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REPORTS OF ORIGINAL INVESTIGATIONS

Limiting the accessibility of cost-prohibitive drugs reduces overall anesthetic drug costs: a retrospective before and after analysis

Limiter l'accès aux médicaments très dispendieux réduit le coût global des médicaments anesthésiques: une analyse rétrospective avant et après

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Abstract

Purpose *Cost effectiveness is becoming increasingly important in today's healthcare environment. Remifentanil, dexmedetomidine, and desflurane are costly agents that often have suitable alternatives to their use. We sought to identify changes in cost and outcomes following interventions that limited the availability of these drugs.*

Methods *We calculated anesthetic drug costs for all operating room procedures performed before and after the accessibility interventions. We retrospectively compared drug costs per case and the frequency of agent use before and after the interventions. In addition, we analyzed the incidence of adverse outcomes, including delayed out-of-room times, postoperative nausea and vomiting (PONV), unplanned intubations, use of naloxone, and reintubations. Wilcoxon-Mann-Whitney and Chi square analyses were used to quantify differences in cost, use, and outcomes between cohorts.*

Results *Of the 27,233 cases we identified, 24,201 cases were analyzed. The mean anesthetic drug costs per case were significantly lower after the interventions vs before at ($21.44 vs $32.39, respectively), a cost savings of $10.95 (95% confidence interval, $9.86 to $12.04; $P < 0.001$). Additionally, a comparison of data after vs before the interventions revealed the following results: remifentanil use was significantly lower (3.5% vs 9.2% of cases; $P < 0.001$). Dexmedetomidine use did not differ significantly (0.4% vs 0.5% of cases; $P = 0.07$), and desflurane use was significantly lower (0.6% vs 20.2% of cases; $P < 0.001$). There was no significant relationship between the interventions and the frequency of delayed out-of-room times (15.5% vs 15.9%; $P = 0.41$), unplanned intubations (0.02% vs 0.03%; $P = 0.60$), and reintubations (0.01% vs 0.03%; $P = 0.28$). Postoperative nausea and vomiting decreased significantly after the interventions (22.8% vs 24.4%; $P = 0.003$), and naloxone use showed a significant increase (0.22% vs 0.11% of cases; $P = 0.04$).*

Conclusions *Reducing the accessibility of these cost-prohibitive agents resulted in significant anesthetic drug cost savings and decreased utilization of remifentanil and desflurane. The interventions had no significant effect on patient recovery time, incidence of unplanned intubations, or incidence of reintubation, but they were associated with a decrease in PONV and an increase in naloxone use.*

Author contributions *Ariana K. Tabing* performed the data analysis and data interpretation and drafted the final manuscript. *Jesse M. Ehrenfeld* and *Jonathan P. Wanderer* assisted with the project design and critically revised the final manuscript. *Jonathan P. Wanderer* carried out the data acquisition.

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Résumé

Objectif *La rentabilité est de plus en plus importante dans l'environnement actuel des soins de santé. Le rémifentanil, la dexmédétomidine et le desflurane sont des agents dispendieux, qui peuvent souvent être remplacés par des alternatives acceptables. Nous avons cherché à identifier les changements en matière de coûts et de pronostics, après avoir introduit des mesures visant à limiter la disponibilité de ces médicaments.*

Méthode *Nous avons calculé le coût des médicaments anesthésiques pour toutes les interventions réalisées en salle d'opération avant et après l'introduction de mesures limitant l'accès. Nous avons rétrospectivement comparé le coût par cas des médicaments et la fréquence d'utilisation des agents, avant et après les interventions. Nous avons également analysé l'incidence d'effets néfastes, notamment les sorties de salle retardées, les nausées et vomissements postopératoires (NVPO), les intubations imprévues, l'utilisation de naloxone et les réintubations. Des analyses de Wilcoxon-Mann-Whitney et de chi carré ont été utilisées pour quantifier les différences en matière de coûts d'utilisation et de résultats entre les cohortes.*

