Anesthesiology
1997; 86:1161-9

Using an Anesthesia Information Management System as a Cost Containment Tool

Description and Validation

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This article is accompanied by two editorials. Please see: Fisher DM, Macario A: Economics of anesthesia care: A call to arms! ANESTHESIOLOGY 1997;86:1018-9 and Shapiro BA: Why Must the Practice of Anesthesiology Change? It's Economics, Doctor! ANESTHESIOLOGY 1997;86:1020-2.

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Received from the Department of Anesthesiology, Duke University Medical Center, Durham, North Carolina. Submitted for publication June 25, 1996. Accepted for publication December 18, 1996. This work was done at Duke University and was not supported by any grants related directly to this project. Arkive®, while it was in business, cooperated with us to develop our database analysis capabilities. Authors have presented information relating to portions of this paper in abstracts at the 1995 American Society of Anesthesiologists' annual meeting, October 21-25, 1995, Atlanta, Georgia; the 1996 American Society of Anesthesiologist's meeting, October 19-23, 1996, New Orleans, Louisiana; and at the 1996 International Anesthesia Research Society annual meeting, March 8-12, 1996, Washington, DC. Those abstracts are: Sanderson IC, Gilbert W, Sibert K, Lubarsky D: Evaluation of a program for calculating and plotting isoflurane utilization. ANESTHESIOLOGY 1995; 83:A388; Lubarsky DA, Gan TJ, Glass PSA, Dear GD, Mythen M, Dentz M, White WD, Pressley CC, Dufore SM, Sibert KS, Gilbert WC, Sanderson IC, Coleman R, Ginsberg B, Temo J, Ferrero-Conover D, Alexander ML, Reves JG: PACU clinical outcomes and financial savings following a pharmaceutical cost containment program in anesthesia using practice guidelines (abstract). Anesth Analg 1996;82:S285; Sanderson IC, Gilbert WC, Lubarsky DA: Cost containment using an automated anesthesia record keeper. Anesth Analg 1996;82:S391; and Lubarsky DA, Gilbert W, Alexander ML, Sanderson I: Validation of the programming of an anesthesia information management system for cost calculations. ANESTHESIOLOGY 85:A1046, 1996.

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Background: **Medical informatics provide a new way to evaluate the practice of medicine. Anesthesia automated record keepers have introduced anesthesiologists to computerized medical records. To derive useful information from the stored data requires programming that is not currently commercially available. The authors describe how they custom-programmed an automated record keeper's database to perform cost calculations, how they validated the programming, and how they used the data in a successful pharmaceutical cost-containment program.**

Methods: **The Arkive® (San Diego, CA) automated record keeper database was programmed at Duke University Medical Center as an independent noncommercial project to calculate costs according to standard formulae and to follow adherence to Duke University Department of Anesthesiology's prescribing guidelines for anesthetic drugs. Validation of that programming (including analysis of discarded drugs) was accomplished by comparing database calculated costs with actual pharmacy distribution of drugs during a 1-month period.**

Results: **Validation data demonstrated a 99% accuracy rate for total costs of the drugs studied (atracurium, vecuronium, rocuronium, propofol, midazolam, fentanyl, and isoflurane). The study drugs represented approximately 67% of all drug costs for the period studied.**

Conclusions: **Programming of an anesthesia automated record keeper's database yields essential information for management of an anesthetic practice. Accurate economic evaluation of anesthetic drug use is now possible. In the future, as definitive identification of best anesthetic practices that yield optimal patient outcomes and higher measures of patient satisfaction is pursued, large numbers of patients should be studied. This is only possible through database analysis and complete computerization of the perioperative medical record. (Key words: Anesthesia, costs. Economics, drugs. Equipment, computers: information systems. Records, anesthesia: automated. Statistics, costs.)**

AUTOMATED anesthesia record keepers (AARK) are becoming more common in the operating room (OR) to record clinical information and to build a clinical database. The ability to maintain a complete record in times of crisis (even unrecognized ones) has led to a decline in malpractice insurance costs for some practices using

