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REVIEW ARTICLE

Optimal surgical care for adolescent idiopathic scoliosis: an international consensus

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Abstract
Purpose The surgical management of adolescent idiopathic scoliosis (AIS) has seen many developments in the last two decades. Little high-level evidence is available to support these changes and guide treatment. This study aimed to identify optimal operative care for adolescents with AIS curves between 40° and 90° Cobb angle.
Methods From July 2012 to April 2013, the AOSpine Knowledge Forum Deformity performed a modified Delphi survey where current expert opinion from 48 experienced deformity surgeons, representing 29 diverse countries, was gathered. Four rounds were performed: three web-based surveys and a final face-to-face meeting. Consensus was achieved with $\geq$70 % agreement. Data were analyzed qualitatively and quantitatively.
Results Consensus of what constitutes optimal care was reached on greater than 60 aspects including: preoperative radiographs; posterior as opposed to anterior (endoscopic) surgical approaches; use of intraoperative spinal cord monitoring; use of local autologous bone (not iliac crest) for grafts; use of thoracic and lumbar pedicle screws; use of titanium anchor points; implant density of <80 % for 40°–70° curves; and aspects of postoperative care. Variability in practice patterns was found where there was no consensus. In addition, there was consensus on what does *not* constitute optimal care, including: routine pre- and intraoperative traction; routine anterior release; use of bone morphogenetic proteins; and routine postoperative CT scanning.
Conclusions International consensus was found on many aspects of what does and does not constitute optimal

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operative care for adolescents with AIS. In the absence of current high-level evidence, at present, these expert opinion findings will aid health care providers worldwide define appropriate care in their regions. Areas with no consensus provide excellent insight and priorities for future research.

Keywords Adolescent idiopathic scoliosis · Surgery · Optimal care · Delphi · Consensus

Introduction

The surgical treatment of adolescent idiopathic scoliosis (AIS) has seen several new operative strategies within the past decade, including regular usage of pedicle screws, new techniques to reduce the curve, the use of bone substitutes, blood conservation techniques, and spinal cord monitoring [1]. These options have added complexity in surgical decision making. It is likely that these changes and perceived improvements are responsible for the variations in operative care for AIS patients [2, 3]. Aubin et al. [4] reported large variability in AIS instrumentation strategy and planning among a small group of experienced spine surgeons assessing the same patient. Similarly, among a group of Canadian spine surgeons surgically treating AIS, several controversies were found [5].

Although epidemiological research has revealed that AIS is a well-defined condition which occurs globally, for many aspects of treatment, there is little evidence to draw upon and most treatment recommendations are based on case studies. Randomized control trials (RCTs) are challenging to perform in AIS patients due to the ethical concerns of applying experimental interventions in a pediatric population. In addition, with few patients treated per center and numerous variables, these trials are logistically challenging. Consequently, high-quality evidence is difficult to establish. In light of this issue, the AOSpine Knowledge Forum Deformity (AOSKF Deformity) conducted a worldwide study investigating surgeons' contemporary perceptions of optimal operative care in AIS patients. The purpose was to survey an international group of highly experienced surgeons treating 'routine' AIS patients between 12 and 20 years of age with scoliotic curves ranging from 40° to 90° Cobb angle to determine what constitutes optimal operative care for the patient.

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Materials and methods

Design

A modified Delphi survey was performed. This flexible survey technique is used to collect information for establishing consensus and/or forecasting future events [6, 7]. It involves the participation of expert individuals known as panelists. Through an iterative and anonymous process, panelists provide individual knowledge and opinions which are synthesized, discussed, and summarized until a high level of agreement is reached.

For the areas of consensus, review of the literature was performed using the Pubmed database until March 28, 2014. The search queries were limited to the AIS patient population, the English-language, and topic-specific keywords. Animal studies, meeting abstracts, editorials, single case reports, and review articles were excluded. Studies identified during the searches were supplemented with literature known to the authors. Only supporting empirical evidence is described.

Panelists

Surgeons were invited to participate by an e-mail which was sent to all AOSpine members ($n = 5{,}608$). To participate, panelists needed to personally manage a minimum of 25 surgical AIS patients per year; have practiced for a minimum of 5 years; be fluent in English; and complete three questionnaires within the study period. Ninety-two surgeons responded, 55 met the criteria, and 41 accepted the study terms and agreed to take part. In addition, seven qualified members from the AOSKF Deformity steering committee joined the panel, totalling 48 panelists from 29 countries, representing all world regions (Table 1; Online Resource 1). Panelists were predominately male, aged 50–59, and over 80 % had been practicing for 10 or more years. The mean percentage of practice focus on pediatric spine was 50 %. To maintain objectivity, the principle investigators (MDK, MI) and project leaders (NMG, SJK, MVT) who designed and developed the surveys and pilot tester/moderator (CS) did not participate as panelists.

