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Effect of Different Cost Drivers on Cost per Anesthesia Minute in Different Anesthesia Subspecialties

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Background: **Little is known about differences in costs to provide anesthesia care for different surgical subspecialties and which factors influence the subspecialty-specific costs.**

Methods: **In this retrospective study, the authors determined main cost components (preoperative visit, intraoperative personnel costs, material and pharmaceutical costs, and others) for 10,843 consecutive anesthesia cases from a 6-month period in the 10 largest anesthesia subspecialties in their university hospital: ophthalmology; general surgery; obstetrics and gynecology; ear, nose, and throat surgery; oral and facial surgery; neurosurgery; orthopedics; cardiovascular surgery; traumatology; and urology. Using regression analysis, the effect of five presumed cost drivers (anesthesia duration, emergency status, American Society of Anesthesiologists physical status of III or higher, patient age younger 6 yr, and placement of invasive monitoring) on subspecialty-specific costs per anesthesia minute were analyzed.**

Results: **Both personnel costs for anesthesiologists and total costs calculated per anesthesia minute were inversely correlated with the duration of anesthesia (adjusted $R^2 = 0.75$ and 0.69, respectively), *i.e.*, they were higher for subspecialties with short cases and lower for subspecialties with longer cases. The multiple regression model showed that differences in anesthesia duration alone accounted for the majority of the cost differences, whereas the other presumed cost drivers added only little to explain subspecialty-specific cost differences.**

Conclusions: **Different anesthesia subspecialties show significant and financially important differences regarding their specific costs. Personnel costs and total costs are highest for subspecialties with the shortest cases. Other analyzed cost drivers had little effect on subspecialty-specific costs. In the light of these cost differences, a detailed cost analysis seems necessary before the profitability of an anesthesia subspecialty can be assessed.**

ANESTHESIOLOGISTS provide anesthesia care for patients in a large variety of surgical subspecialties. Billing of surgery is based in most cases on diagnoses or procedures irrespective of the time needed per case. In contrast, billing of anesthesia is based—at least in most countries—mainly on the time spent for anesthesia care, in many cases combined with a variable base rate for each case. In the American Society of Anesthesiologists (ASA) *Relative Value Guide*, charges increases for specific patient conditions, *e.g.*, extreme ages or higher ASA physical status, or special circumstances, *e.g.*, emergency cases.[1] Recent work has shown that case duration and type of surgery result in large differences regarding the hourly clinical productivity of anesthesiologists providing care for different surgical subspecialties.[2,3] The economic construct of hourly clinical productivity is based on billing data. It is a direct measure of the revenues generated by the anesthesiologist and is defined as the sum of base units and time units divided by the total hours of anesthesia care, as can be calculated from the time units. Hourly clinical productivity varies considerably in anesthesia care for surgical subspecialties, suggesting the possibility of large differences regarding the profitability of different anesthesia subspecialties. Especially longer-than-average anesthesia times have been identified as a factor that influences profitability negatively.[2–4] However, billing data do not necessarily correlate with actual costs.[5,6] To make any conclusions on profitability of anesthesia cases, both types of information are needed: how much input of costly resources (personnel and material) is needed and how much output (*e.g.*, billed ASA units) is generated. We hypothesized that resources needed to provide anesthesia care for different anesthesia subspecialties is inversely correlated with the average case duration, *i.e.*, shorter cases leading to higher costs per anesthesia minute. Furthermore, we studied the effect of other known or presumed cost drivers on the cost per anesthesia minute in anesthesia subspecialties. Based on previous work,[7] the ASA *Relative Value Guide*,[1] and our own experience, we chose five different presumed cost drivers for further analysis: anesthesia duration, emergency status, ASA physical status of III or higher, patient age younger than 6 yr, and placement of invasive monitoring (central venous catheters and arterial line). Using a multiple regression model approach, we analyzed the effect of these cost drivers on the anesthesia cost for the 10 largest anesthesia subspecialties in our hospital.

Materials and Methods

With approval of our ethics committee (Chamber of Physicians, Hamburg, Germany), we retrospectively calculated the actual costs of 10,843 anesthesia cases that were performed in the 10 largest anesthesia subspecial-

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ties from October 2002 through March 2003 in the University Hospital Hamburg-Eppendorf (Hamburg, Germany), a German tertiary-level university hospital. The 10 services with highest numbers of anesthesia cases in our hospital were general surgery (including visceral and thoracic surgery, pediatric surgery, hepatic surgery, and liver transplantation); ear, nose, and throat (ENT; including pediatric ENT); obstetrics and gynecology (OB/GYN); oral and facial surgery; ophthalmology (retina and nonretina); traumatology; neurosurgery (including interventional neuroradiology); cardiovascular surgery (including pediatric cardiac surgery); urology (only major surgical cases, *e.g.*, radical prostatectomies and nephrectomies, without outpatient cases); and orthopedics. Smaller and infrequently served subspecialties, such as interventional cardiology or endoscopy, pediatric radiology, and cases treated in the emergency room, were not included in the analysis. One anesthesia case had to be eliminated because of an incomplete data set. For historic reasons, most of the 10 major surgical subspecialties have their own operating room (OR) suite and recovery room, which allowed exact separation of personnel and nonpersonnel costs between the different subspecialties. Moreover, costs caused by turnover times or OR downtimes could be clearly allocated to the respective subspecialty. In the so-called operative center, the general surgical service runs four ORs and the urology service two ORs with the patients treated in the same recovery room.

