HEALTH SERVICES RESEARCH

Variability in Hospital Costs of Adult Spinal Deformity Care

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Study Design. Retrospective, single-center analysis.
Objective. To calculate the total clinical hospital cost of the Adult Spinal Deformity (ASD) care trajectory, to explain cost variability by patient and surgery characteristics, and to identify areas of process improvement opportunities.
Summary of Background Data. ASD is associated with a high financial and clinical burden on society. ASD care thus requires improved insights in costs and its drivers as a critical step toward the improvement of value, i.e., the ratio between delivered health outcome and associated costs.
Methods. Patient characteristics and surgical variables were collected following ethical approval in a cohort of 139 ASD patients, treated between December, 2014 and January, 2018. Clinical hospital costs were calculated, including all care activities, from initial consultation to 1 year after initial surgery (excl. overhead) in a university hospital setting. Multiple linear regression analysis was performed to analyze the impact of patient and surgical characteristics on clinical costs.
Results. 75.5% of the total clinical hospital cost (€27,865) was incurred during initial surgery with costs related to the operating theatre (80.3%), nursing units (11.9%), and intensive care (2.9%)

being the largest contributors. 57.5% of the variation in total cost could be explained in order of importance by surgical invasiveness, age, coronary disease, single or multiple-staged surgery, and mobility status. Revision surgery, unplanned surgery due to complications, was found to increase average costs by 87.6% compared with elective surgeries (€ 44,907 (± € 23,429) vs. € 23,944 (± € 7302)).
Conclusion. This study identified opportunities for process improvement by calculating the total clinical hospital costs. In addition, it identified patient and treatment characteristics that predict 57.5% of cost variation, which could be taken into account when developing a payment system. Future research should include outcome data to assess variation in value.
Key words: adult spinal deformity, ASD-surgical invasiveness score, cost drivers, costs, value-based healthcare, variation in costs.
Level of Evidence: 4
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Healthcare providers, working with limited healthcare budgets, attempt to achieve better clinical outcomes at lower costs of care and thus, maximize the value in healthcare.[1] Particularly in chronic disorders, such as Adult Spinal Deformity (ASD),[2] characterized by a lifelong outcome and cost impact, value improvements are potentially beneficial, for both society, patients, and care providers.

Accurate cost data are essential in the search for process improvement.[3] Similar to other diseases,[3] "costs" in ASD literature are based on reimbursement data[4–7] and/or the scope is limited to the index surgery.[4,5,8] Instead, costs ideally reflect the monetary value of the largest possible part of all resources used during the entire patient's care trajectory,[9] rather than the peculiarities of different reimbursement systems.

Furthermore, in many countries, innovative reimbursement systems are developed in an attempt to control increasing healthcare costs. Bundled payments[10,11] are one such attempt. Hereby, a fixed amount is reimbursed for all providers in the care trajectory for a certain patient group,

during a certain period of time. It aims to promote clinical continuity and to align incentives for care providers around value instead of volume.[12] An important challenge in introducing bundled payments is the differences in "justified care"[13] for different subgroups. There is, for instance, risk of patient cherry-picking (*e.g.*, patients without comorbidities or favorable surgical episodes) when the bundled payment would not take these factors into account. Data on true costs, including its variability drivers, are needed to implement a bundled payment system that encourages to provide the right care, without inducing adverse selection.

Accordingly, this paper aims to identify the drivers of the total clinical hospital costs of the ASD care trajectory in an academic referral center. We hypothesize 1) that we can explain cost variability by patient and surgical characteristics, needed to move from fee for service to bundled payments and 2) that we will be able to identify areas of process improvement opportunities in the care pathway.

MATERIALS AND METHODS

This study was approved by the KULeuven ethical committee (S61657) and took place at University Hospitals Leuven. One hundred thirty-nine ASD patients met the inclusion criteria and were enrolled in the current study. Patients with lumbar spondylolisthesis, adolescent idiopathic scoliosis, Scheuermann kyphosis, neuromuscular (kyfo-)scoliosis, *de novo* degenerative scoliosis, and (iatrogenic) flat back deformity were included. Initial (=index) surgery was performed between December 2014 and January 2018. The study population was divided into two subgroups, depending on the number and nature of surgical episodes during the 1-year follow-up period. The first subgroup entailed all patients with one (n = 92) or several (n = 22) planned surgeries (Gr1_planned). The second subgroup entailed patients with at least one revision surgery due to complications (n = 25) (Gr2_revision). Both clinical and cost data were collected for all patients.

