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Reengineering Intravenous Drug and Fluid Administration Processes in the Operating Room

Step One: Task Analysis of Existing Processes

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Background: **A reengineering approach to intravenous drug and fluid administration processes could improve anesthesia care. In this initial study, current intravenous administration tasks were examined to identify opportunities for improved design.**

Methods: **After institutional review board approval was obtained, an observer sat in the operating room and categorized, in real time, anesthesia providers' activities during 35 cases (~90 h) into 66 task categories focused on drug/fluid tasks. Both initial room set-up at the beginning of a typical workday and cardiac and noncardiac general anesthesia cases were studied. User errors and inefficiencies were noted. The time required to prepare *de novo* a syringe containing a mock emergency drug was measured using a standard protocol.**

Results: **Drug/fluid tasks consumed almost 50 and 75%, respectively, of the set-up time for noncardiac and cardiac cases. In 8 cardiac anesthetics, drug/fluid tasks comprised 27 ± 6% (mean ± SD) of all prebypass clinical activities. During 20 noncardiac cases, drug/fluid tasks comprised 20 ± 8% of induction and 15 ± 7% of maintenance. Drug preparation far outweighed drug administration tasks. Inefficient or error prone tasks were observed during drug/fluid preparation (*e.g.*, supply acquisition, waste disposal, syringe labeling), administration (infusion device failure, leaking stopcock), and organization (workspace organization and navigation, untangling of intravenous lines). Anesthesia providers (n = 21) required 35 ± 5 s to prepare a mock emergency drug.**

Conclusions: **Intravenous drug and fluid administration tasks account for a significant proportion of anesthesia care, especially in complex cases. Current processes are inefficient and may predispose to medical error. There appears to be substantial opportunity to improve quality and cost of care through the reengineering of anesthesia intravenous drug and fluid administration processes. General design requirements are proposed.**

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ANESTHESIA care is a complex, high-risk job in which intravenous drug and fluid therapy plays a critical role. Every anesthetized patient receives intravenous drugs and fluids, and, in fact, in an increasing majority of cases, intravenous drugs play a dominant role in the anesthesia provided. Yet the technology and processes for intravenous drug and fluid delivery are more cumbersome than those for administering inhaled anesthetics. Syringes must be prepared individually, and several doses of up to 20 different drugs may be administered intravenously during a single case. The "cost" of inefficient drug/fluid administration processes may be reflected in additional time required of anesthesia providers to prepare to administer anesthesia (*e.g.*, preparation of filled syringes during initial case set-up). Poorly designed processes may also promote error (*e.g.*, syringe swaps),[1–3] decrease provider satisfaction, or increase overall cost (*e.g.*, drug waste).

Inefficient intravenous drug/fluid administration processes may impact the cost-effectiveness of anesthesia care. For example, because of the need to respond rapidly to intraoperative emergencies, anesthesia providers may draw up one or more syringes of resuscitation drugs (*e.g.*, ephedrine, phenyleprine, or atropine) "just in case." These emergency drugs are not always needed and some of the prepared doses are discarded unused.[4]

If, as suspected, intraoperative intravenous drug and fluid administration processes contain elements of inefficiency, excess cost, or put patients at risk unnecessarily, then redesign of these processes is indicated. Reengineering refers to a variety of techniques to analyze, redesign, and implement changes in devices, systems, or processes to improve safety, efficiency, effectiveness, or customer satisfaction.[5,6] Reengineering typically begins with a structured assessment of the current process or system and whether it effectively meets users' needs. The initial output of this assessment is typically a list of general design requirements that can then be refined and