Personnel costs consist of costs for anesthesiologists and anesthesia nurses, who are both employees of the hospital. The average costs per anesthesiologist (residents and board certified anesthesiologists) in our hospital are 79,200 Euros/yr, without overtime pay and on-call compensations, but including social security and health insurance. General hospital overhead costs such as costs for personnel administration, accounting, or housekeeping were not included. The comparable average costs per anesthesia nurse are 53,000 Euros/yr. Anesthesiologists' personnel costs were attributed to two different times spent in patient care: time during the preoperative visit and time spent with the patient during attendance in the OR. These times—for the preoperative visits and time spent with the patient in the OR—were regarded as productive time. The total cost of personnel was distributed among cases using the documented productive time per case. Time spent while waiting for the next case was not considered to be productive time. The number of anesthesiologists and anesthesia nurses working in each OR suite during the normal working hours (7:00 AM to 3:30 PM) is relatively constant because the surgical services have a fixed number of ORs where they can schedule operations with anesthesiologist attendance. Induction and extubation rooms are adjunct to each OR. Anesthesia induction can be started before finishing the previous case. Physician staff of the OR suites consists of one anesthesiology resident or fellow staffed per OR. In addition, there is an attending anesthesiologist responsible full-time in each OR suite who medically directs the residents and fellows, supports them in cases of emergencies or complex cases, enables breaks during long-lasting operations, and also starts or finishes cases overlapping with the previous or next case. In the afternoon, the attending anesthesiologists usually take over cases, so the residents can do the preoperative visits for the next day. Each subspecialty service thereby tries to optimize the workflow and minimize overtime. However, most ORs run late, and overtime occurs on a daily basis for almost all anesthesiologists. Day-by-day changes due to smaller-than-average OR programs are accounted for by reduced staffing or staff shift from one OR to the other. For calculating the personnel costs for each OR suite, the actual staffed personnel was extracted from the OR planning records for each day of the study period. Anesthesiologists' personnel costs were calculated on a per-minute basis by dividing the total personnel costs for anesthesiologists for each subspecialty with the productive time as defined above.

After the normal working hours, anesthesia cases are completed by the anesthesiologists responsible for the case, resulting in overtime pay. In addition, six anesthesiologists work in the hospital overnight to cover emergencies. The services with the highest utilization during the nights are the general surgical service, including liver transplantations; the trauma center; neurosurgery; and obstetrics. All productive time generated after normal hours was divided by the total costs of overtime pay and on-call compensations. As a consequence of this on-call pool for all subspecialty services, a uniform per-minute cost of anesthesiologists' productive time for all work after regular working hours was used.

In Germany, anesthesia nurses do not perform anesthesia by themselves but support anesthesiologists, *e.g.*, during the induction period and prepare medications, medical devices, and anesthesia machines. On average, in our hospital, one anesthesia nurse supports two anesthesiologists. The total personnel costs for anesthesia nurses for each subspecialty were calculated on the basis of the staffing list and were divided by the total patient care time in the OR to calculate per-minute anesthesia nurse costs.

The recovery room is also staffed by anesthesia nurses and is adjacent to the ORs of the respective operative services. Recovery room costs were calculated per patient minute, dividing the recovery room anesthesia nurse costs by the total amount of patient recovery room minutes for each subspecialty. Anesthesiologists supervise the recovery room, but because the total time spent for recovery room patients is small, the physician personnel costs were allocated only on the OR costs. Material costs in the recovery room, which account only for a minimal fraction of the total recovery room costs,[8] were not calculated separately but included in the material costs for the actual anesthesia case.

Material costs are recorded for each OR suite separately, including all pharmaceuticals, medical devices, and other supplies. Blood products and antibiotics were not included in the analysis because these items are paid for by the surgical services or the intensive care unit services in our hospital.

Finally, department overhead costs, such as personnel costs for in-house maintenance of anesthesia machines, administration, and teaching, were added as a surcharge on the total costs. Neither depreciation of anesthesia machines nor any costs for buildings, heating, water, and so forth was included in the analysis.

All anesthesia-related times are documented in the anesthesia record in fractions of 5 min. Seven different time spans were extracted from the anesthesia records. The duration of the preoperative visit is documented by the anesthesiologist who visits the patient, usually the day before surgery. The following times are documented by the anesthesiologist consecutively along the time line of the anesthesia chart during and after the operation: patient preparation and positioning by the anesthesiologist before the beginning of anesthesia induction (preparation time); anesthesia induction period, which ends after all anesthesia-related interventions such as catheter placement are completed and the patient is ready to be positioned for the operation on the OR table by the surgical staff (induction time); the procedure time, including surgical positioning and preparation, surgery, and dressing (surgical procedure time); the period after the end of surgery until the end of anesthesia (extubation time); the transfer time to the recovery room (recovery room transfer time); and the time the patient spent in the recovery room (recovery room time). The time definitions used are identical in the whole hospital, and the time spans and time points have been agreed on by all services and the hospital administration. The time documentation in the anesthesia chart is used for statistical, billing, and OR management purposes.