Table 1. Chronology of AIMS Installation at Duke University Medical Center

1972—Radiotelemetry system for surgical patient monitoring
1980—Duke Automated Monitoring Equipment (DAME)
1983—Use of the DAME abandoned
1987—Planning for AIMS purchase
1988—Installed a networked Arkive automated anesthesia record keeping system in cardiothoracic operating rooms
1989—Database developed using Paradox (Borland, Scotts Valley, CA) (database management software)
1990—Preoperative workstation developed and installed
1992—Hospital-wide installation of networked Arkive system
1993—Networked Arkive units installed in preoperative holding unit
1993—Preoperative software developed to interface with the hospital's operating room scheduling system
1995—Arkive ceases production and operation

AARKs.†† Direct electronic billing, an advertised feature of some systems, may increase charge capture and decrease clerical work in the billing office. In addition, reduced stationary costs and a decreased need for personnel to file or retrieve those papers cuts some relatively trivial operational expenses. However, savings sufficient to justify the high cost of AARKs have been difficult to document. The Duke University Medical Center Department of Anesthesiology believed that if an AARK could be made to function as a perioperative anesthesia information management system (AIMS; *i.e.*, by programming database software to extract the information we wanted from the database), great economic benefits would accrue.

That belief in the potential economic benefits of a fully computerized anesthesia information management system has driven our commitment to extend the concept of automated recordkeeping. (For chronology, see table 1.) Duke University continues to operate the largest intraoperative automated anesthesia recordkeeper database in the country, with more than 100,000 cases and growing at a rate of 20,000 per yr. That database can be searched in detail for demographic variables, anesthetic and airway management techniques, material resource utilization, vital signs at 20-s intervals, other electronic monitoring information, drugs and fluids administered, and a variety of standardized text notes. In 1993, a group of physicians and technical support personnel formalized the Anesthesia Section on Information Systems and began custom programming software that could extract information from that large database for use in research. With this structure established, we were prepared to initiate a drug utilization project in 1994.

This article details the development of the programming used in that drug utilization review program, provides data that validates the accuracy of these methods, and describes the instrumental part an AIMS played in an anesthesia pharmaceutical cost-reduction program.

Methods

How the Arkive® Works

The record generated by the Arkive® (Arkive Information Systems, Inc., San Diego, CA; company no longer operational) system is the official legal record of the anesthetic.

The clinician (anesthesiologist or certified registered nurse anesthetist [CRNA]) manually enters on a touch keyboard all drugs, intravenous fluids, fresh gas flows, and concentration of inhalation agents administered.[1,2] The database stores the current time of all entries and records the units for all agents: drug doses in micrograms, fluids in milliliters, and fresh gas flows in liters per min. Additional patient demographic data and pertinent case data (age, weight, type of surgery, members of the anesthesiology care team [anesthesiologist, resident, CRNA], ASA physical status classification, anesthesia and surgery start and end times, event markers for incision and positioning, etc.) are all manually entered for each patient.

Calculating Costs

The database containing anesthetic drug use information was accessed to obtain the drug amounts administered during defined time periods. From the pharmacy acquisition costs, the costs per microgram and costs per milliliter were calculated for each of the 161 different anesthetic drugs in the Arkive® database. Total drug expenditures, based on the actual dosages administered, were calculated. Using standard formulae to determine the amount of volatile anesthetic used[3] and pharmacy acquisition costs of inhalation anesthetics and the fresh gas flow as entered into the Arkive®, costs per case for inhalation agents were calculated. Antibiotic, cytotoxic, and immunosuppressive drugs were excluded because their administration was dictated by the surgical team.

†† Ferrari HA: Defending anesthesia malpractice: role of computerized records. ASA Newsletter, June 1995;59:14–16.

At Duke University Medical Center Hospital, a satellite OR pharmacy distributes almost all drugs on a per patient basis in an individualized drug cassette, which includes all infusion drugs in standard sizes and concentrations. All drugs are returned to the OR satellite at the end of the case, and the pharmacist discards the remainder of any opened vial. Because of this OR satellite pharmacy policy, drugs can only be administered in full vial increments; we created software to round off all drug costs in the database to the costs of full vials (based on most often used size if more than one size was available) and to standard size drug infusions. This allowed an accounting of the cost of discarded and administered drugs. For example: assuming a 10-dollar cost/20 ml vial of propofol, the exact cost of drug administered was based on 0.005 cents/μg $\times$ the number of micrograms administered. The rounding function calculated propofol costs for administration of 1–200,000 μg as 10 dollars. This type of calculation was done for each drug for each patient.

