Management of Adolescent Idiopathic Scoliosis: Institutional Experience, Integration into Neurosurgical Practice, and Impact on Resident Training

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■ OBJECTIVE: **Management of adolescent idiopathic scoliosis (AIS) in neurosurgery residency training may have a significant impact on resident experience, even though few trainees are likely to pursue careers in the field of AIS. The impact of this exposure on resident knowledge in adult spinal disease management is the subject of our retrospective analysis.**

■ METHODS: **An analysis was performed of all adolescent patients undergoing surgical correction of spinal deformity between 2006 and 2016. Patient characteristics, including age at operation, Cobb angles, length of stay, operative time, blood loss, and complications, were collected. Objective benchmarks were created for resident education in the management of AIS. A survey was sent to the last 7 years of graduates to assess the impact of exposure to AIS during neurosurgery training on their current practice.**

■ RESULTS: **Nine male and 37 female patients ages 11 to 22 years were identified. Neurosurgical residents assisted in all procedures without fellows or surgical assistants. Average operative time was 336 minutes (range, 215—575 minutes), and blood loss per procedure was 603 mL (range, 200—4000 mL). The average Cobb angle correction was 72.2% (range, 35.3%—90.9%). Zero of the past 7 graduates currently treat AIS surgically. All 7 graduates agreed that exposure to AIS during residency enhanced their knowledge of adult spinal disease management.**

■ CONCLUSIONS: **Treatment of AIS by surgeons with specialized training can be effective and safe. Resident exposure to these patients enhances their understanding of spinal biomechanics and deformity correction, which is applicable to treating AIS and adult spinal deformity.**

INTRODUCTION

The treatment and classification of adolescent idiopathic scoliosis (AIS) have undergone numerous changes over their decades-long history.[1-3] Harrington rods, sublaminar wires, and segmental hook constructs have largely been replaced by segmental pedicle screw-rod constructs because of improved rates of complications and revisions.[1,4-7] Similarly, neurosurgical involvement in complex spinal procedures has increased over the past 20 years. The treatment of AIS however has remained largely within the purview of orthopedic surgeons. This trend is likely to change similar to other forms of spinal deformity treatment. The trend toward neurosurgical involvement in deformity, especially surgical management of AIS, seems to be a natural progression based on the experience during neurosurgical training and because of major complication avoidance. The worst complication and primary shared concern of both parents of children with AIS and surgeons surgically treating AIS is paralysis.[8] Neurosurgeons deal with the central nervous system regularly and receive at least 5—7 years of training in spine during residency and fellowship, including instrumentation and fusion procedures. The goal of our paper is to provide evidence that getting exposure to the management of AIS during residency training may positively impact a neurosurgery career and how one treats spine conditions, despite the fact that many new neurosurgical attending physicians will not surgically treat patients with AIS.

Key words
- Adolescent idiopathic scoliosis
- Kyphosis
- Neurosurgery resident training
- Pediatric
- Spine deformity

Abbreviations and Acronyms
AIS: Adolescent idiopathic scoliosis

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METHODS

A retrospective analysis of all adolescent patients undergoing neurosurgical management for AIS between November 2006 and December 2016 at Loyola University Medical Center was performed. Full approval was received by the institutional review board. Forty-six consecutive patients underwent a total of 57 surgical procedures, with 11 planned staged procedures, for progressive spinal deformity. The patients were all evaluated preoperatively and treated by the same senior author (R. P. N.). Residents within 3 years of graduation (postgraduate year 5–7) served as first surgical assistants on all procedures.

The 9 male and 37 female patients ranged in age from 11 to 22 years (average 16.2 years). The types of deformity included idiopathic scoliosis (n = 43) and kyphoscoliosis (n = 3). All patients were followed in the outpatient clinic postoperatively, with follow-up ranging from 4 to 72 months (average 21.8 months). All patients had at least 3 follow-up evaluations.

Experience of the Neurosurgical Attending

After completing neurosurgical training, the senior author entered academic practice in 1991 and obtained postgraduate experience in AIS management by senior orthopedic surgeons both nationally and internationally prior to treating these patients. The senior author is also a member of the Scoliosis Research Society.

Preoperative Evaluation

All patients were evaluated in the outpatient clinic and underwent thorough neurologic examination. Preoperative imaging included standing anteroposterior and lateral long cassette scoliosis radiographs with appropriate shielding done. The coronal Cobb angle was measured and followed on serial imaging, with time intervals depending on the severity of the curve and rate of progression of the deformity. In the past 5 years, age-related skeletal maturity has been determined by hand radiographs.

