What would be the annual cost savings if fewer screws were used in adolescent idiopathic scoliosis treatment in the US?

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OBJECTIVE There is substantial heterogeneity in the number of screws used per level fused in adolescent idiopathic scoliosis (AIS) surgery. Assuming equivalent clinical outcomes, the potential cost savings of using fewer pedicle screws were estimated using a medical decision model with sensitivity analysis.

METHODS Descriptive analyses explored the annual costs for 5710 AIS inpatient stays using discharge data from the 2009 Kids' Inpatient Database (Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality), which is a national all-payer inpatient database. Patients between 10 and 17 years of age were identified using the ICD-9-CM code for idiopathic scoliosis (737.30). All inpatient stays were assumed to represent 10-level fusions with pedicle screws for AIS. High screw density was defined at 1.8 screws per level fused, and the standard screw density was defined as 1.48 screws per level fused. The surgical return for screw malposition was set at \$23,762. A sensitivity analysis was performed by varying the cost per screw (\$600–\$1000) and the rate of surgical revisions for screw malposition (0.117%–0.483% of screws; 0.8%–4.3% of patients). The reported outcomes include estimated prevented malpositioned screws (set at 5.1%), averted revision surgeries, and annual cost savings in 2009 US dollars, assuming similar clinical outcomes (rates of complications, revision) using a standard- versus high-density pattern.

RESULTS The total annual costs for 5710 AIS hospital stays was \$278 million (\$48,900 per patient). Substituting a high for a standard screw density yields 3.2 fewer screws implanted per patient, with 932 malpositioned screws prevented and 21 to 88 revision surgeries for implant malposition averted, and a potential annual cost savings of \$11 million to \$20 million (4%–7% reduction in the total cost of AIS hospitalizations).

CONCLUSIONS Reducing the number of screws used in scoliosis surgery could potentially decrease national AIS hospitalization costs by up to 7%, which may improve the safety and efficiency of care. However, such a screw construct must first be proven safe and effective.

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KEY WORDS screw; implant density; scoliosis; curve correction; outcomes; malposition; deformity

SIGNIFICANT heterogeneity exists in the number and distribution of pedicle screws used in the treatment of adolescent idiopathic scoliosis (AIS).^{7,43,48} Pedicle screws are the state-of-the-art implant for the surgical correction of scoliosis.^{10,13,31} Implant density is defined as the number of implants per level fused. Often, pedicle screws are placed bilaterally at every vertebra included in the pos-

terior spinal fusion, representing a maximum density pattern of 2.0 anchors per vertebral level fused. While some practitioners recommend far fewer screws, with implant densities as low as 1.04 screws per level,^{21,32,47,48} the optimum number and configuration of screw placement for the treatment of AIS has not been established.^{5,54}

Compared with previous implants, pedicle screws offer

ABBREVIATIONS AIS = adolescent idiopathic scoliosis; KID = Kids' Inpatient Database.

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significant advantages, including a lower revision surgery rate and higher pullout strength than a hybrid or hook-rod construct.^{10,14,16,17,25,26,28,31,33,37,42,48,49} Pedicle screws may obviate the need for anterior fusion.¹⁷ Also, improved pulmonary function, balance, patient-reported appearance scores, and maintenance of correction over time have been reported.^{16,17,45,53} A recent structured literature review reveals a wide variety in the mean implant density reported in clinical practice.³⁹ Implant densities varied from 1.04 to 2.0 screws per level fused, while in the same studies the mean percentage of major Cobb angle correction only varied from 64% to 70%.⁴⁰

With the introduction of pedicle screws, the cost of scoliosis surgery has increased due to high implant expenses,⁴¹ which comprise on average 29% of the total hospital costs incurred during primary scoliosis surgery.²⁴ Decreasing the number of implants used may lower the surgical implant cost. If low-density constructs are shown to be safe and clinically equivalent to higher density constructs, fewer pedicle screws could be used, which may have significant benefits in terms of surgical efficiency and the effective use of health care resources.