The cost for the following main cost components was calculated per subspecialty: preoperative visit, OR attendance of anesthesiologist and anesthesia nurse during regular hours and after regular hours, material and pharmaceuticals, recovery room cost, and overhead cost. Average costs and cost breakdowns were calculated by dividing the costs by the total anesthesia time per subspecialty. Anesthesia time is defined as the sum of induction time, surgical time, and extubation time.

For regression analysis, average anesthesia time and average cost per anesthesia minute for the 10 subspecialties were used. To further analyze the effect of other presumed cost drivers, multiple regression models were used. The dependent variable was average cost per anesthesia minute. As suggested by previous work[9] and the analysis of residuals, a lognormal transformation of the cost per anesthesia minute was used for further analysis. The independent variables were anesthesia time, emergency status, ASA physical status of III or higher, patient age younger than 6 yr, and placement of invasive monitoring (central venous catheters and arterial line). Because a multiple regression model requires much higher case numbers than the 10 subspecialties examined, the cost per single case was calculated for all 10,843 cases. The cost for preoperative visit and OR attendance of anesthesiologist and anesthesia nurse were calculated on the basis of the recorded times and the respective subspecialty specific cost per productive minute. Work during regular hours and after regular hours was differentiated. Recovery room costs were calculated on the basis of the average per-minute recovery room cost per subspecialty. Material and pharmaceuticals and overhead cost were calculated on the basis of subspecialty-specific average costs per anesthesia minute. The total cost for each case was divided by the anesthesia time to get case-specific costs per anesthesia minute. For each case, besides the anesthesia duration, the presence or absence of the other independent variables was recorded as a binary value.

Statistics

The data were extracted from the hospital's central anesthesia record database (Medlinq®; Hamburg, Germany) and analyzed in Microsoft Excel 2002 (Microsoft, Redmond, WA), SPSS 11.5 (SPSS, Chicago, IL), and Stata (Stata Corp., College Station, TX). If not otherwise stated, mean ± SD are displayed. For each subspecialty, the mean cost per anesthesia minute was determined separately. The 95% confidence intervals of the means were calculated using a bootstrapping approach as described previously,[10] with 1,000 random samples each of the size of the original data set. Because the relation between anesthesia duration and cost is unlikely to be linear,[11] we used a nonlinear model for regression analysis. To find the best-fit regression line for anesthesia duration and average anesthesia minute cost per subspecialty, fractional polygonals of degree 1 were fitted using power transformations and searching for the lowest deviance. An F test was used for the regression line, and the chi-square test of the deviance was used for proof of statistically significant differences in regression line fit. A P value less than 0.05 was considered significant. For the multiple linear regression models, a stepwise forward approach was used including the independent variables described above.

Results

Case numbers, number of theaters run on a full-time basis, patient age, ASA physical status, sex, and urgency status for each subspecialty are shown in table 1. The

Table 1. Characteristics of Anesthesia Subspecialties and Patients

	No. of ORs	No. Cases	Percentage of all Cases in the Hospital	ASA Physical Status* I	II	III	IV	V	Sex* Male	Female	Age Mean ± SD	Age < 6 yr	Urgency Status* Elective	< 24 h	< 4 h	Immediate	Percentage of Patients with Invasive Monitoring: With CVC	With CVC and Arterial Line
Ophthalmology	3	1,115	9%	33%	52%	14%	0%	0%	50%	50%	43.6 ± 28.3	14%	93%	5%	2%	0%	0%	0%
General surgery	4	2,031	17%	19%	43%	28%	9%	1%	60%	40%	40.2 ± 27.1	18%	72%	15%	10%	2%	48%	32%
OB/GYN	3	1,227	10%	24%	69%	7%	0%	0%	0%	100%	44.9 ± 16.6	0%	76%	10%	9%	5%	11%	4%
ENT	3	1,465	12%	34%	57%	9%	1%	0%	58%	42%	41.1 ± 21.7	8%	96%	2%	1%	1%	4%	2%
Oral and facial surgery	2	1,144	9%	33%	51%	15%	0%	0%	55%	45%	38.5 ± 24.6	13%	89%	7%	3%	1%	7%	4%
Neurosurgery	4	827	7%	10%	48%	30%	11%	1%	54%	46%	50.6 ± 19.8	4%	75%	5%	11%	9%	59%	43%
Orthopedics	3	606	5%	32%	47%	21%	0%	0%	50%	50%	44.1 ± 24.7	4%	94%	3%	2%	0%	28%	14%
Cardiovascular surgery	3	753	6%	0%	12%	76%	10%	1%	71%	29%	56.1 ± 24.4	10%	80%	8%	7%	5%	72%	67%
Traumatology	2	1,023	8%	29%	48%	22%	1%	0%	45%	55%	54.1 ± 25.2	2%	57%	35%	7%	1%	19%	3%
Urology	2	652	5%	18%	59%	21%	2%	0%	86%	14%	52.4 ± 20.6	6%	88%	8%	4%	1%	69%	10%
All	29	10,843	88%	24%	49%	22%	4%	0%	51%	49%	45.2 ± 24.5	9%	81%	10%	6%	2%	29%	17%

* Sums might not add up to 100% because of rounding.