Patients with well-balanced structural curves <45° in magnitude and skeletally immature were observed without bracing prior to the study by Weinstein et al in 2013.[9] Subsequently, all such patients with curves measuring 25°–45° were braced. These braces were custom made and modified as axial growth occurred in hopes of preventing curve progression. Most patients that are followed in clinic do not require surgical intervention. Patients that failed bracing were considered for surgical correction. Once a patient was determined to be an operative candidate, updated standing anteroposterior and lateral scoliosis radiographs and lateral bending radiographs were obtained to assess curve progression and flexibility of the curve for operative planning. Computed topography scan was usually performed preoperatively to assess pedicle morphology for placement of pedicle screws. Magnetic resonance imaging was only obtained if any patient had a neurologic deficit, demonstrated an atypical curve pattern, or had signs or symptoms of spinal dysraphism.

Indications for Treatment

Immature patients with scoliosis of <25° were observed and underwent serial neurologic examinations in clinic and standing scoliosis radiographs every 6 months to follow stability or progression of their curve. Immaturity was defined by evidence of open growth plates on hand radiographs. Premenarcheal girls were also considered immature patients usually requiring 18 months after menarche to exhaust their axial growth curve. Immature patients demonstrating >5° of progression and/or a curve with a Cobb angle >25° were braced. Immature patients with curves from 25° to 45° on initial presentation were treated with bracing, whereas surgery was recommended for skeletally mature patients with a >50° curve on presentation. Surgery was also recommended for mature patients with >45° curves if rapid progression (>10° increase in curve magnitude over 6 months) was documented. Three patients had severe kyphoscoliosis. Surgical fixation was recommended for patients with >40° of acute focal kyphosis or >75° of total thoracic kyphosis.[10]

Surgical Procedures

All patients underwent posterior laminotomies, facetectomies, deformity correction, and posterior pedicle screw fixation (Solera [Medtronic, Sofamor Danek, Memphis, Tennessee, USA]). Patients were treated under general anesthesia and received antibiotic prophylaxis. Patients were placed prone on a Jackson table, positioned to ensure that all pressure points were padded to prevent pressure neuropathy. All procedures were performed using somatosensory evoked potentials, motor evoked potentials, and electromyographic monitoring.[11,12] An intraoperative wake-up test was performed on all patients immediately after curve correction. Intraoperative fluoroscopy and intraoperative computed tomography scanning with the use of an O-arm (Medtronic) were used to aid in the placement and confirmation of pedicle screws.

Prior to 2011, patients with a fixed coronal deformity on preoperative lateral bending radiographs underwent a thoracotomy with general surgery for an anterior release to aid in the deformity correction prior to posterior decompression and fusion. After the anterior release was completed, morselized allograft arthrodesis was performed usually at the 2 levels rostral and caudal to the apex of the coronal deformity. Most of these patients underwent staged procedures, whereas some were returned to the prone position to begin the posterior deformity correction under the same anesthesia.

Postoperative Care and Evaluation

All patients were placed in either the pediatric or neurologic intensive care unit after surgery. On the first day after the procedure (or after the second stage for staged procedures), all patients were encouraged to ambulate or at least be up into a chair for meals. A physical therapist worked with every patient to determine any needs on discharge. Chest tube and drains were removed 2–5 days after the patient's last procedure. Patients had an average length of stay of 6.6 days (range, 3–30 days). Standing anteroposterior and lateral standing scoliosis radiographs were obtained on every patient before discharge. Repeat standing radiographs were then repeated at 6 weeks, 3 months, 6 months, and 1 year after surgery to assess alignment and hardware.

Resident Education

Resident education in the management of spinal disorders, including deformity and AIS, comes in many different forms at our institution. Formal instruction comes in the form of bimonthly

Table 1. Patient Demographics and Surgical Data for 46 Patients Undergoing 57 Operations for Adolescent Idiopathic Scoliosis From November 2006 to December 2016 at Loyola University Medical Center

Characteristic	Value
Age (years)	11—22 (16.2)
Sex, male/female	9/37
Preoperative Cobb angle	40°—85° (56.8°)
Postoperative Cobb angle	4°—30° (15.7°)
Percent of correction	35.3%—90.9% (72.2%)
Number of levels fused	8—14 (12.1)
Length of procedure (minutes)	215—575 (336)
EBL (mL)	200—4000 (603)
LOS (days)	3—30 (6.4)
Follow-up (months)	4—72 (21.8)
Complications	1 Delayed distal hardware failure 1 Temporary paraplegia because of delayed anterior spinal artery ischemia 1 Urinary tract infection 1 Postoperative ileus