Targeting the Largest Expenditures

The database was initially programmed to determine and rank cumulative drug expenditures for a 6-week period. (Any defined period of time could have been used.) This directed cost containment to those drugs that had the largest impact on our total costs. The costliest drugs on our list correlated with similar lists generated by others—neuromuscular blocking drugs, inhalation anesthetics, propofol, midazolam, and colloids.[4,5] This knowledge focused our department's consensus for cost containment—targetting expensive drugs for maximal economic effect, while minimizing the number of potentially unpopular, restrictive guidelines.[6] This information specific to the operating rooms was unavailable from the pharmacy, which maintained records mainly for analysis of drug use for the institution as a whole.

"Best Practice" Consensus Group

Five committees of four to six people were formed to define practice guidelines for our target groups of agents: neuromuscular blocking agents, induction drugs, fluids, benzodiazepines and opioids, and inhalation anesthetics. Each committee then fashioned the clearest possible statement of the appropriate use for each drug under its jurisdiction.

Tracking Departmental Success of Educational Initiatives and Adherence to Practice Guidelines

We identified departmental drug use patterns by analyzing records in the Arkive® database during the period of education (March 1994–March 1995) and after practice guidelines and distribution control were introduced in May 1995. (See table 9 in companion article, page 1153.)

For example, the muscle relaxant committee determined that the primary practice guideline was to use pancuronium for cases longer than 90 min. The database was first used to segregate cases into those longer than 90 min *versus* those shorter than 90 min. The cases greater than 90 min were analyzed to tally pancuronium use *versus* the total number of cases using nondepolarizing muscle relaxants. We were able to identify the frequency with which specific anesthesia caregivers did not use pancuronium according to practice guidelines by sorting adherence to this practice guideline by individual.

For fresh gas flows, the database was analyzed to extract the sum total flows of oxygen, nitrous oxide, and air for each min that inhalation anesthetics were in use. This allowed us to differentiate between inappropriate high fresh gas flows during maintenance of inhalation anesthesia and appropriate high fresh gas flows for denitrogenation during preoxygenation, during emergence, and for cases in which monitored anesthesia care (MAC) and regional anesthesia were used. Average fresh gas flows were reported by summing liters of fresh gas flow for each min that inhalation agents were in use and then dividing by the time during which inhalation agents were in use. We also calculated average fresh gas flows for each case. To account for differences in case times, we did not average the average fresh gas flows per case (*i.e.*, averaging the average fresh gas flow for each case does not yield an appropriate time-weighted average).

Discarded to Used Ratios—Helping to Define Default Protocols for the Optimization of Drug Distribution

Default protocols for the efficient distribution of some of the more costly drugs were designed to minimize the amounts being wasted. By analyzing the cost of the amount of drug administered against the cost of the number of vials opened, we were able to calculate used to discarded ratios. We used these data to determine if the current vial size and infusion standards were appropriate (table 2).

As previously mentioned, muscle relaxants were targeted as a key area for cost containment, particularly those drugs

Table 2. Pharmaceutical Wastage via Unused Portions of Vials and Measures Taken for Corrective Measures: March 1995

Drug	Cost of Drug Used† ($)	Cost of Vials ($)	% Discarded	Actions Taken
Midazolam*	9,200	16,600	44	Change from 5 mg to 2 mg vials
Propofol	12,700	23,600	46	Educate faculty to open one vial at a time for bolus or infusion. Infusions were routinely being set up with 2 or 3 vials at the beginning of the case. Limited propofol distribution to 40 ml at beginning of case.
Atracurium	2,000	7,300	73	Change from 10 ml to 5 ml vials. Initiate discussions with pharmacy regarding manual subdivision for pediatric cases (in progress).
Midazolam infusion	1,900	4,400	56	Change standard infusions to 10 *versus* 20 mg at start.
Etomidate	1,700	3,300	48	Consider change from 20 ml to 10 ml ampule. Decision made not to do so secondary to negligible cost difference; emphasis was on limiting use instead.
Labetalol	600	2,600	78	Unable to find distributor of low-cost prefilled small-dose syringe (smaller vial size not available from manufacturer). Discussion to open vials in pharmacy and manually subdivide; not done for lack of data on stability out of vial and increased waste from this practice. Waste continues.

