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Equipment problems during anaesthesia—are they a quality problem?

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Background. Anaesthesia equipment problems may contribute to anaesthetic morbidity and mortality. The magnitude and pattern of these problems are not established. We wanted to analyse the frequency, type and severity of equipment-related problems in our department, and if additional efforts to improve safety were needed.

Methods. The study is based on a system in which anaesthesia-related data are recorded from all anaesthetic cases on a routine basis. The data include intraoperative problems and their severity. When a problem occurs, the anaesthetist responsible for the case writes a short description of the event on the anaesthetic chart. From all recorded cases of general and regional anaesthesia, we selected cases recorded with anaesthetic 'equipment/technical problems'. These charts were retrieved from departmental archives for analysis.

Results. From 83 154 anaesthetics, we found the frequency of anaesthetic equipment problems to be 0.05% during regional anaesthesia, and 0.23% during general anaesthesia. One-third of problems involved the anaesthesia machine, and in a quarter, human error was involved. No patient died and none suffered any lasting morbidity.

Conclusion. The rate of equipment problems was low, and most often of low severity. Aside from improvements in routines for preoperative equipment checks, no specific strategies for problem reduction could be suggested. The incidence of equipment problems is not a good quality indicator because of the low rate of occurrence. However, recorded equipment problems may be useful for improving quality, by analysing causative factors, and suggesting preventative strategies.

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Anaesthesia equipment is important for the safe conduct of anaesthesia, but equipment malfunction may also contribute to morbidity and mortality.[1–3] The anaesthesia machine has most often been involved in equipment-related morbidity,[1 4–7] and this has led to extensive use of preoperative checklists. Previous studies have shown that the frequency of equipment problems has varied from 0.2 to 2.1%. However, study design, method of problem reporting, and problem classification have varied. In addition, routines for the preoperative checking of anaesthesia machines and other equipment have not been specified.[4 5 8–11] In 1985, our department instituted a system for the recording of anaesthetic-related data.[12] We have studied equipment problems recorded from 83 154 consecutive cases from 1996 to 2000. The primary aim of our study was to analyse the frequency, type, and severity of equipment-related problems in relation to our current procedures for the checking of equipment and current working routines. We questioned whether additional efforts were needed to improve safety with respect to equipment issues. A secondary aim was to illustrate how a routine-based system for problem recording can simplify this type of continuous quality improvement in a department.

Methods

The study is based on departmental data recorded over a 5-yr period (1996–2000) from 83 154 consecutive anaesthetics. One part of our standard anaesthetic record is devoted to specified data fields that must be completed by

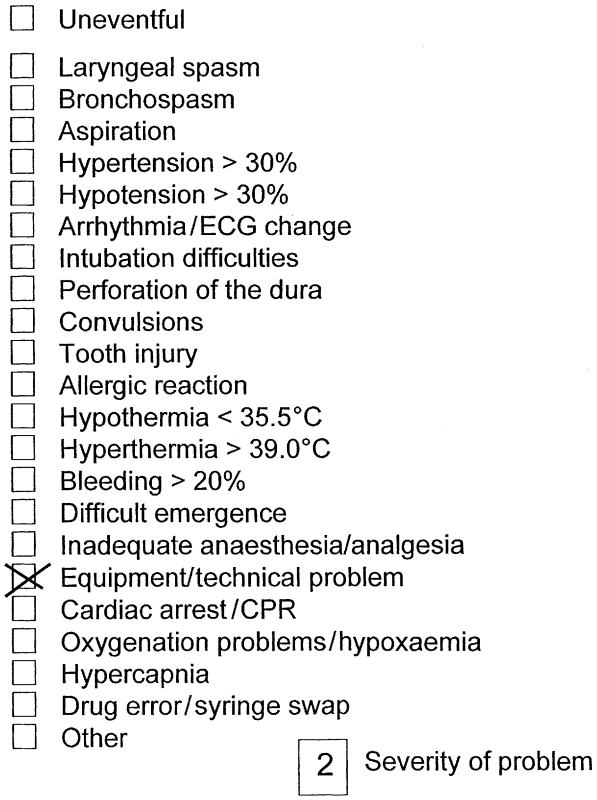

Fig 1 When a problem occurs, the anaesthetist writes a short description of the problem on the anaesthetic chart, and marks the problem check-box according to problem type and severity.

the end of the case. The data fields on all anaesthesia charts are checked for completeness and accuracy by a consultant anaesthetist (SF or SEG) before secretaries enter data into the database. A copy of the anaesthetic record is stored in the department.