Values are range (average) or number of participants.
EBL, estimated blood loss; LOS, length of stay.

didactics that include lectures focused on surgical indications and other management considerations. Additional instruction occurs every day in the operating room, clinic, or at the bedside. The faculty meet weekly to discuss resident progress and give formal feedback with resident evaluations which the residents are able to view every 6 months. The faculty evaluate each resident's progress toward fulfilling objective spine-specific benchmarks which are based on a resident's clinical, bedside, operating room, and conference performance.

A survey was sent out to the past 7 residents that graduated from our academic institution. The survey was used to assess the impact the exposure to AIS during their neurosurgery training had on their current neurosurgical practice.

RESULTS

The 9 male and 37 female patients had an average age of 16.2 years, with a range from 11 to 22 years. Table 1 includes the patient demographics and surgical data for the 46 patients who underwent neurosurgical management for AIS at Loyola University Medical Center. All 46 patients underwent deformity correction and arthrodesis via a posterior approach. Eleven patients underwent a planned, staged procedure to help decrease operative time and blood loss. The 11 patients returned to the operating room the next day or 2 days after their original procedure. Thirty-five patients had their deformity correction completed after 1 posterior procedure. Eleven patients underwent a thoracotomy with general surgery to allow for an anterior release and intradiscal allograft arthrodesis to aid with the posterior deformity correction. All 11 patients also had postoperative chest tube drainage to prevent pneumothorax. The number of spinal levels treated ranged from 8 to 14 (average 12.1 levels). Operative time ranged from 215 to 575 minutes (average 336 minutes).

Cobb Angle

For patients with scoliosis, the coronal Cobb angle was measured on posteroanterior standing long cassette radiographs preoperatively and postoperatively and was measured on follow-up radiographs (Figure 1). The sagittal Cobb angle was measured on lateral standing radiographs for patients with kyphosis. Overall, the preoperative Cobb angle averaged 56.8° (range, 40°—85°). The postoperative Cobb angle average was 15.7° (range, 4°—30°). The average Cobb angle correction was 72.2% (range, 35.3%—90.9%). Three patients had significant kyphoscoliosis. The average preoperative sagittal Cobb angle was 72.7° (range, 48°—85°). The average postoperative Cobb angle was 37.3° (range, 21°—55°) with an average correction of 49.7% (range, 35.3%—57.6%). Rotational correction through apical derotation techniques was adopted in later years, resulting in much greater cosmetic and overall corrective results (Figure 2).[13,14]

Complications and Follow-Up

All patients were followed-up in the clinic postoperatively, with an average follow-up of 21.8 months (range, 4—72 months). During the course of follow-up, there was no evidence of pseudoarthrosis; however, 1 patient presented with distal hardware failure after T4-L3 posterior fusion 1 year after surgery. She was found to have a fractured left L3 pedicle screw after complaining of new-onset left-sided paraspinal pain. The screw was removed along with shortening of the left-sided rod. The same patient 5 years after her original fusion presented with right lower back pain and right lateral thigh pain that did not improve with conservative management. On radiographs, the patient had a broken right-sided rod at the caudal end of her construct between L2 and L3. She was taken to the operating room to remove the right L3 screw and removed the broken rod remnant, which improved her pain.

One patient developed postoperative paraparesis, but gradually regained lower extremity function by 8-month follow-up. One patient developed postoperative urinary tract infection while still an inpatient. Another patient developed postoperative ileus that required a nasogastric tube for gastric decompression after a staged anterior release/posterior fusion procedure. The ileus resolved before she was discharged. There were no wound infections and no patients developed chronic pain syndrome. All patients eventually returned to full activity with no limitations.