Furthermore, some screws are malpositioned. Decreasing the number of screws used may conceivably reduce the number of malpositioned screws. In pediatric patients, up to 1.8% to 9.0% of screws are malpositioned.^{30,51} Assuming that on average 10 spinal levels are fused with 2 screws placed per level, this represents up to 1 to 2 malpositioned screws per patient.^{29,30,35} The implications of asymptomatic malpositioned screws are unknown. However, there are rare reports of catastrophic events resulting from screw malpositioning, including vascular and neurological injury.^{11,19,37,44,46,47,55} Due to poor data regarding the incidence of such rare events, it is difficult to include these events in a medical model. However, return to surgery for implant malposition is well-reported in the literature, affecting up to 0.66% to 4.3% of patients.^{3,7,14,20,38} Thus, if clinically equivalent, using fewer screws overall may incrementally improve patient safety with fewer malpositioned screws and thus fewer returns to the operating room for screw malposition. This may subsequently reduce the cost of scoliosis surgery due to fewer surgical returns for implant malposition.

We undertook this study to determine the effects on US health care spending if surgeons decreased the numbers of screws used in the surgical management of AIS. We used the Kids' Inpatient Database (KID) to estimate the anticipated annual US cost savings from changing from a high- to low-density screw pattern, including both implant costs and returning to the operating room for screw malposition as components in the potential cost savings. This paper describes the estimated economic effects of a practice change to using fewer screws, assuming that this results in no change in patient outcomes.

Methods

We undertook descriptive analyses to explore the annual costs for AIS inpatient stays using discharge data from the 2009 KID (Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality), which is a

national all-payer hospital inpatient database (<https://www.hcup-us.ahrq.gov/kidoverview.jsp>). The analysis was performed from a payer's perspective. Since many of the reported studies did not provide a year for the cost estimates, no conversion to 2009 dollars was performed. Patients between 10 and 17 years of age with an AIS inpatient stay were identified using ICD-9-CM diagnosis code 737.30, which was recorded in the primary diagnosis field. This yielded 5710 hospitalizations. All AIS hospital admissions were assumed to be due to primary spinal fusion for the treatment of AIS. All surgeries were assumed to be posterior instrumentation with pedicle screw fixation over 10 fusion levels, which is the commonly reported mean length of AIS fusion (Table 1).^{4,8,28,24,26} All spinal fusions were assumed to be carried out exclusively with pedicle screws.

Several implant density patterns were considered, including the current standard implant density (1.48 implants per level fused), high implant density (1.8 implants per level fused), low implant density (1.4 implants per level fused), very low implant density (1.06 implants per level fused), and maximum implant density (2.0 implants per level fused) (Fig. 1). Each vertebral level typically has 2 pedicles that could potentially be instrumented. In the literature, the lowest mean implant density reported to have successful results is 1.06 screws per level fused.^{21,32,34,50} Thus, 1.06 screws per level fused was then defined as very low implant density. Multiple models were considered. For the purposes of this paper, however, the primary model discussed was changed from high implant density (1.8 screws per level fused) to standard implant density (1.48 screws per level fused). We selected this case scenario because this represents a modest change in practice. Likely, most surgeons accustomed to a high implant density constructs would be willing to use 3 to 4 fewer screws per construct. The current mean implant density used among US surgeons is unknown.

