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CLINICAL INVESTIGATION

Optimisation of airway management strategies: a prospective before-and-after study on events related to airway management†

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Abstract

Background: Poor medical outcomes often result from series of minor events. The present study assessed events related to airway management to determine whether targeted changes to departmental strategies for airway management can reduce the incidence.

Methods: This prospective before-and-after study was performed with ethics committee approval and written informed consent from patients. Major and minor events related to airway management were prospectively recorded for 9 weeks. After implementation of changes to departmental strategies for airway management, events were again prospectively recorded over 9 weeks. Primary outcome was number of cases with events. Secondary outcomes were various predefined events.

Results: At study baseline, 3668 cases and at follow-up 3786 cases were assessed. Cases with events decreased from 566 (15.4%) to 433 (11.4%) (risk ratio [RR]=0.74; 95% confidence interval [CI], 0.66–0.83; $P<0.01$). As secondary outcomes, the following events decreased: Cormack–Lehane grade 3 or 4 (4.3–2.9%; RR=0.67; 95% CI, 0.52–0.85; $P<0.01$); difficult bag-mask ventilation (3.8–2.7%; RR=0.69; 95% CI, 0.54–0.89; $P<0.01$); hypoxaemia (3.8–2.9%; RR=0.75; 95% CI, 0.59–0.96; $P=0.03$); unplanned use of special equipment (3.2–2.0%; RR=0.62; (95% CI, 0.47–0.83; $P<0.01$); oesophageal intubation (1.3–0.8%; RR=0.61; 95% CI, 0.39–0.96; $P=0.03$); bleeding (0.8–0.2%; RR=0.30; 95% CI, 0.14–0.63; $P<0.01$); insufficient spontaneous breathing (0.3–0.0%; RR=0.09; 95% CI, 0.01–0.68; $P<0.01$); communication errors (0.1–0.0%; RR=0; 95% CI, 0–NA; $P=0.03$).

Conclusions: Implementation of changes to departmental strategies for airway management significantly reduced cases with events related to airway management. Analysis of events and implementation of strategies that specifically target identified issues might be key to improving airway management.

Clinical trial registration: NCT02743767.

Keywords: airway complications; airway management; major airway events; minor airway events; patient safety

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Editor's key points

- Airway management during general anaesthesia is generally safe, but minor and major complications do occur in a limited number of patients.
- This study has indicated that targeted changes to departmental strategies for airway management can reduce the incidence of minor and major complications during anaesthesia.
- Future studies need to assess whether these strategies can reduce the life-threatening complications associated with airway management.

A significant proportion of morbidity and mortality related to anaesthesia is caused by problems with airway management.[1] Management of the airway was judged as inadequate for most cases with major airway events.[1,2] The incidence of major airway complications reported by the UK National Audit Project 4 is at least one in 22 000 cases.[3] Others reported airway complications in healthy anaesthetised infants, with incidences of 16% for multiple laryngoscopy attempts, 35% for hypoxaemia, and 8.9% for bradycardia.[4]

Analyses of poor medical outcomes[3] have shown that usually, as also described by the 'Swiss Cheese Model',[5] a series of minor problems, and much less frequently a single major problem, causes the negative outcome. Therefore, minor events related to airway management – such as a difficult laryngoscopy or brief desaturation – can be seen as surrogate red flags.[6,7] Although such events are common, a literature search before the start of the study provided scant data regarding a wide spectrum of such minor events in patients undergoing general anaesthesia.

The present study prospectively assessed both major and minor airway events in the broad patient population of a university anaesthesia department. This was followed by implementation of several changes to strategies for airway management in the department and teaching of specific aspects of airway management targeted at identified issues. Prospective follow-up assessment of events then completed the study. The present study focused on interventions which were easy to implement, to reduce the incidence of events related to airway management in general. To reflect general anaesthesia practice, this study involved all types of general anaesthesia in a university department, including a broad patient population and a variable group of anaesthesia providers with all levels of expertise and skills, practicing in changing teams.

The primary aim of the study was to determine the rate of anaesthesia cases with major or minor events related to airway management, and to determine whether targeted changes to strategies of airway management can reduce the incidence of airway-related events. The secondary aim was to describe the incidence of each of several pre-specified major or minor events and the number of attempts required for successful airway management.

The null hypothesis was that targeted changes to strategies for airway management and teaching of specific aspects of airway management would not decrease the rate of anaesthesia cases with major or minor airway-related events.

Methods

This prospective before-and-after study, performed in the Department of Anaesthesiology and Pain Medicine, Bern University Hospital (Switzerland), was approved by the Cantonal Ethics Committee of Bern (approval number 092/15), and registered with ClinicalTrials.gov (NCT02743767).