* The unit cost for midazolam had changed between the time periods considered in tables 2 and 3.

† Drugs costing >$25,000/year with >40% waste and actions taken to address the waste. Dollar figures represent a 6-week "snapshot" of costs prior to interventions.

of intermediate duration. Despite our practice guideline suggestion to use pancuronium primarily, there were many instances (*e.g.*, short cases, cases wherein patients may not tolerate any tachycardia, or cases in which patients suffered from renal insufficiency) when pancuronium would not be an appropriate choice. To evaluate which intermediate muscle relaxant to use, we analyzed drug use *versus* time of operation from our database (table 3). Procedures were subdivided into three categories: those less than 60 min, those 60–90 min, and those 90–120 min. The database was further used to define weight constraints of 50–100 kg to limit our considerations to adults. The cost of the amount of drug administered and the total cost of each drug rounded up to the nearest whole vial were calculated for mivacurium (20-mg vial), atracurium (50-mg vial), rocuronium (50-mg vial), and vecuronium (10-mg vial).

Mivacurium was seldom used at our institution and hence excluded from final analysis, and cis-atracurium was not yet available on formulary. As a result of our database analysis, the practice guideline for the most costly drug — atracurium — suggested limiting its use to patients with hepatic or renal impairment. Rocuronium costs less per vial than vecuronium or atracurium, and despite more vials being opened for cases lasting longer than 60 min, its average cost per patient was still slightly less than that of vecuronium and much less than that of atracurium. Because the anticipated costs of rocuronium and vecuronium were similar and because considerations such as patient weight, required speed of intubating conditions, and concurrent medical problems also influence drug selection, practice guidelines for short cases requiring muscle relaxants allowed a choice of rocuronium or vecuronium. More recently, a repeat analysis suggested the use of cis-atracurium as the preferred intermediate duration nondepolarizing muscle relaxant on the basis of its markedly lower cost per vial. We anticipate the introduction of generic atracurium will cause us to revisit this analysis. The ability to constantly update information and use that knowledge to help guide use of pharmaceuticals is an advantage of having a computerized database.

Pharmaceutical Costs Per Case or Per Hour by Anesthesia Provider

We fashioned programming that would extract pharmaceutical costs from the database for each case and

Table 3. Parameters of Muscle Relaxant Use

	Atracurium	Rocuronium	Vecuronium
Procedure of <60 min, n = 82 (procedures measured from anesthesia ready, *i.e.*, surgeons may start prep/positioning, to surgery end, *i.e.*, dressing on)			
Subgroup n	23	35	24
1 vials opened	23/23	28/35	23/24
2 vials opened	0	7/35	0
3 vials opened	0	0	1/24
4 vials opened	0	0	0
Average total cost* ($)	22.51	19.87	21.22
Procedures of 60–90 min, n = 153			
Subgroup n	43	63	47
1 vial opened	38/43	57/63	45/47
2 vials opened	5/43	5/63	2/47
3 vials opened	0	0	0
4 vials opened	0	1/63	0
Average total cost* ($)	25.92	18.26	21.80
Procedures of 90–120 min, n = 154			
Subgroup n	33	50	71
1 vial opened	28/33	41/50	63/71
2 vials opened	5/33	8/50	8/71
3 vials opened	0	1/50	0
4 vials opened	0	0	0
Average total cost* ($)	25.92	18.26	21.80

* Cost equals the cost per vial multiplied by the total number of vials opened during the test period, then dividing that total by the number of cases during the test period. Prices: atracurium = $22.52/5 ml; rocuronium = $15.22/5 ml; vecuronium = $19.59/10 mg.

then attribute those costs twice—once to the primary attending physician noted in the Arkive® record and once to the resident physician or CRNA being medically directed. We then rank ordered attending physician providers based on average cost per case and average cost per hour for a set period. There was a separate tabulation of the pharmaceutical costs for the resident physicians and CRNAs.