Clinical Data

Clinical data were collected retrospectively between August and December 2018 via electronic patient record analyses on demographics, comorbidities, and surgical characteristics (see Table 1). Next to the American Society of Anesthesiologists -score, the five-item modified frailty index (5i-mFI)[14] was calculated to score the patient's physiological status based on the presence of diabetes mellitus, congestive heart failure, hypertension requiring medication, history of COPD, and a partially dependent functional status. The 5i-mFI has been demonstrated to correlate with the length of stay (LOS), readmission, and complications[14] and could thus affect costs. In addition, the ASD surgical invasiveness score[15] (ASD-S) was calculated.[15] Vertebral column resection was scored in the same way as a three-column osteotomy. For every patient, a second ASD-S score was determined, adding up all ASD-S scores of the individual surgical episodes, further referred to as the "ASD-S$_{combined}$."

Finally, patients' primary diagnoses were labeled using The Spine Tango[16] diagnostic classification.

Cost Data

The clinical cost of the care trajectory analyzed in our study equals the sum of the different costs of all in- and outpatient pre-, peri-, and postoperative services, provided within the university hospital. Both direct and indirect costs of clinical care within the hospital are included.

Medication and implants were registered per patient and are therefore direct costs, directly attributed to the patients. Other clinical hospital costs were allocated on the basis of the classic two-stage ABC-allocation principle,[17] using the data of the hospital's own Activity Centre—Care program[18] model. This model permits calculating the costs of the care trajectory within the hospital by taking the different activities and their frequency per patient into account. First, costs of each resource (*e.g.*, nurses, utilities, equipment) are allocated by a resource cost driver to activity centers, which are functional units where each of the activities is performed, such as the operating room, the lab, the ward, *etc*. Next, the activity cost pool at the level of the activity centers is allocated to patient groups through activity cost drivers, such as the number of X-rays, the operating time, the length of stay.

Costs of supporting services such as administration, cleaning services, or the human resources department are not included in the present analysis because of the limited effect of ASD patients on the total overhead costs. This approach implies that the cost data are mainly suitable to identify and assess cost differences between patient groups or different care approaches—and cannot be used to set "full" reimbursement rates (although the data could be used to differentiate reimbursement rates between subgroups of patients).

This total clinical cost of the hospital care trajectory will be further referred to as the total cost per patient, although it should be kept in mind that this "total" cost does not include overhead costs.

Statistics

Statistical analyses were carried out using SPSS software (v. 25.0.0; SPSS Inc, Chicago, IL). Descriptive statistics including means and standard deviations were performed on patient and surgery characteristics, as well as on costs. Independent t tests were performed to assess the differences in patient and treatment characteristics between GR1_planned and GR2_revision. In addition, bivariate linear correlation analyses were used to assess the level of correlation between patient and treatment characteristics on the one hand and the total cost per patient on the other hand. Means and variation of the total cost per patient were calculated and compared between subgroups. The nonparametric Mann–Whitney U and Kruskall–Wallis test, combined with *posthoc* tests if needed, were performed, to examine the link between the independent categorical variables and the dependent right-skewed variable of the total