Table 1. Drug/Fluid Administration Task Categories

Grouped Task Categories*	Individual Task Categories (n = 66)*
1. Drug preparation tasks	
Open/close anesthesia cart	Open/close anesthesia cart drawers
Remove wrapping	Remove wrapping
Assemble syringe	Retrieve syringe from drawer; retrieve needle; attach needle to syringe
Label syringe	Label syringe
Manipulate/attach/remove to/from syringe	Remove cover from needle; remove needle or cap; recap needle; place needleless cap on syringe; retrieve cap; handle needle/cap/syringe
Prepare vial for medication draw	Retrieve drug vial/ampule; retrieve alcohol swab; inspect drug vial/ampule; place drug vial/ampule; open vial/ampule; swab top of drug vial/ampule
Draw drug/fluid into syringe	Withdraw drug from vial/ampule; withdraw fluid/drug from intravenous bag; inspect syringe
2. Drug administration tasks	
Retrieve/place syringe	Retrieve syringe; place syringe
Transfer syringe to/from other provider	Transfer syringe to/from someone
Deliver drug intravenously	Attach syringe to stopcock; insert syringe and needle into intravenous port; turn/manipulate stopcock; inject syringe; remove syringe (stopcock/intravenous port)
3. Intravenous fluid/tubing manipulation tasks	
Observe intravenous equipment/fluids	Observe intravenous equipment and fluids
Manipulate IV pole	Manipulate intravenous pole
Add/change intravenous fluids	Retrieve intravenous fluids; hang/unhang intravenous fluids; retrieve intravenous tubing; attach/remove fluids to tubing
Manipulate intravenous tubing/stopcock	Retrieve stopcock; manipulate intravenous tubing/stopcock
Flush/squeeze/adjust intravenous bag	Adjust intravenous equipment (flow rate); flush/squeeze intravenous bag
4. Fluid delivery equipment–related tasks	
Set-up infusion pump	Turn on/off infusion pump; insert tubing into infusion pump; program infusion pump
Syringe pump–related tasks	Turn on/off syringe pump; attach syringe to syringe pump; attach tubing to syringe or stopcock; insert needle in tubing; attach tubing end or needle to intravenous line; program syringe pump; adjust syringe pump; refill syringe pump
4. Documentation and organization tasks	
Charting drugs/fluids given	Charting drugs/fluids given
Organize workspace	Organize workspace (drug-related)
5. Waste disposal tasks	
Dispose of sharps/trash	Dispose of wrapping; dispose of needle; dispose of syringe; dispose of intravenous materials; dispose of vial/ampule; dispose of other; dispose of unknown item
6. Other drug tasks	
Other drug task	Other drug task (includes unlocking anesthesia cart, locking/unlocking narcotics safe, rummaging around in anesthesia cart drawers, pressurizing intravenous bags, drawing blood/fluid from stopcock, and unidentified drug/fluid tasks)
Inspect other	Inspect other
7. Unidentified tasks	
Retrieve/place unknown item	Retrieve unknown item; place unknown item
Handle/manipulate unknown item	Handle/manipulate unknown item
8. Non-drug/fluid tasks	
Non-drug/fluid task	Non-drug/fluid task

* Raw data were collected using the individual task categories. Some analyses were performed on grouped task categories.

made more specific. The design requirements comprehensively define the desired characteristics of the reengineered process, technology, or system.[7]

As a first step in an effort to reengineer anesthesia intravenous drug and fluid administration, we began to rigorously examine existing processes in the operating room (OR). In this initial study, a validated observational task analysis technique[8,9] was used to measure the amount of time spent on different drug/fluid-related tasks during clinical care and to document inefficiencies and possible causes of error in existing processes. From these data, general design requirements are proposed.

Methods

After institutional review board approval and written informed consent were obtained, a trained observer sat in the OR and categorized in real time the activities of anesthesia providers into 66 discrete task categories (table 1) using a standardized protocol.[8–10] A comprehensive list of drug/fluid-related tasks was developed based upon preliminary observations and, after review and validation, was incorporated into custom data collection software. Data were collected between June 1999 and August 2000.

The observer was a premedical undergraduate student (D. B. F.) with over a year of training and experience in anesthesiology-specific behavioral task analysis. Each task occurrence was recorded by clicking with a mouse on the appropriate button on the computer display. The software then automatically logged the time and task initiated. If two tasks occurred simultaneously, the observer recorded the dominant task first and then toggled between the two tasks based on the frequency with which each dominated the provider's time.[8,10] Individual drug/fluid tasks were listed under specified headings on the computer interface in order to facilitate data collection for the observer. Whenever a drug/fluid task was not being performed, a larger "non–drug/fluid task" button was selected. The task "other drug task" was infrequently selected with the occurrence of otherwise unclassified drug/fluid-related tasks.

User errors and inefficiencies, as well as unsuccessful actions, were specifically noted in the data log. The observer also recorded the occurrence of specific case segments, including initial (preanesthetic) set-up, induction, surgical incision, maintenance, end of surgery, and emergence (or start of bypass in cardiac cases) using previously well-defined and validated behaviorally based event markers.[8–10] Data collection was suspended when the provider was out of the OR on a break.

To provide a wider cross-section of providers and types of drug tasks, data were collected at two different institutions, the San Diego VA Medical Center and the University of California San Diego Medical Center (composed of two different hospitals with similar anesthesia carts). Throughout the study period, the routine intravenous tubing sets used during surgery at all three hospitals included needleless ports and an in-line three-way stopcock.

Initial case preparation (*e.g.*, early morning room set-up) as well as routine noncardiac and cardiac general anesthesia cases were studied. In noncardiac cases, the end of induction (start of maintenance) was defined as the time when the anesthesia provider completed all manual tasks related to securing of the airway and stepped away from the patient. The start of emergence was defined by the cessation of anesthetic agent delivery and administration of 100% O_2. In cardiac cases, the end of induction was defined by completion of insertion of the pulmonary artery catheter (always performed after intubation). Cardiac case data collection ceased upon initiation of cardiopulmonary bypass (*i.e.*, only the pre-bypass period was studied for logistical reasons).