The study consisted of prospective data collection over 9 consecutive weeks (May to July 2015) (baseline assessment), followed by implementation of a 'bundle' of changes to the department's strategies for airway management and targeted teaching of specific aspects of airway management. These interventions were based on findings from the analysis of the baseline assessment, as detailed below. One year after the baseline assessment, prospective follow-up data collection was performed over 9 consecutive weeks (May to July 2016). During both phases, all consecutive cases of airway management were prospectively screened for major and minor events related to airway management, as detailed below.

All patients included in this study gave written informed consent for use of their anaesthesia-related data for research purposes. Patients undergoing elective or emergency anaesthesia with any form of airway management were included. Uvdrology patients being treated in remote urology theatres were not included, as assuring the presence of study personnel would not have been possible. However, out-of-hours urology patients treated in central theatres were included.

For every patient, anaesthesia providers filled out an electronic questionnaire. A more detailed questionnaire was used if an event related to airway management occurred at any time between the start of anaesthesia and handover of the patient from the anaesthesia team to the postoperative care unit, the ICU, or the ward. To ensure high data quality and to prevent potential bias from underreporting, dedicated study personnel, not involved in clinical care circulated through the theatres daily from 6:30 AM to 8:00 PM during both data collection phases. Study personnel reminded staff to fill out the questionnaires, checked questionnaires for completeness and clarity, answered questions regarding the study, and reminded staff of the changes to airway management in the follow-up phase. They did not take an active role in anaesthesia management. In addition, lists of the previous day's patients were checked daily for completeness and clarity, and missing information was retrieved. Finally, the electronic anaesthesia patient data management system (COPRA System GmbH, Berlin, Germany) was checked for hypoxaemic events, comments regarding airway management, and use of special airway equipment, such as introducers and bougies or Magill forceps. Clinicians were approached in case of suspected underreporting.

The primary outcome measure of this study was the number of anaesthesia cases that involved a major or minor event related to airway management.

Secondary outcome measures included the incidence of individual pre-defined major or minor airway events, and the number of attempts needed to establish a patent airway. In line with the National Audit Project 4,[3] major events were defined as complications of airway management leading to death, brain damage, emergency front-of-neck access, or unanticipated admission to the ICU. All other events were classified as 'minor'. These were Cormack–Lehane grade 3 or 4, difficult bag-mask ventilation, hypoxaemia (oxygen saturation <95% or decrease of ≥5% from baseline), unplanned use

of special equipment (such as introducers, bougies, or Magill forceps), failure to advance a tracheal tube, oesophageal intubation, soft tissue injury to lips or the mucosa, blood in the airway or on the airway device, laryngospasm or bronchospasm, supraglottic airway device failure on induction of anaesthesia (not possible to position the device adequately or failure to ventilate the patient's lungs because of leakage), non-functional equipment (e.g. no image on the screen of a videolaryngoscope, or no light with a standard laryngoscope), insufficient spontaneous breathing after anaesthesia, signs of regurgitation or aspiration, dislocation of the tracheal tube, difficult fibreoptic intubation, airway obstruction, tracheal tube cuff leakage, nosebleed (in case of nasal instrumentation), communication error within the team, glottic oedema, gas leak during the use of a supraglottic airway device intraoperatively, laryngoscopy abandoned because of bradycardia or secretions, ventilatory system leakage, unplanned admission to postoperative care unit, dental damage, pneumothorax or pneumomediastinum, problems with a tracheal cannula, cannot-intubate cannot-ventilate, negative pressure pulmonary oedema, and unplanned admission to an intermediate care unit.

Patient characteristics were recorded, including sex, age, BMI, ASA physical status, acuteness of surgery, duration of anaesthesia, and surgical specialty. Postoperative side-effects, such as sore throat, hoarseness, dysphagia, and minor soft tissue trauma were assessed.

After collection, data from the baseline assessment were analysed, and interventions with the potential to reduce the number of cases with events were selected to maximise outcome with reasonable effort (Pareto's principle: 20% effort to achieve 80% results; https://en.wikipedia.org/wiki/Pareto_principle, accessed February 24, 2021). The baseline data are reported in the Results section and the rationale for the implemented changes is described in the Discussion section. The following changes to airway management strategies were implemented:

(i) Administration of neuromuscular blocking agents immediately after the loss of consciousness, before attempted bag-mask ventilation when tracheal intubation was planned. This aimed to reduce difficult bag-mask ventilation.
(ii) Emphasis on correct preoxygenation with the end-tidal oxygen concentrations $\geq$90% before induction of anaesthesia, and apnoeic oxygenation with low-flow nasal cannula oxygen of 2–4 L min^{-1} whenever possible. This aimed to reduce the rate of hypoxia.
(iii) Implementation of an airway-safety checklist filled out electronically immediately before induction of anaesthesia, which aimed to optimise equipment preparation, clear communication of roles in the team, and airway back-up plans. It included equipment check, patient check, communication check, and feasibility of the anaesthetic and contingency plan in case of difficulties.
(iv) After two failed attempts at securing the airway, the most senior team member takes over. This aimed at reducing the number of attempts in a teaching hospital.
(v) Use of videolaryngoscopy for tracheal intubation whenever possible, aiming to reduce problems with intubation.