TABLE 1. Patient and Surgery Characteristics

Characteristic	All Included Patients (n = 139)	P (Sign. Correlation With Total Cost)	Statistic Gr1_planned (n = 114)	Gr2_revision (n = 25)	P (Sign. Difference Between Subgroups)
Demographics					
Mean age in years (SD)	55.4 (±17.2)	0.015§	54.0 (±17.5)	61.4 (±14.4)	0.046§
Female (%)	94 (67.6%)	0.675	78 (69.0%)	16 (61.5%)	0.462
Mean body mass index (SD)	25.6 (±4.7)	0.050	25.2 (±4.4)	27.3 (±5.5)	0.045§
Mobility status		0.024§			0.301
Walking independently (%)	109 (78.4%)	0.012§	91 (80.5%)	18 (69.2%)	
Walking with device (%)	25 (18.0%)	0.075	18 (15.9%)	7 (26.9%)	
Wheelchair bound (%)	5 (3.6%)	0.057	4 (3.5%)	1 (3.9%)	
Functional status		0.003§			0.314
Living independently	110 (79.1%)	0.001§	92 (81.4%)	18 (69.2%)	
Living partially dependently	23 (16.5%)	0.010§	16 (14.2%)	7 (26.9%)	
Living dependently	6 (4.3%)	0.054	5 (4.4%)	1 (3.8%)	
Smoking (%)	34 (24.5%)	0.360	27 (23.9%)	7 (26.9%)	0.746
Primary diagnosis					
Degenerative deformity	91 (65.5%)	0.000§	70 (62.0%)	21 (80.8%)	0.076
Nondegenerative deformity	26 (18.7%)	0.130	25 (22.1%)	1 (3.9%)	0.061
Foraminal stenosis	7 (5.0%)	0.885	6 (5.3%)	1 (3.9%)	0.759
Central stenosis	6 (4.3%)	0.014§	5 (4.4%)	1 (3.9%)	0.896
Others	9 (6.5%)	0.002§	7 (6.2%)	2 (7.7%)	0.780
Comorbidities*					
Arterial hypertension	36 (25.9%)	0.711	27 (23.9%)	9 (34.6%)	0.264
Mitral valve prolapse	22 (15.8%)	0.350	19 (16.8%)	3 (11.5%)	0.509
Osteoporosis	20 (14.4%)	0.976	17 (15.0%)	3 (11.5%)	0.647
Spinal cord injury	17 (12.2%)	0.219	12 (10.6%)	5 (19.2%)	0.234
Depression	10 (7.2%)	0.839	7 (6.2%)	3 (11.5%)	0.349
Modified Frailty index†		0.039§			0.039§
Nonfrail	76 (54.7%)		66 (58.4%)	10 (38.5%)	
Frail	45 (32.4%)		35 (31.0%)	10 (3.5%)	0.096
Severely frail	18 (13.0%)		12 (10.6%)	6 (23.1%)	
Surgery characteristics					
ASD-S score (SD)	32.7 (± 12.5)	<0.001§	33.5 (±13.0)	29.3 (±10.0)	0.128
ASD-S$_{combined}$ (SD)	37.2 (±15.7)	<0.001§	36.0 (±15.2)	42.6 (±16.6)	0.061
LOS initial hospitalization (SD)	11.8 (±9.1)	<0.001§	10.4 (±4.1)	18.0 (±18.4)	0.02§
Combined LOS care trajectory‡ (SD)	19.0 (±23.1)	<0.001§	13.4 (±10.8)	43.1 (±41.1)	<0.01§

Numbers are rounded to the first decimal place.

*Comorbidities with less than five observations such as Parkinson, cerebral palsy, congestive heart failure, etc., were not visualized and excluded from further statistics.

†Modified frailty index: frailty was scored on five items including diabetes mellitus, congestive heart failure, hypertension requiring medication, history of COPD, and functional status: partially dependent. The authors categorized patients with 0, 1, and 2 or more on a scale of 5 as resp. ''non-frail,'' ''frail,'' and ''severely frail,'' respectively.

‡Combined LOS of all hospital admissions during the care trajectory.

§Significantly different (P < 0.05).

SD indicates standard deviation, LOS, length of stay.

cost per patient. Finally, a multiple linear regression model was used to explain the total cost per patient, the costs of the three phases (preparation, initial intervention, and follow-up phase), and the cost of initial surgery. Logarithmic (natural base) transformations were performed for follow-up costs and total cost per patient to deal with their skewed distribution. For all analyses, the level of significance was set at 0.05 and assumptions were validated.

RESULTS

Patient and Surgery Characteristics

One hundred thirty-nine ASD patients were included in this study. 67.6% were female and 24.5% were smoking. The BMI ranged from 16.1 kg/m^2 to 40.1 kg/m^2 with 25.6 kg/m^2 as average. 18.0% of patients were walking with a device, 3.6% were wheelchair-bound, whereas 78.4% could walk independently. 16.5% were living partially dependent (with
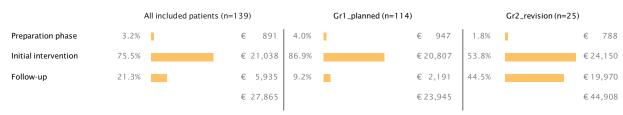
	All included patients (n=139)		Gr1_planned (n=114)		Gr2_revision (n=25)	
Preparation phase	3.2%	€ 891	4.0%	€ 947	1.8%	€ 788
Initial intervention	75.5%	€ 21,038	86.9%	€ 20,807	53.8%	€ 24,150
Follow-up	21.3%	€ 5,935	9.2%	€ 2,191	44.5%	€ 19,970
		€ 27,865		€ 23,945		€ 44,908

Figure 1. The relative contribution of the different phases to the total cost per patient for all patients, Gr1_planned and Gr2_revision.

the help from a nurse or a relative), 4.3% were living completely dependent (*e.g.*, in a retirement home), 79.1% lived independently. 96.4% of all patients had at least one comorbidity. Most common comorbidities were arterial hypertension (25.9%), mitral valve prolapse (15.8%), osteoporosis (14.4%), spinal cord injury (12.2%), and depression (7.2%). The most common primary diagnoses were degenerative deformity (65.5%) and nondegenerative deformity (18.7%), followed by foraminal stenosis (5.0%) and central stenosis (4.3%). Independent *t* tests revealed significant differences between Gr1_planned and Gr2_revision in age, BMI, and modified frailty-index.