Résultats *Sur les 27 233 cas identifiés, nous avons analysé 24 201 cas. Le coût moyen par cas des médicaments anesthésiques était significativement plus bas après avoir limité l'accès, par rapport à avant (21,44 $ vs 32,39 $, respectivement), soit une économie de 10,95 $ par cas (intervalle de confiance 95 %, 9,86 $ à 12,04 $; P < 0,001). De plus, la comparaison des données après vs. avant a révélé les éléments suivants : l'utilisation du rémifentanil était significativement plus basse (3,5 % vs 9,2 % des cas; P < 0,001); il n'y a pas eu de différence significative dans l'utilisation de la dexmédétomidine (0,4 % vs 0,5 % des cas; P = 0,07); et l'utilisation du desflurane était significativement plus faible (0,6 % vs 20,2 % des cas; P < 0,001). Aucune relation significative n'a été observée entre les interventions et la fréquence de retards dans la sortie de salle (15,5 % vs 15,9 %; P = 0,41), les intubations imprévues (0,02 % vs 0,03 %; P = 0,60) et les réintubations (0,01 % vs 0,03 %; P = 0,28). Les nausées et vomissements postopératoires ont baissé de façon significative après l'introduction des mesures (22,8 % vs 24,4 %; P = 0,003), et on a observé une augmentation significative de l'utilisation de naloxone (0,22 % vs 0,11 % des cas; P = 0,04).*

Conclusion *La réduction de l'accès aux agents très dispendieux a entraîné d'importantes économies en matière de coûts des médicaments anesthésiques, et réduit l'utilisation du rémifentanil et du desflurane. Ces interventions n'ont eu aucun effet significatif sur le temps de récupération des patients, l'incidence d'intubations imprévues ou l'incidence de réintubations, mais elles ont été associées à une réduction des NVPO et une augmentation de l'utilisation de naloxone.*

Increased worldwide attention on controlling healthcare expenditures has resulted in considerable focus on cost-conscious behaviour within anesthesia clinical practice. Despite an emphasis on containing medical costs, the United States and Canada rank fifth and sixth, respectively, out of the 34 nations in the Organization for Economic Co-operation and Development when it comes to expenditure on pharmaceuticals as a percentage of their gross domestic product (GDP).[1] The United States and Canada also rank first and second in pharmaceutical expenditure per capita, spending $1,010 and $771, respectively, per person (US dollars).[1] Hospitals make up a large percentage of these costs, with perioperative care serving as the major source of both revenues and expenses.[2] This environment has led to an emphasis on cost-conscious behaviour in many hospitals and anesthesia departments.

Significant savings in perioperative care have been achieved through a variety of methods, such as decreasing the amount of preoperative laboratory testing, using local and regional *vs* general anesthesia, and decreasing unnecessary use of blood products during surgery.[3] A major focus of research has been in the selection of appropriate anesthetic regimens and their cost-benefit comparisons. Some strategies for anesthetic cost containment have included systems to reduce fresh gas flow rates[4-6] and deliver provider-specific cost data.[4] Departments have also undertaken educational programs, implemented practice guidelines, and increased availability of anesthetic drug prices.[6-9] These strategies have been associated with a reduction in drug costs, and utilization of less expensive anesthetic agents with appropriate substitutes has been shown to result in net cost reduction.[10] Nevertheless, some studies have shown conflict between anesthetic drug costs, recovery time, and patient outcomes.[11,12]

Remifentanil, dexmedetomidine, and desflurane are costly agents that often have suitable alternatives to their use. We implemented an intervention that required identification of the attending anesthesiologist before the use of remifentanil and dexmedetomidine during a case. Concurrently, we removed desflurane vaporizers from all main operating rooms, rendering desflurane available only by request. We hypothesized that these interventions would result in a significant decrease in the average anesthetic drug cost and a decrease in the utilization of these cost-prohibitive agents with minimal difference in patient recovery time and outcomes.

Methods

Patient population

The study received approval (April 2011) by the Vanderbilt University Medical Center Institutional Review Board (IRB). The requirement for written informed consent was waived by the IRB. All patients who received an anesthetic in the main operating rooms from April 2013 to February 2014—representing five months before and after the final intervention—were screened. Cases occurring between interventions, incomplete cases, and cases with data entry errors were excluded as described below.

Interventions

On August 8, 2013, the inhalational agent desflurane and Tec 6 desflurane vaporizers were removed from all operating rooms following a manufacturer recall due to potential leaks.[A] Prior to this date, desflurane, isoflurane, and sevoflurane were available in every operating room. After addressing the recall, desflurane was made available only by request from an anesthesia technician. These changes constituted our volatile anesthetic cost intervention. Beginning on September 10, 2013, the Department of Anesthesiology implemented an intravenous medication cost intervention by adding an additional step when requesting either remifentanil or dexmedetomidine. Before dispensing these drugs to the anesthesia provider (i.e., resident, certified registered nurse anesthetist, or student registered nurse anesthetist), the operating room pharmacy was to request the name of the attending anesthesiologist supervising their use for a particular case. Data were compared retrospectively in two cohorts: one prior to the volatile anesthetic cost intervention and one following the intravenous medication cost intervention.