The cost of return to the operating room for screw malposition was set at \$23,762.^{2,39,56} (Table 2). There is only 1 paper that provides cost data regarding screw revision surgery.⁵⁶ Other citations describe the cost of revision lumbar decompression and fusion surgery, but this is likely more expensive than straightforward screw revision.^{2,39} Thus, the lower end of the cost spectrum was used in our model for the cost of returning to the operating room for screw revision. A sensitivity analysis was performed by varying the cost per screw (\$600–\$1000 per screw). The rate of return to surgery for screw malposition also varied from 0.117% to 0.483% of screws placed (Table 3).^{3,14,20,27,36,38} The reported outcomes include the anticipated cost savings from implant costs, potential number of malpositioned screws prevented, and cost savings from averted returns to surgery for screw malposition. The total annual cost savings (in 2009 US dollars) were estimated based on the implant costs and averted returns to surgery. No attempt was made to assess the cost of catastrophic screw malposition that resulted in vascular or neurological compromise. No assessment was made for changes in surgical time due to fewer screws placed at the time of surgery. Clinical outcomes and complications were assumed to be equivalent regardless of implant density.

Since only limited data sets were used for this study, institutional review board approval was not required. This

TABLE 1. Cited references for the numbers of levels fused in patients with AIS

Authors & Year	Study Type	Surgery	No. of Patients	No. of Levels Fused*
Gebhart et al., 2014	Retrospective review	Posterior spinal fusion for AIS, all curve patterns	119	10.7 (range 5–15)
Kamerlink et al., 2010	Retrospective review	Posterior spinal fusion for AIS, all curve patterns	111	10.5 ± 1.9
Arlet et al., 2009	Retrospective review	Posterior spinal fusion for AIS, Lenke 1 and 2 curve patterns	40	10.3
Bharucha et al., 2013	Retrospective review	Posterior spinal fusion	91	9.0 ± 1.6
Kim et al., 2006	Retrospective review	Posterior spinal fusion for AIS	58	11.7 ± 1.6

* The mean, mean ± standard deviation, or mean (range) is shown.

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Results

According to the 2009 KID, the total annual costs for 5710 AIS hospital stays was \$278 million. This represents a cost of \$48,900 per patient. If 29% of the surgical costs are secondary to implants, as reported by Kamerlink et al.,²⁴ this represents \$81 million dollars spent on implants. Due to the limited data contained in KID, the type and number of implants used are unknown. Modeling, however, was undertaken to estimate the cost savings if the practice patterns changed.

The results of medical modeling with sensitivity analysis are reported with the estimated national and individual cost savings for changes in a variety of screw densities (Table 4). We estimated that changing from a high-density (1.8 screws per level fused) to a standard screw pattern (1.48) would result in \$10 million to \$18 million in annual US health care savings from implant costs alone. By including the costs of the predicted 21 to 88 averted surgi-

cal returns due to malpositioned screws, this would reduce costs by \$11 million to \$20 million annually. This would effectively reduce the total US cost of AIS surgery by 4% to 7%. If even fewer screws were used, this would obviously result in greater potential cost savings (Figs. 2 and 3).

Discussion

This study reports the anticipated cost reduction from a payer's perspective if fewer screws are used for AIS surgery. This model assumes that the complications, clinical results, and patient recovery are equivalent between low implant density and high implant density cohorts. This hypothesis has not yet been proven. This study was undertaken to evaluate the anticipated payer cost savings if a low-density pedicle screw construct could be safely substituted for a high- or maximum-density construct.

Characteristics of the Medical Model

Significant uncertainty and assumptions are required for any medical model. In this study, some of the uncertainty in the model parameters was accounted for by using a sensitivity analysis to evaluate the reported variability in

FIG. 1. Implant density is defined as the number of screws, rods, and hooks per level fused. These radiographs show examples of constructs with various implant densities. **A:** Maximum-density construct (2.0 screws per level fused). **B:** High-density construct (1.8 screws per level fused). **C:** Low-density construct (1.4 screws per level fused). **D:** Minimum-density construct (1.06 screws per level fused).