In addition, teaching sessions based on analysis of the baseline data were conducted. The sessions included lectures on the reasons for the implemented changes and lectures on airway guidelines, and hands-on training of various airway management techniques. Posters showing the bundle of changes were placed on each anaesthesia machine, and were handed to each anaesthesia provider to enhance 'airway awareness'.

Statistical analysis

For sample size calculation, no data existed on the incidence of anaesthesia cases with the wide spectrum of major or minor airway management-related events studied in a broad patient population. It was also unclear how changes to the strategies for airway management in the department might impact events related to airway management. We opted for a study period of 9 weeks, which was feasible in our environment. Based on the total number of patients treated in the department, we estimated to collect data from 3000–4000 patients in the period studied. In fact, 3668 cases were included at baseline, and events related to airway management occurred in 566 cases. We considered a 20% reduction in absolute events to be clinically relevant. Given this assumption, to detect a statistically significant difference with a β-error of 0.2 and an α-error of 0.05, each cohort would need to include 1970 patients. We therefore scheduled the follow-up phase for another 9 week period.

In terms of descriptive statistics, binary and categorical variables are presented as numbers and percentages. Continuous variables were tested for normality using a Shapiro-Wilk test and are presented as the mean and the standard deviation for normally distributed continuous variables and as the medians with 25th and 75th percentiles otherwise. Statistical comparisons of data from the baseline and follow-up phases were performed using χ^2 tests in case of binary and categorical data. Simulated P values based on a sample size of 10 000 simulations were used for contingency tables larger than 2×2. Continuous variables were compared using Student's t-test for normally distributed variables and the Wilcoxon rank sum test otherwise.

Risk ratios (RRs) and associated Wald-type 95% confidence intervals (CIs) were calculated both for the primary outcome measure (number of anaesthesia cases with a major or minor event related to airway management) and for the list of secondary outcome measures (incidence of each individual predefined major or minor event related to airway management).

As a sensitivity test for the primary outcome measure, we present the adjusted analysis to baseline covariates based on a multivariable logistic regression model in the Supplementary material.

Post hoc comparisons were done for the primary outcome and for the number of attempts required for successful airway management. These compare the RR of one or several events related to airway management compared with the baseline category of no event, and the RR of several attempts needed for successful airway management compared with the baseline category of a first successful attempt, respectively. These were adjusted for multiple comparisons using the Holm correction.[8] Step-by-step hypothesis tests within the Holm framework are presented in the Supplementary material.

In terms of hypoxia, we present kernel density estimates of lowest oxygen saturation levels for the baseline and follow-up data, and we performed a Wilcoxon rank sum test to examine if the saturation levels differ between the two groups.

A probability (P) of <0.05 was considered statistically significant. Data were analysed using Stata V.14.1 (StataCorp, College Station, TX, USA) and R (R Core Team 2020, R Foundation for Statistical Computing, Vienna, Austria).

Table 1 Patient characteristics at study baseline and study follow-up. Data are number (%), or median (IQR). *Missing data for 159 patients at baseline and 153 at follow-up. †Missing data for 20 patients at baseline. ‡Emergency 1, life-threatening, immediate treatment required; Emergency 2, health hazard if not treated within 1–6 h; Emergency 3, health hazard if not treated within 6–12 h; Emergency 4, health hazard if not treated within 24 h. §Missing data for 40 patients at baseline ‖For example endoscopy, catheter laboratory, MRI. IQR, inter-quartile range.

