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Original Article

Risk factors for excessive tidal volumes delivered during intraoperative mechanical ventilation, a retrospective study

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Abstract: Background: Lung Protective Ventilation (LPV) refers to a combination of measures aimed at reducing ventilator-associated lung injury. This includes: delivering tidal volumes of 6-8 ml/kg of ideal body weight, use of positive end expiratory pressure and recruitment maneuvers. With Postoperative Pulmonary Complications (PPCs) contributing towards significant morbidity and mortality following surgery, evidence indicates that effective use of LPV measures intraoperatively has been associated with reduced rates of PPCs. Methods: We conducted a post-hoc analysis using data from a recent clinical audit on departmental ventilation practices. Potential risk factors for excessive tidal volume ventilation were assessed using univariable and multivariable regression models. Results: Obesity and gender are independently associated with risk of excessive ventilation. In contrast, the urgency and length of surgery, the choice of airway devices and the mode of ventilation were not associated with excessive ventilation. Conclusion: There is an association between female gender, obesity and excessive tidal volume ventilation. This may be addressed through formal, protocolized intraoperative ventilation setting.

Keywords: Intraoperative care, lung diseases, lung protective ventilation, perioperative care, postoperative complications

Introduction

Lung Protective Ventilation (LPV) refers to a ventilatory strategy comprising of measures including relatively low tidal volumes (TV) of 6-8 ml/kg of Ideal Body Weight (IBW) accompanied by Positive End Expiratory Pressure (PEEP); and use of alveolar recruitment maneuvers. Its use is established in patients with Acute Respiratory Distress Syndrome (ARDS), with the ARDSnet trial being of particular significance [1]. LPV is thought to reduce ventilator-associated lung injury via minimizing atelectotrauma, barotrauma, volutrauma and biotrauma [2]. Indeed, it is associated with improved mortality and ventilator-free days [1, 3].

It is increasingly recognized that the benefits of LPV are not just limited to the critical care setting. Postoperative Pulmonary Complications (PPCs) are a significant and costly burden following surgery, with a rate of < 1-33% depending on surgery type [4, 5]. They are associated with increased 30-day mortality and financial cost [6, 7]. The intraoperative implementation of LPV has been linked with reduced PPCs [8], with an international consensus on intraoperative LPV recommendations [9] published by Young et al. relatively recently in October 2019.

Expert consensus recommends the use of LPV even in low risk patients undergoing general anaesthesia requiring positive pressure ventilation. While IBW is calculated based on patient characteristics, such as the method described by Devine et al [10]; Anecdotal evidence suggests that there is variability in clinical practice, which includes: use of the Devine formula; use of actual body weight; or bedside estimates of either height or weight - some of which may not accurately reflect the calculated IBW, thereby leading to inappropriate TVs being delivered. Furthermore, there is initial evidence showing that patient obesity is linked with underutilization of LPV strategies, which may be explained by clinicians using actual body weight rather than IBW to determine TVs [11]. Respiratory physiology is altered in obesity, with this patient group being more susceptible to PPCs [12], further reinforcing the need for application of LPV strategies. In this study, we aimed to evaluate if obesity, alongside other factors, contribute to greater TVs being delivered.

Methods

Clinical setting

The study was carried out in a high turnover district general hospital, with 16 operating rooms offering services in General Surgery as well as Orthopedics, Vascular, Gynecology, Head and Neck surgery (including Neurosurgery). The study was done as a *post hoc* analysis of a departmental ventilation practice audit, approved by the institutional audit review board (Barking, Havering and Redbridge University Hospitals NHS trust), and written informed consent was waived.

The main aim of the initial audit was to evaluate departmental practice regarding adherence to LPV measures and to review documentation rates of ventilatory parameters on the anaesthetic chart, in accordance with standards of good record-keeping practice [13].

Two audit cycles were completed, with each cycle including a 5-day data collection period. The first audit cycle (n = 114) showed that 40% of patients were receiving TVs in excess of 8 mL/kg IBW, this was presented at the departmental audit meeting. The second audit cycle (n = 106) was completed a year later, with similar patient and surgical demographics. It showed that documentation rates of TV had improved (59% to 88%), but ventilatory practice remained constant (54% receiving excessive TVs, P = 0.14, when compared to the initial audit).

Outcomes definition

The primary outcome was excessive TVs delivered, defined as TVs over 8 ml/kg according to the patient's IBW. IBW was calculated using the Devine formula, based on patient height and gender [10].

Data collection

The data were collected from two cycles of clinical audit, which occurred over 2018-2019. Data were extracted from anesthetic records of patients in the post-anesthesia care unit. Anesthesiologists on duty were not informed of the dates for data collection and were expected to provide anesthesia according to their usual practice.