One of the data fields is a check-box for 'intraoperative problems' (Fig. 1), including a list of 22 common anaesthetic problems, and a field for the severity. One of the problems is 'equipment/technical problems'. The anaesthetist responsible for the patient writes a short description of the event and marks the check-box accordingly. If the case was 'uneventful', this also must be indicated. Other data fields relate to the patient, the operation, type of anaesthetic, and timing of events.

An 'intraoperative problem' is defined as 'an event that requires one or more measures, either to prevent further complications, or to treat a situation that is currently or potentially serious, and does not routinely occur during the conduct of anaesthesia'. The problem is graded according to severity. Severity 'Grade 1' is a trivial problem, 'Grade 2' is a moderately difficult problem, with some effect on the patient, but of a low severity. 'Grade 3' is a serious situation that either proves very difficult to handle or causes a serious deterioration in the patient's state, which may or may not contribute to postoperative morbidity. 'Grade 4' problems are associated with a fatal outcome.

About 16 500 anaesthetics are given in our hospital each year, and most types of surgery are performed (Trondheim University Hospital, 960 beds, annual admission rate 43 000 patients, in 1999). In Norway, as in the rest of Scandinavia, the physician anaesthetist works in cooperation with a qualified nurse anaesthetist who has 18 months postgraduate education in anaesthesia. The doctor has the medical responsibility. Each morning the nurses do an extensive check of the anaesthesia machine according to departmental procedures. This check includes medical gas supplies, flowmeters, oxygen failure protection, vaporizers, machine/breathing system leakage, machine/breathing system function, ventilator, scavenging, suction and intubation equipment. Between patients a simpler check is performed. One nurse is working full-time to educate all staff on equipment issues, and the department engages two engineers for continuous maintenance and repair of equipment.

The charts recorded with anaesthetic 'equipment/technical problem' were retrieved from our departmental archives. They were sorted according to the type of equipment involved and analysed by the authors according to frequency, severity and contributory factors. We analysed not only cases of 'true equipment failure' where the equipment failed to perform as specified, but also equipment problems where 'human error', 'failure to check', or some form of failing 'human–equipment' interface was the most important factor. We did not include problems with surgical equipment or 'technical' problems with anaesthetic or surgical procedures.

For categorical data, we used a χ^2-test or Fisher's exact test as appropriate. We used a 'χ^2-test for trend' for testing trends in binomial proportions.[13] $P<0.05$ was considered statistically significant.

Results

We recorded 83 154 anaesthetics during 1996 to 2000. The age and ASA-class of the patient and type of surgery are presented in Table 1.

Frequency of equipment problems (Table 2)

We retrieved 198 charts in which 'equipment/technical problems' were recorded. Of these, 41 were not included in the final analysis, as 29 cases represented difficulties with the actual performance of anaesthetic or surgical procedures, six records were entered incorrectly into the database, two charts were missing from the archives, and in four cases the contributory factors of the problems were not described. We reviewed the resulting 157 cases of anaesthetic equipment problems (0.19% of all cases). These equipment problems represented 1.1% of all recorded problems (157/13 756). The occurrence of equipment problems was higher during general anaesthesia than regional anaesthesia (0.23% *vs* 0.05%), in contrast to other (non-equipment related) problems, where the frequency was

Table 1 Patient characteristics—83 154 anaesthetics

	Regional anaesthetics		General anaesthetics		All anaesthetics	
	n	%	*n*	%	*n*	%
Age 0–20 yr	308	1.5	17 357	27.7	17 665	21.2
Age 20–60 yr	9598	46.7	31 974	51.1	41 572	50.0
Age >60 yr	10 658	51.8	13 259	21.2	23 917	28.8
ASA I	5401	26.3	21 079	33.7	26 480	31.8
ASA II	9128	44.4	27 718	44.3	36 846	44.3
ASA III	5197	25.3	9646	15.4	14 843	17.9
ASA IV	826	4.0	3923	6.3	4749	5.7
ASA V	12	0.1	224	0.4	236	0.3
General surgery	4804	23.4	18 130	29.0	22 934	27.6
Orthopaedic surgery	13 122	63.8	13 319	21.3	26 441	31.8
Neurosurgery	18	0.1	3881	6.2	3899	4.7
Gyn/Obst surgery	1956	9.5	13 256	21.2	15 212	18.3
Other	664	3.2	14 004	22.4	14 668	17.6
All anaesthetics	20 564	100.0	62 590	100.0	83 154	100.0

Table 2 Frequency and severity of problems. Higher frequency of equipment problems during general anaesthesia compared with regional anaesthesia, but increased frequency of 'other problems' during regional anaesthesia (*$P<0.01$)