Resident Survey

The last 7 graduates of our institution are practicing all over the country. Three resident graduates went on to do a vascular/skull base fellowship, 1 graduate did a neuro-oncology fellowship, and 3 residents did not do a fellowship, but instead went straight into private practice after graduating. Six of the 7 graduates are part of a private practice and manage spine patients, whereas 1 graduate is in

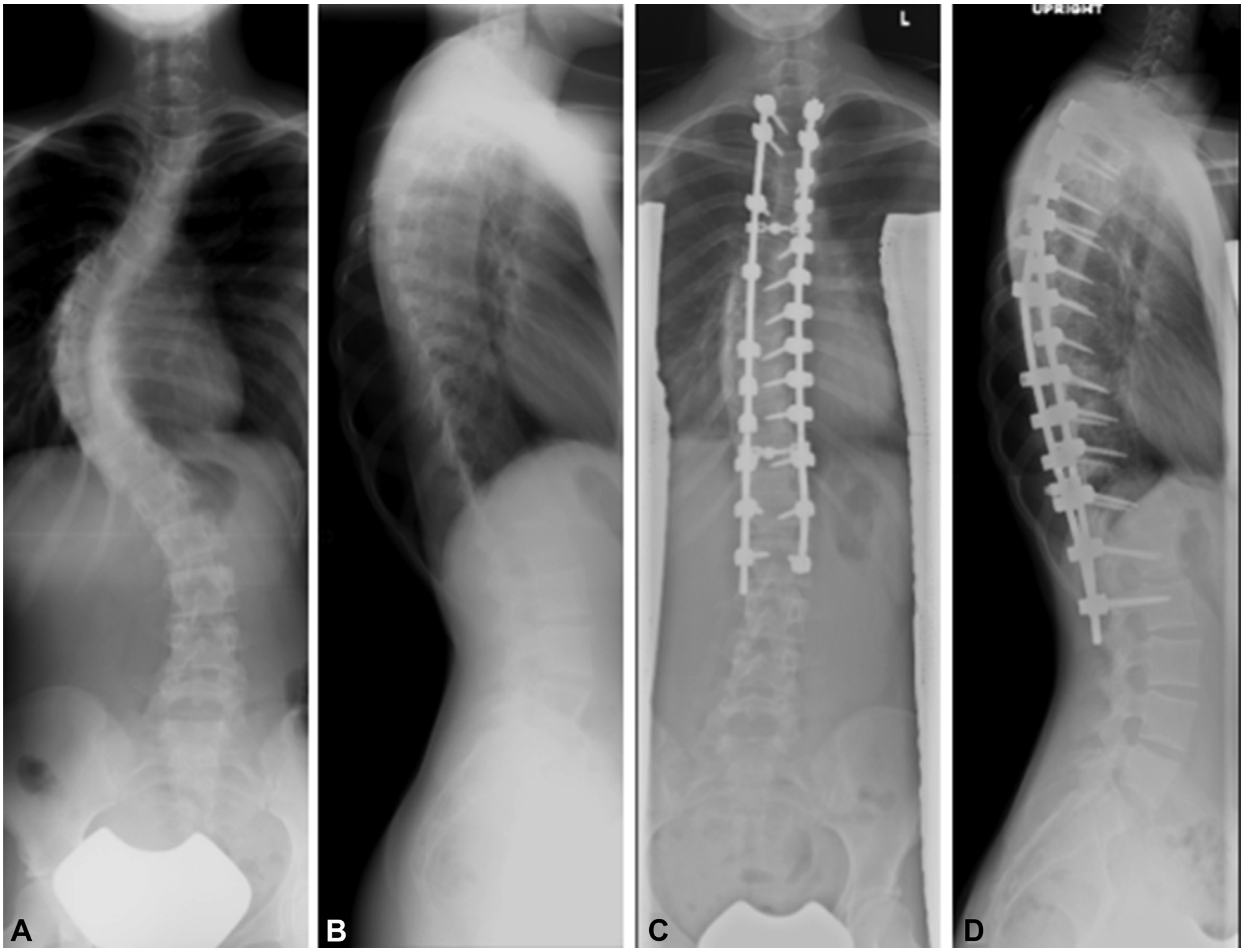

Figure 1. Pre- and postoperative standing scoliosis radiographs: combined approach. (**A** and **B**) Preoperative anteroposterior (AP) and lateral views show a 70° dextroscoliosis with its apex at T9. (**C** and **D**) Postoperative AP and lateral views after right thoracotomy and T7-12 anterior release with T2-L2 posterior segmental instrumentation and deformity correction to 20° (71.4% correction).

an academic institution and does not manage spine patients. The 6 graduates that manage spine patients estimate that spinal pathologies constitute 35%–85% of their overall practice, and 2 of these graduates currently manage patients with AIS; however, both of these surgeons only manage patients with AIS nonoperatively. Three of the 7 past graduates were exposed to surgical treatment of 5–12 patients with AIS during their residency, whereas the remaining 4 graduates did >12 surgical cases for the treatment of AIS during residency. None of the past 7 graduates manage patients with AIS surgically, but all stated that AIS exposure (both operative and nonoperative) during residency has enhanced their clinical knowledge of spinal mechanics and deformity correction. Specifically, past residents felt that exposure to AIS management during residency had a positive impact on spinal nonoperative treatment, bracing, spinal anatomy, pedicle anatomy, biomechanics, and implant design (**Supplemental Appendix S1**).