Data collection

Data were extracted from Vanderbilt's perioperative information management system (PIMS), de-identified, and labelled with a unique case number. The following demographic data elements were retrieved for each case: the American Society of Anesthesiologists (ASA) physical status classification, age, sex, body mass index (BMI), and preoperative diagnosis. The case-specific data retrieved included: procedure description, surgical provider, anesthetic technique, attending anesthesiologist, and specified times (i.e., in-room, surgical incision, end-of-case, and out-of-room).

Drug acquisition costs were obtained from the central pharmacy, and there were no substantial shifts in drug costs during the study period. A case cost calculator was constructed to determine the total amount of each anesthetic drug administered for each included case. This institution mandates that each drug vial must be used for a single patient only. These totals were divided by the quantity of drug dispensed per vial, rounded up to the whole number of vials, and then multiplied by the drug acquisition cost per vial. Volatile anesthetic costs per case were determined by measuring total fresh gas flows, percentage of inspired volatile anesthetic, and the cost per millilitre to acquire the volatile anesthetic.[13] Dosages for drug infusions were calculated using the patient weight documented in the PIMS.

Patient outcomes were assessed before and after the interventions without excluding cases with incomplete or incorrect drug cost data. We used data from the postanesthesia care unit (PACU) to determine the incidence of administering medications for postoperative nausea and vomiting (PONV) and administering naloxone. Antiemetic agents were defined as ondansetron, dexamethasone, haloperidol, droperidol, scopolamine, metoclopramide, prochlorperazine, and promethazine. The incidence of intraoperative unplanned intubations was determined by counting the events recorded in the PIMS. Frequency of postoperative reintubation was found by screening the associated billing data from the operative day for emergent intubations, i.e., current procedural terminology (CPT) code 31500, and then performing a manual chart review of these cases to identify those that required emergent intubation postoperatively.

Data processing

Cases occurring between the two interventions were excluded from analysis. The 1,200 most expensive cases were reviewed for errors in drug cost data entry. These errors occurred primarily due to incorrect selection of dosage unit, most commonly grams charted rather than milligrams. Cases missing end-of-case and out-of-room times and any cases with a listed procedure of "Cancelled upon entry to OR" were also excluded.

Statistical analysis

Data analysis was performed using SAS® statistical analysis software (SAS Institute in Cary, NC, USA). We

[A] Recall # Z-2161-2013: Class 2 Device Recall Tec 6 Plus Vaporizer. Manufacturer: GE HealthCare. Reason: Low pressure leak test at the 1% dial setting of the Tec 6 and Tec 6 Plus Vaporizers were found not to have been detecting the full range of leaks from seal wear degradation in the vaporizers. Users are now to perform the user manual recommended preoperative low-pressure leak test with the dial on every vaporizer turned to the 12% setting instead of the specified 1% setting.

performed normality assessments using Kolmogorov-Smirnov analysis. Demographic variables were reported as median [interquartile range; IQR] for continuous variables and summarized as counts and percentages for categorical variables. Case durations are reported as median [IQR]. Total anesthetic drug costs were calculated for each case and the mean (SD) and median [IQR] total anesthetic drug costs were determined in the months before the volatile anesthetic cost intervention and in the months after the intravenous medication cost intervention. Means were compared with Wilcoxon-Mann-Whitney analysis. All reported *P* values are two-sided. Median end-of-case to out-of-room times were calculated before and after the interventions and reported as median [IQR].

The frequency and percentage of cases using remifentanil, dexmedetomidine, and desflurane before the volatile anesthetic cost intervention and after the intravenous medication cost intervention were compared using Chi square analysis. The incidence of prolonged time to extubation was determined by comparing the percentage of cases before and after the interventions with an interval > 15 min from end-of-case to out-of-room times.[16] The incidence of PONV, unplanned intubation, naloxone use, and reintubation before and after the interventions was compared using Chi square analysis.

Cost analysis

Separate top-down and bottom-up cost analyses were performed to quantify the resulting annual cost savings of these interventions. In 2013, 32,823 cases took place in our main operating rooms. The change in mean total anesthetic drug cost per case was extrapolated over the 32,823 cases.[14,15] Alternatively, the cost difference resulting from only the three drugs (remifentanil, dexmedetomidine, and desflurane) was determined using the percentage change in usage, mean cost per case of each drug, and extrapolating these data over 32,823 cases. This cost difference was offset by making assumptions regarding the most commonly substituted medications for each of these agents, calculating the percentage change in usage and mean cost of these drugs per case, and extrapolating these data over 32,823 cases.

