Titles

- Full title: Developing models to predict early postoperative patient deterioration and adverse events
- Running head: Modelling perioperative decisions

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Subjects	747
Mean age (SD) (years)	57 (17)
Male gender	399 (53.4%)
Mean BMI (SD) (kg/m^2)	30 (6)
ASA status	
I	55 (8.9%)
II	326 (52.8%)
III	228 (38.5%)
IV	11 (1.5%)
V	0 (0.0%)
Cases by surgical specialty	
Breast-endocrine	46(6.2%)
Colorectal	50 (6.7%)
Ear, nose and throat	78 (10.4%)
General surgery, not otherwise specified	28 (3.8%)
Hepatobiliary	19 (2.5%)
Maxillofacial	31 (4.1%)
Neurosurgery	40 (5.4%)
Gynaecology	54 (7.2%)
Orthopaedics	121 (16.2%)
Plastics	82 (11.0%)
Spinal	49 (6.6%)
Upper gastrointestinal	17 (2.3%)
Urology	106 (14.2%)
Vascular	26 (3.5%)
Surgical duration	
d60 minutes	86 (11.5%)
61-120 minutes	224 (30.0%)
121-180 minutes	206 (27.6%)
181-240 minutes	128 (17.1%)
>240 minutes	102 (13.7%)
Mean (SD) (minutes)	154 (91)

NICE surgical grade	
1	18 (2.4%)
2	307 (41.1%)
3	241 (32.3%)
4	181 (24.3%)

Table 1: Sample demographics and surgical data

System	Complication	PACU	Ward			
			Day 0-1	Day 2	Day 3	Patients
Cardiovascular	Hypotension	58 (7.5%)	55	15	3	64 (8.2%)
	Tachycardia	1 (0.1%)	1	2	1	4 (0.5%)
	Bradycardia	2 (0.3%)	0	2	1	3 (0.4%)
Respiratory	Desaturation	54 (7.2%)	27	28	12	59 (7.9%)
	Sedation	46 (5.9%)	2	1	1	4 (0.5%)
Other	RRT call	0 (0.0%)	19	12	4	33 (4.4%)
	Unplanned ICU transfer	5 (0.6%)	5	2	0	7 (0.9%)
	1:1 nurse special initiated	0 (0.0%)	12	6	4	15 (2.0%)

Table 2: Number of patients experiencing deterioration or an adverse event

PACU event (independent)	Hypotension	Desaturation	Sedation
Ward event (dependent)	RRT call	RRT call	RRT call
Relative risk	3.08	2.21	10.67
95% confidence interval	1.40-6.77	0.89-5.48	5.77-19.72
Z score	2.80	1.72	7.55
P value	0.01	0.09	<0.01

Table 3: PACU events vs RRT calls

Adverse event	n	Events	ROC	Variables	P value	Odds ratio	95% CI
RRT call	609	27	0.87	Weight (preop)	0.05	0.98	0.95-1.00
				ASA 2 (preop)	0.01	0.25	0.08-0.76
				Atrial fibrillation	<0.01	12.45	3.05-50.75
				Chronic lung disease	0.02	3.23	1.20-8.68
				Chronic liver disease	<0.01	12.94	2.25-74.21
				Other serious medical issue	0.02	3.09	1.24-7.72
				Surgical duration	<0.01	1.01	1.00-1.01
				PACU: sedation	<0.01	16.45	5.97-45.46
Desaturation	613	49	0.95	Oxygen saturation (preop)	<0.01	0.61	0.49-0.76
				Cerebrovascular accident	0.01	4.61	1.36-15.59
				Surgical duration	0.02	1.01	1.00-1.01
				NICE surgical grade	0.05	1.73	1.01-2.94
				PACU: review by anaesthetist	<0.01	0.22	0.08-0.59
				PACU: sedation or hypotension	<0.01	72.82	27.49-192.87
Hypotension	626	52	0.76	Systolic blood pressure (preop)	0.02	0.98	0.97-1.00
				Heart failure	0.07	3.14	0.91-10.88
				COPD	0.02	2.51	1.12-5.26
				IV drug use	0.07	5.10	0.88-29.58
				Surgical duration	<0.01	1.01	1.00-1.01
				PACU: hypotension	<0.01	4.14	1.97-8.71
Unplanned ICU Transfer	747	12	0.90	ASA 2 (preop)	0.06	0.22	0.04-1.09
				Chronic liver disease	0.01	20.85	1.94-223.84
				Surgical duration	<0.01	1.01	1.00-1.01
				PACU: sedation or hypotension	<0.01	21.13	5.17-86.38
1:1 nursing special initiated	597	10	0.93	Weight (preop)	0.03	1.19	1.02-1.39
				Height (preop)	0.02	0.82	0.69-0.97
				BMI (preop)	0.04	0.62	0.40-0.97
				Atrial fibrillation	0.06	13.49	0.87-209.16
				Renal impairment	<0.01	15.56	2.84-85.26

				Surgical duration	<0.01	1.02	1.02-1.02

Table 4: Multivariate predictive models (units as stated in Table S1).