	Regional anaesthetics		General anaesthetics		All anaesthetics	
	n	%	*n*	%	*n*	%
Equipment problems						
Severity Grade 1–2	10		143		153	
Severity Grade 3	0		4		4	
Severity Grade 4	0		0		0	
Total	10	(0.05)*	147	(0.23)*	157	(0.19)
Other problems						
Severity Grade 1–2	3492	(17.0)	9671	(15.4)	13 163	(15.8)
Severity Grade 3	39	(0.2)	343	(0.5)	382	(0.5)
Severity Grade 4	0		54	(0.1)	54	(0.1)
Total	3531	(17.2)*	10 068	(16.1)*	13 599	(16.4)
All problems	3541	(17.2)	10 215	(16.3)	13 756	(16.5)
All cases	20 564		62 590		83 154	

slightly higher during regional anaesthesia (17.2% *vs* 16.1%).

Severity of equipment problems

As presented in Table 3, most equipment problems (n=112) were trivial (Severity Grade 1). About one-quarter (n=41) were of intermediate severity (Severity Grade 2), and four were serious (Severity Grade 3). All the serious problems and 29 of the intermediate problems affected the patient to some degree (Table 4), but no patient suffered any lasting morbidity or needed prolonged postoperative care.

In four cases, the problems were judged as serious (Severity Grade 3). In one case the ventilator was inadvertently turned off during anaesthesia. This was a new anaesthetic machine, where the 'power button' protruded from the cabinet, and it was inadvertently pushed by the anaesthetist. The ventilator stopped and the patient's pulse oximeter reading decreased to 45% before the error was detected. In one case, the non-invasive arterial pressure readings were falsely high, and the patient received a large dose of volatile anaesthetic, while the patient in reality was severely hypotensive. In two cases the cardiopulmonary bypass machine was involved: in one there were misconnection and oxygenation problems; in the other case the system was primed incorrectly. All these problems involved elements of human error.

Types of equipment involved (Table 3)

One-third of the problems (49/157) occurred with the anaesthesia machine, with the most common problem being leakage from, and misconnection of, the breathing system (n=24). Other problems included gas leakage from the vaporizer–machine connection (n=7), leakage in the ventilator (n=8), and malfunction of the one-way valve.

The majority of other problems occurred with invasive and non-invasive arterial blood pressure monitoring

Table 3 Type of equipment involved and severity of problem

Equipment involved	Severity Grade 1 *n*	Severity Grade 2 *n*	Severity Grade 3 *n*	Total equipment problems *n*
Anaesthesia machine	26	22	1	49
Invasive arterial pressure	14	4		18
Non-invasive arterial pressure	14	1	1	16
Gas analyser	12			12
Other monitor	8	2		10
ECG	10			10
Cardiopulmonary bypass machine		5	2	7
Pulse oximeter	7			7
Endotracheal tube	4	1		5
Infusion pump	4	1		5
Temperature measurement	4			4
Capnograph	3	1		4
I.V. access	1	1		2
Central venous pressure	2			2
Defibrillator	1	1		2
Blood warmer	1			1
Chest drain		1		1
Laryngoscope	1			1
Urometer		1		1
Total	112	41	4	157

Table 4 Untoward effects on the patient caused by equipment problems

Equipment involved	Problem	Effect on patient	*n*
Anaesthesia machine	Misconnection	Hypoxaemia	5
	Ventilation problems	Hypoxaemia	2
	Low flow in Mapleson–D system	Hypercapnia	2
	Valve occlusion	High airway pressure	1
	Power supply—ventilator stopped	Hypoxaemia	1
	Adult equipment to child	Hypercapnia	1
	Vaporizer failure	Hypotension	1
Cardiopulmonary bypass machine	Short stops from various causes	Hypoperfusion, short periods	7
Non-invasive arterial pressure	Error in measurement	Undetected hypotension	4
Invasive arterial pressure	False low pressures	Unnecessary pressor treatment	3
Infusion pump	Malfunction	Drug overdose, hypotension	2
Urometer	Occlusion in set	Unnecessary fluids and diuretics	1
Defibrillator	Failure to shock	Delayed treatment	1
I.V. access	Disconnection	Hypovolaemia, hypotension	1
Chest drain	Disconnection	Lung collapse	1
Total			33

equipment, and other monitoring equipment. Most of the problems with invasive arterial blood pressure equipment represented low readings from a radial artery cannula compared to the aortic cannula during cardiac surgery. However, measurement errors, drifting, and cable failure also occurred. Non-invasive arterial blood pressure equipment failure was also common, and related to technical failure—including leaks from the tubing and cuff. Other problems related to malfunction of other monitors, and malfunction of the cardiopulmonary bypass machine during cardiac surgery.