To reduce complexity of the data presentation and analysis, individual drug/fluid-related tasks were organized to create a task ontology with eight highest-level task categories (table 1). Data were analyzed using custom software written in Microsoft Visual Basic on a Microsoft Excel platform (Microsoft Corp., Redmond, WA). Case data were segregated into induction, maintenance, and emergence (noncardiac cases only). Data were analyzed for actual and percent of the time spent on individual drug/fluid tasks as well as the number of task occurrences (task incidence) and the duration of individual task episodes.

Differences in tasks performed during different phases of the anesthetic were compared with one-way repeated measures analysis of variance. Task distribution during cardiac *versus* noncardiac cases were compared statistically during the induction or maintenance periods using two-way mixed analysis of variance (type of case x tasks). Significant main effects were examined further with Newman-Keuls *a posteriori* tests. A P value < 0.05 was considered statistically significant, and data are presented as mean $\pm$ SD.

A link analysis was performed on total case task data.[8] Pairs of sequential tasks were identified for each case and then summed across all cardiac and noncardiac cases. For example, the link score between the categories "observe monitors" and "recording" was calculated by adding the number of occurrences when "observe monitors" was followed immediately by "recording" and the occurrences when "recording" was followed by "observe monitors." The bidirectional links were summed to reduce analytical complexity due to the very large number of possible links. The duration of each task incidence was not considered in this analysis. A link percentage was calculated by dividing each link score by the total number of links occurring in that case.

Emergency Drug Preparation

To assess the speed with which anesthesia providers could unexpectedly prepare to administer an emergency drug, a realistic standardized procedure was designed and described to randomly selected anesthesia providers with at least 6 months of training. The protocol was carefully explained to each subject and then demonstrated (in slow motion) by the investigator. Although a single sequence of tasks to be accomplished was described, the subjects were told that they could prepare the drug in any sequence they felt was appropriate, as long as all of the tasks were included. The test protocol, which was conducted in the OR in otherwise empty rooms between cases, consisted of the following steps: open anesthesia cart drawer and remove a 10-ml vial of saline (the putative emergency drug), 10-ml syringe, and 18-gauge needle; remove all wrappings and dispose of them; assemble syringe/needle; draw up drug; remove and dispose of needle; and insert filled syringe into female cap (to simulate a stopcock). Thus, the time to perform this procedure did not include either actual stopcock manipulations or injection of the drug into an intravenous line. Subjects were instructed to perform the task as rapidly as possible ("as if their patient's life depended on it") but to do so safely, just as they would in routine practice. The total time to complete the task

sequence was measured with a stopwatch with the investigator saying "start" and the subject indicating when they were done (observed and confirmed by the investigator).

Results

A total of 35 cases involving 20 providers were studied during 89.9 h of direct observation.‖ Precase set-up data were collected in 17 cases, but in only 9 of these cases were data obtained from the subsequent anesthesia case. The 20 noncardiac cases involved 15 experienced certified registered nurse anesthetists, as well as one first-year (CA1; > 6 months of training), 1 second-year (CA2), and three third-year (CA3) residents. The 8 cardiac cases were performed by two CA1 (> 9 months of training), four CA2, one CA3, and one faculty anesthesiologist.

In this sample of cases, the total case duration was 165 ± 164 min (mean ± SD; range, 48–373 min) in noncardiac and 167 ± 28 min (range, 132–209 min) (prebypass only) in cardiac cases. The induction phase took 34 ± 13 min in noncardiac cases and 57 ± 13 min in cardiac cases (nonsignificant difference, $P > 0.05$). Maintenance lasted 115 ± 67 min in noncardiac cases, while the postinduction prebypass period averaged 109 ± 31 min in the cardiac cases ($P > 0.05$).

General Observations

Many inefficiencies and errors in the drug/fluid administration process were observed, especially with regard to tasks involving drug preparation and in the organization of the anesthesia cart. Even though the subjects were mostly experienced anesthesia providers who were quite familiar with their anesthesia carts, in the majority of cases, subjects were frequently observed opening (and then closing) one or more inappropriate cart drawers during searches for specific items. This item search task, which accounted for up to 6% of all drug/fluid tasks during the maintenance phase of noncardiac cases (a notable finding given the fine granularity of the task data and the large number of individual tasks performed) was associated with obvious clinician frustration.

Unneeded items were commonly thrown onto the anesthesia work surfaces, which became cluttered and sometimes appeared disorganized. There was not always a clear physical separation between used (contaminated) and unused (sterile) drug-filled syringes. Anesthesia providers were inconsistent in their efforts to keep controlled substance-containing syringes secure.

The clinicians were frequently observed having difficulty removing the preprinted drug name labels from the rolls on the dispensing reel on top of the anesthesia cart. The providers showed frequent frustration in performing this task, and several reported cutting their knuckles on the label dispenser. Some syringes were labeled by hand with a marking pen, and, on rare occasions, syringes were left unlabeled after filling (*e.g.*, drugs that were drawn up and then immediately administered).