DISCUSSION

Spinal deformities affect all age groups. Indeed, an age-related continuum of sagittal and coronal malalignment can be envisioned beginning with AIS, untreated AIS in midlife, and degenerative deformities prevalent in the fifth decade of life and beyond.[15,16] Although differences exist regarding spinal location, degree of curvature, rigidity, and associated neurologic symptoms between old and young patients, similarities also exist. Use of universal spinal instrumentation, applied corrective forces, and preservation of neurologic function are keystones to the successful clinical management of these complex patients, regardless of age.[17,18] Insight into the issues is reinforced through contact with patients presenting at different stages of this continuum.[19,20] Through such contact by neurosurgery residents, it is thought that career-long enhancements in the perception of causes and treatment of adult deformities will develop (**Table 2**).

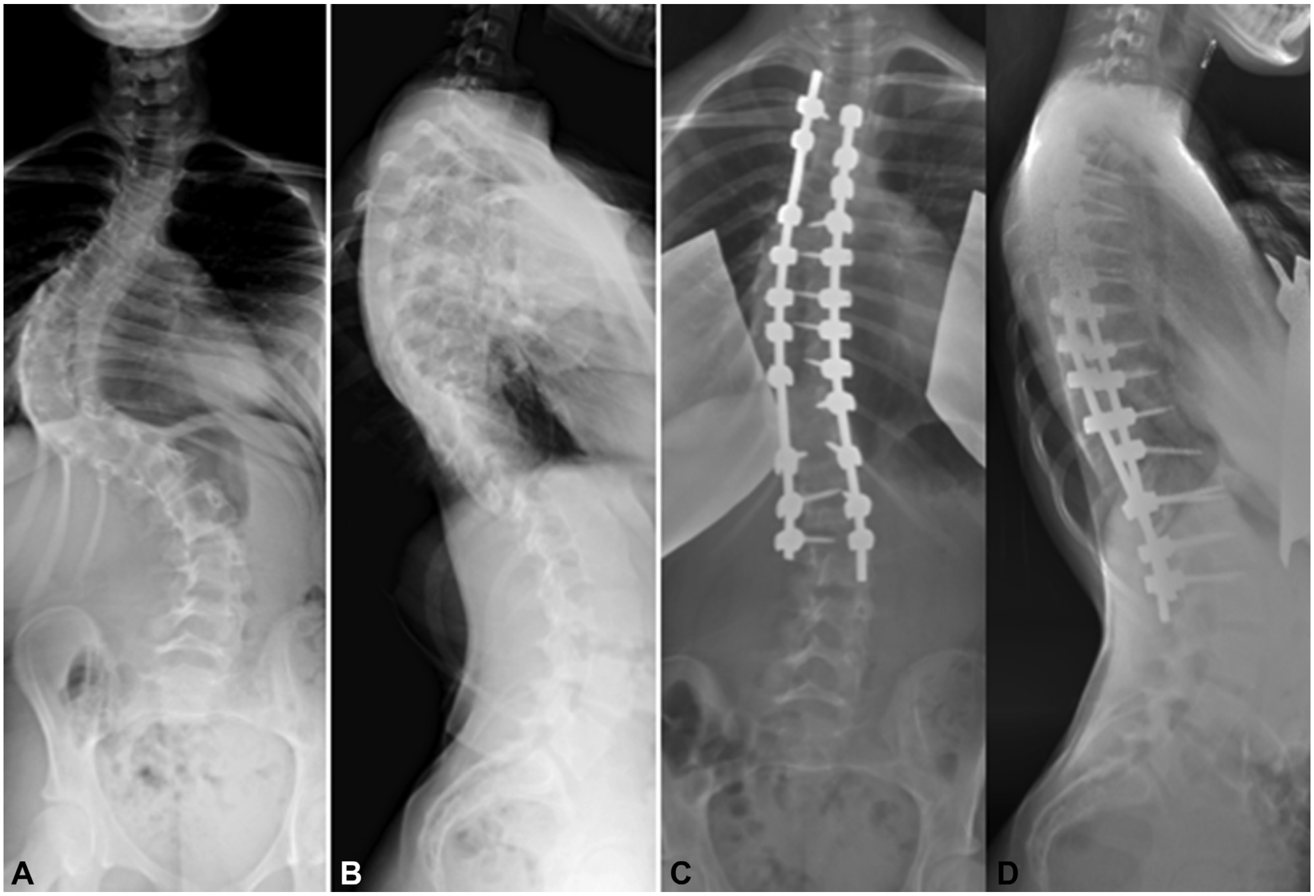

Figure 2. Pre- and postoperative standing scoliosis radiographs: posterior-only approach. (**A** and **B**) Preoperative anteroposterior (AP) and lateral views show 84° dextroscoliosis with its apex at T8. (**C** and **D**) Postoperative AP and lateral views after T3-L2 posterior segmental instrumentation and deformity correction with apical derotation to 28° (66.7% correction).

Although this summary is not an exhaustive study of these factors, we think the synthesis of patients with AIS into our training program has significantly enhanced the degree to which residents experience and perceive spinal column deformities and their management. Furthermore, these experiences appear through such contact to solidify the notion that the spinal column ages and deforms under predictable patterns and the mechanisms to counter these effects play a significant role in surgical strategies.

Deformity Correction

Numerous options exist for approaches to correcting deformity in AIS. Anterior approaches have been used as an isolated deformity correction option and in combination with a posterior approach. Anterior only approaches have been shown to have similar corrections and cosmetic outcomes to posterior approaches; however, they have been associated with significant reduction of pulmonary function and increased risk of vascular spinal cord injury resulting from segmental vessel ligation.[21] A meta-analysis comparing combined anterior-posterior versus posterior-only approaches showed similar radiographic results with reduced complication rate, blood loss, operative time, and length of stay with posterior-only approaches.