Linear regression model

Multivariable linear regression was used to model the relationship between the average anesthetic drug costs per case, case duration, and the pre-intervention or post-intervention epochs. This model predicts the average anesthetic drug costs per case, Y, based on the average duration per case, X_1; the epoch of pre-intervention (0) or post-intervention (1), X_2; and the interaction between duration and epoch, X_3.The coefficients of these variables are represented by β_1, β_2, and β_3, where β_1 represents the cost per minute of maintenance anesthesia shared between the two epochs, β_2 represents the difference in fixed costs of anesthesia between the two epochs, and β_3 represents the additional difference in maintenance cost per minute of anesthesia between the two epochs.

Results

Demographic data

There were 27,233 unique cases identified, and 2,932 cases that occurred between interventions were excluded from analysis. For cost analysis, 228 cases were excluded due to errors in data entry of drug costs, 35 cases due to missing end-of-case or out-of-room times, and 17 cases due to case cancellation (Figure). For outcomes analysis, four cases were excluded due to missing PACU data. The distribution of age, sex, BMI, ASA status, and anesthetic technique showed no significant differences between the two cohorts (Table 1).

To assess potential differences in case mix before and after the interventions, the most frequent CPT codes in cases that used each of the index drugs were determined

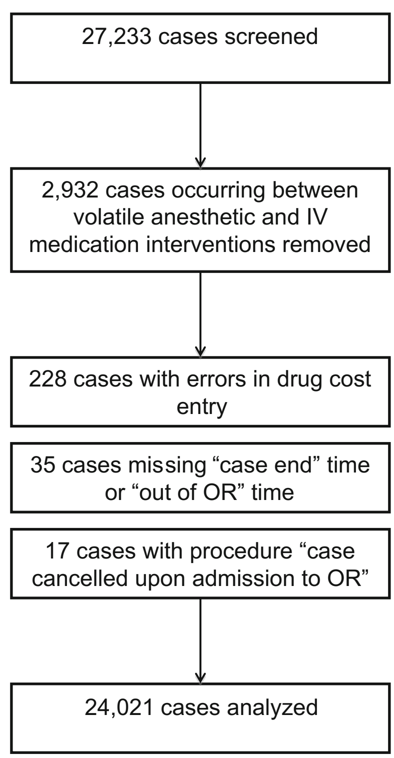

Figure Flow chart for cases included in cost analysis

Table 1 Demographic data (24,021 cases)

	Before volatile anesthetic cost intervention (Epoch 1) (n = 10,553)	After intravenous medication cost intervention (Epoch 2) (n = 13,468)	P value*
Age (yr)†	55 [41-66]	55 [42-66]	0.38
Body Mass Index ($kg \cdot m^{-2}$)†	27.8 [23.9-32.9]	27.9 [23.9-32.8]	0.71
Sex			0.06
Male	5,354 (49.3%)	6,664 (49.5%)	
Female	5,198 (50.7%)	6,803 (50.5%)	
ASA Physical Status			0.89
I-II	4,102 (38.9%)	5,248 (39.0%)	
III-V	6,443 (61.1%)	8,214 (60.1%)	
Anesthetic technique			0.07
General	8,924 (84.5%)	11,425 (84.3%)	
Monitored Anesthesia Care	727 (6.9%)	987 (7.3%)	
Other	902 (8.5%)	1,056 (7.9%)	
Case duration (minute)†	87.5 [44-154]	87.0 [43-152]	0.11

*Chi square and Wilcoxon-Mann-Whitney analysis used for differences between frequencies and medians, respectively. †Median [interquartile range]. ASA = American Society of Anesthesiologists

Table 2A Top 5 CPT codes that used remifentanil

	Before volatile anesthetic cost intervention (frequency)	After intravenous medication cost intervention (frequency)
1	31620: Endobronchial ultrasound (69)	61867: Craniectomy with stereotactic implantation (49)
2	61510: Craniectomy (51)	31620: Endobronchial ultrasound (28)
3	61867: Craniectomy with stereotactic implantation (50)	31628: Bronchoscopy (39)
4	60240: Thyroidectomy (45)	36215: Cerebral angiogram (18)
5	31628: Bronchoscopy (27)	61510: Craniectomy (17)

(Table 2a-c). The top procedures using remifentanil remained similar, with the exception of thyroidectomy, which became less frequent, and cerebral angiogram, which became more frequent after the intervention. Use of dexmedetomidine and desflurane became infrequent, and therefore, any changes in the cases utilizing these drugs were difficult to analyze.