Delphi rounds

The study consisted of four rounds: three rounds used a web-based survey tool (Survey Monkey, http://www.surveymonkey.com/) over 5 months (July–November 2012) and the final round was a face-to-face meeting (April

Table 1 Demographic profile of Delphi panelists

Characteristic	Rounds 1–3 ($n = 48$) n (%)	Round 4 ($n = 22$) n (%)
Gender		
Female	1 (2)	0 (0)
Male	47 (98)	22 (100)
Age (years)		
30–39	5 (10)	1 (5)
40–49	18 (38)	11 (50)
50–59	20 (42)	7 (32)
60–69	5 (10)	3 (14)
Region		
Asia Pacific	12 (25)	4 (18)
Europe	18 (38)	8 (36)
Latin America	6 (13)	3 (14)
Middle East	6 (13)	2 (9)
North America	6 (13)	5 (23)
Years in practice		
<10	8 (17)	3 (14)
10–19	18 (38)	7 (32)
20–29	16 (33)	9 (41)
30–39	5 (10)	2 (9)
40–49	1 (2)	1 (5)

2013). Panelists were given 3 weeks to complete each questionnaire and ~6 weeks were allocated for analysis and questionnaire development. After each round, panelists received de-identified summaries of all responses.

The objective of Round 1 was to identify the key features involved in the surgical treatment of AIS. Panelists were asked to answer each question in terms of the procedures routinely used at their institution. This round consisted of 36 questions, including open-ended questions and requests for explanations and general feedback. These results were used to generate and refine questions for Round 2.

In Round 2, the objective was to elicit opinions about what constitutes 'optimal' care. Panelists were asked to answer each question based on what is optimal, not necessarily what is routinely used or feasible in their clinic (e.g., panelists may not routinely use spinal cord monitoring because of lack of facilities, but may consider it part of optimal care). There were 47 primary questions and 17 additional questions appeared through branching logic.

In Round 3, the objective remained consistent with Round 2 and included six questions. This round was performed in an attempt to reach consensus on items which required additional clarification by asking more structured questions and limiting response options.

In Round 4, 12 topics where consensus was not found were further discussed in a face-to-face meeting. Topic selection was based on previous questionnaire responses, their clinical importance, and the likelihood of reaching consensus with 'live' discussion. Twenty-five of 48 panelists were selected to attend the meeting based on geographic spread, years of experience, and age distribution. Through a moderated discussion, participants developed 23 questions relating to the 12 pre-selected topics. An electronic audience response system (PowerComARS, Jiangsu, China) allowed anonymous voting on each question.

Analysis

Consensus was defined a priori as $\geq$70 % agreement among panelists [6, 8]. When consensus was not reached on a question, it was included in the next round if clarification of the wording or refinement of response options could reasonably facilitate consensus. The frequency of each response was determined and converted to percentages. For ranking questions, mean ranks (a value of 1 was most important) were calculated and the top two items retained. Final conclusions for each question were classified as: routinely used (consensus that the practice is routinely performed), not routinely used (consensus that the practice is not routinely performed), optimal (consensus that the practice constitutes optimal care), not optimal (consensus that not performing the practice constitutes optimal care), and no consensus (no consensus whether performing the practice constitutes routine use or optimal care). For the purposes of readability, percentages appear in the text only where consensus was achieved.

Results

Response rates were excellent, 46 of 48 (96 %) panelists completed Round 1 and all panelists completed Rounds 2 and 3. For Round 4, 22 of 25 (88 %) invited panelists attended the meeting (Table 1; Online Resource 1). In Round 4, similar results were obtained for non-consensus questions asked in previous rounds, suggesting Round 4 panelists were representative of all panelists.

Aim of surgery

The primary aims of surgery were to achieve a balanced spine (mean rank of 1.9 and a total of eight options) and to prevent curve progression through solid fusion (mean rank of 2.8). Full correction or cosmesis was less important (mean rank $\geq$4.9).

Preoperative management

Preoperative treatment was investigated with 17 questions, grouped into three areas: health assessment tests, imaging, and surgical preparation (Table 2).

Consensus achieved

Preoperative imaging Performing either a standing full spine posterior–anterior (PA) or anterior–posterior (AP) radiograph and a standing full spine lateral radiograph was ranked as optimal (mean rank $\leq$2.1 and a total of five options). When taking full spine lateral radiographs, placing hands on clavicles or head/cheeks (95 %) and having hips visible (85 %) were optimal. There was consensus that sitting (83 %) and supine (80 %) full spine radiographs were not routinely used. There was 100 % consensus that routinely performing dynamic preoperative radiographs was optimal. In addition, there was consensus that non-radiographic measurements (81 %) such as forward bending scoliometer, forward bending rib hump, clinical photographs, and standing surface topography constitute optimal care. However, there was no consensus which was optimal.

Surgical preparation In routine care scenarios, performing preoperative traction was not optimal (98 %). The optimal head position when the patient was prone during posterior approach surgery was in a face mask (79 %).

Supporting empirical evidence

Preoperative imaging Current clinical practice and all research on the treatment of AIS make use of radiographs, but there is no direct evidence on their need. Modern classification systems are based on coronal (AP or PA), sagittal and dynamic radiographs [9], and new insights regarding sagittal alignment of spinal deformities require a full spine lateral radiograph with the hips visible [10, 11]. According to a prospective study by Horton et al. [12], the best position for taking these radiographs is with the hands on the clavicles.

Prone positioning There is a technical note that recommends positioning prone patients in a face mask which allows for better positioning of the head, avoiding compression of vessels and nerves in the neck, and better protection of the eyes and better endotracheal tube positioning [13]. This is especially relevant to AIS patients whose trunk is manipulated during surgery.