We believed it was most appropriate to assess attending physician costs by comparing their costs with others whose practice encompassed similar cases. There are eight basic intraoperative subspecialty areas at our institution; each anesthesiologist is primarily affiliated with one subspecialty group. With the exception of the cardiothoracic anesthesiologists, anesthesiologists do cross over from their primary specialty to do other cases as necessary for clinical service needs. We grouped providers into their primary area of work—regional or orthopedic, obstetric, ophthalmologic, vascular or high-risk, general, cardiothoracic, pediatric, and neurologic. Comparisons among these subspecialty groups and among the providers within each subspecialty group (table 4) helped to spur further discussions on the indications and uses of expensive drugs.

Cataloguing Individual Use Patterns For Each Drug

We also were also able to rank by cost each caregiver's use of each particular drug in the Arkive® database. For instance, hetastarch use at the beginning of this project ranged from 0 dollars to more than 1000 dollars per month for different attending caregivers. We concentrated on the top eight expenditures for the department. Obtaining these individual drug costs per provider allowed identification of those spending the most on each drug in the database. This additional data allowed us to identify those who were using inordinate amounts of a "favorite" costly drug, but whose total costs per case or per hour did not stand out when compared with their peers. Maximum effect of cost-containment initiatives can be expected by targeting those with the largest expenditures for a particular item.

Preventing Erroneous Entries from Skewing the Database

The database was programmed with maximum acceptable doses to help identify any provider who mistakenly keyed in excessive dosages (*e.g.*, 2000 *gm* of magnesium as opposed to 2000 *mg*). The programming was done on the back end, with the database, after case completion. It would have been better if the organiza-

Table 4. Comparison among Specialty Groups, Actual Average Costs per Case: November 1–30, 1995

Attendings by Service*	Minimum ($)	Maximum ($)	November 1995 Average ($)
Department	14.39	84.79	36.52
Cardiac	37.18	84.79	65.50
Neurologic	33.23	45.43	38.26
Ophthalmologic	28.33	41.84	35.09
Vascular/high risk	29.73	47.10	34.86
General	27.36	39.57	33.83
Pediatric	17.74	52.14	33.52
Regional/orthopedic	27.33	36.33	31.82
Obstetric	14.39	28.08	21.23

* Attending coverage crossed subspecialty lines except in the cardiothoracic group.

tions producing recordkeepers put in a front end edit to prevent grossly inaccurate entries. Each time the database was accessed for reports on provider costs, the program identified all doses exceeding the defined thresholds and displayed them in tabular form for evaluation and review. We noted that deviations of even a single entry by two orders of magnitude could potentially skew the data for 1000 cases. After quick review, we usually ignored errors less than five dollars unless the same error appeared frequently. Errors less than five dollars were almost always correct entries that exceeded the upper dosage limits based on case duration. Clear errors (*e.g.*, 6000 dollars for propofol for a single case) were deleted from the database for the purpose of cost calculations. Possible errors greater than five dollars underwent review. In the first quarter of 1996, more than 6000 cases had costs calculated. It took less than 5 min to eliminate obvious errors and those less than five dollars; about 15 min was needed to access and review four anesthesia records that contained possibly correct entries exceeding the maximum dosages. All were in error. Not only did this programming for erroneous entries prevent database corruption, it also allowed us to identify an anesthesia care provider who consistently made inaccurate entries by three orders of magnitude for one particular drug (aminocaproic acid).

Although falsely low entries remained in the database, occasional falsely low values would not affect costs because even the cost of a minuscule dose would be rounded up to the cost of a full vial. A number of these errors would have an effect on the ratio of used-to-discarded drugs.

Follow-up Evaluation

For each of 4 weeks after the institution of practice guidelines, all of the previously discussed reports were generated. Those anesthesia caregivers using expensive drugs out of proportion to that used by their peers were informally approached with the data on their practice pattern. In almost all cases, this had the desired effect of decreasing use of that drug by that caregiver.