[22] In an international consensus for optimal treatment of AIS published by de Kleuver et al.,[23] the panel agreed that anterior release was not recommended for routine cases, hence our gradual move away from anterior release surgery. Additionally, greater experience with posterior column instrumentation has afforded excellent surgical corrections and subsequent stability without any anterior transcavitary procedures.

Staging of the Procedure

Eleven patients underwent a planned, staged procedure to help decrease operative time and blood loss. Three patients that had a posterior-only approach underwent a staged procedure, whereas 8 patients underwent a staged procedure for a combined anterior release with posterior fusion. The ultimate goal of staging the procedure was to decrease complications. There have been

Table 2. Impact of Adolescent Idiopathic Scoliosis Management on Resident Training and Clinical Practice

Progression of Institutional Experience in the Management of AIS	Impact on Neurosurgical Training	Potential Clinical Application
Increased consideration of rotational issues in AIS	Greater understanding of 3-dimensional deformity correction and applied biomechanics	Choice of pedicle screw design (fixed plane vs. multiaxial)
Movement away from anterior release in structural thoracic AIS	Improved insight into the determinants of posterior construct lengths and geometry	Lever arm biomechanics, intraoperative cantilever forces
Impact of bracing on the management of early AIS	Greater awareness of nonsurgical treatments for deformity and biomechanics of external bracing	Clamshell TLSO vs. Jewett-type bracing
Degree of correction achieved by flexibility of curve, intraoperative positioning, and osteotomies	Greater understanding of the role spinal degeneration plays in curve flexibility	Choice of magnitude of surgical correction (osteotomy or no osteotomy, type of osteotomy) of adult spinal deformities
Familiarity and application of the Lenke classification for AIS	Greater understanding of compensatory spinal mechanisms	Importance of sagittal balance and alignment in adult patients

AIS, adolescent idiopathic scoliosis; TLSO, thoracic lumbar sacral orthosis.

multiple studies connecting longer operative time and greater blood loss with increased risk for postoperative morbidity.[24] Carreon et al.[25] concluded that increased operative blood loss, prolonged surgery time, and prolonged anesthesia time increased nonneurologic complications such as respiratory complications and wound infections. Puffer et al.[26] was another study that showed increased anesthesia time increased the risk of surgical site infections in spinal fusions.