Particularly during cardiac cases, anesthesia providers were commonly observed to actively have to avoid intravenous tubing as they moved around the workspace. Some subjects tripped over intravenous tubing and, especially in cardiac cases, were observed to lift intravenous tubing over their heads in order to move past it. Providers also commonly needed to move intravenous poles out of their way during workspace navigation. Providers accidentally banged their bodies into the intravenous poles on a number of occasions. Anesthesia providers were observed to hit their head on the top of the intravenous pole or have the intravenous pole catch on the overhead lights or the OR door as a patient was being transported into or out of the room. We also observed two shorter anesthesia providers standing on wheeled chairs to hang intravenous fluids. On two occasions, intravenous fluid was observed leaking from stopcocks (due to either a disconnection or an incorrect stopcock valve position). During one cardiac case, an infusion pump malfunctioned and required replacement. Preparing a drug for instrumented infusion was time-consuming, requiring multiple mechanical (*i.e.*, plumbing) and programming steps.

Several ergonomic problems were identified involving waste disposal in OR. Anesthesia workspaces were observed to become cluttered with unwanted sterile packaging, occasionally obscuring a clear view of more critical items like drug syringes or airway supplies laying on the anesthesia cart or anesthesia machine workstation. When disposing of trash, it was common for anesthesia providers to miss the trash can. On one occasion, a provider inadvertently dropped a needed item into the trash and had to retrieve it. In addition, providers commonly dropped things (especially drug-filled syringes) on the floor and had to retrieve them (and occasionally without assuring their sterility prior to use on the patient).

Tasks Performed during the Start of the Day Case Set-Up

Drug/fluid-related tasks comprised nearly 50% of all clinical activities during the initial set-up at the beginning of the workday in noncardiac cases and 75% of the set-up activities in cardiac cases ($P < 0.01$, noncardiac *vs.* cardiac; table 2). During the case set-up in noncardiac cases, the most common grouped drug/fluid-related task was drawing drug or fluid into a syringe. During the set-up for cardiac cases, the predominant drug/fluid-related task categories were (1) adding and changing

‖ Additional figures and tables of data that provide detailed demographic information and the task analysis results for percent time on task, task occurrences, and task duration for each case segment (induction, maintenance, and emergence) are available in the Web Enhancement.

Table 2. Percent and Actual Time Spent on all Drug/Fluid Tasks by Case Segment

	Non-Cardiac				Cardiac			
	Percent Time*		Actual Time†		Percent Time*		Actual Time†	
Setup	46.4 ± 16.5	(36.2–56.6)#	6.3 ± 9.7	(0.2–12.3)	75.2 ± 16.3	(62.1–88.3)	11.2 ± 4.7	(7.4–15.0)
Total case‡	21.9 ± 15.6	(15.7–28.2)#	20.7 ± 11.2	(16.2–25.2)#	39.0 ± 17.7	(28.5–49.4)	39.5 ± 20.9	(27.1–51.8)
Induction	19.7 ± 7.7	(16.3–23.0)**	6.4 ± 3.0	(5.1–7.7)‖	26.8 ± 8.4	(20.9–32.6)	14.8 ± 4.4	(11.8–17.9)
Maintenance	15.2 ± 7.0	(12.2–18.3)‖	15.0 ± 7.6	(11.7–18.3)‖	27.9 ± 8.1	(22.2–33.5)	30.9 ± 12.8	(22.1–39.8)
Emergence	11.6 ± 6.7	(8.7–14.5)	1.8 ± 1.6	(1.1–2.5)	§		§	

* Mean ± SD (95% confidence intervals) in percent. † Mean ± SD (95% confidence intervals) in minutes. ‡ Excludes case setup. § Cardiac cases were studied only until bypass; thus, there is no emergence data for these cases. ‖ $P < 0.001$, noncardiac *versus* cardiac cases. # $P < 0.01$, noncardiac *versus* cardiac cases. ** $P < 0.05$, noncardiac *versus* cardiac cases.

intravenous fluids; (2) manipulating intravenous tubing and stopcocks; and (3) disposing of sharps and trash. Other common tasks in all case set-ups were labeling syringes, opening and closing the anesthesia cart drawer, preparing vials for medication draw, and assembling syringes.

Tasks Performed over the Entire Case

During the entire intraoperative case (excluding the initial set-up), drug/fluid-related tasks comprised nearly 20% of all anesthesia tasks in noncardiac cases and almost 30% of all anesthesia tasks in cardiac cases (table 2). The most common individual drug/fluid-related task was charting drugs/fluids administered, comprising 14 ± 10% of noncardiac and 17 ± 11% of cardiac cases. During noncardiac cases, the next most common individual drug/fluid task was adjusting intravenous flow rate (9 ± 5%). During cardiac cases, the most common tasks included programming infusion pumps (10 ± 6%) and manipulating intravenous tubing/stopcocks (10 ± 4%). However, when compared at the highest level of grouped task categories (table 3), drug preparation tasks dwarfed in frequency all other task categories, being, for example, more than twice as common as drug administration tasks in both case cohorts. Drug preparation tasks were significantly more common (by percentage of total time) in noncardiac ($P < 0.001$ *vs.* cardiac) cases, whereas intravenous drug/fluid infusion-related tasks were more common in the cardiac cases ($P < 0.01$).