Consensus not achieved

Consensus was not achieved on the need for preoperative nutritional status and pulmonary function tests; on which type of dynamic radiograph is optimal (fulcrum side bending over a bolster, traction, or supine side bending); on routine preoperative (full spine) MRI; on the need for preoperative traction for patients with large rigid curves; and on the optimal type of surgical positioning table.

Intraoperative management

Intraoperative treatment was investigated with 54 questions, grouped into six areas: infection control, spinal cord monitoring, surgical techniques, implants, bone grafting, and blood conservation (Table 3).

Consensus achieved

The posterior surgical approach was considered optimal (96 %), while the anterior thoracoscopic approach was not routinely used (78 %). Motor-evoked potentials (MEP) (92 %) and somatosensory-evoked potentials (SSEP) (75 %) were optimal methods of intraoperative spinal cord monitoring; however, only if neither is available, the Wake-up Test was considered optimal (81 %). In patients with large, rigid curves, osteotomies (Ponte) were required for optimal care (85 %); a complete facetectomy into foramen including flavectomy (Ponte osteotomies) in all or part of the instrumented spine was considered optimal (73 %). There was consensus that the lamina (96 %), transverse processes (72, 83 %), and facet joints (98 %) were decorticated, and the spinous process was harvested (72 %) to prepare the fusion bed. Routine use of intraoperative navigation systems (88 %), intraoperative traction (100 %), and anterior release (100 %) was considered not optimal. Accompanying routine surgical procedures on the rib cage, such as performing a convex (81 %) or concave (92 %) thoracoplasty, was considered not optimal.

Supporting empirical evidence

Spinal cord monitoring There is evidence from uncontrolled series that supports the use of SSEP, MEP, or both in the surgical treatment of AIS [14–16]; however, there are no studies directly comparing neural complications between cohorts of operated patients with or without monitoring.

Ponte osteotomies A recent case series concluded no benefit from the routine use of Ponte osteotomies in terms of improvement to coronal or sagittal correction, their use also came at the cost of greater blood loss and longer operative time [17].

Computer-assisted navigation There are a small number of retrospective studies concerning the use of intraoperative computer-assisted navigation in AIS, which report more accurate screw placement, but not increased safety

Table 2 Consensus findings for the preoperative treatment of adolescent surgical AIS patients

Area	Question	Item (% agreement) or (mean rank)
Health assessment tests	Is routinely performing preoperative pulmonary function tests optimal care?[a,b]	Optimal (50 %)
		Not optimal (50 %)
	Is assessing preoperative nutritional status by performing a blood test optimal care?[a,b]	Optimal (42 %)
		Not optimal (58 %)
Preoperative imaging	Indicate the type of preoperative radiographs used at your institute	Sitting radiographs:
		Used (2 %)
		Not used (83 %)
		Missing (14 %)
		Supine radiographs:
		Used (6 %)
		Not used (80 %)
		Missing (14 %)
	What type of standing preoperative radiograph is optimal? Rank the list of options in order of importance (e.g., 1 is most important,…5 is least important)[a]	**Full spine posterior–anterior + full spine lateral (1.7)**
		Full spine anterior–posterior + full spine lateral (2.1)
	What hand/arm position is optimal for full spine lateral radiographs? Refer to Horton et al. [12] for additional information. Select only one option	**Hands on clavicles or head (95 %)**
		Arms in front with hands supported (5 %)
		Arms in front with hands unsupported (0 %)
	Is it optimal for hips to be visible in full spine lateral radiographs?[a,b]	**Optimal (85 %)**
		Not optimal (15 %)
	Are dynamic preoperative radiographs needed for optimal care?[a]	**Optimal (100 %)**
		Not optimal (0 %)
	Considering adolescent surgical AIS patients with a Cobb angle of 40°–70°, indicate which of the following dynamic preoperative radiograph is optimal to assess flexibility? Select only one option	Fulcrum side bending over a bolster (10 %)
		Traction (20 %)
		Supine side bending (5 %)
		Both: fulcrum side bending over a bolster and supine side bending (65 %)
	Considering adolescent surgical AIS patients with a Cobb angle of 70°–90°, indicate which of the following dynamic preoperative radiograph is optimal to assess flexibility? Select only one option	Fulcrum side bending over a bolster (33 %)
		Traction (38 %)
		Supine side bending (29 %)
	Are non-radiographic measurements required to provide optimal care? Select only one option[a]	Yes, forward bending scoliometer (21 %)
		Yes, forward bending rib hump in centimeters (6 %)
		Yes, clinical photographs (46 %)
		Yes, standing surface topography (8 %)
		No, none (19 %)
	Is routinely performing a preoperative (full spine) MRI optimal care?[a,b]	Optimal (54 %)
		Not optimal (46 %)
Surgical preparation	Is preoperative traction optimal care? Select only one option[a,b]	Always (2 %)
		In some cases (50 %)
		Never (48 %)
	Considering adolescent surgical AIS patients with large, rigid curves, is preoperative traction (any form) needed for optimal care?	Optimal (63 %)
		Not optimal (37 %)
	What type of surgical positioning table is optimal? Select only one option[a,b]	Radiolucent table with bolsters, support blocks, and/or cushions (23 %)
		Radiolucent spine table with supplementary frame (23 %)
		Jackson table (54 %)
	What head position is optimal? Select only one option[a,b]	**In mask (79 %)**
		On gelmat (21 %)