Complications

Besides operative time and blood loss, the anterior approach has also been connected with higher rates of complications. According to the database search done by De la Garza Ramos et al.,[27] the rates of postoperative complications for posterior, anterior, and combined approaches were 6.7%, 10.0%, and 19.8%, respectively ($P < 0.001$). The traditional combined anterior release/posterior fusion approach has become increasingly replaced by the posterior-only spinal fusion. Several advances in instrumentation and surgical technology are presumed to be responsible for these trends. Elsewhere in the literature, similar trends have been observed in which posterior-only approaches to the spine combined with the introduction of more advanced instrumentation have resulted in decreased complication rates and blood loss and an increase in patient satisfaction associated with the posterior-only approach.[22,24,28]

Our most severe complication occurred in the previously described 17-year-old young man who underwent a T3-L2 posterior fusion. During the corrective phase of the procedure, cobalt chrome rods and cantilever maneuvers were used to correct the deformity. In situ maneuvers were also used to further adjust the correction slightly. After correction of the deformity, the patient was found to have a normal wake-up test and normal examination postoperatively. Early the next morning, the patient was noted to have flaccid paralysis in his lower extremities. Imaging studies were carried out, and the neural axis failed to demonstrate any other potential cause for the neurologic deficit; however, imaging was limited by the presence of the instrumentation. Magnetic resonance imaging of the spine demonstrated T2 hyperintensity from T3-10 in the anterior cord, consistent with spinal cord infarction in the distribution of the anterior spinal artery. Fortunately, after extensive rehabilitation, the patient has regained full strength in his lower extremities and normal bladder function at 8 months postoperatively.

Curriculum/Objective Benchmarks for Residents

The education that a resident receives throughout his or her neurosurgery residency lays the foundation for a successful surgical career. Our institution has instituted objective clinical benchmarks that each resident should strive toward during training. These spine-specific benchmarks are evaluated by our spine specialists to assess if the resident is competent in all aspects of spine surgery.

The first benchmark is understanding basic spine anatomy. This knowledge is to be the base on which all other information sits. Basic anatomic knowledge helps lead to mastering spine anatomy and fosters the formation of a 3-dimensional understanding of the spine, an essential component of treating spine disorders in the operating room. The second benchmark is understanding common spinal pathologies. A resident must be able to identify spinal pathologies based on presenting symptoms and the use of the neurologic examination. A resident must be able to formulate a differential diagnosis based on the neurologic examination without relying solely on the spine imaging. The knowledge from daily rounds, experience in the spine clinics, and didactics aid a resident in meeting these first 2 benchmarks.

To surpass the next benchmark, the resident must exhibit basic surgical skill and knowledge. This starts during the second and third year at our institution, when junior residents operate concurrently with a senior-level resident and attending surgeon. Surgical knowledge begins with choice of operating table, surgical equipment, positioning to allow access to the site of interest while avoiding positional neuropathies, exposure, and wound closure. This is also the time where residents learn about the use of intraoperative monitoring and appropriate interpretation and reaction to the data it provides. Residents will also gain surgical skill and knowledge as junior residents as they begin to do cases, such as diskectomies and laminectomies.

The fourth benchmark focuses on the management of spinal patients. This is a very important skill set that is built throughout residency in which the resident must display the ability to not only manage patients postoperatively, but also be able to appropriately and safely select patients for surgery. Residents must display the ability to treat patients conservatively and be able to correctly identify indications for surgical intervention.

The fifth benchmark ensures that the neurosurgery resident is able to treat complex spinal patients, including patients with kyphotic deformities, scoliosis, AIS, spinal tumors, and other spinal deformities. Residents must display an understanding of sagittal alignment, pelvic parameters, and mismatch of pelvic incidence and lumbar lordosis. The resident is expected to be able to participate in advanced spinal cases, including long-segment pedicle screw fixation and deformity correction, which reinforces and tests 3-dimensional understanding of anatomy, deformity correction, and applied biomechanics. Ultimately, the graduating resident should be able to fulfill the final benchmark, exhibiting the ability to take everything that was learned from residency and safely manage patients with complex spinal disorders, from clinic presentation and hospital admission, through surgery, and to hospital discharge and follow-up.

Resident Survey

During the postgraduate year 6 at our institution, each resident is the spine service chief resident, and it is during that time when our institution's residents get exposure to nonoperative and operative management of patients with AIS. Although each resident has exposure to surgical management of patients with AIS, according to the survey, none of our recent graduates are currently surgically treating patients with AIS. Two of the past 7 graduates manage patients with AIS nonoperatively, with bracing or with serial imaging to closely evaluate for progression of the coronal deformity. The survey's results confirmed that exposure to AIS management goes beyond just treating patients with AIS when out practicing after residency. Although none of the residents currently treat AIS surgically, all 7 graduates agreed that AIS exposure enhanced their knowledge in adult spinal disease management. AIS management has become more prevalent in neurosurgical training, but remains a field traditionally dominated by orthopedic surgery. As we continue to expand the integration of AIS management into our training program's curriculum, we hope to expand the range of surgeons capable of safely caring for this subset of patients. Our results suggest that AIS can be safely managed by neurologic surgeons with appropriate specialized training, and in time we expect to see select graduates from our program treating these patients.