In terms of the number of individual incidences of drug/fluid tasks during each noncardiac case, the most frequently occurring (albeit brief) tasks were open/close anesthesia cart drawers, adjust intravenous flow rate, and retrieve and place syringe. In the cardiac cases, the most frequent drug/fluid tasks were adjust intravenous line, retrieve syringe, and turn/manipulate stopcock. Some of the most time-consuming drug/fluid tasks (per individual task occurrence) were charting (23 ± 20 s) and labeling syringes (13 ± 8 s). Syringe labeling took significantly longer in cardiac than in noncardiac cases.

Since the study was conducted at two different institutions with different anesthesia carts, patient populations, and to some extent anesthesia providers, a separate analysis compared the results across institutions. The only significant difference between the two institutions was that record keeping (charting of drugs/fluids given) comprised a greater percentage of all drug/fluid tasks during each case at the VA (17 ± 10%) compared with UCSD (9 ± 7%; $P < 0.01$). The VA uses an electronic anesthesia record-keeping system (AIM System v4.02; Life Care Technologies, Manchester, NH) exclusively, whereas charting is performed manually at UCSD. Regardless of the type of documentation system, contemporaneous charting of drugs/fluids administered was rare during the induction phase.

Tasks Performed during Anesthesia Induction

During the induction phase, drug/fluid tasks consumed almost 20% of noncardiac case tasks and 27 ± 9% of cardiac case tasks (table 2). In noncardiac cases, the three most common tasks were deliver drugs *via* intra-

Table 3. Percent Time Spent on Major Drug/Fluid-Related Task Categories

Major Grouped Task Category*	Noncardiac†	Cardiac‡
Drug preparation	31.6 ± 8.8 (27.7–35.4)§	15.6 ± 8.1 (10.0–21.2)§
Drug administration	19.1 ± 6.0 (16.5–21.7)**	14.7 ± 4.7 (11.5–18.0)
Intravenous fluid/tubing manipulation	22.1 ± 6.9 (19.1–25.2)#††	29.2 ± 6.5 (24.6–33.6)#**
Documentation/organization	15.9 ± 9.8 (11.6–20.2)**	18.2 ± 11.1 (10.5–25.9)
Waste disposal	6.3 ± 3.2 (4.9–7.7)**	4.3 ± 1.2 (3.4–5.1)††
Infusion/syringe pump	1.1 ± 2.6 (0.0–2.3)‖**	11.2 ± 6.2 (6.9–15.5)‖
Other drug tasks	3.6 ± 4.1 (1.8–5.4)**	6.9 ± 5.9 (2.8–11.0)‡‡

* See table 1 for list of individual tasks included in each major grouped task category. † Mean ± SD (95% confidence intervals) percent, N = 20. Total intraoperative case. ‡ Mean ± SD (95% confidence intervals) percent, N = 8. Prebypass period only. § $P < 0.001$, noncardiac *versus* cardiac cases. ‖ $P < 0.01$, noncardiac *versus* cardiac cases. # $P < 0.05$, noncardiac *versus* cardiac cases. ** $P < 0.001$, compared with drug preparation tasks in this case cohort. †† $P < 0.01$, compared with drug preparation tasks in this case cohort. ‡‡ $P < 0.05$, compared with drug preparation tasks in this case cohort.

venous line, flush/squeeze/adjust intravenous line, and retrieve/place, accounting for almost 50% of all drug/fluid tasks. In cardiac cases, the most common task categories (manipulate intravenous tubing/stopcock, deliver drugs *via* intravenous line, add/change intravenous fluids, and flush/squeeze/adjust intravenous line) accounted for almost 55% of drug/fluid tasks. "Manipulate intravenous tubing/stopcock" was significantly more common in cardiac cases ($P < 0.001$), while "place/retrieve syringe" ($P < 0.001$), "deliver drugs *via* intravenous line" ($P < 0.01$), and "flush/squeeze/adjust intravenous line" ($P < 0.05$) were more common in the noncardiac cases. In both noncardiac and cardiac cases, the three most common linked pairs of tasks were "turn/manipulate stopcock"–"inject syringe," "attach syringe to stopcock"–"turn/manipulate stopcock," and "adjust intravenous flow rate"–"non–drug/fluid task," comprising almost 20% of the hundreds of different link pairs observed.

Tasks Performed during Maintenance and Emergence

During the maintenance phase of noncardiac cases, drug/fluid tasks accounted for about 15% of all tasks (table 2). The most common drug/fluid task categories were: chart drugs/fluids given (19 ± 15%), draw drug/fluid into syringe (11 ± 4%), flush/squeeze/adjust intravenous line (10 ± 7%), and dispose of sharps/trash (7 ± 4%). In cardiac cases, during the prebypass period, drug/fluid tasks accounted for almost 30% of all tasks. The most common task categories were "charting drugs/fluids given" (24 ± 14%), "set-up infusion pump" (13 ± 8%), and "flush/squeeze/adjust intravenous line" (10 ± 5%). The grouped tasks of "charting drugs/fluids given" ($P < 0.001$), "set-up infusion pump" ($P < 0.001$), "flush/squeeze/adjust intravenous line" ($P < 0.01$), "deliver drugs *via* intravenous line" ($P < 0.01$), and "label syringe" ($P < 0.01$) all consumed significantly more time in the cardiac compared with noncardiac cases.

