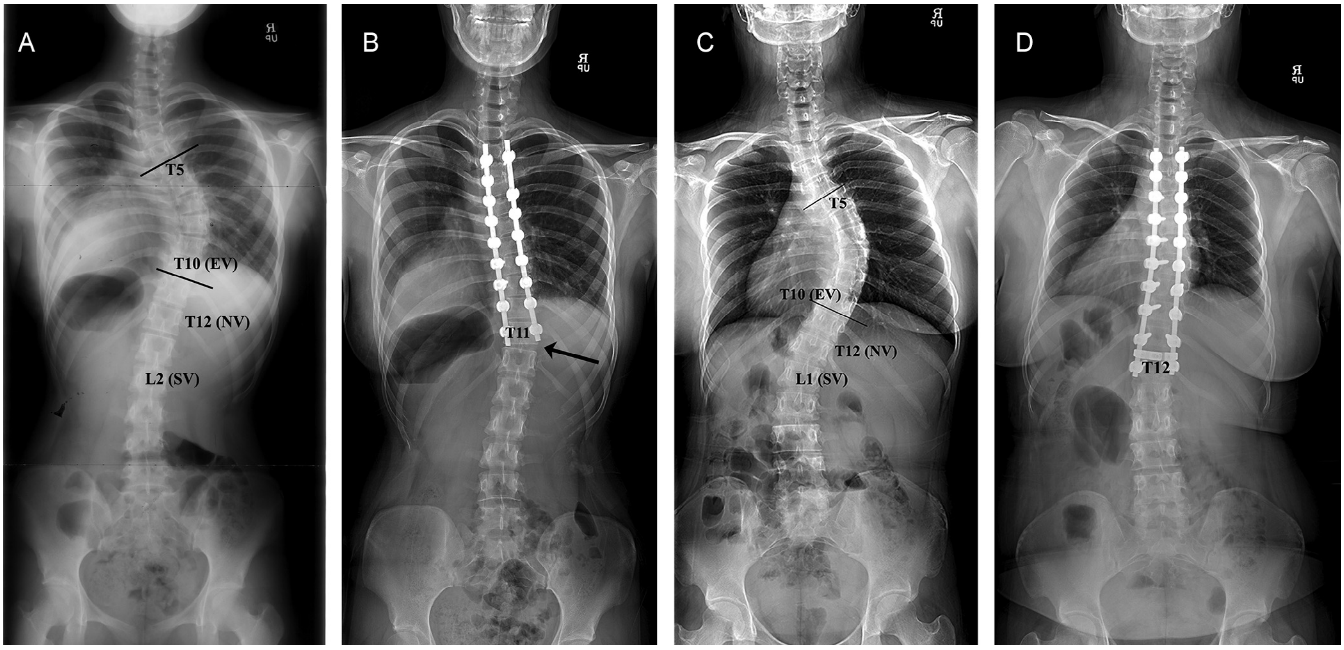

Fig. 4. Two cases illustrating distal fusion level selection in selective thoracic fusion. (A) 14-year-old female patient with a Lenke type 1A curve. (B) Adding-on phenomenon (arrow) observed at postoperative 1 month after distal fusion stopped at NV-1 (T11). (C) 15-year-old female patient with a Lenke type 1B curve. (D) A well-balanced spine was observed after distal fusion stopped at NV (T12).

reportedly increased in patients with fusion to L4 as compared with those with fusion to L2 or L3 [43]. However, no clinical difference was observed according to the distal fusion level (L3 vs. L4) in another study [44]. As intradiscal pressure increases in the disc subjacent to the LIV [45], the preservation of one more distal mobile segment in the lumbar curve may be vital for achieving a better long-term prognosis. Hence, if distal fusion can be terminated at L3, more favorable long-term outcomes can be expected. In major TL-L curves, it had been considered that fusion should be extended to L4 in the era of Harrington instrumentation. However, the termination of distal fusion at L3 instead of L4 has been recently proposed. In 1993, Lenke et al. proposed the criteria for the termination of distal fusion at L3, as follows: (1) less than Grade I rotation of L3; (2) tilt of L3<30° and tilt of L4<20°; (3) L4 VB was bisected by the CSVL; (4) apical disc should be located above L1–L2; (5) the direction of opening at the L3–L4 level should be parallel to or opposite the L4–L5 disc level; and (6) the location of L3 should be centered by bending [46]. However, these criteria were limited because of their complexity, and hence, their application was not practical. Kim et al. proposed simpler criteria for the selection of the distal fusion level. If the degree of L3 rotation was less than Nash-Moe Grade II and of L3 was the SV on bending radiographs, then the distal fusion level could be L3 [47] (Fig. 5). These authors also showed LIV would be selected at L3 when the curve is flexible, which meant that L3 crossed the CSVL with a rotation of less than Grade 2 by bending radiographs in the subsequent study [48]. Moreover, the last touching vertebra was found to be important for predicting suboptimal correction and possible progression of adjacent disc wedging [49]. However, definite guidelines for the selection of LIV have not been defined. Studies on the selection of the distal level in major TL-L curves are summarized in Table 3 [44,47–51].