Areas highlighted in grey and bolded represent consensus

[a] Considering adolescent surgical AIS patients with curves between 40° and 90° Cobb angle

[b] Considering only routine care scenarios

Table 3 Consensus findings for the intraoperative treatment of adolescent surgical AIS patients

Area	Question	Item (% agreement) or (mean rank)
Intraoperative infection control	What infection prevention measures (other than antibiotics) are optimal? Select as many as are applicable from the list of options[a,b]	**Use of intraoperative irrigation (90 %)**
		Preoperative treatment of acne vulgaris (proprionibacterium) (54 %)
		Change of gown, mask, and gloves during procedure (52 %)
		Use of topical antibiotics (e.g., vancomycine powder) (33 %)
		Other (38 %)
Intraoperative monitoring	If readily available and/or feasible, is the use of intraoperative navigation systems optimal (e.g., O-arm, Brainlab, etc.)? Select only one option[a,b]	Always (13 %)
		In some cases (40 %)
		Never (48 %)
	If MEP was readily available, is this method of intraoperative spinal cord monitoring optimal care?[a]	**Optimal (92 %)**
		Not optimal (6 %)
	If SSEP was readily available, is this method of intraoperative spinal cord monitoring optimal care?[a]	**Optimal (75 %)**
		Not optimal (25 %)
	In the event that MEP and SSEP are not available, is routine performance of the Wake up Test optimal care?[a]	**Optimal (81 %)**
		Not optimal (17 %)
Surgical techniques	Indicate the type of fusion bed preparation used at your institute. Select as many as are applicable from the list of options	**Facet decortication (98 %)**
		Lamina decortication (96 %)
		Transverse process decortication (T spine) (83 %)
		Transverse process decortication (L spine) (72 %)
		Spinous process harvest (72 %)
		Spinous process preservation (48 %)
	Indicate the surgical approaches regularly applied at your institute	Anterior thoracic open:
		Used (46 %)
		Not used (41 %)
		Blank (13 %)
		Anterior thoracolumbar:
		Used (67 %)
		Not used (24 %)
		Blank (9 %)
		Anterior thoracoscopic:
		Used (2 %)
		Not used (78 %)
		Blank (20 %)
	Is the posterior surgical approach optimal care?[a,b]	**Optimal (96 %)**
		Not optimal (4 %)
	Is intraoperative traction (e.g., halo-femoral traction, cotrel traction table, etc.) optimal care? Select only one option[a,b]	Always (0 %)
		In some cases (50 %)
		Never (50 %)
	Are osteotomies (Ponte) required for optimal care? Select only one option[a]	Always (6 %)
		In some cases (85 %)
		Never (8 %)
	Considering adolescent surgical AIS patients with large, rigid curves, is it optimal care to have a complete facetectomy into foramen including flavectomy (Ponte osteotomies) in all or part of the instrumented spine?	**Optimal (73 %)**
		Not optimal (27 %)
	Is taking down the interspinous ligament (at the apex) optimal care?[a,b]	Optimal (68 %) Not optimal (32 %)
	Is taking down the spinous process (at the apex) optimal care?[a,b]	Optimal (65 %)
		Not optimal (35 %)

Table 3 continued

Area	Question	Item (% agreement) or (mean rank)
	Is performing an anterior release optimal care? Select only one option[a]	Always (0 %)
		In some cases (58 %)
		Never (42 %)
	For a Lenke 5 curve, is the anterior approach optimal?	Optimal (53 %)
		Not optimal (47 %)
	Considering only routine care scenarios and accompanying routine surgical procedures on the rib cage, is performing a convex thoracoplasty optimal care?[a]	Optimal (19 %)
		Not optimal (81 %)
	Considering only routine care scenarios and accompanying routine surgical procedures on the rib cage, is performing a concave thoracoplasty optimal care?[a]	Optimal (8 %)
		Not optimal (92 %)
Implants	In adolescent surgical AIS patients that require anchor points in the thoracic spine, is the use of pedicle screws optimal care?	**Optimal (92 %)**
		Not optimal (8 %)
	In adolescent surgical AIS patients that require anchor points in the lumbar spine, is the use of pedicle screws optimal care?	**Optimal (100 %)**
		Not optimal (0 %)
	Is the use of hooks also optimal care? Select only one option	Always (10 %)
		In some cases (77 %)
		Never (13 %)
	In adolescent surgical AIS patients that require anchor points in the thoracic spine, is the use of hooks (secondary to pedicle screws) optimal care?	**Optimal (84 %)**
		Not optimal (16 %)
	In adolescent surgical AIS patients that require anchor points in the thoracic spine, is the use of hooks an optimal method of choice for the proximal area?	Optimal (47 %)
		Not optimal (53 %)
	Is the use of titanium anchor points (e.g., screws or hooks) optimal care?[a,b]	**Always (79 %)**
		In some cases (21 %)
		Never (0 %)
	Is the use of 5.5 or 6.0 mm diameter rods optimal care?[a,b]	**Optimal (92 %)**
		Not optimal (6 %)
		Blank (2 %)
	Is the use of titanium rods optimal care? Select only one option[a,b]	Always (54 %)
		In some cases (42 %)
		Never (4 %)
	Considering adolescent surgical AIS patients with a Cobb angle of 70°–90°, which of the following correcting rod materials is optimal? Select only one option	Titanium (50 %)
		Stainless steel (0 %)
		Cobalt chrome (50 %)
	Considering adolescent surgical AIS patients with a Cobb angle of 40°–70°, what implant density is optimal care?	**<80 % (73 %)**
		>80 % (27 %)
	Considering adolescent surgical AIS patients with a Cobb angle of 70°–90°, what implant density is optimal care?	<80 % (33 %)
		>80 % (67 %)
	Considering adolescent surgical AIS patients with a Cobb angle of 70°–90°, optimal implant density is based on several factors (e.g., bone density, curve rigidity, sagittal profile, etc.)?	**Optimal (100 %)**
		Not optimal (0 %)