	Study baseline (n=3668)	Study follow-up (n=3786)	P-value
Males, n (%)	2094 (57.1)	2118 (55.9)	0.33
Age (yr), median (IQR)	55 (31–70)	54 (29–69)	0.17
Children, n (%), Total	568 (15.5)	613 (16.2)	0.43
Subgroups of children by age, n (% of all children)			0.48
<1 yr	75 (13.2)	93 (15.2)	
1 to <8 yr	273 (48.1)	300 (48.9)	
8 to <16 yr	220 (38.7)	220 (35.9)	
BMI (kg m^{-2}), median (IQR)*			
Patients >16 yr	25.4 (22.6–29.0)	25.5 (22.5–29.3)	0.72
ASA physical status, n (%)†			<0.01
1	538 (14.7)	652 (17.2)	
2	1238 (33.9)	1089 (28.8)	
3	1201 (32.9)	1307 (34.5)	
4	594 (16.3)	669 (17.7)	
5	74 (2.0)	61 (1.6)	
6	3 (0.1)	8 (0.2)	
Acuteness of surgery, n (%)‡			0.50
Elective	2625 (71.6)	2735 (72.2)	
Emergency 1 or 2	643 (17.5)	670 (17.7)	
Emergency 3 or 4	400 (10.9)	381 (10.1)	
Duration of anaesthesia (min), median (IQR)§	150 (94–238)	143 (90–229)	<0.01
Surgical specialty, n (%)			<0.05
Ophthalmology	196 (5.3)	168 (4.4)	
Gynaecology/obstetrics	267 (7.3)	284 (7.5)	
Ear–nose–throat	444 (12.1)	484 (12.8)	
Cardiac/vascular	456 (12.4)	469 (12.4)	
Paediatric	404 (11.0)	469 (12.4)	
Neuro	380 (10.4)	392 (10.4)	
Orthopaedic	598 (16.3)	539 (14.2)	
Plastic	120 (3.3)	143 (3.8)	
Urology (emergencies only)	10 (0.3)	5 (0.1)	
General/thoracic	409 (11.2)	424 (11.2)	
Anaesthesia outside theatres‖	323 (8.8)	320 (8.5)	
Electroconvulsive therapy	61 (1.7)	89 (2.4)	

Results

A total of 7454 cases were assessed and analysed: 3668 at baseline and 3786 at follow-up (Fig. 1a). There was no significant difference between baseline and follow-up (P=0.10) in the distribution of the weekly number of cases with events, nor was there a linear trend in the number of cases with events over the weeks for either of the study periods (baseline P=0.59, follow-up P=0.98; Fig. 1b).

Patient characteristics are given in Table 1. Duration of anaesthesia, ASA physical status, and surgical specialities differed significantly between the study phases.

In terms of the primary outcome, the total number of cases with a major or minor event related to airway management decreased from 566 (15.4%) to 433 (11.4%) (P<0.01; RR=0.74; 95% CI, 0.66–0.83; Table 2). This result is robust with regard to covariate adjustment of baseline characteristics (Supplementary Table S1).

The distribution of events significantly differed between the baseline and follow-up periods (P<0.01, Table 2). For example, the risk of having one event (RR=0.80; 95% CI, 0.68–0.93; P=0.02) or two events (RR=0.65; 95% CI, 0.52–0.82; P<0.01) was significantly lower in the follow-up period (Table 2).

In terms of secondary outcomes, the incidence of the various pre-defined major and minor events is given in Table 3. In total, there were 918 events (0.25 average number of events per case) in the baseline period and 649 events (0.17 average number of events per case) in the follow-up period.

There were no major events related to airway management except one unplanned ICU admission at baseline of a patient who self-extubated because of agitation before planned extubation after pneumonectomy. The patient's trachea was reintubated as the patient showed respiratory failure and agitation. Subsequent extubation in the ICU was uneventful.

There were statistically significant decreases in several minor events between baseline and follow-up (Table 3), but none of the measured events increased.

Various degrees of hypoxaemia occurred, with most cases demonstrating minimum values >80%. Some patients, however, had values as low as 30% without cardiovascular instability (Fig. 2). All patients recovered without neurological sequelae. Data analysis showed that the median of the lowest

Table 2 Anaesthesia cases with major or minor airway management-related events. Data are number (%). Risk ratios with associated 95% confidence intervals (CIs) are given as effect size. *Post-hoc* comparisons are adjusted for multiple comparisons using the Holm method. Ref., reference; NA, not applicable.

	Study baseline (*n*=3668)	Study follow-up (*n*=3786)	Risk ratio (95% CI)	*P*-value
Total cases with events, *n* (%)	566 (15.4)	433 (11.4)	0.74 (0.66–0.83)	<0.01
Distribution of events, *n* (%)				<0.01
Cases with no events	3102 (84.6)	3353 (88.6)	ref.	
Cases with one event	318 (8.7)	269 (7.1)	0.80 (0.68–0.93)	0.02*
Cases with two events	173 (4.7)	119 (3.1)	0.65 (0.52–0.82)	<0.01*
Cases with three events	54 (1.5)	40 (1.1)	0.69 (0.46–1.03)	0.08*
Cases with four events	14 (0.4)	4 (0.1)	0.27 (0.09–0.80)	0.04*
Cases with more than four events	7 (0.2)	1 (<0.1)	0 (0–NA)	0.04*