A link analysis of maintenance phase data showed substantially less heterogeneity of the drug/fluid task patterns (suggesting more uniformity in the task sequences performed) in cardiac than noncardiac cases. In noncardiac cases, the most common linked pair was "adjust intravenous flow rate"–"non–drug/fluid task" (6 ± 4%). In contrast, during cardiac cases, the most common link pair was "program infusion pump"–"non–drug/fluid task."

Emergence was studied only in noncardiac cases. Drug/fluid tasks accounted for 12 ± 7% of all emergence activities. The most common task categories were "add/change intravenous fluids," "manipulate intravenous tubing/stopcocks," "flush/squeeze/adjust intravenous line," and "place/retrieve syringe."

Table 4. Typical Sequence Required to Administer an Unprepared Intravenous Drug Bolus

1.	Open anesthesia cart drawer [open/close anesthesia cart drawer]*
2.	[Retrieve syringe from drawer]
3.	[Remove wrapping]
4.	[Dispose of wrapping]
5.	[Retrieve needle] from cart
6.	[Remove wrapping]
7.	[Dispose of wrapping]
8.	[Attach needle to syringe]
9.	Close anesthesia cart drawer [open/close anesthesia cart drawer]
10.	Obtain appropriate label [label syringe]
11.	Attach label to syringe [label syringe]
12.	Open anesthesia cart drawer [open/close anesthesia cart drawer]
13.	[Retrieve alcohol swab] from cart
14.	[Remove wrapping]
15.	[Dispose of wrapping]
16.	Close anesthesia cart drawer [open/close anesthesia cart drawer]
17.	Open anesthesia cart drawer [open/close anesthesia cart drawer]
18.	Retrieve drug vial from cart [retrieve drug vial/ampule]
19.	Open drug vial [open vial/ampule]
20.	[Dispose of wrapping]
21.	[Swab top of drug vial/ampule] with alcohol
22.	Insert needle/syringe into vial [withdraw drug from vial/ampule]
23.	Draw up dose drug into syringe [withdraw drug from vial/ampule]
24.	Assure no air in syringe [inspect syringe]
25.	[Place drug vial/ampule] on/in cart
26.	Close anesthesia cart drawer [open/close anesthesia cart drawer]
27.	[Dispose of wrapping]
28.	[Remove needle or cap] from syringe
29.	[Attach syringe to stopcock]
30.	Turn stopcock [turn/manipulate stopcock]
31.	Inject appropriate drug amount [inject syringe]
32.	Turn stopcock [turn/manipulate stopcock]
33.	Assure adequate intravenous flow [observe intravenous equipment and fluids]
34.	Open anesthesia cart drawer [open/close anesthesia cart drawer]
35.	[Retrieve cap]
36.	[Remove wrapping]
37.	[Dispose of wrapping]
38.	Close anesthesia cart drawer [open/close anesthesia cart drawer]
39.	[Place needleless cap on syringe]
40.	Place syringe on top of cart [place syringe]
41.	Document drug dose and time given [charting drugs/fluids given]

* Items in brackets represent the task category actually used in this study.

Preparation of a Bolus Drug Dose for Emergency Administration

A detailed analysis revealed 41 discrete tasks are involved in preparing and administering a single drug bolus into the patient (table 4). Because some have decried the prophylactic preparation of emergency drugs due to the substantial cost of unadministered drugs, it is important to know how long it takes for a provider to prepare and administer an emergency drug.

Twenty-seven anesthesia providers of varying levels of training (10 faculty, 11 certified registered nurse anesthetists, and 6 junior residents with more than 6 months of experience) were able to prepare a 10-ml syringe of saline as if for "emergency" intravenous administration in 35 ± 5 s (range, 25–43 s). There were no significant effects of level of training (faculty, 34 ± 6 s; certified registered nurse anesthetists, 36 ± 5 s; residents, 36 ± 6 s) or of gender (male, 35 ± 6; female, 36 ± 4).

Discussion

Although many anesthetic techniques and devices have evolved substantially over the last century, syringe and needle technology dates back to the mid-1800s. Intravenous infusion pumps and processes have not changed appreciably for several decades, and errors in set-up or programming occur and can have adverse consequences.[11,12] Intravenous bolus drug administration is a multistep manual process in which syringes are prepared individually and then infused as needed into a patient, often in a predetermined sequence. Several bolus doses of up to two dozen drugs may be administered intravenously during a single general anesthesia case. In this initial observational study, we demonstrated that preparing (including labeling), administering, documenting, and disposing of drugs is time-consuming and contain inefficient process elements that may affect cost of care and patient safety. The discussion that follows summarizes some of the key issues and provides suggested design requirements (in italicized text) for the next step in the reengineering of intravenous processes and equipment.