Table 3 continued

Area	Question	Item (% agreement) or (mean rank)
Bone grafting	Indicate the type of graft material(s) routinely used at your institute from the following list of items	Autologous rib graft:
		Used (50 %)
		Not used (41 %)
		Blank (9 %)
		Freeze-dried corticocancellous allograft bone granules/chips:
		Used (20 %)
		Not used (70 %)
		Blank (11 %)
		Allograft bone from a bone bank:
		Used (41 %)
		Not used (50 %)
		Blank (9 %)
		Bone marrow with DBM:
		Used (11 %)
		Not used (78 %)
		Blank (11 %)
		Bone graft extenders/enhancers:
		Used (37 %)
		Not used (57 %)
		Blank (7 %)
	Is the use of local autologous bone graft as a graft material optimal care?[a,b]	**Optimal (92 %)**
		Not optimal (8 %)
	Is the use of autologous ICBG as a graft material optimal care?[a,b]	Optimal (27 %)
		Not optimal (71 %)
	Is the use of local bone graft plus one supplement as a graft material optimal care?[a]	**Optimal (77 %)**
		Not optimal (23 %)
	Is the use of supplemental BMPs optimal care?[a,b]	Optimal (8 %)
		Not optimal (92 %)
Blood conservation	Indicate the type of blood conservation method(s) routinely used at your institute from the following list of items	Preoperative autologous blood donation:
		Used (37 %)
		Not used (59 %)
		Blank (4 %)
		Preoperative EPO:
		Used (17 %)
		Not used (72 %)
		Blank (11 %)
		Coagulation technology:
		Used (24 %)
		Not used (63 %)
		Blank (13 %)
		RhVII A:
		Used (4 %)
		Not used (80 %)
		Blank (15 %)
		Batroxobin:
		Used (0 %)
		Not used (85 %)
		Blank (15 %)
		Hemodilution:
		Used (37 %)
		Not used (57 %)
		Blank (7 %)

Table 3 continued

Area	Question	Item (% agreement) or (mean rank)
	Is the use of topical hemostatic agents an optimal blood conservation method?[a]	**Optimal (81 %)**
		Not optimal (19 %)
	Is the use of antifibrinolytics (e.g., Tranexamic acid, Cyklokapron, Transamin, Transcam, Espercil, Traxyl, Cyclo-F, Femstrual) an optimal blood conservation method?[a]	Optimal (62 %)
		Not optimal (38 %)
	The definition of hypotensive anaesthesia for optimal care is a mean arterial pressure of between 60 and 70 mmHg?[a]	**Optimal (100 %)**
		Not optimal (0 %)
	Is the use of hypotensive anaesthesia as a blood conservation method optimal care?[a,b]	**Optimal (77 %)**
		Not optimal (23 %)
	Is routinely allowing the patient to return to normotensive levels (mean arterial pressure >70 mmHg) during correction manoeuvres optimal care?[a]	**Optimal (78 %)**
		Not optimal (22 %)
	With a hemoglobin <7 g/dL (<4.3 mmol/L), is the use of intraoperative allogenic RBC transfusion optimal care?[a]	**Optimal (95 %)**
		Not optimal (5 %)
	Do you use a postoperative trigger to determine whether allogenic RBC transfusion is optimal care?[a]	Used (52 %)
		Not used (48 %)
	If cell saver was readily available, is this the optimal blood conservation method?[a]	**Optimal (71 %)**
		Not optimal (29 %)

Areas highlighted in grey and bolded represent consensus

L Lumbar, *T* Thoracic, *MEP* Motor-evoked potentials, *SEP* Somatosensory-evoked potentials, *ICBG* Iliac crest bone graft, *BMP* Bone morphogenetic proteins, *DBM* Demineralized bone matrix, *RBC* Red blood cell, *EPO* Erythropoietin

[a] Considering adolescent surgical AIS patients with curves between 40° and 90° Cobb angle

[b] Considering only routine care scenarios

(less complications of pedicle screws, less re-interventions), these studies do not report on cost effectiveness [18–20].

Intraoperative traction All published evidence concerning intraoperative traction in AIS surgery applies to large rigid curves recommend that it not be applied as a routine care procedure [21–24].

Anterior release Hempfing et al. [25] published results from a small case series which provided low level evidence that an anterior release does not increase flexibility of the scoliotic spine.

Thoracoplasty While there are several published uncontrolled studies investigating routine procedures on the rib cage (concave or convex thoracoplasty), their effect with respect to rib hump, cosmesis, outcome scores, curve correction, and pulmonary function is not clear [26–29].