TABLE 2. Cited references for the cost of revision spine surgery

Authors & Year	Study Type	Surgery	No. of Patients	Cost*
Parker et al., 2012	Retrospective review	Revision lumbar fusion procedure	150	\$32,915 (range \$24,935–\$63,769)
Watkins et al., 2010	Cost analysis	Screw revision	Hospital data	\$23,762
Adogwa et al., 2012	Retrospective review	Revision lumbar fusion procedure	42	\$21,060 ± 4,459
Adogwa et al., 2015	Retrospective review	Revision fusion for pseudoarthrosis	47	\$23,865 ± 270

* The mean, mean ± standard deviation, or mean (range) is shown.

the rates of return to the operating room due to screw malposition and the costs of pedicle screws. The results are reported as a range and take into account the variability in screw costs and rates of screw malposition.

Rate of Screw Malposition

One may argue that decreasing the overall number of pedicle screws may not decrease the number of malpositioned screws. We would argue that if only a certain number of screws are to be used, surgeons would be most likely to place screws in the most easily accessible, reliable pedicles. If the goal of surgery is only to instrument 50% of the pedicles for a 1.0 implant density, surgeons may be more likely to not instrument a pedicle if the initial trajectory is not satisfactory or if the pedicle appears narrow and highly cortical on preoperative imaging. The highest rate of screw malposition is typically at the levels where the pedicles are smallest (T-6, T-7, and T-8).²⁹ The optimum strategic array of pedicle screws, however, has not been determined in the literature, and wide surgeon variability exists in terms of both the number and chosen array of screw placement.^{5,6,40} Thus, this study made the reasonable assumption that, should the overall number of screws decrease, the overall rate of malpositioning would

proportionately decrease. We acknowledge that the data on this topic are limited.

Limitations of the Medical Model

Additional parameters, however, were not included in the model, including operative time, fluoroscopy time, and the cost to the payer from asymptomatic malpositioned screws. Fewer pedicle screws have been shown to result in a shorter operative time and decreased radiation if intraoperative fluoroscopy is used.⁵² The minimum screw density pattern reduces the operative time (mean 145 minutes vs 177 minutes for 10-level fusion) required for screw placement.^{12,22} Shorter operative time may conceivably decrease the rate of infections and other medical complications.¹² However, due to the lack of reliable available data, these factors were not included in the model.

Similarly, the payer costs for asymptomatic malpositioned pedicle screws were not included in the model. At this time, malpositioned screws are thought to be well tolerated, but long-term outcomes data are not available for determining the cost or significance of the medial and lateral screw violations reported for 1.8% to 9% of screws placed for idiopathic scoliosis.^{30,51} The adult literature does reveal several case reports resulting in delayed vascular

TABLE 3. Cited references regarding return to surgery

Authors & Year	Study Type	Surgical Indication	% Malpositioned Screws (% of Patients w/ Malpositioned Screw)	Screws Resulting in Return to OR	Patients Returning to OR for Screw Malposition
Amiot et al., 2000	Retrospective comparison	Spine fusion	0.6% w/ fluoroguidance & 0% w/ fluoro navigation	5/544 fluoro screws (0.9%)	5/100 w/ fluoro guidance (5%) & 0/50 w/ fluoro navigation (0%)
Belmont et al., 2002	Retrospective review	Spine fusion, fluoro guidance	1–2% (10%)	2/399 screws (0.5%)	4% (2/47 patients)
Koktekir et al., 2014	Retrospective review	Spine fusion, fluoro assisted	2.2% (10.6%)	15/1218 screws (1.2%)	7.5% (15/198 patients)
Motiei-Langroudi et al., 2015	Prospective study	Spine fusion	2.3%	1/770 screws (0.13%)	0.8% (1/114 patients)
Parker et al., 2011	Retrospective review	Spine fusion, freehand	1.7% (9.0%)	8/6818 (0.117%)	0.8% (8/964 patients)
Hicks et al., 2010	Systematic review	AIS	4.2% (11%)	12/4570 (0.26%)	0.66% (11/1666 patients)
Di Silvestre et al., 2007	Retrospective review	Scoliosis patients, primarily AIS, mini laminotomy	1.7% (11.3%)	5/1035 thoracic screws placed (0.483%)	4.3% (5/115 patients)

Fluoro = fluoroscopic; OR = operating room.