Drug Preparation Processes

The results of this task analysis suggest that the anesthesia work environment does not adequately support safe and efficient drug preparation. For example, the design of the traditional anesthesia cart shows substantial opportunities for improvement. Anesthesia cart drawers contain hundreds of items that are not always well organized and may not be uniformly stocked from one hospital to the next. In a majority of cases, experienced anesthesia providers were observed searching unsuccessfully through one or more drawers of our standardized anesthesia carts for desired items. Confounding the task of efficiently obtaining supplies and equipment, the location of needed items not found in the anesthesia cart (including some medications, intravenous supplies, order sheets, *etc.*) can vary substantially from one OR to the next. *Anesthesia supply systems should allow rapid and reliable access to equipment, supplies, and drugs at the time they are needed, and generate an automated accounting of what is used.*

Labeling prepared syringes is a process problem. When labels are hand-written on syringes, they are often difficult to read and may wear off. When anesthesia providers utilized premade standardized labels, as is often the case, they were often observed having difficulty tearing the drug labels off of their rolls. The preprinted labels differed between the hospitals in this study, creating a risk of misrecognition-based drug errors for the providers that practice at multiple locations. In addition, medications tend to be coded by manufacturer rather than by drug type, making it more difficult for anesthesiologists to locate specific drugs among the dozens stored in the cart. Because there is appreciable inconsistency among the numerous drug manufacturers in packaging drug vials and hospitals purchase drugs from different vendors over time (often changing sources based solely on cost), there remains a substantial risk of drug errors. *All intravenous drugs should be provided at the point-of-care in clearly identified, ready-to-administer packaging.*

The anesthesiologist's work surfaces (typically the top of the anesthesia cart and an area of the anesthesia machine) are small and often cluttered. This limited space may affect providers' performance of drug preparation and administration tasks. For example, in high-stress or emergency situations, the workspace's disorganization or clutter could impair a provider's ability to identify and administer in a timely fashion life-critical medications. *All of the drugs commonly needed for each anesthetic case should be available and organized in a manner that optimizes correct recognition and selection of the desired drug(s), especially during times of crisis or high workload.*

The conduits for drug and fluid administration (*i.e.*, intravenous tubing, stopcocks, *etc.*) are a source of task inefficiency and an occupational hazard. It was common for anesthesia providers to struggle with intravenous tubing organization. In complex cases, they were also frequently observed to navigate (sometimes unsuccessfully) around intravenous tubing and intravenous poles, and occasionally acted unsafely when hanging intravenous fluids onto intravenous poles. In addition, we documented two occurrences of maladjusted stopcocks leading to inadvertent cessation of intravenous fluid flow and the potential for blood loss or failed therapy. *Intravenous fluid packaging and delivery systems should improve workspace organization, reduce waste, and eliminate the risks of injury to patients and providers. Access sites for medication administration should be needleless, maintain sterility during multiple uses, and prevent leakage or backflow.*

Drug Administration Processes

The risks of faulty or inefficient processes may be most apparent during high workload or emergency situations.[13,14] Anesthesia providers recognize these risks and

frequently prepare in advance for potential emergencies. Perhaps the most common way to intervene in an unexpected OR event is with intravenous administration of drugs or fluids. The survival of the patient may depend on the length of time required to prepare and administer an intravenous drug. In this study, a realistic simulation of emergency drug preparation took approximately 35 s, and the duration was largely unrelated to provider experience. An additional 10 s, approximately, is required to administer a prepared drug (and then there is a lag of tens of seconds before the drug actually has its desired physiologic effects). Similarly, for drugs given by instrumented infusion (*e.g.*, nitroprusside or dopamine), substantial time may be required to set up and program the infusion pump. In many emergencies, delays in definitive therapy could affect patient outcome. Yet, to reduce cost, there may be pressure to avoid prophylactic preparation of emergency drugs. To save time in an emergency situation while still reducing costs, one can set up and label syringes for emergency drugs and leave the prepared syringe and respective unopened vial on top of the anesthesia cart ready for use. For the future, *new systems should facilitate emergency drug administration while reducing the cost of wastage or outdating.* In addition, *emergency drug administration should be facilitated by the immediate availability of these drugs in prepackaged, properly constituted (including most appropriate dose concentration), cost-effective, needleless preparations.*

The present study was not designed to detect the occurrence of intraoperative medication errors. However, any process redesign must address this issue. Although syringe/needle/tubing technology has been touted as simple and intuitive, it is a known cause of patient injury.[2,15] Drug administration errors are a major contributor to the large number of patient injuries that occur each year in the United States; at least one half of these injuries involve surgical patients.[15–17] Anesthesia providers likely give more intravenous drugs in the OR than in any other clinician–patient context. Dosing errors are reported to be the most common type of drug-related error in anesthesia.[15] In fact, syringe swaps and other failures of drug administration appear to be the most frequent general class of errors committed by anesthesia providers.[1–3] *Drug packaging and administration systems should strive to eliminate the risk of all types of drug errors (*i.e.*, wrong patient, drug, dose, route, time, or speed of administration)*.