Preoperative	
Age (years)	Diabetes mellitus, insulin dependent
ASA status (1-5)	Heart Failure
BMI (kg/m^2)	History of cerebrovascular accident
Diastolic blood pressure (mmHg)	History of seizures
Height (cm)	Intravenous drug abuse
Regular medications (number)	Male gender
Pulse rate (beats/min)	Obstructive sleep apnoea
Oxygen saturation (%)	Other serious medical issue
Systolic blood pressure (mmHg)	Peripheral vascular disease
Weight (kg)	Poor cognition
Alcohol abuse	Poor exercise tolerance
Antihypertensive use	Poor mobility
Atrial fibrillation	Preoperative clinic assessment
Cardiac disease, active	Prescription analgesia use
Cardiac disease, previous	Pulse irregularity
Chronic liver disease	Regular bronchodilators
Chronic lung disease	Regular smoking
Chronic obstructive pulmonary disease	Renal impairment
Diabetes mellitus	Systemic steroid use
Operative	
Duration (minutes)	NICE grade (1-4)
MBS item number (1-20)	General anaesthetic
PACU	
Anaesthetist review	Oxygen saturation d90%
Systolic blood pressure <90 mmHg	Respiratory rate <5 breaths/minute
Heart rate <40 beats/minute	Respiratory rate >35 breaths/minute
Heart rate >140 beats/minute	Patient rousable but unable to stay awake

Table S1: Preoperative, operative and PACU factors

ABSTRACT

Introduction

Accurate identification of patients at risk of early postoperative deterioration allows needs-based allocation of patients to appropriate levels of care. This study aimed to record the incidence of early postoperative deterioration and identify factors predictive of at-risk patients. Doing so may assist future evidence-based perioperative planning and allocation of patients to high acuity facilities.

Methods

With ethical approval, data from elective non-cardiac surgical patients were collected between May and August, 2013. Patient and surgical factors potentially related to postoperative deterioration were collected from preoperative assessment records. Data on deterioration in the post-anaesthesia care unit (PACU), and on the wards were collected prospectively for a period of 72 hours postoperatively. Patient factors, surgical factors and PACU events were compared with ward events using binomial logistic regression analysis.

Results

Of the 747 patients, postoperative deterioration was common both in PACU (155 (20.1%) patients) and on the wards (125, (16.7%)). Common ward events included hypotension (64, (8.2%)) and desaturation (59 (6.2%)). A Rapid Response Team call occurred for 33 (4.4%) patients and an unplanned ICU admission for 7 (0.9%) patients.

A history of atrial fibrillation and chronic liver disease, duration of surgery and excessive sedation in PACU, amongst others were strongly associated with subsequent ward deterioration. However, measures of surgical complexity were not.

Conclusions

Patient factors, duration of surgery and events in PACU can be predictive of subsequent early post-operative ward clinical deterioration. Such information may aid appropriate perioperative decision making with respect to post-operative utilisation of high acuity facilities.

INTRODUCTION

Multiple factors should be considered when planning perioperative care. Postoperative patients are at risk of acute deterioration, with almost 10% of hospital-wide Rapid Response Team (RRT) callouts occurring within 24 hours of surgery[1] and almost 1% of these requiring an unplanned intensive care unit (ICU) admission in the same period.[2] Risk stratification tools aiding perioperative decisions have the potential to improve health outcomes by directing high-risk patients to high acuity facilities.[3] Such tools also have key resource benefits by guiding the allocation of postoperative ICU beds and the distribution of patients between central and peripheral surgical centres.[4]

A number of models have analysed the risk of surgical outcomes such as 30-day mortality and end-organ dysfunction. These include the NSQIP Surgical Risk Calculator,[5] POSSUM,[6] and the Goldman Cardiac Risk Index.[7] These are often context-specific, and their focus on outcomes beyond the early postoperative period provides limited value in guiding perioperative decisions. In contrast, predicting potentially life-threatening complications, and the need for intervention early in the postoperative period, is critical to planning surgical lists and determining the need for high acuity postoperative care. Early complications therefore represent a more relevant endpoint in perioperative risk stratification.