ASA = American Society of Anesthesiologists; CVC = central venous catheter; ENT = ear, nose, and throat surgery; OB/GYN = obstetrics and gynecology; OR = operating room.

number of 10,843 anesthesia cases accounted for 88% of all anesthesia cases performed by the department over the 6-month period and represents 93% of total anesthesia time during this period. Case numbers were highest in general surgery, followed by ENT and OB/GYN. General surgery, cardiovascular surgery, and neurosurgery had the highest percentage of patients with ASA physical status III and IV, with the cardiovascular surgery service reaching almost 90%. The lowest percentage of patients with ASA physical status III and IV was seen in the OB/GYN, ENT, and ophthalmology services. The percentage of urgent surgery (within 4 h after OR registration and cases that had to be started as emergencies immediately) ranged from 2% in the ophthalmology service to 20% in the neurosurgical department.

Table 2 displays the different time spans during which the anesthesiologist is occupied with one patient. The average duration of the preoperative visit ranges from 22 min in the ophthalmology service to 35 min in the cardiovascular surgery service. The average time spans of patient preparation before induction, of extubation, and of transfer to the recovery room after extubation differed only by a few minutes between the subspecialties. Much larger differences were seen in the induction time. As to be expected from the time needed for the placement of central venous and arterial lines, the aver-

Table 2. Time Spans of Anesthesia Subspecialties

	Preoperative Visit	Preparation before Induction	Induction	Surgical Procedure Time	Extubation	Recovery Room Transfer	Recovery Room Time	Anesthesia Time (Induction, Procedure Time, Extubation)	ACT/TPT
Ophthalmology	22.1 ± 6.8	7.2 ± 7.1	9.4 ± 5.2	60.2 ± 30.0	6.0 ± 5.0	4.0 ± 4.1	61.5 ± 28.6	75.6 ± 32.3	31%
General surgery	25.9 ± 10.5	9.4 ± 10.2	18.8 ± 16.6	138.9 ± 110.1	9.9 ± 10.9	5.7 ± 6.1	116.9 ± 84.6	167.6 ± 123.8	24%
OB/GYN	23.9 ± 9.8	8.1 ± 7.5	8.3 ± 9.3	89.5 ± 79.6	4.1 ± 5.5	4.3 ± 4.8	68.5 ± 59.3	101.9 ± 85.1	22%
ENT	23.8 ± 7.0	5.8 ± 5.2	8.0 ± 5.9	64.0 ± 50.2	5.7 ± 5.5	5.1 ± 4.3	80.3 ± 33.9	77.7 ± 53.8	28%
Oral and facial surgery	25.6 ± 7.9	7.2 ± 6.9	11.2 ± 8.8	78.1 ± 63.0	6.1 ± 6.4	4.5 ± 5.1	70.3 ± 38.0	95.4 ± 69.0	27%
Neurosurgery	25.8 ± 11.6	10.8 ± 10.3	25.7 ± 17.1	173.9 ± 99.9	10.2 ± 9.2	5.4 ± 5.8	73.7 ± 36.5	209.8 ± 109.6	23%
Orthopedics	27.2 ± 8.7	10.3 ± 13.0	19.5 ± 14.4	173.4 ± 102.1	7.7 ± 11.2	6.7 ± 8.2	108.5 ± 95.3	200.7 ± 112.9	20%
Cardiovascular surgery	35.3 ± 17.3	9.4 ± 7.7	29.7 ± 19.7	226.9 ± 122.9	9.6 ± 10.0	6.4 ± 7.3	86.6 ± 40.8	266.1 ± 137.4	20%
Traumatology	24.2 ± 8.1	10.0 ± 10.5	16.0 ± 12.9	111.3 ± 66.8	5.5 ± 6.2	4.7 ± 4.5	89.8 ± 60.2	132.8 ± 72.4	25%
Urology	27.4 ± 8.5	10.5 ± 8.4	17.5 ± 11.0	175.1 ± 87.6	7.2 ± 6.9	6.5 ± 6.4	145.6 ± 71.0	199.8 ± 93.6	19%
All	25.6 ± 10.2	8.6 ± 8.9	15.3 ± 14.3	119.1 ± 98.1	7.2 ± 8.2	5.2 ± 5.6	89.7 ± 64.7	141.6 ± 109.4	23%

Data are displayed as mean ± SD. For further details regarding the time spans, see Materials and Methods.

ACT = anesthesia controlled time (preparation + induction + extubation + recovery room transfer); ENT = ear, nose, and throat surgery; OB/GYN = obstetrics and gynecology; TPT = total procedure time (preparation + induction + surgical procedure time + extubation + recovery room transfer).