Change in anesthetic drug costs

Before the interventions, the mean (SD) cost of anesthetic drugs per case was $32.39 ($55.40). Following the interventions, the mean (SD) cost of anesthetic drugs per case was significantly lower at $21.44 ($29.24). This represents a significant decrease in anesthetic drug cost per case (difference in means, $10.95; 95% confidence interval, $9.86 to $12.04; $P < 0.001$). The distribution of the cost reduction was assessed using analysis of the median drug costs per case, which showed a smaller difference in medians of $2.93.

The relationship between the average anesthetic drug costs per case, case duration, and the pre-intervention or post-intervention epochs was modelled by the regression equation ($Y = 9.98 + 0.19X_1 - 1.39X_2 - 0.08X_3$, $P < 0.001$), with an R^2 of 0.144 (Table 3). The cost per minute of maintenance anesthesia shared between the two epochs was $0.19. The coefficient for the epoch indicator variable shows a $1.39 decrease in the fixed costs. The coefficient for interaction between epoch and duration shows that the maintenance cost of anesthesia decreased in the second epoch by a further $0.08 per minute. Entering the average case duration per epoch and epoch indicators into the model, the costs in the first and second epochs were $26.51 and $18.22, respectively, resulting in a calculated decrease in total anesthetic drug costs per case of $8.30.

Table 2B Top 3 CPT codes that used dexmedetomidine

	Before volatile anesthetic cost intervention (frequency)	After intravenous medication cost intervention (frequency)
1	27447: Total knee arthroplasty (13)	61867: Craniectomy with stereotactic implantation (7)
2	61867: Craniectomy with stereotactic implantation (3)	27447: Total knee arthroplasty (6)
3	63030: Laminectomy, facetectomy & foraminotomy (2)	32663: Thoracoscopy with lobectomy (2)

Table 2C Top 5 CPT codes that used desflurane

	Before volatile anesthetic cost intervention (frequency)	After intravenous medication cost intervention (frequency)
1	55866r: Laparoscopic robotic prostatectomy (97)	58661: Laparoscopic bilateral salpingo oophorectomy (3)
2	52353: Ureteroscopy w/wo lithotripsy (51)	15100: Skin graft; split thickness (2)
3	43644: Laparoscopic gastric bypass (43)	20245: Excisional bone biopsy (2)
4	52332: Cystoscopy; ureteral stents (39)	43644: Laparoscopic gastric bypass (2)
5	47563: Laparoscopic cholecystectomy (36)	58570: Laparoscopic total hysterectomy (2)

CPT = current procedural terminology

Table 3 Multivariable linear regression analysis of the relationship between average anesthetic drug costs to case duration and pre-intervention or post-intervention epochs

Variables	Coefficient (β)	95% Confidence Interval	*P* value
Intercept	9.98	8.83 to 11.14	
Time (X_1)	0.19	0.19 to 0.20	< 0.001
Epoch (X_2)	−1.39	−2.61 to −0.16	0.008
Time by epoch interaction (X_3)	−0.08	−0.09 to −0.07	< 0.001

The coefficients of these variables are defined as: time (the cost per minute of maintenance anesthesia shared between the two epochs); epoch (the difference in fixed costs of anesthesia for epoch two with respect to epoch one); time by epoch interaction (the additional difference in per minute maintenance cost of anesthesia between the two epochs)

Change in drug usage

The frequency and percentage of use per case of remifentanil, dexmedetomidine, and desflurane were determined before and after the interventions (Table 4). The frequency of cases that used remifentanil after the interventions was significantly lower at 472 cases (3.8%) compared with 1,024 cases (9.7%) before the interventions ($P < 0.001$), an absolute decrease of 5.91% (relative decrease of 60.8%). The frequency of cases that used dexmedetomidine after the interventions was *not* significantly lower at 51 cases (0.4%) compared with 56 cases (0.5%) before the interventions ($P = 0.07$). Finally, the frequency of cases that used desflurane after the interventions was significantly lower at 76 cases (0.6%) compared with 2,727 cases (25.8%) before ($P < 0.001$) the interventions, an absolute decrease of 25.2% (relative decrease of 97.7%).

Cost analysis

A top-down projected annual cost savings was first determined by extrapolating the overall cost difference of $10.95 per case over the 32,823 cases performed per year, yielding a total cost savings of $359,411.85. A bottom-up, projected annual cost savings using only changes in case usage of the three drugs and their substituted agents showed a cost savings of $233,857.57 (Table 5).