Table 3 Major and minor events related to airway management at study baseline and at study follow-up (secondary outcomes). Data are number (%). Risk ratios and associated 95% confidence intervals (CIs) are given as effect size. **Study baseline:* loss of vision of the glottis after insertion of a nasogastric tube, leading to a second laryngoscopy attempt; repeated laryngoscopy attempts for confirmation of the anatomy during a teaching intubation; unsuccessful intubation via an intubating laryngeal mask airway Fastrach in a patient who came to the emergency room with an intubating laryngeal mask airway inserted by the Helicopter Emergency Medical Service; two cases of insufficient anaesthesia for airway management requiring deepening of anaesthesia and a second attempt of airway management. *Study follow-up:* tube change caused by an error in choosing the correct tube for the patient; difficult intubation via a supraglottic airway requiring several attempts and a change of operator. NA, not applicable.

	Study baseline (*n*=3668)	Study follow-up (*n*=3786)	Risk ratio (95% CI)	*P*-value
Major events, *n* (%)				
Death	0 (0)	0 (0)	NA	NA
Brain damage	0 (0)	0 (0)	NA	NA
Emergency front of neck access	0 (0)	0 (0)	NA	NA
Unanticipated ICU admission	1 (0)	0 (0)	NA	0.49
Minor events, *n* (%)				
Cormack–Lehane grade 3 or 4	157 (4.3)	108 (2.9)	0.67 (0.52–0.85)	<0.01
Difficult bag-mask ventilation	141 (3.8)	101 (2.7)	0.69 (0.54–0.89)	<0.01
Hypoxaemia	139 (3.8)	108 (2.9)	0.75 (0.59–0.96)	0.03
Unplanned use of special equipment	118 (3.2)	76 (2.0)	0.62 (0.47–0.83)	<0.01
Failure to advance a tracheal tube	92 (2.5)	79 (2.1)	0.83 (0.62–1.12)	0.25
Oesophageal intubation	49 (1.3)	31 (0.8)	0.61 (0.39–0.96)	0.03
Soft tissue trauma (lips/mucosa)	37 (1.0)	25 (0.7)	0.65 (0.39–1.09)	0.13
Blood in the airway or on the airway device	29 (0.8)	9 (0.2)	0.30 (0.14–0.63)	<0.01
Laryngospasm or bronchospasm	28 (0.8)	22 (0.6)	0.76 (0.44–1.33)	0.40
Supraglottic airway device failure at induction of anaesthesia	19 (0.5)	26 (0.7)	1.33 (0.74–2.39)	0.37
Non-functional equipment	15 (0.4)	16 (0.4)	1.03 (0.51–2.09)	1.00
Insufficient spontaneous breathing after anaesthesia	11 (0.3)	1 (0.0)	0.09 (0.01–0.68)	<0.01
Regurgitation or aspiration	11 (0.3)	6 (0.2)	0.53 (0.20–1.43)	0.23
Dislocation of the tracheal tube	10 (0.3)	10 (0.3)	0.97 (0.40–2.32)	1.00
Difficult fibreoptic intubation	8 (0.2)	4 (0.1)	0.48 (0.15–1.61)	0.26
Airway obstruction	8 (0.2)	3 (0.1)	0.36 (0.10–1.37)	0.14
Tracheal tube cuff leakage	7 (0.2)	11 (0.3)	1.52 (0.59–3.92)	0.48
Nosebleed	7 (0.2)	4 (0.1)	0.55 (0.16–1.89)	0.38
Communication error within the team	5 (0.1)	0 (0.0)	0 (0–NA)	0.03
Glottic oedema	4 (0.1)	0 (0.0)	0 (0–NA)	0.06
Leak of the supraglottic airway device intraoperatively	4 (0.1)	3 (0.1)	0.73 (0.16–3.24)	0.72
Laryngoscopy abandoned because of bradycardia or secretions	3 (0.1)	0 (0.0)	0 (0–NA)	0.12
Leak of the ventilatory system	3 (0.1)	1 (0.0)	0.32 (0.03–3.10)	0.37
Unplanned admission to postoperative care unit	3 (0.1)	0 (0.0)	0 (0–NA)	0.12
Dental damage	2 (0.1)	2 (0.1)	0.97 (0.14–6.87)	1.00
Pneumothorax or pneumomediastinum	1 (0.0)	0 (0.0)	0 (0–NA)	0.49
Problems with a tracheal cannula	1 (0.0)	0 (0.0)	0 (0–NA)	0.49
Cannot-intubate cannot-ventilate	0 (0.0)	1 (0.0)	NA	1.00
Negative pressure pulmonary oedema	0 (0.0)	0 (0.0)	NA	NA
Unplanned admission to ICU	0 (0.0)	0 (0.0)	NA	NA
Others*	5 (0.1)	2 (0.1)	0.39 (0.08–2.00)	0.28
Total number of events (*n*)	**918**	**649**		