The ASD-S of the initial surgical episode was 32.7 (range 7–77). The mean ASD-S$_{combined}$ was 37.2 (range 7–144). The average LOS of the initial surgical episode was 11.8 ± 9.1 days and the average combined LOS of all hospital stays during the defined care trajectory was 18.9 ± 23.1 days. Independent *t* tests revealed significant differences between Gr1_planned and Gr2_revision in LOS of the initial hospitalization and the combined LOS. Table 1 gives a detailed overview of all patient and surgery characteristics, both overall and on subgroup level.

Costs

The average total cost per patient of the entire 1-year care trajectory was € 27,865 (n = 139) with a standard deviation of € 14,493. On average, the largest part of these costs is incurred during the initial intervention and hospital stay (75.5%). 21.3% of costs were incurred during the follow-up phase, 3.2% was incurred during the preparation phase (Figure 1). During the initial intervention and hospital stay, the bulk of costs was incurred in the operating theater (80.3%) with the most important cost categories being implants (32.9%), other materials (16.1%), medical and nonmedical staff (resp. 13.9% and 12.1%). A breakdown of initial intervention costs is found in Figure 2.

As summarized in Table 1, age, BMI, mobility status, functional status, degenerative deformity, central stenosis, other diagnosis, modified frailty index, ASD-S, ASD-S$_{combined}$, and length of stay, were all significantly related to the total cost per patient.

As shown in Figure 3, revision surgery (Gr2_revision) was found to increase costs by 87.6% compared with elective surgery (Gr1_planned), with average costs of resp. € 44,907 and € 23,944. This increase was additionally associated with an increased standard deviation of resp. ± €

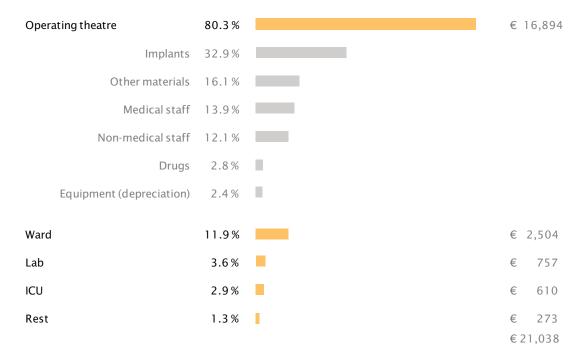|		
Operating theatre	80.3 %	€ 16,894
Implants	32.9 %	
Other materials	16.1 %	
Medical staff	13.9 %	
Non-medical staff	12.1 %	
Drugs	2.8 %	
Equipment (depreciation)	2.4 %	
Ward	11.9 %	€ 2,504
Lab	3.6 %	€ 757
ICU	2.9 %	€ 610
Rest	1.3 %	€ 273
		€ 21,038

Figure 2. Relative contribution to the cost of the initial intervention and hospital stay.
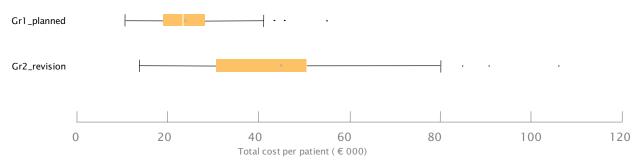
Figure 3. Boxplot comparing total clinical hospital costs (€ 1000 s) between Gr1_planned and Gr2_revision. The white line within each box represents the mean, the X represents the average. The whiskers extend to the most extreme data point within the range of 1.5 × IQR from the box. Outliers, data points outside the range of the whiskers are shown as dots.

23,429, compared with ± € 7302. The follow-up phase showed the largest significant difference (*P* value <0.001) in costs between Gr2_revision (€ 19,969) and Gr1_planned (€ 2191).