The study showed an absolute reduction in remifentanil usage of 5.91%, with a mean cost per case of $68.14. When we extrapolate over 32,823 cases, the result is an annual cost savings of $132,180.64. Sufentanil represents a commonly substituted drug for remifentanil, and the study showed an absolute increase in usage of 1.61%. Mean cost per case of sufentanil was $9.66, resulting in an annual cost increase of $5,104.83. Together, the contribution to cost savings by decreasing the use of

Table 4 Anesthetic drug usage before and after interventions

	Before volatile anesthetic cost intervention	After intravenous medication cost intervention	*P* value
Remifentanil	1,024 cases (9.70%)	472 cases (3.79%)	< 0.001
Dexmedetomidine	56 cases (0.53%)	51 cases (0.39%)	0.07
Desflurane	2,727 cases (25.8%)	76 cases (0.56%)	< 0.001

Table 5 Comparison of cost and usage changes with commonly substituted agents

	Cost per case	Change in use	Estimated cost difference per year (32,823 cases)	Total cost difference
Remifentanil	$68.14	−5.91%	−$132,180.64	
Sufentanil	$9.66	+1.61%	$5,104.83	−$127,075.81
Desflurane	$13.20	−25.2%	−$109,182.43	
Sevoflurane	$0.63	+2.6%	$537.64	
Isoflurane	$0.33	+17.2%	$1,863.03	−$106,781.76
				−$233,857.57

Table 6 Patient outcomes

	Before volatile anesthetic cost intervention (*n* = 10,677)	After intravenous medication cost intervention (*n* = 13,628)	*P* value*
Median end-of-case to out-of-room time (min)†	8 [5-12]	8 [5-12]	0.10
Delayed extubations (> 15 min from end-of-case to out-of-room time)	1,657 (15.5%)	2,167 (15.9%)	0.41
Unplanned intraoperative intubations	2 (0.02%)	4 (0.03%)	0.60
Post-operative nausea and vomiting in the PACU	2,604 (24.4%)	3,102 (22.8%)	0.003
Naloxone use in the PACU	12 (0.11%)	30 (0.22%)	0.04
Postoperative reintubation	1 (0.01%)	4 (0.03%)	0.28

*Chi square and Wilcoxon-Mann-Whitney analysis was used for differences between frequencies and medians, respectively. †Median [interquartile range]. PACU = postanesthesia anesthesia care unit

remifentanil offset by increasing the use of sufentanil was $127,075.81.

The study showed an absolute reduction in desflurane usage of 25.2%, an absolute increase in sevoflurane usage of 2.6%, and an absolute increase in isoflurane usage of 17.2%. The mean costs per case of the drugs were: desflurane, $13.20; sevoflurane, $0.63; and isoflurane, $0.33. Summing these changes in costs resulted in an estimated annual contribution to cost savings of $106,781.76. Since there was no significant change in dexmedetomidine use, we did not calculate the change in cost or usage.

Patient outcomes

The patient outcomes of delayed end-of-case to out-of-room times, unplanned intubations, PONV, reintubations, and naloxone use are shown in Table 6. There was no significant difference in median [IQR] end-of-case to out-of-room times of 8 (5-12) min per case both before and after the interventions ($P = 0.10$). Overall, 15.7% of cases reported > 15 min from end-of-case to out-of-room times, which is associated with prolonged time to extubation. The percentage of cases with delayed end-of-case to out-of-room times before the interventions was

15.5% compared with 15.9% after the interventions (P = 0.41).

A comparison of data before *vs* after the interventions revealed several notable results. The incidence of unplanned intubations showed no significant difference before and after the interventions (0.02% *vs* 0.03%, respectively; P = 0.60). The incidence of reintubations in the PACU also showed no significant difference (0.01% *vs* 0.03%, respectively; P = 0.28). The incidence of PONV showed a significant decrease after the interventions (24.4% *vs* 22.8%, respectively; P = 0.003). On the other hand, the frequency of use of naloxone in the PACU showed a significant increase after the interventions (0.11% *vs* 0.22%, respectively; P = 0.04).