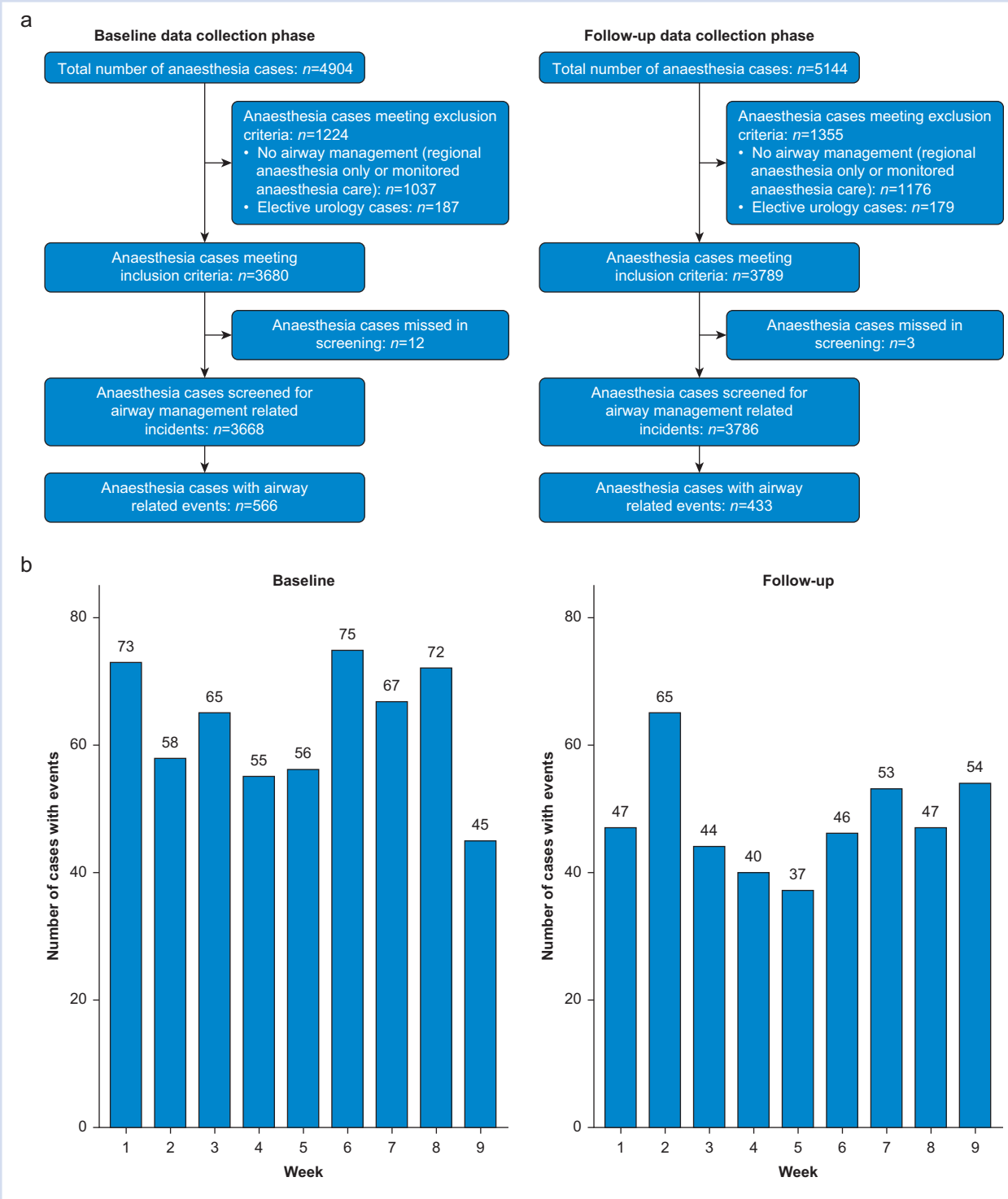

Fig 1. Study flow diagram (a) and number of anaesthesia cases with airway management-related events (b) shown for each study week. There was no difference in the distribution of the events per week between the baseline and the follow-up phase (P=0.10).

saturation was 85.0 (inter-quartile range [IQR], 75.0–89.0) at baseline and 86.0 (IQR, 78.0–90.0) at follow-up (P=0.22).