Figure 4 shows the average cost per phase with standard deviation for all patients and for the subgroups separately. The quartile coefficient of dispersion shows that the initial intervention, overall and for each subgroup, has the least relative variation. In contrast, the cost of the follow-up phase is characterized by a large variation.

Table 2 summarizes the different stepwise linear regression models, including regression coefficients, *P* values, and R^2. Variation in total cost per patient could be explained, in order of importance, by the ASD-S$_{combined}$, age, coronary disease, multiple *versus* single planned surgery, and mobility status. Together, these variables explain 57.5% of variation. 43.0% of the variation in initial surgery cost could be explained by the ASD-S and American Society of Anesthesiologists score only.

DISCUSSION
The purpose of this study was to calculate the total cost per patient of the ASD (1-year) care trajectory and examine its variability at an academic referral center, to identify the cost of the different phases of the hospital care trajectory and to investigate causes of cost variations between subgroups of patients.

Overall, the initial surgery accounted for 75.5% of the total clinical hospital cost, which is in line with recent literature.[19] A large proportion (80.3%) of these costs was incurred in the operating theater, which makes the surgery the primary focus for value improvement for this population. As such, ASD-S is a good candidate to support more precise planning of surgery time slots and adjust the standard average times that are currently in place at our hospital. Indeed, this study showed that the ASD-S predicts almost half of the variation in surgery time. 88.5% of index surgeries had at least 30 minutes overtime, with 64.7% of surgeries exceeding 2 hours of overtime, resulting in 410 hours of total overtime. In addition, 4.3% of surgeries were at least 30 minutes shorter than originally planned. ASD-S-based surgery time allocation is thus expected to be more in line with reality and thus allow better use of excess

capacity or avoiding over time resulting in a lower capacity cost rate.

Thirdly, surgeons and management could use these data to decide on investments in techniques or changes in the work flow, which reduce surgery time. Because our model includes all activities over the care cycle period, it will be possible to check how such changes in work flow, or new techniques are beneficial over the entire care trajectory (*e.g.*, can the introduction of a team briefing pre and postsurgery (thereby increasing staff time) reduce the operating time (thereby reducing—more expensive—OT staff time?)).

At University Hospitals Leuven, surgeons currently plan preoperative examinations according to the presented comorbidities of the patient. Therefore, it was expected that variability in the costs of the preoperative phase could be predicted, based on the presented comorbidities. However, this was not reflected in our data. More in-depth analyses showed that the preoperative preparation was not as standardized as presumed. Therefore, our data suggest an opportunity for adopting a more standardized evidence-based workflow of preoperative examinations and corresponding actions depending on the comorbidities of the patient, following the guidelines[20] of the Belgian Health Care Knowledge Centre.

Evidently, we strive to avoid revision surgery due to complications, both for quality and cost reasons. Indeed, this study illustrates that revision surgery due to complications (infection, material failure, and neuro-compression) significantly increases costs (total cost per patient of € 44,907 instead of € 23,429). These insights can help to decide on investment strategies. Theoretically, investing in a technique that costs € 2262 per patient, bringing down revision surgery due to complications by 50% from 22.0% to 11.0% would be breakeven (*i.e.*, no extra cost) and thus, be justifiable, from an economic point of view (due to better outcomes, *i.e.*, less complications).

The second aim of this study was to identify drivers of the variability in the total clinical hospital costs. As a recent study concluded,[11] accounting for payment variation would be the greatest challenge in spine surgery when moving to bundled payments. ASD-S$_{combined}$, age, coronary disease, one or multiple planned surgeries, and mobility status were all found to affect the total cost per patient. Therefore, these
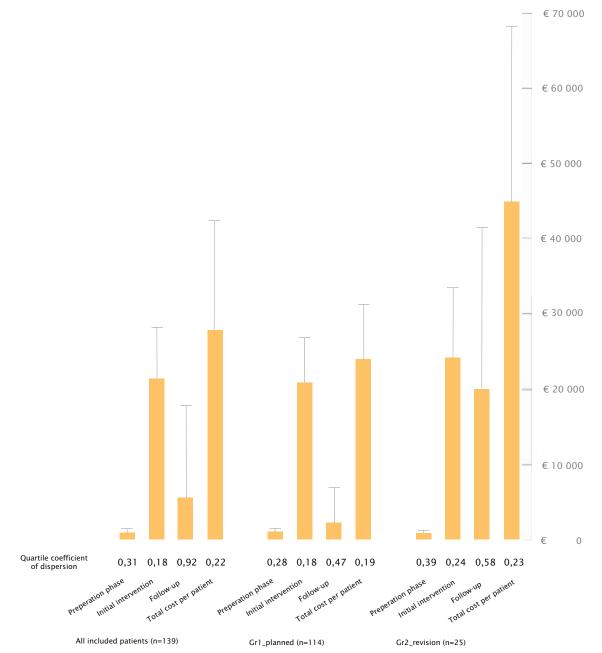
Figure 4. Error Bar chart representing the average cost per phase with SD (whiskers) for all patients and for Gr1_planned and Gr2_revision separately.