Drug infusion technology has been identified as a significant threat to patient safety, primarily due to inadequate user interface design.[11,12] In the approximately 24 h of observation of cardiac anesthesia cases in this study, we detected one outright infusion pump failure. Current pump technologies may place undue cognitive burdens on clinicians and facilitate error due to, for example, distracting false alarms and other user interface deficiencies. Existing infusion systems are generally bulky, heavy, awkward, and do not communicate effectively with each other or with other medical devices. *Drug administration technologies should be highly usable (with little or no training) and support user requirements, especially during crisis situations. Instrumented infusions of drugs and fluids should be automatically documented. New technologies should be smaller and lighter to better facilitate patient transfer into and out of the OR.*

Documentation

This study shows that documentation of intravenous drug/fluid therapy is time-consuming. Current manual anesthesia records routinely contain inaccuracies (*e.g.*, dose and timing of administered medications) and omissions. Electronic record-keeping systems have their own limitations, primarily due to usability issues. With narcotic drugs, the stakes are higher, given regulatory requirements and risk of diversion. *The act of administering an intravenous medication (or fluid) should produce an automatic electronic audit trail that documents the drug, dose, route, time, person administering, patient receiving, and the therapeutic response achieved.*

Cost-Effectiveness

Because of concerns about infection control,[18] drug syringes incompletely used on one patient are not administered to subsequent patients. Emergency drugs prepared prophylactically are not often needed, and some of the prepared doses may be discarded at the end of a clinical workday. The potential magnitude of drug wastage (*i.e.*, drugs that are drawn up into syringes and not fully used, or opened drug vials that cannot be reused due to contamination or out-dating) may be significant.[4,19–21] In a recent study at one of our hospitals, drug wastage amounted to an average cost per case of almost $15.[4] This and other work[20] suggest that drug waste could account for more than 25% of a hospital's anesthesia drug budget. Drug administration systems should minimize the amount of unused drug that must be discarded. Specifically, *next-generation drug administration technologies should safely permit reuse of sterile drugs on multiple sequential patients.* This would significantly reduce drug wastage and the risk of drug errors, and enhance documentation.

In the short-term, drug waste can be significantly reduced by drawing up drugs into several syringes (*i.e.*, "split doses") if the contents of the vial are likely to be used on more than one patient. Although the use of multidose vials may decrease waste, careful inventory control is required to minimize the incidence of partially used outdated vials. Use of original manufacturer or local preparations of drugs with longer shelf-lives should be promoted. Hospital pharmacies can prepare anesthesia

drugs sterilely in syringes and deliver them each day to the operating room. The added pharmacy costs can often be paid for by the resulting reduced drug waste.[4]

Study Limitations

This study has a number of limitations. Only a relatively small number of cases were studied and, especially given the goal of obtaining a representative sample across two institutions and typical surgical subspecialties, may limit how well the results generalize to any specific practice setting. The study of anesthesia residents and nurse anesthetists in an academic medical center also limits the results' applicability to anesthesiologists in community practice.

Because we only studied the first case of the day, the results may overestimate the magnitude of drug and fluid tasks across all cases, especially during the maintenance phase. End-of-the-day cases (which were not studied) may contain fewer drug/fluid tasks because clinicians do not need to prepare new drugs for their subsequent cases. Differing case lengths may also affect the results.

Our results during the initial early morning case set-up could have underestimated the proportion of necessary preparatory drug/fluid tasks since some anesthesia providers have been observed preparing labeled syringes and even filled syringes the night before. Finally, it was sometimes difficult to discern when the provider was charting the drugs/fluids administered, as opposed to the charting of other types of clinical data.

Step Two: Process Redesign Recommendations

The results of this initial task analysis and process evaluation study suggest that there is substantial opportunity to improve cost and quality of care by redesigning intravenous drug and fluid administration processes in the OR. Any redesign should have the following general goals: (1) reduced probability of error and injury (to both patients and providers); (2) increased clinical efficiency; (3) improved cost-effectiveness; and (4) reliable documentation and accountability. These goals can be achieved by reengineering intravenous preparation and delivery processes and systems, beginning with the general design specifications that were derived from the task analysis data. The development of new technologies for drug packaging, drug/fluid delivery, and information management will be critical. For example, next-generation drug packaging should be clearly labeled to minimize risk of identification error, support immediate use *via* rapid bolus or infusion, allow sequential use on multiple patients without waste or loss of sterility, and contain imbedded technology to document contents usage (*i.e.*, who gave how much when to which patient) and to transmit that information as appropriate to other medical devices and documentation systems. A close collaboration between anesthesia providers and industry will be required to attain the desired goals.

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