Several events occurred during planned fibreoptic intubation (eight events at baseline, four events at follow-up; Table 3). These included deep sedation resulting in apnoea, but also difficulties with compliance because of insufficient local anaesthesia or sedation, and repeated attempts, including handover to more experienced practitioners

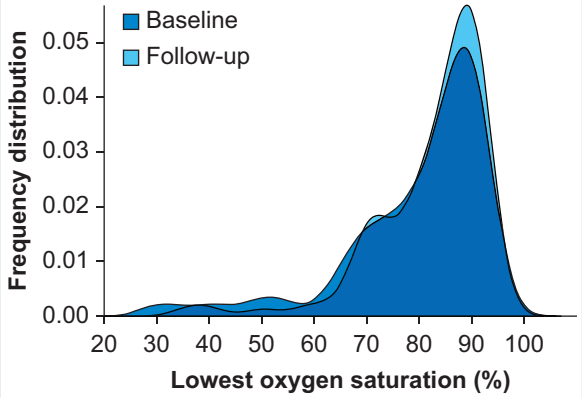

Fig 2. Frequency distribution of the lowest oxygen saturation for the baseline and the follow-up phase.

because of anatomical difficulties or in teaching situations. A cannot-intubate cannot-ventilate situation occurred in the follow-up period in a patient with a mouth opening of <2 cm who had previously received radiation therapy to the head and neck region. Apnoea resulted from sedative drugs given for insertion of a slit Guedel airway. Bag mask ventilation and a supraglottic airway device failed, but spontaneous breathing returned after drug reversal, and the patient regained consciousness without neurological sequelae.

At follow-up, more attempts at airway management were successful at first attempt (RR=1.02; 95% CI, 1.005–1.03; $P<0.01$) (Table 4).

The overall use of a videolaryngoscope in this study increased from 141 (3.8%) to 392 cases (10.4%, $P<0.01$). This was attributable to an increase in the use of a videolaryngoscope as the primary tool for airway management (increase from 110 [3.0%] to 350 [9.2%]; $P<0.01$), whereas the use of a videolaryngoscope as a rescue tool remained unchanged (31 [0.8%] at baseline, 42 [1.1%] at follow-up; $P=0.21$).

Side-effects for the baseline and follow-up data collection, respectively, were sore throat 20.4% and 17.5% ($P<0.01$), hoarseness 28.8% and 28.0% ($P=0.55$), dysphagia 15.5% and 15.1% ($P=0.73$), and minor soft tissue trauma 6.7% and 6.4% ($P=0.68$).

Discussion

This prospective study assessed major and minor events related to airway management before and after implementation of a bundle of simple changes to strategies for airway management has indicated that the incidence of events decreased from 15.4% at baseline to 11.4% at follow-up 1 year later (RR=0.74; 95% CI, 0.66–0.83), supporting our main hypothesis.

The overall incidence of airway events was higher in our study than in two recently published studies (0.08% and 6.0%).[9,10] The definition of events in these studies varied and was broader in the present study compared with the published reports. Moreover, it is likely that the active prospective screening for events, with a high presence of study personnel in theatres during data collection in the present study, decreased the likelihood of underreporting compared with longer-term audits with self-reporting only.

Changes in strategies for airway management in the department were not assessed as single interventions, but as a bundle of adjustments. All changes were relatively easy to implement, were deemed to have a high potential for improvement of airway management, and were specifically tailored to relatively frequent events identified at baseline.

Difficult bag-mask ventilation occurred in 3.8% of our patients at baseline. This is in agreement with previous data reporting incidences of 0.9%–5.0%.[11] Studies suggest that difficult bag-mask ventilation is less frequent if a neuromuscular blocking agent is administered before bag-mask ventilation is attempted.[12] Early administration of a neuromuscular blocking agent was thus part of the implemented bundle of changes. In fact, difficult bag-mask ventilation occurred significantly less frequently during the follow-up period than during the baseline period.

Hypoxaemia also occurred in 3.8% of our patients at baseline. Preoxygenation with 100% oxygen[13] and a tight-fitting facemask[14] are known to extend safe apnoea time. However, preoxygenation was reported as insufficient in 56% of cases in a study by Baillard and colleagues.[15] To improve preoxygenation, we introduced the requirement of achieving end-tidal O_2 of 90% before induction of anaesthesia, which in itself constitutes a requirement for a tight-fitting facemask to enable measurement. In addition, administration of high-flow or low-flow oxygen during apnoea is known to extend the safe apnoea time.[16–18] Administration of high-flow oxygen during every induction was deemed impossible in our study because of the limited availability of devices. Therefore, low-flow nasal cannula oxygen during apnoea was promoted. The incidence of hypoxia decreased significantly (Table 3).