Since the late 1990s, many Australian hospitals have used a rapid response system (RRS) to provide physician-directed acute care for the management of deteriorating patients.[8, 9] RRT criteria represent early triggers for intervention,[9,10] and may therefore be markers of acute deterioration for patients at risk of postoperative complications. These criteria are used commonly and consistently in clinical practice, and so may be useful endpoints for predictive risk modelling. Furthermore, their presence in the post-anaesthesia care unit (PACU) may be indicative of subsequent complications on the wards.

Preoperative assessment acts as a key data source in determining perioperative risk and a triage point for postoperative care, and patient progress in PACU may represent a second triage point for referral to high acuity care. This study therefore examined the relationship of preoperative, operative and PACU data with that of ward-based patient adverse events in the early postoperative period.

METHODS

With approval from the Royal Adelaide Hospital (RAH) Ethics Committee (approval number 20130420), data from elective surgical cases were prospectively collected at the RAH, an adult tertiary referral centre in Adelaide, South Australia, from May to August, 2013. Formal power analysis was not conducted, but based on results of a similar study conducted in 2012[10] our sample size was expected to be adequate to develop initial models of risk.

Approximately 10 patients were selected each weekday using a random number generator. Patients who underwent elective surgery, received a general anaesthetic or major regional anaesthetic block, were admitted immediately postoperatively to PACU and whose hospital stay was at least one postoperative night were eligible. Excluded were postoperative direct ICU admissions, ophthalmology (largely local anaesthesia), and cardiothoracics (dedicated perioperative pathway).

Patient deterioration was recorded using (i) RRT criteria (respiratory rate <5 or >35 breaths per minute, heart rate <40 or >140 beats per minute, systolic blood pressure <90 mmHg) and (ii) other defined adverse events (myocardial infarction, oxygen saturation d90%, excessive sedation (patient rousable but unable to stay awake), RRT call, unplanned ICU transfer, nursing escalation to a higher level patient-staff ratio). Multiple instances of the same problem, on the same day, and for the same patient, were recorded only once, as these were considered a recurring instance of the same problem.

Patient factors potentially associated with postoperative deterioration were identified from pre-anaesthetic assessments (Table S1). Due to the exploratory nature of the study a broad range of factors were selected, including those used previously to predict the need for high-acuity care and preoperative investigations,[10-12] as well as preoperative physiological

variables previously described as significant predictors of postoperative complications.[13-16] Preoperative factors were recorded as present only if documented in the preoperative assessment, thus reflecting the availability of information in clinical practice. Additional factors included anaesthetic type, surgical duration and National Institute for Clinical Excellence surgical grade.[17] Lastly, the unit value of Medicare Benefits Schedule item numbers[18] was included as an additional indicator of surgical severity. Problems in PACU were also recorded, with the same physiological criteria as those used on the ward. The requirement for an unplanned review in PACU by an anaesthetist was also recorded.

All postoperative problems were recorded in a standardised case report form. Two investigators collected all relevant preoperative, operative and postoperative data. This was accomplished by physically rounding on patients to view their progress notes 72 hours postoperatively.

Data were entered into a spreadsheet and pooled, and the incidence of key postoperative events was calculated. To explore the possibility that PACU events may be associated with ward events, relative risk analysis was used initially to assess these relationships in isolation. Data were then imported into Systat V13 (Systat Software, Inc., Chicago, IL, USA) for regression analysis.

Binomial logistic regression analysis was used to determine the relationship between postoperative events on the wards and preoperative patient factors, surgical factors and events in PACU. Subjects with data points missing in preoperative assessments were excluded from models, resulting in different subject numbers for each model. Models were developed for a subset of the most common ward events. For each event, all 42 patient and surgical factors, as well as PACU events, were analysed. Due to an apparent strong association with ward events in relative risk analysis, the use of certain PACU factors were also trialled in combination.

Initially, backwards stepwise binary logistic regression analysis, with a maximum of 100 steps, was used to eliminate factors for which $p>0.10$. The remaining independent variables were then entered into a complete model. When complete modelling converted any variable to $p>0.10$, it was removed and the model was re-run. The fit of the model to the data is indicated by the area under the curve (AUC) of the Receiver Operating Characteristic (ROC). The weighting of each variable is indicated by the odds ratio, with its precision indicated by the 95% confidence interval.

RESULTS

The study group demographics are outlined in Table 1. There was a high prevalence of obesity and chronic disease, although exclusion of patients transferred directly to ICU resulted in low numbers of ASA 4 and 5 patients. The exclusion of day surgery patients resulted in NICE Surgical scores mostly between Grade 2 (e.g. inguinal hernia repair) and Grade 4 (e.g. total hip replacement).[19]

Postoperative events were common, both in PACU and on the wards. Most events were cardiovascular or respiratory in nature, most commonly hypotension and desaturation. Events decreased in frequency throughout the 72-hour postoperative period. Of the 747 subjects, 155 (20.1%) experienced one or more events in PACU and 125 (16.7%) experienced one or more on the wards (Table 2).