An important finding in cases where L3 is selected as the LIV in major TL-L curves is the occurrence of disc wedging just inferior to the LIV, which can be judged as the adding-on phenomenon (Fig. 6). However, no long-term results of subjacent disc wedging have been proposed thus far.

Several important factors have been suggested to determine the distal fusion level. One report states that the L4 could be saved by traction X-ray under general anesthesia [52]. Sacral slanting and lumbosacral transitional vertebra are other factors to be considered during distal fusion level selection [53,54]. The incidence of sacral slanting and lumbosacral transitional vertebra was not negligible. If those findings were evident, it was recommended by these authors to stop distal fusion at L3 [53,54].

In summary, the selection of the LIV in major TL-L curves has been debatable, and many factors have been proposed. The clinical advantage of stopping fusion at L3 also remains unclear, although it may be important to save mobile lumbar segments. Radiologically, subjacent disc wedging can be a problem in the long term. Nevertheless, further comparative and long-term follow-up studies are required to clarify this controversial issue.

Proximal fusion level selection and shoulder imbalance

If the proximal thoracic curve (PT curve) is structural (King type 5 or Lenke type 2 or 4), two major issues need to be

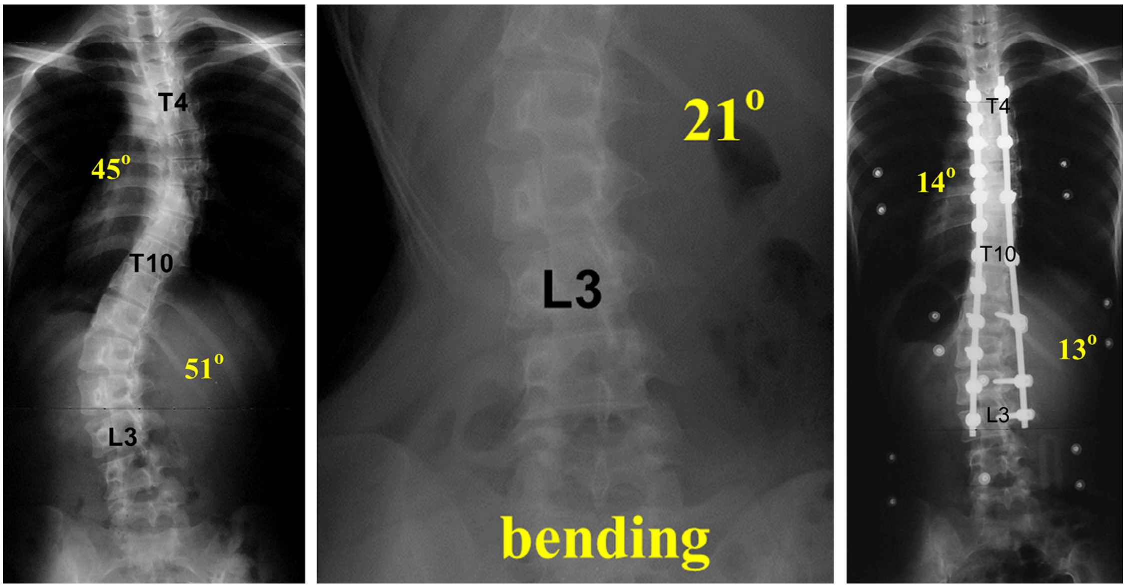

Fig. 5. An example of distal fusion terminated at L3. (Left) The degree of rotation of L3 was Grade 2, based on the Nash and Moe classification. (Middle) The stable vertebra was found to be L3, as observed on bending radiographs. (Right) Fusion was achieved to L3 distally, as this case met the criteria.

carefully considered. The first issue is whether the PT curve should be included in correction and fusion, and the second issue is the level up to which fusion should be performed proximally. Inappropriate proximal fusion level selection could result in poor outcomes such as shoulder imbalance or coronal imbalance.