After the initial month, monthly reports and yr-to-date reports were generated with similar feedback. Once attending caregivers were comfortable with the data analysis, feedback also was begun on a per provider basis to CRNAs and residents. For attending physicians, CRNAs, and residents, confidential feedback consisted of a memorandum noting specific costs per case and provided the average and range of costs per case for the department and by subspecialty for comparison. Each caregiver was given their costs per case from the previously reported period so they could assess their progress. Each caregiver also was notified if he or she was among the top five users of the most costly drugs. Subspecialty section chiefs were encouraged to discuss the techniques used by the attending caregiver in their section who had the least costs and to attempt to standardize the administration of anesthesia to that level if appropriate.

Certified registered nurse anesthetists and resident physicians were not grouped by subspecialty because they often moved from one area to the next. The residents and CRNAs were provided with attending physician averages for each of the subspecialty sections so that if they were predominantly practicing in one area during that period, they could assess their own performance.

Cost Savings

In a previous report,[6] we detailed the cost savings and associated outcomes associated with implementation of practice guidelines. At Duke University Medical Center wherein 27,728 anesthetics were administered in 1995, use of the AIMS was instrumental in generating a recurring pharmaceutical savings of approximately one million dollars per yr.

Validation of Drug Use

During November 1995, the information calculated by Arkive® for the largest pharmaceutical budget items during 2068 cases at the main operating suites in Duke North Hospital was validated by comparison with drugs actually dispensed by the OR satellite pharmacy to the main ORs. Atracurium, vecuronium, rocuronium, propofol, midazolam, fentanyl, and isoflurane were studied. These drugs represented approximately 67% of drug expenditures during that period. With the exception of isoflurane, these drugs distributed through the OR satellite pharmacy have minor patterns of use outside the ORs in a variety of off-site anesthetizing locations, the postanesthesia care unit (PACU), and preoperative staging areas, and on rare occasion, in the cardiac or surgical intensive care units (SICU; drugs almost always supplied by main pharmacy).

All inhalation vaporizers in the main OR were filled, and the inventory of all study drugs in the satellite OR pharmacy was recorded as of 5 PM on October 31, 1995. On November 30 at 5 PM, all vaporizers were filled again, and the inventory of all study drugs was restocked to original levels.

Table 5. Verification of Arkive Records: Drug Charges Recorded by Arkive Compared with Pharmacy Drug Charges*

Drug	Arkive ($)	Pharmacy ($)	% Arkive/Pharmacy
Midazolam	9,272	10,735	86
Propofol	8,074	6,966	116
Vecuronium	3,526	3,996	88
Rocuronium	3,607	4,311	84
Atracurium	1,058	1,203	88
Fentanyl	1,437	1,722	83
Isoflurane	15,188	15,024	101
Total	42,162	43,597	*96.7

* Data do not include 2.4% of cases done outside of main ORs but supplied by OR satellite pharmacy; also, data do not include correction for distribution of postoperative epidural fentanyl infusions. Corrections included yield >99% accuracy overall. The overall percent is weighted over all costs, allowing the $285 lost on fentanyl, for example, to be more than made up by the $1,108 gained on propofol.

Initial Arkive® cost calculations for these drugs were 96.7% of actual costs recorded by the pharmacy (table 5). The 3.3% discrepancy in costs between pharmacy distribution and Arkive® calculations noted previously are a result of several factors:

1) 2.4% of cases outside of the main ORs were supplied by the OR satellite pharmacy and were included in their costs.
2) The Arkive® recorded cost for fentanyl was 17% too low—the most unreliable figure—because the first bag of postoperative epidural infusions of bupivacaine plus fentanyl are mixed in the OR satellite pharmacy and distributed to the PACU and SICU by the anesthesia resident or attending caregiver for the case. A 1-week survey in February 1996 revealed eight infusions requiring 500 μg of fentanyl and eight infusions requiring 1000 μg each. Assuming this use pattern was indicative of November use, epidural infusions with fentanyl accounted for approximately 25% of the fentanyl discrepancy recorded by Arkive®. We assume that fentanyl distribution for intravenous dosing in the PACU and excessive waste with use of 20-ml vials accounted for the rest.

After adjustments for the provision of postoperative epidural narcotic infusions and the 2.4% of cases supplied by the OR satellite pharmacy but not on the Arkive® database, calculated costs were more than 99% of costs incurred by the pharmacy.