TABLE 4. Analysis of total US cost savings in changing from high-density to low-density pedicle screw constructs in 2009 dollars*

Change in Implant Density (Screws Per Level Fused)	Screw Reduction Per Patient	Mean Cost Savings Per Patient	Inpatient National Cost Savings (Implant Costs)	% Reduction from Current Costs	Prevented Return to OR for Malposition (0.117–0.483% of screws)	Prevented Malpositioned Screws
High (1.8) → standard (1.48)	3.2	\$2000–\$3500	\$11M–\$20M (\$10M–\$18M)	4%–7%	21–88	932
Standard (1.48) → very low (1.06)	4.2	\$2600–\$4700	\$15M–\$27M (\$14M–\$24M)	5%–10%	28–116	1223
High (1.8) → very low (1.06)	7.4	\$4600–\$8200	\$26M–\$47M (\$24M–\$42M)	9%–17%	49–204	2255
High (1.8) → low (1.4)	4.0	\$2511–\$4459	\$14M–\$26M (\$14M–\$23M)	5%–9%	26–110	1165
Maximum (2.0) → very low (1.06)	9.4	\$5900–\$10,000	\$34M–\$60M (\$32M–\$54M)	12%–22%	63–260	2737

M = million.

* In 2009, Healthcare Cost and Utilization Project reported 5710 hospitalizations at \$48,900 per patient.

injury from screw malposition.²⁵ Similarly, neurological and vascular injury have been reported from severely malpositioned pedicle screws.¹⁵ Since reliable data regarding the incidence of such events are not available, these were not included as factors in our model.

Finally, we assumed that there was no clinical benefit from using a high-density construct over a standard-density construct. There is a theoretical risk of increased pseudoarthroses and revision rates using a low implant density construct, but this has not yet been addressed in the literature. Further work is needed to verify that there are an equivalent clinical results using standard-density pedicle screw instrumentation.

Additional Literature on the Cost Savings From Using Low Implant Density

A recent poster presentation estimated \$11 million to \$20 million in US annual savings by changing from all-pedicle screws to an alternating screw pattern,⁹ which sup-

ports our results. Yang et al. demonstrated a statistically significant positive association between increased spending on implants per level fused and the percent Cobb angle correction; however, they found no clinically measurable differences in outcomes based on the surgeons' assessment of clinical photos.⁵⁷ Other studies of predominantly screw constructs have not found a significant difference in curve correction or other parameters.^{32,34,48,50}

Conclusions

Should low and high screw-density patterns be determined to have similar clinical and radiographic results, as shown by this model, even a modest reduction in the number of screws may result in significant cost savings of 4% to 7% for the payer. In addition, fewer malpositioned screws and a decreased return to surgery for screw malposition may improve patient safety and the quality of surgical care. Additional studies are necessary to determine if

FIG. 2. The majority of anticipated cost savings from reducing the number of screws used results from decreased implant costs rather than savings from averted returns to the operating room (OR) for screw malposition. The y-axis shows the screw density, with the number of screws per level fused shown in parentheses. The bars represent the mean cost of returning to the OR, and the whiskers indicate the standard deviation. M = million.

FIG. 3. Switching from a maximum (2.0) to minimum (1.06) implant density pattern would decrease the costs of scoliosis surgery by upwards of 15%, assuming equivalent clinical results.

a low implant density construct provides equivalent results to standard or high implant density constructs.

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Author Contributions

Conception and design: Larson, Polly, Lonner, Shah, Emans, Richards. Acquisition of data: Larson. Analysis and interpretation of data: Larson, Polly, Ackerman, Ledonio, Shah, Emans, Richards. Drafting the article: Larson, Ledonio. Critically revising the article: Larson, Polly, Ackerman, Ledonio, Lonner, Richards. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Larson. Statistical analysis: Ackerman. Administrative/technical/material support: Larson, Polly, Ledonio. Study supervision: Polly.

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