There were 44 RRT calls amongst 33 (4.4%) patients during the study period, with the following reasons documented for the calls: hypotension (15), tachycardia (4), hypertension (2), bradycardia (2), myocardial infarction (2), chest pain (2), anaphylaxis (1), desaturation (7), sedation (2), tachypnoea (1), acute pulmonary oedema (1), seizure (1), fever (1), pain (1), hyperglycaemia (1), rectal bleeding (1).

Initial relative risk analysis yielded associations between PACU events and RRT calls on the wards (Table 3). This supported our decision to include them in subsequent multivariate analysis.

Binomial logistic regression analysis was then used to develop models for common post-operative events on the wards, resulting in models with strong ROC values (Table 4). In this exploratory study, certain factors considered logically associated with the relevant outcome were forced into the models, and retained if $p<0.10$. This improved the strength of

the models for RRT calls and desaturation. A combination of preoperative, operative and PACU factors appeared in four of the five resulting models, while all included both preoperative and surgical data. Surgical duration was a significant factor in all models, while indicators of surgical severity, such as NICE grade and MBS item numbers, were not. Continuous variables (with low unit values) had smaller odds ratios than categorical variables like chronic liver disease, despite small p-values.

PACU events were common and strongly associated with ward events, with sedation being the strongest and most predictive factor. When trialled in combination, hypotension and sedation in PACU, were strongly associated with certain ward events whereas other individual PACU events were not. PACU events had the highest odds ratios of any data points.

DISCUSSION

This prospective study aimed to explore patterns of early postoperative deterioration and adverse events in a broad adult sample of 'medium risk' surgical inpatients (primarily ASA scores, 2-3). It revealed that adverse postoperative events occur commonly both in PACU and the wards, particularly on the first postoperative day, and that statistical relationships make it potentially feasible to estimate patient risk from pre-operatively derived information. Furthermore, addition of PACU data might enhance the estimate of risk of postoperative ward deterioration.

The total ward complication rate of 20.1% over three postoperative days was similar to that observed by the REASON study among elderly patients in the first five postoperative days.[20] Furthermore, records kept by the Australian Council on Healthcare Standards (ACHS) report that up to 0.77% of patients undergo an unplanned ICU admission within 24 hours postoperatively,[2] which is consistent with our figure of 1.3% for the same period.

The presence of surgical duration in all models may reflect the physiological consequences of prolonged surgical trauma and anaesthesia. The low impact of surgical complexity, however, suggests a focus on patient co-morbidities may be more relevant in clinical decisions on postoperative care.

Some individual associations with risk warrant comment. ASA scores are a widely used and subjective indicator of postoperative risk.[21], which is supported by the association between ASA 2 and a lower risk of adverse events. Increased preoperative weight, atrial fibrillation and chronic liver disease were strongly associated with multiple events, indicating that they may be indicators of perioperative risk. The negative correlation between preoperative systolic blood pressure and postoperative hypotension potentially affirms the emerging practice of withholding some anti hypertensives prior to surgery to prevent

hypotensive episodes, particularly with recent findings relating hypotension to postoperative cardiovascular complications.[22]

The presence of PACU events in most models strongly suggests these are valuable indicators of the risk of subsequent ward events – a fact logical at face value, but not well demonstrated in prospective studies. Importantly, these data suggest there is an identifiable cohort of patients at risk of adverse events on the ward for whom higher acuity postoperative care is not currently available or being utilised, providing an evidence base for investment in high acuity postoperative facilities[3].

It was notable that the association between either PACU or preoperative factors provided relatively imprecise models, but including preoperative, operative and PACU factors led to models with strong ROC AUCs ranging from 0.76 to 0.95, with the majority of independent variables having $p<0.05$. These findings suggest that predictions of need for high acuity care cannot be determined from preoperative assessment alone, and planning for high acuity facilities must cater for evidence of at-risk patients which emerges immediately postoperatively.

While this study was exploratory, the sample of 747 elective patients is of sufficient size to guide future work and the method of collection of preoperative factors reflects a 'real world' approach to risk prediction. However, the large number of variables found to be predictive in these models limits their utility in clinical practice, and the use of a single site may not be representative of other hospitals. Larger and multicentre datasets may allow more generalizable models, and potentially collapse of the number of variables. Such models could be used to develop evidence-based decision support systems to facilitate needs-based allocation of patients to high acuity postoperative care and between surgical centres, potentially improving outcomes and hospital efficiencies.

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