Human error

About one-quarter of the equipment problems (n=40) were considered to be related to human error on the part of the users (Table 5). Twenty-nine of the problems concerned the anaesthesia machine, and of these, 18 were related to inadequate pre-use checks. Most of these errors occurred when the anaesthesia machine was checked between cases, rather than at the start of the day. Contributing factors were 'last-minute changes' because of a change in schedule (change in type of breathing system, ventilator, or type of anaesthesia).

Continuous quality improvement

No trends were noted in the rate of occurrence of equipment problems between 1996 and 2000. In the same period, we recorded an increased occurrence of other problems (Table 6).

Table 5 Human errors contributing to equipment problems

Equipment involved	Problem	*n*
Anaesthesia machine	Misconnected patient systems	13
	Undetected leakage from patient systems	5
	Wrong gas flow—patient system	2
	Power accidentally turned off	1
	Vaporizer leakage—after changeover	6
	Other	2
Non-invasive arterial pressure	False normal readings, delayed detection of low arterial pressure	3
Invasive arterial pressure	False low readings—treated with vasopressor	3
Cardiopulmonary bypass machine	Misconnection and wrong priming of system	2
Endotracheal tube	Kinked tube, not checked, bronchodilators given	1
Laryngoscope	Low batteries, no spare immediately available	1
Chest drainage	Disconnection—wrong connectors used	1
Total		40

Table 6 Variation in occurrence of problems from 1996 to 2000. There was no change in frequency of equipment problems, but an increase in frequency of other problems

	1996	1997	1998	1999	2000	Trend	*P*-value
Equipment problems	45	25	29	25	33	No change	0.25
Other problems	2644 (15.5%)	2730 (16.0%)	2726 (16.5%)	2645 (17.3%)	2854 (17.1%)	Increase	<0.001
Cases per year	17 023	17 020	16 544	15 829	16 738		

Discussion

Having prospectively recorded problems in 83 154 cases of anaesthesia, we found equipment problems to be rare, and of low severity. Human errors (for example failure to check equipment and man–machine interaction failure) were important factors, in addition to 'pure' equipment failure. The low frequency of equipment problems limits its usefulness as a numerical quality indicator. However, analysis of patterns and causes of these problems can be a useful part of a quality assurance programme in a department.

Methodology

In all incident reporting, under-reporting is a potential problem. This is related to the added workload from completion of forms, a belief that reporting is of limited value, and fear of consequences of reporting.[14–17] We believe that the reporting compliance in our study is good. All patients receiving an anaesthetic were followed, and included in the study. The incidents were recorded in a prospective manner, and as information from all cases was included, important events were less likely to be missed. This is in contrast to studies where information is collected only from selected samples of patients.

Our system is designed to add minimal workload, as all recording is done directly on the anaesthetic chart, and no additional form is needed. We are using the data actively in the department, for problem discussions and quality projects, and we have created a non-punitive attitude towards the occurrence of problems.[12] All cases are recorded, the recording is obligatory, and both a physician and a nurse are involved in every case. The recording has been part of departmental routine for 15 yr, and definitions and severity assessment are continuously discussed in departmental meetings. Consequently, we believe that the agreement between observers is good. We also believe that the total frequency of problems and the frequency of equipment problems are representative of the occurrence of these problems in our practice, and are a result of routines for checking and maintenance of equipment in the department, and routines for follow-up when problems occur.

Frequency and severity of equipment problems

Four studies have been published representing mandatory reporting, with data recorded from all anaesthetic cases.[8–11] Our results are of the same magnitude as those of Cohen and colleagues[8] who found an incidence of 0.1–0.4% for equipment problems in 27 184 cases of anaesthesia from four different hospitals. In that study, a check-off form was completed for every patient, and 18 types of intraoperative problems were included in the data set. However, severity was not assessed. The frequency of total problems varied from 14.9% to 27.8% amongst the four hospitals.