Discussion

Within hospitals, operating rooms account for 40% of total expenses while generating 70% of the revenue.[2] Intraoperative anesthesia costs account for 5.6% of total perioperative costs, with most of the costs derived from labour.[2] Pharmaceutical costs account for 6% of the hospital expenses, with anesthesia drugs making up 22% of these costs.[2] At the University of Michigan, 24% of the Department of Anesthesiology's budget went towards anesthetic drugs, whereas 54% of the budget went towards salaries.[9] Though we do not have the data to calculate the proportion of our institution's total cost of anesthesia represented by our anesthetic drug cost savings, we can infer from previous literature that this represents a small proportion of the total costs. Nevertheless, although these anesthetic drug costs may comprise a small fraction of the overall costs, given many cases, this small difference aggregates to a significant amount.

Research focused on cost interventions within departments of anesthesiology across the United States has previously met with mixed results. Beyond switching to less expensive volatile agents, an alternative practice for limiting costs would be the use of low fresh gas flows. Techniques for implementing low flow anesthesia include new departmental policy, periodic feedback, or using a more advanced anesthesia machine. Though our department does not have a policy on limiting gas flows, several studies have shown significant annual savings using this technique.[4-6] A study at the University of Washington showed a significant reduction in fresh gas flows as well as a calculated annual savings of $104,916 by using a real-time decision support tool.[4] Implementation of a cost education program at the University of Michigan resulted in a decrease in cost per case of volatile anesthetics and neuromuscular blocking drugs after the intervention.[9] A study at a West Virginia University (WVU) hospital showed a 23% reduction in anesthetic drug expenditures after a cost-containment lecture series; however, the program lost effectiveness and drug usage returned to pre-education levels.[8]

There has been much debate on the cost and evidence-based benefit of remifentanil, dexmedetomidine, and desflurane. Remifentanil is characterized by rapid equilibration into the plasma and a very short half-life that is independent of infusion duration. This has associated the agent with faster induction and recovery from anesthesia and allowed the use of high-dose opioids and low-dose hypnotic anesthesia. A recent systematic review comparing remifentanil with conventional opioids observed inconsistency in outcomes across 85 randomized control trials and concluded that the agent may be more useful only for selected patients.[17] Dexmedetomidine has been used as an alternative to traditional drugs for mild to moderate sedation. A recent review of six economic evaluations and two guidelines sought to evaluate the cost and outcome benefits of using dexmedetomidine in the intensive care unit. The report showed inconsistent economic value and marginal clinical benefit, but it also suggested that the use of dexmedetomidine might be preferred over the benzodiazepine sedatives.[18] Desflurane has a low blood-gas solubility coefficient, allowing for rapid induction and recovery from anesthesia. A meta-analysis of volatile anesthetic choice and its effect on postoperative recovery and complications showed a modest earlier recovery of four to five minutes with desflurane *vs* isoflurane and no difference between desflurane *vs* sevoflurane.[19]

Our study showed a significant decrease in average anesthetic drug cost and decreased utilization of remifentanil and desflurane after two accessibility interventions. No significant difference in utilization of dexmedetomidine was shown. This decrease in average anesthetic drug cost resulted in a savings of $10.95 per case, which can be extrapolated using the top-down analysis to $359,411.85 per year. The smaller change in median costs as compared with the change in mean costs indicates a reduction in primarily cost-prohibitive agents. Our linear regression model calculated a decrease in anesthetic drug costs per case between epochs ($8.30) that was less than the actual average difference in anesthetic drug costs. This is likely due to interactions among variables not represented in this model. Nevertheless, this model showed that there is a statistically significant decrease in both fixed costs and per-minute maintenance costs. This analysis of our institution's interventions adds to the current literature by showing the effect of physical changes in departmental policies *vs* education alone on overall anesthetic drug costs, medication utilization, and patient outcomes.

A large proportion of these cost savings may be attributed to a decrease in case usage of remifentanil and desflurane (a relative decrease of 60.8% and 97.7%, respectively) and a corresponding increase in the usage of commonly substitutable agents. The bottom-up savings analysis showed an approximate savings of $233,857.57 from these agents alone. Given little change in case mix and demographic data between the two groups, additional observed cost savings may be due to the Hawthorne effect, where awareness of these two interventions could have led to an overall increase in cost-conscious behaviour in clinical practice. To expound upon the fiscal importance of this observed cost difference, the annual anesthetic drug cost savings of $359,411.85 can be translated to full-time equivalents of anesthetic providers. Using median annual salaries,[B] this cost savings translates to 2.17 nurse anesthetists or 1.02 attending physicians working full time. As labour costs make up the largest proportion of intraoperative anesthesia costs, it is notable that the overall anesthetic drug cost savings we observed are comparable to the annual salaries of one to two anesthesia providers. To put this into context, we had 274 anesthesia providers (attending physicians, resident physicians, nurse anesthetists, and student nurse anesthetists) working at our institution during the period studied.