Table 3. Cost Breakdown and Cost Composition of Main Cost Drivers

	Cost in Euro per Anesthesia Minute							Cost Composition as Percentage of Total Cost*						
	Anesthesiologist Personnel Cost		Anesthesia Nurse Personnel Cost					Anesthesiologist Personnel Cost		Anesthesia Nurse Personnel Cost				
	Preoperative visit	OR	OR	Recovery Room Care	Material and Pharmaceuticals	Overhead Costs	Total	Preoperative Visit	OR	OR	Recovery Room Care	Material and Pharmaceuticals	Overhead Costs	Total
Ophthalmology	0.37	1.50	0.69	0.28	0.51	0.58	3.93	9%	38%	17%	7%	13%	15%	100%
General surgery	0.16	1.02	0.75	0.26	0.68	0.50	3.37	5%	30%	22%	8%	20%	15%	100%
OB/GYN	0.28	1.26	0.58	0.20	0.49	0.49	3.30	8%	38%	18%	6%	15%	15%	100%
ENT	0.34	1.17	0.53	0.28	0.75	0.53	3.60	9%	32%	15%	8%	21%	15%	100%
Oral and facial surgery	0.30	1.20	0.73	0.35	0.64	0.56	3.79	8%	32%	19%	9%	17%	15%	100%
Neurosurgery	0.14	1.13	0.71	0.06	0.64	0.46	3.13	4%	36%	23%	2%	20%	15%	100%
Orthopedics	0.15	1.16	0.55	0.26	0.62	0.48	3.23	5%	36%	17%	8%	19%	15%	100%
Cardiovascular surgery	0.15	1.05	0.68	0.03	0.86	0.48	3.24	4%	32%	21%	1%	26%	15%	100%
Traumatology	0.21	1.20	0.63	0.27	0.54	0.49	3.34	6%	36%	19%	8%	16%	15%	100%
Urology	0.13	0.98	0.70	0.35	0.68	0.49	3.33	4%	29%	21%	10%	20%	15%	100%
All	0.20	1.13	0.67	0.22	0.66	0.50	3.38	6%	33%	20%	7%	19%	15%	100%

Data are displayed as mean (left) and ratio of the mean (right).

* Sums might not add up to 100% because of rounding.

ENT = ear, nose, and throat surgery; OB/GYN = obstetrics and gynecology; OR = operating room.

age time was highest for cardiovascular surgery and neurosurgery and lowest for OB/GYN, ENT, and ophthalmology. The average operation time differed by almost a factor of 4. It was lowest for ophthalmology and highest for cardiovascular surgery. Also displayed in table 2 is the ratio of anesthesia controlled time to total procedure time. Anesthesia controlled time is the sum of preparation before anesthesia, induction, extubation, and transfer to the recovery room divided by the total procedure time. It gives a percent value of how much of the total case time is occupied by solely anesthesia-related work. This ratio varies from 19% in urology to 31% in ophthalmology.

The breakdown for the main cost components are shown in table 3, both as cost per anesthesia minute and as percentage of the total cost for each subspecialty. There are large differences for all cost components examined. In subspecialties with shorter cases, the cost fraction caused by the preoperative visit becomes more important. The costs of recovery room care are relatively low for subspecialties with a high rate of transfers to the intensive care unit, as in neurosurgery and cardiovascular surgery. Material and pharmaceutical costs are highest for the cardiovascular surgery service, followed by ENT, general surgery, and urology. The personnel costs for anesthesiologists per anesthesia minute are highest in subspecialties with shorter cases and overall correlated well with the anesthesia time. Also, the total costs per minute, including all personnel and material costs, correlated with the anesthesia duration, with costs being highest for subspecialties with the shortest cases (figs. 1 and 2). The best-fit regression line was received with the function $y = 3303.7/x^2 + 1.15$ for the personnel cost in figure 1 and $y = 3659.6/x^2 + 3.16$ for the total cost in figure 2. Increasing the complexity of the term did not improve the fit. For the personnel cost of anesthesiologists, the test statistic was $F = 28.77$, with $P = 0.0007$ and an adjusted $R^2 = 0.75$. For the total cost the test statistic was $F = 21.13$, with $P = 0.0018$ and an adjusted $R^2 = 0.69$. As it can be seen in figures 1 and 2, the cost curve displays a specific curvature, with a sharp increase of both personnel and total costs for subspecialties with shorter average case duration.

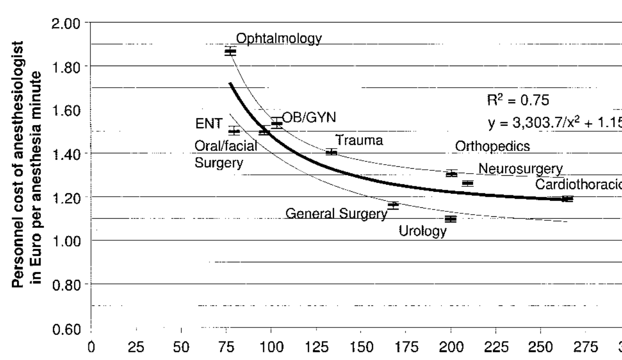

Fig. 1. Correlation between anesthesiologists personnel costs and anesthesia time per anesthesia subspecialty. Physician personnel costs include personnel costs occurring during attendance in the operating room and during the preoperative visit. Displayed are the average physician personnel costs in Euros per minute calculated separately for each subspecialty with the 95% confidence interval for each subspecialty. Anesthesia time is the average anesthesia time for each subspecialty in minutes. Also displayed is the best-fit regression line (*thick line*; adjusted $R^2 = 0.75$) with its 95% confidence intervals (*thin lines*). ENT = ear, nose, and throat surgery; OB/GYN = obstetrics and gynecology. Further details are provided in the Materials and Methods.