3) Unrecognized waste for 10-ml atracurium and rocuronium vials. Rocuronium and atracurium, which were available in two sizes (5- and 10-ml vials), had a relatively high degree of inaccuracy because of unrecorded amounts being discarded, given that the Arkive® rounding program assumed only 5-ml vials were being used. Arkive® tabulated use underestimated actual use by 12–16% for those two drugs. This was rectified by notifying the pharmacy to promote distribution of only 5-ml vials and limit 10-ml vials to attending physicians only. In a follow-up 1-week inventory survey of rocuronium, this distribution restriction increased Arkive® calculated cost accuracy to 98% for this drug and virtually eliminated excessive discarding of atracurium and rocuronium.
4) Overestimation of propofol costs were a result of remainder of vials of propofol used for induction being started as an infusion. Arkive® programming assumed a vial had been used for intermittent intravenous bolus dosing and a second vial used for infusion of propofol. This was rectified by adjusting the program to apply the unused portion from the bolus to the infusion. Having done this, the November calculated costs were 7366 dollars, a change from 116% of actual administration to 106% of drug actually administered. The remaining overestimation most likely resulted from splitting single vials of propofol for use on two patients (against hospital pharmacy policy).
5) The rocuronium and propofol calculated cost changes offset each other almost exactly and will not change the future cost accuracy of the Arkive® programming. These changes will give a more accurate representation of actual drug use.

Discussion

Accurate data and a large database collected for a long time are necessary to generate accurate reflections of institutional and individual use patterns. Conscientious clinicians will voluntarily respond to reasonable requests to review their practice pattern when it is dramatically different from their peers. However, the physician should have faith that the utilization review is a reflection of his or her practice. The open computerized database available with an AIMS is ideal for that.

Long-term cost containment usually is hard to maintain. It has been shown that constant reinforcement and distribution control is necessary to achieve success at cost containment, especially if pharmaceutical representatives oppose

the process.[5,7-11] By periodically accessing the open Arkive® database on drug administration, by continually monitoring practice patterns and providing input to the anesthesiologist, the goal of constant reinforcement can be easily accomplished. After initial database programming, it has to be someone's job to provide feedback and maintain vigilance. At our institution, an administrative staff assistant (TP) and the Anesthesia Information Systems Administrator (WG) oversee these follow-up tasks. In addition, a peer or committee should vigorously pursue any necessary discussion of practice patterns based on these reports (DL).

Positive feedback on individual progress also is important. An educational reward program (consisting of a fund for professional expenditures) has just been established for each practitioner based on the success of the program. Further contributions to those funds are planned for those making the most progress, those most consistently providing cost-conscious care according to the established practice guidelines, and those generating new ideas by which costs can be curtailed. These economic rewards are the result of payments made by Duke University Hospital as part of a cost-savings incentive program. Remarkably, the successes to date have been accomplished and sustained by the goodwill of the department because all the results reported here were obtained before the actual implementation of an economic reward. Despite the lack of tangible rewards during the course of this study, for 1 yr, our costs per case have consistently remained within 3% of our initial postpractice guidelines' May 1995 rate of 36 dollars per case. Recent decreases in the price of isoflurane have actually resulted in further case cost decreases.

New drugs are no exception to the oversight capability we have established. Our inhalation anesthesia practice guideline committee decided that after Food and Drug Administration approval, sevoflurane would principally be used for pediatric induction of anesthesia and as an alternative to propofol administration during the final portion of a case (used as a method to speed wake up at the end of some cases). All attending caregivers who were not pediatric anesthesiologists but who were freely using sevoflurane were identified and informed that they were using the drug outside the department's established guidelines. This successfully curtailed their use of the drug.

Future innovations to our analyses are planned. As our database grows, we plan to assess drug costs for specific operations and perform exact comparisons between attending caregivers for the same types of cases. Accurate knowledge of average drug costs per case will allow for fewer unknowns when case contract pricing is offered and will make it easier to enter into capitation agreements with pharmaceutical vendors. Analysis of all resource consumption during cases is being currently programmed for the same reason. Database analysis is being used to follow our department's adherence to US government Health Care Financing Administration (HCFA) documentation rules regarding teaching physicians. The use of relational databases in medical practice management will certainly expand and be an area of great opportunity as the future of medicine unfolds.