Three studies have been published from a large German quality assurance project concerning perioperative incidents (both operating room and recovery room).[9–11] Data were collected from all anaesthetics, 63 types of incidents and five levels of severity were defined. The frequency of equipment problems was 0.7% in 18 350 cases,[9] 0.9% in 26 907 cases,[10] and 1.2% in 96 000 cases.[11] The frequency of all problems was 23.2%, 27.9% and 22% respectively.[9–11] We found a lower occurrence of total equipment

problems and total problems than in the German studies. The cause of this is difficult to discern, as the German studies included the whole perioperative period and the intraoperative problems are not reported separately. In addition, definitions and classifications were different. Finally, there is of course a possibility of differences in problem occurrence, reporting compliance, or both. However, the general conclusions from these and our studies are similar, as equipment problems were rare and of low severity, but some had untoward effects on patients, without causing any lasting morbidity. These problems do carry a potential for serious adverse outcome, and preventative measures are important.[1 3 7 9 18]

Other studies have collected data by voluntary reporting only of problem cases. The overall problem figures are generally lower, as under-reporting is well recognized.[16 17] Short and colleagues[5] reported a frequency of 0.23% of equipment/breathing system problems in 16 379 anaesthetics, but an overall problem rate of only 0.76%. Spittal and colleagues[4] reported a 2% incidence of equipment-related problems in 5056 cases, with an overall problem rate of 6.68%. The case mix, routines for preoperative checking of the anaesthesia machine, and level of maintenance of other equipment, were not specified in these studies.

Type of equipment involved

The anaesthesia machine, including the breathing system, was the most common cause (31%) of equipment problems in our study. This was also the most common cause in the studies by Bothner, Georgieff and Schwilk (30%),[11] and Schwilk and colleagues (22%).[10] Also, in other incident studies where the denominator is not known,[1 4–6] problems related to the anaesthesia machine were most common, ranging from 52 to 73%.

We found most of the anaesthesia machine problems to be related to the breathing system, as has been found in other studies where this information is supplied.[1 4–6] The breathing system is often reconnected for cleaning and change of system between patients, and this may predispose it to errors, despite the routines for checking the machine at the start of the day.

Non-invasive and invasive arterial pressure measurements were involved in many of the equipment problems. This equipment has many potential problems, and readings may not be correct. This predisposes it to errors, and our findings are a reminder that numbers from invasive and non-invasive automated arterial blood pressure measurement should be constantly evaluated against the patient's clinical condition.

Human error

Human error and misuse of equipment have been shown to be more common than 'true' equipment failure.[3 5] In our study, human error was the main contributing factor in one-quarter of cases, and most of these involved the anaesthesia machine. The main cause was insufficient checking of the anaesthesia machine before use, especially between cases. This was also shown by Short and colleagues.[19] The problems often occurred as a consequence of 'last-minute modifications', when breathing systems and vaporizers were changed after the checking procedure had been performed.

To reduce the possibility of human error causing equipment problems a three-level approach has been suggested: (i) when possible, equipment should be designed such that the possibility of human error is minimized; (ii) if human error cannot be prevented, systems should be designed to minimize the injury caused by such errors; (iii) if neither of the previous safety approaches is possible, the system should be equipped with monitors and alarms to alert the user of an adverse condition that may be caused by equipment failure or change in the patient's condition. This approach is an example of a 'systems' approach to error management, where the working environment of the anaesthetist is optimized to avoid errors.[20 21]

Continuous quality improvement

We found no change in occurrence of equipment problems during the period of our study, while there was an increasing trend for other problems. However, the low rate of equipment problems limits statistical appraisal, as variation may be the result of chance. The low rate of equipment problems also limits its use as a continuous quality indicator, as changes in occurrence caused by efforts to improve are difficult to separate from natural variation. Therefore, the most suitable analysis of these data may be as 'sentinel events', where problems are analysed individually, or in groups, to elucidate causative factors and preventative measures, rather than a numerical approach.

The low rate of equipment problems recorded indicates that our routines for use, checking and maintenance of equipment are adequate. However, there is still a potential for serious problems, and strategies to prevent human error should be implemented as this contributed to a quarter of problems. In addition, an improved check between cases may reduce the occurrence of equipment problems with the anaesthesia machine, which was the main cause of problems.

Ideally, follow-up of problems as part of continuous quality improvement efforts should lead to a decreased problem frequency. Short and colleagues[19] studied improvements in anaesthetic care resulting from a critical incident reporting programme, but found no change in incidence of problems. However, the programme was considered effective in detecting latent system errors. Changes in the frequency of problems may be explained as a result of quality-related activities in the department, but also changes in reporting compliance, or changing anaesthesia practice may influence the results. A routine-based recording system will give us the possibility of evaluating

problem rates, as the total number of anaesthetics is known, but care must be taken when the occurrence is rare.

Conclusion

With our checking and maintenance routines, we found equipment to cause few problems, both related to number of cases (0.19%), and related to the occurrence of other problems during anaesthesia (1.1%). Human factors were important causes of problems, and the anaesthesia machine was most often involved. Although we recorded no morbidity from equipment problems in 83 154 cases, both this and other studies have indicated that a potential for equipment-related morbidity exists. The type of data retrieved from our analysis provides valuable information for departmental quality projects.

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