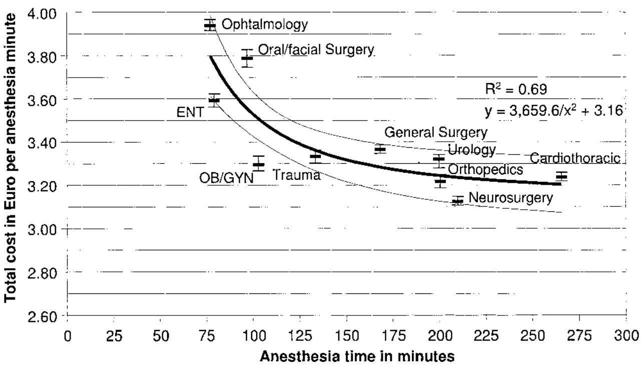

Fig. 2. Correlation between total costs and anesthesia time per anesthesia subspecialty. Total costs includes anesthesiologists and anesthesia nurse personnel costs, recovery room costs, material and pharmaceuticals, and overhead costs as described in the Materials and Methods. Displayed are the average total costs in Euros per minute per subspecialty with the 95% confidence interval for each subspecialty. Anesthesia time is the average anesthesia time per subspecialty in minutes. Also displayed is the best-fit regression line (*thick line*; adjusted R^2 = 0.69) with its 95% confidence intervals (*thin lines*). ENT = ear, nose, and throat surgery; OB/GYN = obstetrics and gynecology. Further details are provided in the Materials and Methods.

The results of the multiple linear regression models are given in table 4. Anesthesia time alone explained most of the regression. Inclusion of information on invasive monitoring (central venous catheters and arterial line), patients younger than 6 yr, and emergency cases all helped to improve the model. However, despite statistically significant improvement of the model, these additional independent variables increased R^2 only minimally. That is, the inclusion of these variables had only a very small effect on the predictive value of the model. ASA physical status of III or higher was not included because it did not further improve the model.

Discussion

The aim of our study was to examine how subspecialty-specific differences transfer into different costs of anesthesia care in different anesthesia subspecialties. Our study is based on almost 11,000 anesthesia cases from 10 different anesthesia subspecialties that were performed during a 6-month period in a German university hospital. With a total of almost 25,000 anesthesia cases/yr, our department belongs to the largest anesthesia departments in Germany. Case number, number of regularly staffed OR sites, and average case duration are similar to anesthesia departments ranking in the 75th percentile of US academic medical centers.[4] The surgical subspecialties that are served by our department are very heterogeneous, as can be seen in the patient characteristics. Surgical subspecialties with longer and more invasive surgical procedures such as cardiovascular surgery, general surgery with major abdominal or thoracic surgery, or neurosurgery have more patients with limited functional status as displayed in the ASA physical status, have much longer anesthesia induction periods and higher rates of invasive monitoring placed. The percentage of patients younger than 6 yr ranged from less than 1% for OB/GYN (without care for newborns) to 18% in the general surgery service, with a large number of general pediatric surgery cases. The percentage of the total procedure time that is solely anesthesia related ranges from 20 to 30%. This is of importance because the higher this fraction is, the more the anesthesia processes influence the overall OR performance.

The main finding of our study is that differences in cost per anesthesia minute in the different subspecialties are strongly predicted by differences in average case duration. Other known or presumed cost drivers add little to explain the cost differences between subspecialties. The effect of case duration on costs might have been expected regarding personnel costs of the anesthesiologists during the procedure, because shorter procedures lead to lower OR utilization with more turnover time and more OR downtimes. However, the personnel costs of the anesthesiologist in the OR during the case accounted for only a third of the total cost in our study. Other costs, such as nursing costs, recovery room costs, supplies and drugs, and preoperative visits, cannot be directly linked to OR utilization. Moreover, other factors increasing anesthesia costs, such as patient age and condition and required monitoring, are to be considered. We found only small effects of these other known or presumed cost drivers to explain the cost differences between subspecialties.

Table 4. Results of the Multivariate Regression Models for the Dependent Variable LnCost per Anesthesia Minute

Model No.	Model Composites	*R* of Model	Adjusted R^2 of Model	Change in Adjusted R^2 of Model	*P* Value of ANOVA
1	Anesthesia time	0.582	0.339	0.339	< 0.001
2	Anesthesia time, CVC/AL	0.588	0.345	0.006	< 0.001
3	Anesthesia time, CVC/AL, patient aged < 6 yr	0.590	0.348	0.003	< 0.001
4	Anesthesia time, CVC/AL, patient aged < 6 yr, Emergency	0.593	0.351	0.003	< 0.001

For each subspecialty all single cases were entered into the model as described in the Materials and Methods.