In 1993, it was proposed that both the PT and the MT curves should be fused when the left shoulder was elevated or PT curves were rigid, as the correction and fusion of the lower thoracic curve aggravated shoulder balance [55]. According to this study, a positive T1 tilt was not an important factor, as previously believed. However, this trend has changed since the advent of strong instrumentation systems such as the pedicle screws system. Lenke et al. proposed that, even in patients with an elevated right shoulder, PT curve fusion may occasionally be required, particularly in cases where the PT curve is >30° and >20° on bending radiographs [56]. The need for fusion of the PT curves was also proposed by Suk et al. [57], who recommended both PT and MT curve fusion in patients with a PT curve of >25° and a balanced or elevated left shoulder [57]. However, the selection of the proximal fusion level in double thoracic curves remains controversial. Spontaneous PT curve correction after instrumented correction of the MT curve has been suggested [58]. Moreover, a non-fusion strategy for PT curves between 35° and 45° has been

Table 3
Comparisons of clinical and radiological outcomes according to the distal fusion level in patients with AIS with major thoracolumbar-lumbar curves

Authors	No. of patients	Curve type	Follow-up (y)	Conclusions
Wang et al. [50]	40	Lenke type 3C, 6C	2	The deviation of the lumbar curve improves when the LIV is either at or below the lumbar apical vertebra.
Ding et al. [44]	60	NA	2	No significant clinical differences were noted between the L3 and the L4 groups.
Sun et al. [51]	34	Lenke type 5C	2	The correction rate of the main thoracic and TL-L curves did not differ between LIV=LEV patients and LIV=LEV+1 patients. LIV translation was slightly less in the LEV+1 group (p=.028).
Kim et al. [47]	66	TL-L curves	Min. 2	L3 can be the LIV when L3 crosses the CSVL with rotation of less than Grade II on bending films.
Lee et al. [49]	229	Lenke type 3C, 5C, 6C	Min. 2	Stopping at L3 may be sufficient in cases with LEV≥L3 and LTV≥L4. However, in other cases, care must be taken when stopping at L3 because of the potential for suboptimal correction and progression of the adjacent disc wedging.
Chang et al. [48]	64	Major TL-L curves	Min. 2	L3 (LEV) would be selected as the LIV when the curve is flexible. However, if the curve is rigid, the LIV should be extended to L4 (LEV+1) to prevent the adding-on phenomenon, in the treatment of major TL-L AIS using rod derotation and direct vertebral rotation.

Min., minimum; TL-L, thoracolumbar-lumbar; LIV, lowest instrumented vertebra; LEV, lower end vertebra; CSVL, central sacral vertical line; LTV, last touching vertebra; AIS, adolescent idiopathic scoliosis.

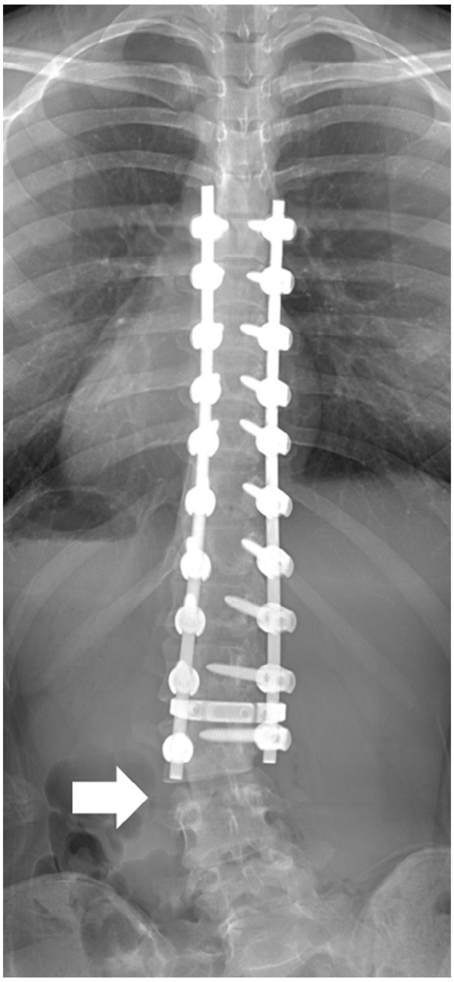

Fig. 6. Increased disc wedge angle at the L3–L4 disc level in the postoperative period (arrow).

recommended because of the spontaneous correction of the PT curve [59].

Regardless of both PT and MT curve fusion, shoulder imbalance remains a critical problem. A reduced correction of the distal thoracic curve is recommended because of the inherently rigid nature of the PT curve [60]. This opinion is supported by a recent study that showed that a higher postoperative PT-to-MT curve ratio affected the development of postoperative shoulder imbalance [61]. However, these suggestions are impractical in the real clinical setting because the degree of ideal correction is not proposed.