Implants There was consensus that the use of pedicle screws in the thoracic (92 %) and lumbar (100 %) spine was optimal care. The use of hooks was optimal in some cases (77 %), especially in the thoracic spine when pedicle screws placement was not possible (84 %). In all cases, titanium anchor points were optimal (79 %). The use of 5.5 or 6.0 mm diameter rods was considered optimal care (92 %), and titanium was the optimal rod material in most cases (96 %). Considering curves with a Cobb angle of 40°–70°, an implant density <80 % was optimal (73 %). Implant density was defined as the number of anchor points in the construct related to the number of vertebrae fused, where 100 % implant density means two anchor points per fused vertebra. In patients with a Cobb angle of 70°–90°, there was 100 % consensus that optimal implant density should be based on several factors (e.g., bone density, curve rigidity, sagittal profile) and not on coronal curve magnitude alone.

Supporting empirical evidence

Pedicle screws versus hooks There are multiple retrospective comparative studies which report on improved coronal correction of the curve [30–32] and improved patient satisfaction [31] with all pedicle screw constructs versus hook-only constructs. There are reports which show increased costs [30] and increased incidence of proximal

Table 4 Consensus findings for the postoperative treatment of adolescent surgical AIS patients

Area	Question	Item (% agreement) or (mean rank)	
Postoperative infection control and pain management	Indicate the type of postoperative management used at your institute: drains	High/low vacuum?	
		High (7 %)	
		Low (52 %)	
		Other (41 %)	
		Reinfusion drainage systems?	
		Used (9 %)	
		Not used (87 %)	
		Other (4 %)	
	Is the use of drains during postoperative management optimal care?[a,b]	Yes, placed subfascially (46 %)	
		Yes, placed subcutaneously (29 %)	
		Yes, placed subcutaneously and subfascially (13 %)	
		No (13 %)	
	Optimal drain removal is determined based on which of the following variable? Select only one option[a]	Time (42 %)	
		Output (58 %)	
	Is the use of epidural pain catheters during postoperative management optimal care?[a,b]	Optimal (33 %)	
		Not optimal (67 %)	
	Optimal care involves initial IV antibiotic administration for what time period? Select only one option[a]	<24 h (31 %)	
		24–72 h (40 %)	
		>72 h (4 %)	
		Until drains are removed (25 %)	
	Indicate the type of postoperative management used at your institute: antibiotics (oral administration only)	Used (9 %)	
		Not used (85 %)	
		Blank (7 %)	
Postoperative imaging	Indicate when postoperative radiographs are taken at your institute	Intra-operative post-instrumentation	
		Anterior–posterior	Lateral
		Used (48 %)	Used (35 %)
		Not used (37 %)	Not used (46 %)
		Blank (15 %)	Blank (20 %)
		Prior to discharge home	
		Anterior–posterior	Lateral
		Used (91 %)	**Used (87 %)**
		Not used (7 %)	Not used (11 %)
		Blank (2 %)	Blank (2 %)
		2–6 weeks follow-up	
		Anterior–posterior	Lateral
		Used (54 %)	Used (50 %)
		Not used (33 %)	Not used (35 %)
		Blank (13 %)	Blank (15 %)
		3 months follow-up	
		Anterior–posterior	Lateral
		Used (78 %)	**Used (70 %)**
		Not used (20 %)	Not used (24 %)
		Blank (2 %)	Blank (7 %)
		6 months follow-up	
		Anterior–posterior	Lateral
		Used (80 %)	Used (67 %)
		Not used (13 %)	Not used (24 %)
		Blank (7 %)	Blank (9 %)

Table 4 continued

Area	Question	Item (% agreement) or (mean rank)	
		12 months follow-up	
		Anterior–posterior	Lateral
		Used (96 %)	**Used (89 %)**
		Not used (4 %)	Not used (9 %)
			Blank (2 %)
		24 months follow-up	
		Anterior–posterior	Lateral
		Used (87 %)	**Used (80 %)**
		Not used (4 %)	Not used (9 %)
		Blank (9 %)	Blank (11 %)
	Is performing postoperative CT scans optimal care?[a,b]	Optimal (6 %)	
		Not optimal (94 %)	
	Is the routine measurement of outcomes other than radiographs optimal care?[a,b]	**Optimal (71 %)**	
		Not optimal (29 %)	
Aftercare	Indicate the type of postoperative management used at your institute: brace	Used (26 %)	
		Not used (72 %)	
		Blank (2 %)	
	Optimal care involves returning to unrestricted activity ≤6-months postoperative?[a]	Optimal (43 %)	
		Not optimal (57 %)	
	Optimal care involves returning to unrestricted activity 7–12 months postoperative?[a]	**Optimal (86 %)**	
		Not optimal (14 %)	
	Is permitting the return to collision sports at some point postoperative optimal care?[a]	**Optimal (81 %)**	
		Not optimal (19 %)	
Registries	If a registry was available, is entering data for quality control purposes optimal care?[a]	**Optimal (94 %)**	
		Not optimal (6 %)	

Areas highlighted in grey and bolded represent consensus

IV Intravenous

[a] Considering adolescent surgical AIS patients with curves between 40° and 90° Cobb angle

[b] Considering only routine care scenarios

junctional kyphosis [33] for all pedicle screw constructs versus hybrid and hook-only constructs.