Inclusion of American Society of Anesthesiologists physical status of III or higher as an independent variable did not further significantly improve the model.

Anesthesia time = anesthesia time in minutes; ANOVA = analysis of variance; CVC/AL = central venous catheter and arterial line placed; Emergency = operation was within 4 h after operating room registration necessary.

Why does the correlation between anesthesia time and costs display the specific curvature with a sharp increase for subspecialties with shorter procedures? Why do those subspecialties with more invasive, long cases with high material and drug costs have lower costs approaching a specific baseline cost per minute? The reason seems to be that for each case, startup costs occur, and accordingly, the regression functions we found are consistent with the concept of fixed cost degression. The startup costs consist of several components, such as preoperative evaluation, preparation before anesthesia, time needed for recovery room transfer, and recovery room costs. There are also startup material and drug costs, but it is difficult to separate these from anesthesia maintenance costs. Another important part of startup costs is caused by OR downtime: waiting for the next patient after the previous case has been finished. All of these startup costs become more important for subspecialties with shorter cases, and these startup costs make short anesthesia cases much more expensive than longer cases if the costs are calculated per anesthesia minute.

It is important to note several points. First, the cost drivers are different from the cost components displayed in table 3. Cost components are directly part of the total cost. The cost drivers we examined are thought to influence the costs more indirectly. Second, we examined cost differences of anesthesia subspecialties, not of single cases. The multiple regression models were based on single cases only to enable a higher number of independent variables to be included in the models. Our conclusion on the effect of emergency status, ASA physical status, patient age, and other factors on anesthesia cost therefore cannot be generalized on cases within one subspecialty. Third, R^2 values in the multiple regression models are much lower than in the regression in figures 1 and 2. The regressions in figures 1 and 2 are calculated on mean values of the subspecialties, which have an inherently smaller variance than single cases.

Some values in the cost composition analysis deserve further comment. The costs for recovery room care are very low for the neurosurgical and cardiovascular surgery cases because of the high rates of intensive care unit transferals. However, the long recovery room times for patients from the urology and general surgery services are caused by patients after major abdominal surgery such as Whipple operations or radical prostatectomies who are not transferred to the intensive care unit in our hospital but cared for in the recovery room for several hours.

Studies on anesthesia costs have inherent difficulties. In our opinion, the two most important are how to allocate OR downtime and turnover time to cases[3] and how to distribute fixed (*e.g.*, depreciation costs of anesthesia machines) and semifixed costs (*e.g.*, recovery room staffing) on cases.[6,12] We circumvent these problems by using the specific situation in our anesthesia department: All anesthesia subspecialty services are run as separate cost centers, with all resources (personnel and material) being strictly separated from the other subspecialties. Therefore, we were able to calculate the input side of anesthesia care: an average cost per anesthesia minute.

It is important to note that the calculated average costs cannot predict costs of additional cases.[12] In some instances, the additional, *i.e.*, marginal, costs for an additional case are much lower than the average cost. This is true when the workforce is underutilized and can do another case without any extra personnel cost occurring. In this circumstance, the extra case leads to decreased average costs. Conversely, when the personnel are fully utilized, additional cases cause very high marginal cost because extra personnel must be employed or overtime is required. This can be exemplified with the situation in the recovery rooms. If the recovery room is not fully utilized, the number of patients and the duration of stay are irrelevant to the total cost. If additional nurses must be employed to handle an increased influx of patients, the marginal costs for these cases are very high, and the total cost and the average cost increase.[8]

In what ways does our study differ from previous studies regarding OR utilization in different subspecialties? First, many cost components we have examined are not affected by OR utilization. Second, as we have mentioned above, we cannot assume that an increase in OR utilization would decrease automatically the average cost. It depends on the specific situation in each service, how an increase in OR utilization would affect average costs, especially when the increase of OR utilization can only be achieved by an increase of personnel or material costs.

Like all studies examining costs in detail, our study has some major limitations. The structure of our hospital has profound effects on the economics. With a central recovery room, the recovery room per-minute cost would be identical for all subspecialties. In addition, the costs of anesthesiologists and anesthesia nurses are in part influenced by the local situation with separate OR suites. More fundamentally, the structure of the surgical departments and the operative case mix of each department might be very different in other hospitals. For example, the urology patients included are only those from the urologic main surgical suite, with an important focus on large operations such as radical prostatectomies and open surgical kidney and bladder operations. In previous work regarding billing productivity, pediatric ENT, pediatric surgery, and nonretina ophthalmology have been shown to be much different than general ENT, general surgery, and retina ophthalmology.[3] In our study, we used the subspecialties that run separate OR suites in our hospital to have unquestionable cost allocation. Pediatric ENT, pediatric surgery, and nonretina ophthalmology are integral parts of the respective surgical subspecialties, and it was impossible for us to separate the block time and the material cost, recovery room cost, and so forth.