The selection of the upper instrumented vertebra (UIV) in double thoracic curves is also debatable. Shoulder imbalance was found to occur despite the selection of correct UIV by several methods [62]. This suggests that the selection of an appropriate UIV is very complex. Furthermore, the proximal extension of fusion should be carefully considered for many reasons. First, cervical problems can develop in the future following upper thoracic fusion. Second, an upper surgical scar can be stressful for teenage female patients. Third, the spontaneous correction of the PT curve is frequently observed without correction [58]. Because of these reasons, some authors remain skeptical about the extension of fusion to T2 or T3 in cases of nonstructural PT curves [63]. Thus, the selection of the exact end of the proximal fusion level is debatable, despite the basic principle of fusion of all structural curves. The results of various studies on proximal fusion level selection in double thoracic curves are summarized in Table 4 [56–59,63].

The related factors for postoperative shoulder imbalance in double thoracic curves have not been clearly defined. The T1 tilt was not likely to be related to shoulder balance in many studies [61,62,64]. However, the effect of preoperative shoulder height difference on postoperative shoulder imbalance was debatable. In a previous study, preoperative shoulder imbalance was not predictive of postoperative shoulder imbalance [59]. In another study, the preoperative shoulder level difference was reported to be a determinant of postoperative shoulder balance [65]. Recently, the clavicle chest cage angle difference has been suggested as a preoperative predictor of postoperative shoulder imbalance [66]. However, this finding has been disputed by another report [61]. In fact, the related factors for

Table 4
Articles on proximal fusion level selection in AIS with double thoracic curves

Authors	No. of patients	Curve type	Follow-up (y)	Conclusions
Lenke et al. [56]	54	King type III	—	If the structural upper thoracic curve is identified by using specific criteria, then an extension up to T2 is recommended to maintain shoulder balance and coronal balance.
Suk et al. [57]	40	PTC>25 degrees	Min. 2	PTC of >25° and level or elevated left shoulder should be fused.
Kuklo et al. [58]	85	PTC≥20 degrees	Min. 2	Spontaneous correction of the PTC was observed when the PTC was left unfused. The findings of preoperative bending radiographs were positively correlated with postoperative spontaneous PTC correction.
Cil et al. [63]	37	Nonstructural PTC (side-bending Cobb<25 degrees)	Min. 2	There was no difference in outcomes when including a nonstructural PTC in the fusion or when fusing the main thoracic curve. In this case, proximal extension to T2 or T3 was unnecessary.
Elfiky et al. [59]	30	Large PTC>35 degrees	Min. 2	Spontaneous correction of the PTC occurs in structural curves of >35° and <45°. Thus, non-fusion of the PTC can be considered in this condition.

Min., minimum; PTC, proximal thoracic curve.

Table 5
Related factors for postoperative shoulder imbalance after corrective surgery for AIS

Authors	No. of patients	Curve type	Follow-up (y)	Conclusions
Ilharreborde et al. (2008) [64]	91	Lenke type 1, 2	2.5	No correlation was found between the T1 tilt and shoulder balance.
Hong et al. (2013) [65]	89	All curve types	Min. 2	The middle-to-distal curve change ratio was significantly lower in patients with aggravated shoulder balance. In addition, the preoperative shoulder level difference can be a determinant of postoperative shoulder balance.
Yagi et al. (2013) [66]	89	All curve types	Min. 2	A significant difference was observed in preoperative CCAD between the balanced and the unbalanced shoulder group. CCAD is a novel predictor of PSI.
Cao et al. (2014) [67]	142	Lenke type 2	2	PSI and the distal adding-on phenomenon were weakly but significantly associated with each other.
Matsumoto et al. (2014) [68]	106	Lenke type 1A	Min. 2	PSI was more common with better correction of the main curve, in patients with a larger preoperative clavicle angle, and with a larger, more rigid PT curve. The distal adding-on phenomenon may compensate for PSI.
Lee et al. (2016) [61]	80	Lenke type 2	Min. 2	A higher Risser grade, larger postoperative proximal wedge angle, and higher postoperative PTC-to-MTC ratio are correlated with PSI.

Min., minimum; CCAD, clavicle chest cage angle difference; PSI, postoperative shoulder imbalance; PTC, proximal thoracic curve; MTC, mid-thoracic curve.

postoperative shoulder imbalance have not been clearly elucidated thus far. The results of studies on the related factors for postoperative shoulder imbalance are summarized in Table 5 [61,64–68].