Implant material In the retrospective study performed by Lamerain et al. [34], they concluded that surgery using cobalt chrome rods produces higher correction rates in the frontal plane as compared to stainless steel rods of the same diameter.

Rod diameter The evidence regarding the effect of rod diameter on the coronal and sagittal correction is inconsistent [35–37].

Implant density With the increasing use of pedicle screws, there have been multiple recent reports on the effect of implant density. Some studies have shown slightly larger radiographic correction with high implant density [38–40], while others have shown no correlation between implant density and curve correction [41–43]. A recent prospective cohort study with 10-year follow-up conducted by Min et al. [44] has shown good correction with a pedicle screw implant density of 50 %. High implant density has not shown improvement in patient reported outcomes [38–44] or cosmesis [39], and has contributed to less thoracic kyphosis [38, 40, 41], and high costs [42, 45]. In contrast to what might be expected, it was shown through a finite element analysis and computational study that high implant density does not improve the distribution of forces and correction [46, 47].

Bone grafting The use of local autologous bone as a graft material was considered optimal (92 %), and supplementing this with one other graft material (e.g., autologous rib graft, allograft bone from a bone bank, and bone graft extenders/enhancers) was optimal (77 %). There was no consensus which supplement was optimal. However, autologous iliac crest bone graft (71 %) and bone morphogenetic proteins (92 %) were not optimal.

Supporting empirical evidence

There are multiple case series and cohort reports supporting the effectiveness (fusion rates) and safety (adverse effects) of local autologous bone, without the use of iliac crest bone, but supplemented by materials such as bone bank allograft, Beta tricalcium phosphate, hydroxyapatite, or bioactive glass. However, there are no studies which demonstrate superiority of one graft material over another. The uncontrolled studies of Dodd et al. [48] and Ilharreborde et al. [49] support the recommendation that autologous ICBG is no longer the routinely used graft for spine fusion in AIS patients. There is no evidence which evaluates the effectiveness of BMP use in AIS patients, yet there is evidence to indicate its use in pediatric spinal fusions is increasing [50].

Blood conservation Hypotensive anesthesia was an optimal blood conservation method during exposure and implant placement (77 %). Allowing the patient to return to normotensive levels (mean arterial pressure >70 mmHg) during correction of the spinal deformity was optimal (78 %). There was consensus that the use of topical hemostatic agents (e.g., gelatin sponges, collagen foam) was an optimal method for blood conservation (81 %). Cell saver was also considered an optimal, if available (71 %). However, preoperative erythropoietin (72 %), intraoperative RhVII A (80 %), and batroxobin (85 %) were not routinely used.

Supporting empirical evidence

There are several studies concerning blood management strategies in AIS surgery from before 2000 [51, 52]. Since then, surgical and anesthetic techniques have changed significantly, making the current value of these studies limited. In a recent retrospective cohort review of neuromuscular and idiopathic scoliosis patients, Hassan et al. [53] reported that a modern comprehensive blood management protocol (which included hypotensive anesthesia) led to 1.7 % blood transfusion rate (versus 36 %) in AIS patients. The value of each component cannot be determined from this study. There is evidence from uncontrolled studies that cell saver reduces perioperative transfusion rate in patients undergoing posterior spinal fusion for AIS patients [54, 55].

Consensus not achieved

Surgical techniques and implants Consensus was not achieved on conducting routine anterior thoracic open and anterior thoracolumbar releases; on performing an anterior approach for lumbar curves (Lenke 5 curves); on taking down the spinous processes and interspinous ligaments (at the apex); on routinely preserving the spinous process to prepare the fusion bed; on whether hooks were optimal for the proximal area in the thoracic spine ("topping off" to avoid violating the proximal facet joints and to prevent proximal junctional kyphosis); and on implant density or on the type of correcting rod material for curves with a Cobb angle of 70°–90°.

Blood conservation There was no consensus on the use of preoperative autologous blood donation, coagulation technology, hemodilution, and antifibrinolytics.

Postoperative management

Postoperative treatment was investigated with 21 questions, grouped into four areas: infection control and pain management, imaging, aftercare, and registries (Table 4).

Consensus achieved

Postoperative infection control and pain management: There was consensus that the use of drains (88 %) during postoperative management was optimal. Reinfusion drains were not routinely used (87 %). When considering the administration of antibiotics, intravenous (IV) administration was optimal (100 %), while oral administration was not optimal (85 %).

Supporting empirical evidence

There is very little published evidence related to the use of drains in AIS. A recent practice survey found that drains are routinely placed out of habit with a wide range of patterns [56], despite the fact that a randomized controlled trial performed by Blank et al. [57], showed that subcutaneous drains conferred an advantage regarding wound care.

Postoperative imaging Most panelists considered using postoperative radiography prior to discharge (anterior–posterior: 91 %; lateral: 87 %), at 3- (anterior–posterior: 78 %; lateral: 70 %), 12- (anterior–posterior: 96 %; lateral: 89 %), and 24-month follow-up (anterior–posterior: 87 %; lateral: 80 %) optimal. Performing routine postoperative CT scans was not considered optimal (94 %). There was consensus that the routine measurement of patient reported outcomes other than radiographs (e.g., SRS 22, EQ-5D) was optimal (71 %).