Specific costs might be very different in other countries. For example, the total personnel costs for an anesthesiologist in Germany are approximately 80,000–90,000 Euros/yr, with anesthesia residents and fellows earning only 10–15% less than board-certified anesthesiologists. Therefore, German anesthesia residents and fellows cause higher costs for the hospital than their US counterparts.[13] However, the personnel costs of board certified anesthesiologists are much higher in the United States, ranging from $200,000 to $280,000 for academic and private-practice anesthesiologists.[14,15] The difficulty of a uniform anesthesia costing model is that each cost component has its own unit, and in some cases, it is not evident which unit to use. Costs for personnel attendance during the surgical case are best displayed as per anesthesia minute, but the costs for the preoperative visit can also be calculated as costs per case.[16] A large variety of material costs and pharmaceutical costs can also be seen as costs per case, but the variability of drug and supply costs is higher for costs per case than for other measures combining several factors, including time units.[7] To evaluate the efficiency of a recovery room, the calculation of per recovery room minute can also be valuable. Especially those subspecialties with low absolute costs have very high per-minute recovery room costs. Because of small patient numbers and relatively high fixed personnel costs, these recovery rooms are constantly underutilized.

To put all the different costs together, we calculated per-minute anesthesia costs for each subspecialty. Anesthesia time, defined as the time from the beginning of induction to the end of anesthesia (*e.g.*, extubation), is widely used for billing and benchmark purposes. Other time spans to be considered would be pure surgical time (incision to closing, *i.e.*, skin to skin), surgical procedure time (surgical time plus positioning and preparation by the surgeons), or anesthesiologists' attendance time, including times before cases started and after cases were finished. From the standpoint of OR management, the average total cost per staffed OR hour can be of interest. However, this measurement must be used with caution because several costs are semifixed or fixed costs, as described above. For example, reducing staffed OR hours would not reduce the cost of the recovery room *per se*. Moreover, for the comparison of costs per staffed regular hour between subspecialties, it is necessary that the service actually delivered during regular hours is the same in all subspecialties, *e.g.*, the percentage of preoperative visits done during regular hours. Whether staffing costs must be treated as fixed or variable is a complex issue and depends largely on the point of view, the specific circumstances, and the specific question to answer. In a recent study about the effects of longer-than-average case duration on staffing costs, the staffing costs during regular hours were viewed as fixed, and the staffing costs after hours were viewed as variable.[17] In our study, we quantified actual staffing requirements based on the actual number of personnel employed in each OR for each day during the study period using the daily staffing list of the ORs. Therefore, the personnel costs are treated to be fixed on a single day, but they are treated to be variable on a day-to-day basis. Is this approach economically sound? First, in our department, the number of anesthesiologists assigned to single OR sites can be adjusted based on the actual daily needs. If a surgical department has a smaller-than-average program, a whole OR is closed for the day, and no anesthesiologist will be staffed, but the anesthesiologist who would have been staffed in this OR will do work in another OR instead. In a large department with more than 90 anesthesiologists, additional and reduced staffing needs in different services equal out quite well in our experience. In addition, as we stated in the Materials and Methods, underutilization of services during a single day (*e.g.*, early program finish) is not a real issue in our department because almost all services run late every day. We have included these late-run costs together with all on-call activities for each service based on the actual overtime and on-call work that occurred as described in the Materials and Methods. But what happens if there is a real surplus in anesthesiologists during a single day? Different than in other economic enterprises, such as automotive manufacturing, it seems reasonable to us to assume that academic personnel will do other productive work if they are not employed in the OR. Clinically underutilized hours should therefore not be considered as wasted time.

Because turnover time is not compensated, the base unit in the ASA *Relative Value Guide* can be viewed as a compensation for increased resources needed to do shorter cases. It would have been desirable to compare cost data with billing data to understand whether increased input offset the increased output in subspecialties with shorter cases. Unfortunately, we cannot provide this data because the ASA *Relative Value Guide* is not used in Germany, and because we do not code procedures according the US Current Procedural Terminology system, we cannot calculate the ASA base units per anesthesia case.

Our study sheds new light on the results of recent studies that clinical productivity calculated on the basis of billing data decreases as the duration of cases increases.[2,18] Based on our study, we suggest also that the cost of anesthesia care decreases as the duration of cases increases and that other cost drivers do not seem to influence the subspecialty-specific costs to the same extent. Are the observed differences among the subspecialties financially relevant? This depends largely on the perspective and the billing system for anesthesia care.

The differences observed in our study regarding anesthesia subspecialty costs seem relatively small compared with the manifold higher differences in the total hospital variable costs[19] or the differences in the hospital contribution margins among different surgeons.[20,21] However, if anesthesia departments receive specific budgets to cover their costs or generate their income on the basis of delivered anesthesia time, as is common in many European hospitals, even small differences in costs have important impact on the profitability of the department. In this setting, the impact of increasing services for specific subspecialties or portfolio changes within the hospital have relevant effects on the costs within the anesthesia department. Furthermore, understanding the effect of average anesthesia durations on costs is important if benchmarking is used within and between hospitals. Finally, knowing the cost to provide care for each surgical subspecialty is as important as knowing how much revenue is to be expected. To estimate the costs of anesthesia in different surgical subspecialties, our study suggests that the average duration of anesthesia is much more important than other cost drivers.

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