On some occasions, occurrence of several events along with the subjective descriptions of anaesthesia providers indicated that airway management did not 'go smoothly'. These were attributed to improper preparation and the use of equipment, inadequate anaesthesia, unclear airway strategies, or miscommunication. As checklists may reduce such events,[19,20] we introduced a pre-induction airway-safety checklist, which had to be filled out in our patient data management system. In fact, the number of cases with two, four or more than four events decreased significantly (Table 2).

This study was carried out in a teaching hospital, and involved providers with a range of expertise at a variety of levels. At baseline there were cases that required four or more attempts at airway management. It is known that despite complications would increase, with increasing numbers of attempts,[21] a handover to more experienced providers or a change to alternative strategies is often not performed.[21] With the implemented changes to airway management, the number of cases with multiple airway management attempts was reduced significantly (Table 2).

A substantial proportion of events at baseline were related to tracheal intubation. We aimed to reduce these with better visualisation, and used a videolaryngoscope as the primary intubation tool whenever possible.[22–26] Its use increased from 3.8% at baseline to 10.4% at follow-up. The lower incidence of Cormack–Lehane grade 3 or 4 and oesophageal intubations at follow-up compared with baseline might well be a result of the increased use of a videolaryngoscope, which likely was used particularly for patients who had indicators of a difficult airway. We thus believe in encouraging anaesthetists to use a videolaryngoscope, whenever possible.

Table 4 Attempts required for successful airway management. Data are number (%). Risk ratios with associated 95% confidence intervals (CIs) are given as effect size. *Post-hoc* comparisons are adjusted for multiple comparisons using the Holm method. Ref., reference.

	Baseline (*n*=3668)	Follow-up (*n*=3786)	Risk ratio (95% CI)	*P*-value
Number of attempts, *n* (%)				<0.01
First attempt unsuccessful	306	254	Ref.	
First attempt successful	3362	3532	1.02 (1.005–1.03)	
Distribution of successful attempts, *n* (%)				<0.01
First attempt successful	3362 (91.7)	3532 (93.3)	Ref.	
Second attempt successful	247 (6.7)	226 (6.0)	0.88 (0.74–1.05)	0.31*
Third attempt successful	44 (1.2)	24 (0.6)	0.52 (0.32–0.86)	0.04*
Fourth attempt successful	12 (0.3)	3 (0.1)	0.24 (0.07–0.84)	0.06*
More than four attempts	3 (0.1)	1 (0.0)	0.32 (0.03–3.05)	0.36*

Apart from these five specific interventions, the fact that we were performing a study on airway incidents likely raised the overall 'airway awareness' of the team. This might be considered part of the intervention bundle.

The number of cases with events per week did not change in either of the data collection phases, indicating that each phase represents a 'snapshot' of a *status quo* rather than a time series in itself.

Limitations

Our aim was to assess the bundle of changes, not single interventions, and it is therefore impossible to discern which change had an effect on which event. For example, it is known that videolaryngoscopy improves the average glottic view, but it is impossible to discern whether the incidence of a poor Cormack–Lehane grade decreased because of increased use of a videolaryngoscope, earlier administration of a neuromuscular blocking agent, or other factors.

The study assessed all events occurring between the start of anaesthesia and handover of the patient by the anaesthetic team to the team taking care of the patient postoperatively. We are not aware of any major events happening in the recovery period, but we did not assess the events in this period.

To avoid selection bias in this before-and-after study, we studied a high number of patients in the same 2 months of the year for the baseline and follow-up phase. Despite this, there was a significant difference between baseline and follow-up for ASA group, surgical specialty, and the duration of anaesthesia. As all aspects of airway management either remained stable or improved, it is likely that changes were as a result of the interventions rather than other factors. This is also supported by the covariate-adjusted logistic regression of the primary outcome, as presented in the Supplementary material.

Minor events can 'pave the way' for major, potentially life-threatening, complications.[5,7,19,20] We suggest that minor airway events should be used as surrogate measures to monitor quality and safety of airway management. As there were significant positive effects after implementation of changes, it would be interesting to perform a multicentre trial to see if this positive effect can be repeated, and whether the 'common airway themes' are similar across institutions. Even if common airway themes differ between departments, the present study demonstrates that it is possible to improve airway management through targeted interventions.

In conclusion, the number of cases with events related to airway management was reduced by implementing an easily applicable bundle of interventions. Creating interventions that are specifically suited to local problems may be a key to the optimisation of airway management in anaesthesia departments.

Authors' contributions

Conception and design: RG, LT, MKB.
Acquisition of data: THP, FU, TH, RG, LT, MKB.
Analysis and interpretation of data: THP, MH, MKB.
Drafting the article: THP, MKB.
Critical revision of the article for important intellectual content: FU, TH, RG, LT, MH.
All authors gave final approval of the version to be published and agreed to be accountable for all aspects of the work.

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Declarations of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

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