Importantly, these interventions and subsequent changes in drug usage were not associated with an increase in the frequency of prolonged time to extubation, as defined as an interval > 15 min from the end of the case to removal of the tracheal tube. Dexter and Epstein established that prolonged extubation is associated with increases in the time from the end of the case to exit from the operating room.[16] There was no change in the frequency of unplanned intraoperative intubations and reintubations in the PACU before and after these interventions, and there was a significant decrease in the incidence of PONV. On the other hand, there was a small but significant increase in the use of naloxone after the interventions. We speculate that this could be due in part to providers' reduced experience delivering total intravenous anesthesia (TIVA) with sufentanil or other narcotics rather than with remifentanil.

This study has several limitations. We examined only one large academic medical centre, and thus, these practice patterns may not be applicable to community hospitals, same-day surgical centres, or other settings where trainees are not present. In these environments, the concept of requiring "attending name" may not be a transferable intervention. One other concern of these interventions would be the potential to limit the experience of trainees; however, these agents were not prohibited from use but made available only by request. We studied retrospective data, which presented a challenge in filtering confounding factors that may have led to a change in the cost environment of the hospital. There is always a possibility of changes in case mix over time, and the most frequent procedures using remifentanil were similar. Nevertheless, analyzing types of procedures using desflurane and dexmedetomidine was difficult due to the small number of cases using these agents after the interventions. The possibility of a charting error was assessed through thorough analysis of anesthetic drug cost data and exclusion of significant errors. Other methodology, such as the assumption that one vial was used per patient as mandated by this institution, could also have altered cost data.

Another limitation may be that the decrease in the volume of sales in these particular drugs may become associated with an increase in supplier selling costs and thus short-lived cost benefits. Alternatively, a consequence of decreased consumer demand could be the total elimination of production of these drugs by manufacturers and/or suppliers. By decreasing economies of scale, accessibility interventions may inadvertently cause the loss of a medically necessary drug from the market. More research must be done to elucidate changes in sales volume, specifically in anesthetic drugs, and their effects on overall supplier prices. Interestingly, reducing the overall number of drugs available for administration may improve patient safety through the reduction of medication errors, and it may also lead to further savings through decreasing inventory complexity and costs.

Additionally, though this study analyzed potential adverse effects on patient outcomes due to limiting the use of certain medications, it is important to keep in mind possible immeasurable ethical concerns regarding patient-specific care. We did not assess other patient outcomes such as postoperative pain score, patient satisfaction, time to ambulation, and other potential patient complications. In regard to delayed patient recovery time, we estimated this duration through end-of-case to out-of-operating room times, and thus, there could have been minor differences in recovery that did not show a delay.

Economic analysis of a new agent or technology should seek to define the added value as the ratio of the difference in costs between the next best comparator, typically standard of care, and the difference in outcomes.[20] In this way, best practices can be defined among anesthesia departments based on the measurement of both cost and evidence-based benefit. In our study, we observed a decrease in cost with minimal changes in outcomes.

[B] Annual median salary in the US is $164,995 per year for a certified nurse anesthetist and $352,706 per year for a physician anesthesiologist. These are public data extracted from www.salary.com.

Nevertheless, our analysis of cost comparisons of commonly substituted drugs is limited, for instance, a variety of different techniques may have been used to attain a similar anesthetic plan rather than using sufentanil as the sole substitute for remifentanil. While fentanyl is also a medication that can be used as a substitute for remifentanil in some cases, providers at our institution favour the pharmacokinetics of sufentanil as a component of TIVA in cases over several hours. Thus, we did not include this potential substitution into our analysis. Because of this and other substitutions that were difficult to predict, our bottom-up calculations of individual drug cost savings per case may be an under- or overestimation. Also, it is possible that removing the agents altogether could have led to potentially greater savings; however, our study was unable to examine this due to its retrospective design. Further studies to elucidate changes in anesthetic technique could explain the exact manner of cost savings per agent and other effects on patient outcomes.

Conclusion

In conclusion, we have analyzed the effects of two interventions on the use of several cost-prohibitive drugs. We found a significant decrease in the average cost of anesthetic drugs and decreased utilization of remifentanil and desflurane. We identified no significant effect on patient recovery time, the incidence of unplanned intubations, and the incidence of reintubation. We observed a small decrease in PONV and a small increase in the use of naloxone in the PACU.

Conflicts of interest None declared.

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