Aftercare Routinely prescribing a postoperative brace was not considered optimal (72 %). Return to unrestricted activity at 7–12 months postoperative (86 %) was considered optimal, as was return to collision sports at some point postoperative (81 %) (no consensus as to when).

Registries If a registry was available, entering data for quality control purposes was considered optimal (94 %).

Consensus not achieved

Consensus was not achieved on: drain location (subfascia, subcutaneous, or both), duration, and removal parameters; the type of surgical vacuum drains; the use of epidural pain catheters; and the IV antibiotics administration period.

Discussion

AIS is well defined from a diagnostic point of view, yet its surgical treatment methods are varied with little high-level evidence to guide treatment. Using the Delphi method, we gained consensus from an international group of surgeons on many clinically important aspects of what is currently considered optimal surgical care for AIS patients and pinpoint areas for further research.

Through panelist feedback, we identified a subgroup of patients with large, rigid curves for whom optimal care seemed to differ from the main patient group. For these patients, there was consensus to perform routine Ponte osteotomies, but there was no consensus on preoperative traction (any form), preoperative assessment of curve flexibility to be performed with traction radiographs, and the use of higher implant density.

This study highlighted areas of no consensus. We interpret a lack of consensus on some questions to mean they may require further research, while others may not have substantial clinical consequences. For example, there was consensus on the need for intraoperative spinal cord monitoring, but no consensus on which type (SSEP or MEP). This could be left at the discretion of the surgeon and institution. Similarly, there was consensus that the use of local bone (not including iliac crest) plus one supplement as a graft material was optimal. There was no consensus or supporting empirical evidence indicating which graft material should be used.

While there is empirical evidence to support some of our findings, the AIS literature base is weak, consists almost entirely of cohorts of patients, mostly treated 10–20 years ago in well-known spine centers across the world, predominantly from the USA. Other findings diverge or remain unsupported by published empirical evidence. In addition, evidence is often conflicting, difficult to interpret due to confounding variables, and not always centered on the most clinical relevant outcome. For example, we noted a strong preference for the posterior approach, while 5–10 years ago there were multiple reports of anterior approaches including anterior video-assisted (thoracoscopic) releases and instrumentations [58]. These approaches are now no longer considered optimal for routine care, except perhaps for lumbar Lenke 5 curves. This raises an interesting question whether some of these techniques were "fashions and hypes", or innovations that have been superseded by newer, better posterior techniques. Conversely, current concepts of optimal care will also change over time. Of course, under certain circumstances, treatment options not considered optimal for patients with a "routine 40°–90° curve" may still be required for the individual patient.

We defined optimal care as the set of services that provide the greatest possible improvement to the health of the patient. It is patient centered and differs from maximum care. For example, every diagnostic or therapeutic procedure may have undesired effects. Therefore, performing a preoperative full spine MRI or pulmonary function test in every patient may be considered maximum care, but there was no consensus whether they were optimal by this panel. While we believe the findings of this study will result in the best possible outcome for the "routine" AIS patient ("optimal care"), this may not always be feasible depending on available health care resources and funding. Those responsible for health care provision, however, must continuously strive for 'appropriate treatment'; high-quality services in an appropriate setting that will improve the health of the patient in the most cost-effective manner for society (appropriate care is society centered). This also does not necessarily correspond to maximal treatment. For instance, this international panel sees no need for maximum care in the areas of implant density for 40°–70° curves, use of intraoperative pedicle screw navigation, and routine postoperative CT. These findings provide possible saving of unnecessary costs, thus, in-line with appropriate care. Interestingly, both the expert opinion and published empirical evidence support an implant density below 80 % (and possibly lower) for routine care scenarios, but more research is warranted.

The strength of this study was that the design enabled the generation of up-to-date information from 48 surgeons from 29 countries worldwide. The panelists were well distributed in age and experience. All rounds were performed anonymously which eliminated the possibility of panelists being influenced or pressured by their peers. Consequently, we believe it unlikely that the findings would differ substantially if given to another panel of similar composition, and these findings are less likely to reflect treatment regimes based on tradition, familiarity, or bias (e.g., industry), but instead reflect contemporary perceptions of optimal care. The expert opinion-based findings for the consensus items were well supported by published empirical evidence, including studies published after the levels of consensus were established. Lastly, a near perfect response rate was achieved for all rounds which emphasizes the perceived need and dedication of the panelists in defining optimal surgical management for AIS.

A limitation, as with any Delphi method, was that the findings are based on expert opinion and on the assumption that if several people with diverse backgrounds agree on an issue (through anonymous voting), there is less chance of arriving at an incorrect response [6]. Even though we employed 48 panelists worldwide, we may not have represented all caregivers.

In conclusion, multiple areas of international consensus for the current optimal surgical management for AIS were identified and supported by empirical evidence. The areas of no consensus require further research. Although many of these results are based on expert opinion and may need to be validated through quantitative research, they provide a basis for formulating current optimal surgical management recommendations. We encourage health care providers to standardize care for AIS patients and to use these findings to define appropriate care in their region. These findings should not limit future innovations. As patient care evolves, it may be necessary to diverge from what we have described as optimal care, but then future research should be performed in a controlled environment, and patient outcomes should be closely monitored and prospectively documented in a registry.

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