Translating Experience with AIS Management to General Spine Practice

Resident involvement with the management of AIS enhances the understanding of general spine practices by providing a unique perspective on spinal deformity that is not universal within neurosurgical training. Table 2 summarizes many of the components of treatment of AIS that can be applied to general neurosurgical practice and resident education. The right choice of spinal instrumentation and the nuances of its placement are important and unavoidable considerations in the surgical management of AIS. Understanding the characteristics, advantages, and limitations of these instruments is vital to determining their optimal use. The varied and complex anatomic variances within AIS and their interplay with skeletal immaturity provide a unique illustration of the physics of spinal pathology and lever arm biomechanics and cantilever forces that instrumentation and spinal structures exert in adults and pediatrics. Form follows function is an important principle in anatomy and medicine that is vital to consider in the treatment of AIS and can be translated to adult practice as well.

Considerations of anatomic variants, unusual spinal disorders, and deformity flexibility are vital when designing a surgical plan in AIS. These same considerations can be applied to adult spinal deformity. Whereas spinal dysraphism in a pediatric patient may lead to dissection strategies to avoid durotomy or neural compromise, similar maneuvers can be used in adult patients with prior surgeries. Osteotomies and anterior releases for fixed curves in the pediatric spine can aid the surgeon in selecting strategies to increase deformity correction in the adult spine, where degeneration, compressive forces, and prior surgeries can lead to fusion and spinal malalignment.

Finally, a keen eye for patient safety, complication avoidance, and conservative measures is essential for AIS management. Meaningful use of intraoperative monitoring, clear communication with anesthesia and nursing personnel, and strategies to protect nervous structures during spinal deformity correction maneuvers are as vital in adult practice as they are in AIS. Likewise, meaningful and safe use of conservative measures such as bracing is vital for all patients to avoid unnecessary and complex surgery.

Limitations

This review was limited by a relatively small patient population and its retrospective nature. Approaches to surgical treatment of AIS can vary greatly from surgeon to surgeon, and there is little high-level evidence to provide guidance. Future study should use expert opinions and consensus to prospectively evaluate treatment options and strategies for complication avoidance. Likewise, assessing the influence of AIS exposure to neurosurgery residents is difficult to quantify, but sufficient evidence from studies of deficiencies in neurosurgeons' perception of spinal deformities suggests, given proper guidance and expertise, residents can develop enhanced skill sets as outlined in Table 2.[17,29]

Careful consideration should be given before incorporating the management of AIS into residency training. Specialized experience is required, blending the expertise of both neurosurgery and orthopedics. The senior author and primary surgeon in this study benefited from training with complex spine surgeons from both disciplines, without which this experience would not be possible. Given the adoption of combined fellowships incorporating both orthopedics and neurosurgery, this degree of training will likely become more easily accessible and efficient in the near future. Another trend that has developed is pediatric neurosurgeons who have undergone spine-specific training who are surgically treating patients with AIS. Time will tell for who is best to care for these patients.

It is also our specialty's responsibility to oversee the expansion of surgical care within the field of spinal neurosurgery, to ensure surgeons performing these cases are properly trained. Organizations, such as the Scoliosis Research Society, which have strict membership criteria, can serve as a mechanism of governance for neurosurgeons that want to include management of spinal deformity into their clinical practice. Members of the senior society think that neurosurgery residency prepares the graduate for an adult degenerative spine practice without further fellowship, but additional training is suggested for oncology, adult deformity, and pediatric deformity. As neurosurgeons start to perform adult and pediatric deformity cases, it is important to ensure good outcomes with low complications. The lives and well-being of our patients depend on this self-governance.

CONCLUSIONS

Surgical and nonsurgical management of AIS is a complex and evolving matter. Safe and effective performance of these surgeries requires a thorough understanding of spinal biomechanics, surgical risks, safe techniques, and the natural history of idiopathic curves. Many of these same principles serve to enhance resident preparation for the wide variability encountered in clinical practice among adult patients. Although not necessary to promote adequate treatment strategies and techniques for adult patients, our institutional experience is such that it has focused resident adoption of complication avoidance and outcome optimization in all patients.

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