In addition, there is another important aspect that should be considered for shoulder imbalance. The shoulder height difference based on the subjective symptoms of patients may differ from the radiographic findings (Fig. 7). Moreover, the shoulders were not found to be level in the normal population, and this imbalance did not lead to an asymmetric body perception in that population [69]. Hence, care must be taken when selecting the proximal fusion level while considering shoulder imbalance.

In summary, the problem of shoulder imbalance is most controversial. Postoperative shoulder imbalance in AIS is a complex multifactor problem, with a gap between radiological and cosmetic aspects. In this regard, no consensus guidelines about selection of UIV, surgical methodology, and risk factors to prevent shoulder imbalance have been established. Further studies should be focused on the methodology to assess clinical shoulder imbalance and its relationship with other radiological parameters.

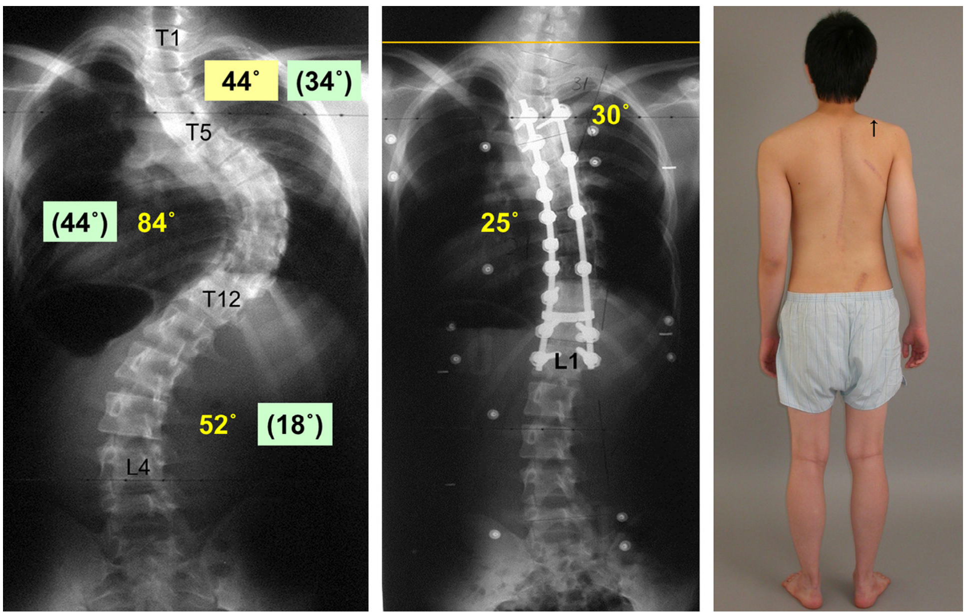

Fig. 7. Case showing the difference between subjective symptoms and radiographic findings with regard to shoulder imbalance. (Left) 17-year-old male patient showed a rigid proximal thoracic curve that required correction and fusion of the PT curve, following classical indications. (Middle) However, the PT curve was left unfused. At 1.5 years postoperatively, the left shoulder was found to be elevated on radiographs. (Right) However, the patient complained of elevation of the right shoulder instead of the left one.

Limitations

Our study has a few limitations. As this study is not a systematic review, the evidence of brief suggestions or opinions about each debatable issue is inherently insufficient. However, this study will provide the current concept about fusion level selection in AIS. In addition, specific guidelines could not be suggested because of the paucity of highly qualified, relevant studies.

Conclusion

Although many difficult problems in the diagnosis and treatment of AIS have been resolved by understanding its mechanism and via technical advancement, definite guidelines for fusion level selection have still not been established. Selective thoracic fusion and selective TL-L fusion can help reduce the number of fusion segments. Nevertheless, the careful selection of patients and the fusion level is critical to avoid complications such as coronal decompensation or progression of residual curves. Generally, wider indications for selective fusions are associated with more frequent complications. However, definite selection criteria have not been standardized thus far.

The adding-on phenomenon is also a critical complication after corrective surgery in AIS with Lenke 1A curves, and is related to attempts to reduce fusion level. Although authors suggested various criteria to prevent it, no consensus has been reached on the appropriate selection of LIV. Distal fusion level selection in major TL-L curves is another controversial issue. The main point is whether distal fusion stops at L3. Unfortunately, comparative studies to provide bases for a conclusion are few. The problem related to shoulder imbalance and proximal fusion level selection remains to be elucidated, from its etiology to its prevention. Various studies have attempted to elucidate the problem.

Thorough validation studies about the abovementioned controversial issues are required to address these unsolved issues.

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