factors should be included in a risk-adjusted bundled payment system, as seen in other payment models in spine surgery.[12,21]

The results of this study must be interpreted within the context of its design. First, the clinical data were gathered retrospectively and are susceptible to registration bias. If a certain comorbidity was not documented in the patient record due to incomplete registration, it was incorrectly assumed that this patient did not have that comorbidity. Second, cost analyses were performed only at a tertiary academic center. Costs of care provided outside the hospital, for example, GP consultations, home medication, or ambulatory physiotherapy services were not included because of a

lack of data on these activities within the current study design. Third, only care-related hospitals costs were taken into account. Overhead hospital costs were excluded because adding these costs would not add additional insights into true reasons for variation in the cost data. Furthermore, these costs are not expected to be affected when improving care delivery.

In conclusion, this study identified the total cost of care over the full 1-year hospital cycle and its composition, together with areas of process improvement opportunities. It also identified variability drivers to the total cost of care, needed for bundled payments. Further research should focus on including costs incurred outside the hospital and on

TABLE 2. Stepwise Regression Models			
Total Clinical Hospital Cost[*]	**Coefficient (β)**	***P* Value**	**R²**
Intercept	4921	<0.001	0.575
Surgical invasiveness score combined	0.014 p	<0.001	
Age	0.004	0.002	
Coronary disease	0.500	0.001	
Multiple planned surgeries	0.209	0.001	
Mobility status			
Walking with device	0.141	0.023	
Wheelchair-bound	0.259	0.045	
Cost preparation phase[†]	**Coefficient (β, euros)**	***P* value**	**R²**
Intercept	891	<0.001	0.055
Functional status			
Living dependently	589	0.005	
Cost initial hospitalisation[†]	**Coefficient (β, euros)**	***P* value**	**R²**
Intercept	10,286	<0.001	0.474
Surgical invasiveness score	295	<0.001	
Mobility status			
Walking with device	4004	0.001	
Wheelchair-bound	14,037	<0.001	
Carotid artery disease	6419	0.002	
Cerebral palsy	−10,423	0.003	
Previous blood clot [‡]	4621	0.049	
Cost follow-up[*]	**Coefficient (β)**	***P* value**	**R²**
Intercept	4024	<0.001	0.335
Surgical invasiveness score combined	0.040 n	<0.0011	
Coronary disease	2.240	0.004	
Age	0.020	0.006	
Diabetes mellitus	1.181	0.014	
Other neurological disorders	0.676	0.017	
Cost initial surgery[†] **(operating theater)**	**Coefficient (β, euros)**	***P* value**	**R²**
Intercept	8897	<0.001	0.430
Surgical invasiveness score	240	<0.001	
ASA score of 3	1445	<0.029	

[*]*We used a logarithmic transformation for dependent variables with a skewed distribution: $logY_i = \alpha + \beta X_i + \varepsilon_i$: Each 1-unit increase in X multiplies the expected value of Y by e^β.*

[†]*We used a general linear model for dependent variables that were normally distributed: $Y_i = \alpha + \beta X_i + \varepsilon_i$: Each 1-unit increase in X increases the expected value of Y by β.*

[‡]*Includes deep vein thrombosis, pulmonary embolism.*

SD indicates standard deviation, LOS, length of stay.

outcome data, to assess changes in value and to move toward outcome-based bundled payments. This cost study was a first step in the shift from outcome to value-driven healthcare for the ASD population.

➣ **Key Points**

❏ The total clinical hospital cost of the 1-year intrahospital ASD surgical care trajectory is € 27,865 (± €14,493) per patient.

❏ Patient characteristics, such as age, coronary disease, and preoperative mobility status, together with surgery characteristics such as the surgical invasiveness index and single *versus* multiple staged surgery are significant cost predictors in the 1-year intrahospital ASD surgical care pathway.

❏ Revision surgery due to complications is a major driver of the total clinical hospital cost, increasing costs by 87.6% compared with elective surgery.

Acknowledgments

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