Limitations

The Arkive® database is imperfect. We were unable to identify drugs withdrawn from the vial and not given at all. This would cause an underestimation of cost. Also, despite pharmacy regulations stipulating that leftover drugs withdrawn from a multidose vial should not be used on a subsequent patient, this occasionally occurs, especially in the pediatric and eye center suites. This would falsely increase the amount recorded as discarded in the Arkive® database. These two factors act in opposite ways on cost calculations. The validation data that compare actual pharmacy costs to Arkive® calculated drug costs suggest that these are not major issues.

Inaccurate or omitted entries are not only possible, but likely. This occurs especially if there are frequent changes, as may occur in the recording of inhalation anesthetic concentrations and fresh gas flows. Because inhalation drug calculated costs were deemed the least likely value to be correct, we initially retrospectively calculated a 6-week use of all inhalation agents and compared that amount with the total dollars of inhalation agents purchased during that same period. The calculated value was within 3% of actual expenditures based on a 6-week sample.[3] A more complete study detailed previously was prospectively performed in November with strict inventory control of costly drugs and inhalation agents, with similar results (99% accuracy). This suggests that omitted entries probably are not very important to our calculation of vials used. Other problems with accuracy within the system relate to the fact that the Arkive® system cannot differentiate multiple types of the same drug. For example, different types of lidocaine are administered—spinal, epidural, intravenous, topical—in concentrations ranging from 0.5-4%. Arkive® can only record milligrams administered. (A recent software release by Synergie Health Information Systems Inc., San Diego, CA, for use with the Arkive® corrects this problem.) An educated average of cost based on the most commonly

used type of drug in these rare circumstances was necessary. The price differentials for clinically administered amounts of lidocaine were very small when the rounding function for lidocaine was considered, and this assured we were not significantly under- or overestimating cost. For a variety of reasons, the OR satellite pharmacy was unable to perform an inventory control study on this drug.

Also, in a few cases, more than one vial size is available for a drug (*e.g.*, 20- or 40-mg size of etomidate), and a survey of use patterns was done to decide what the appropriate price per milligram and vial cost should be for that particular drug. We chose the 40-mg size based on our clinical use pattern and the relative cost parity (about one dollar) between the two vial sizes. The greater the difference in vial size, the more likely Arkive® will not adequately reflect costs. We were especially concerned about fentanyl, available in 5- and 20-ml sizes. Arkive® was programmed to round off to a new vial every 5 ml. This underestimates waste every time someone uses a 20-ml vial and uses less than 15-ml of the drug. Because three 5-ml vials (0.45 dollars each) cost about the same as a single 20-ml vial (1.45 dollars), as long as more than 11 ml were used, we would accurately represent or overestimate the cost of fentanyl for that case. In the event 1–10 ml were used out of a single 20-ml vial, we would underrepresent the cost of fentanyl. Given the very low generic pricing of this drug, the error rate we described in November 1995 would have had negligible impact (0.10 dollars per case), and the systematic nature of that type of error would not affect drug cost trends. Overall, these problems were few and of little importance to the large expenditures we were trying to influence.

We recommend that future generations of anesthesia information management systems adopt client–server database technology to facilitate data exchange in as close to real-time as possible. Arkive® does not do this at present. Through the use of standard information transmission protocols, such as HL-7 or ODBC (open database connectivity), patient information can be shared with information management systems in the pharmacy, intensive care units, hospital administration, and throughout the hospital. A relational database is crucial to use anesthesia information management systems in clinical research, assessing economic data such as resource utilization, and forecasting case prices. It would be beneficial if corporations producing AARK and AIMS would all use an open database format. Hopefully, if we elucidate problems, producers of AIMS will incorporate solutions for vial sizes, costs accounting, and routes of administration into the next generation of software. An investment in a better product makes sense because AIMS can help direct and sustain cost saving programs, which can more than pay for the hardware and software expenses.

Conclusions

Combining the data collection of an automated anesthesia recordkeeper with custom software programming allows us to generate cost data by physician and by subspecialty, which accurately assesses drug use in our practice. Turning an AARK in to an AIMS has provided the data necessary to sustain a pharmaceutical cost reduction program that has generated savings greater than 1 million dollars per year.

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