Inclusion criteria for the clinical audit were any adult patients undergoing surgery with general anesthesia, with cases taking place between 08:00 and 18:00; while exclusion criteria were patients under the age of 16 and those having surgery under regional anesthesia or local anesthesia only. Baseline information collected included: age; gender; American society of Anesthesiology (ASA) classification; history of smoking and obstructive airway disease; name of the surgical procedure and the actual length of the procedure. In relation to ventilation, the following information was collected: patient height; weight; body mass index (BMI); mode of mechanical ventilation; choice of airway and the TV delivered.

While patients who were spontaneously ventilating without assistance under anesthesia were initially included in the audit, these cases were excluded in our analysis as spontaneous ventilation does not reflect clinical practice in setting ventilatory volumes. We also excluded cases where the primary outcome (TV > 8 ml/kg IBW) could not be derived, this included cases where height, gender or TVs during ventilation were not recorded.

Statistical analysis

Continuous variables are presented as means with standard deviation, while categorical variables are presented as numbers. Patients were initially grouped into two cohorts, based on whether they received TVs greater or equal/less than 8 ml/kg IBW. Differences between these cohorts were tested using Student's T-test (for continuous variables) and Chi square test (for categorical variables).

The relative contribution of each variable on the risk of excessive TVs delivered was then assessed using univariable logistic regression as previously described [14], with the findings

Table 1. Characteristics of included patients (n = 135)

Weight	
Normal	36 (27%)
Overweight	41 (30%)
Obese	43 (32%)
Airway	
Endotracheal tube	77 (57%)
LMA	58 (43%)
Age (SD)	49.2 (18.0)
Gender	
Female	82 (61%)
Male	53 (39%)
Urgency	
Non-Urgent	97 (72%)
Urgent	35 (26%)
ASA	
I	30 (22%)
II	49 (36%)
III	21 (16%)
IV	1 (1%)
History of COPD/ Asthma	
No	108 (80%)
Yes	27 (20%)
History of smoking	
No	85 (63%)
Yes	44 (33%)
Surgical specialty	
General	29 (21%)
Lap General	8 (6%)
Gynecology	31 (23%)
Lap Gynecology	3 (2%)
ENT/MaxFax	27 (20%)
Neurosurgery	16 (12%)
Ophthalmology	7 (5%)
Orthopedic	11 (8%)
Vascular	3 (2%)
Ventilator mode	
Pressure control	19 (14%)
Volume control	69 (51%)
Volume AutoFlow	21 (16%)
Pressure support	7 (5%)
Length of surgery (SD)	93.6 (83.4)

reported as odds ratios and the 95% confidence interval, along with their associated *p*-values.

For the purpose of the multivariable logistic regression, three models were considered: 1. Adjusted for all variables of interest, 2. Adjusted for variables demonstrating statistical significance (*P*-value < 0.05) in the univariable analysis, 3. Adjusted for variables with *P*-value less than 0.1 in the univariable analysis [15-17]. Multivariate logistic regression was carried out using methods described by Lee et al [17]. We then compared the Akaike information criterion (AIC) and the residual to determine the optimal model. Data were collected on Microsoft Excel, with statistical analysis performed in R Studio.

Results

During data collection, a total of 220 cases were recorded; ten cases involving spontaneous ventilation were excluded. Additionally, a further 75 cases were excluded due to lack of primary outcome data with the remaining 135 cases included in the analysis.

A total of 64 cases were identified with excessive TVs (> 8 ml/kg IBW) delivered (47%), and 71 cases with TVs ≤ 8 ml/kg IBW (53%). A comparison of the two cohorts is displayed in **Table 1**. Notably, significant differences in patient characteristics include BMI category (normal = BMI > 20 and < 25; overweight = BMI ≥ 25; obese = BMI ≥ 30 [18] and gender. There was no significant association between excessive TV, choice of airway devices, ventilator modes, length or type of surgery.

Following univariate regression analysis, excessive TV ventilation was noted to be strongly associated with obesity (P < 0.001) and female gender (P < 0.0001) (**Table 2**). As there were no other covariates with *P*-value less than 0.1, two multivariable models were considered, one with all covariates and one with the significant covariates only. Both models identified obesity (P < 0.002) and female gender (P < 0.001) as factors associated with excessive TV ventilation (**Table 3**). Combined, the odds ratio of an obese female patient receiving excessive tidal volume compared to a non-obese male patient is 17.1 (**Figure 1**).

Discussion

Previous studies have similarly evaluated intraoperative ventilation practice, although the definition of excessive TV varies from > 8 ml/kg to 10 ml/kg IBW [19-22]. In our study, the rate of excessive TV ventilation was found to be 47%, a relatively high proportion. This may be explained

Table 2. Findings of the univariable regression analyses for factors associated with excess TV ventilation

	Normal tidal volume (n = 71)	Excess tidal volume (n = 64)	Odds ratio (95% CI)	*P* value
Weight				
Normal	25	11	1	
Overweight	20	21	2.38 (0.94-6.24)	0.07
Obese	13	30	5.24 (2.06-14.23)	< 0.001
Airway				
Endotracheal tube	45	32	1	
LMA	26	32	1.73 (0.87-3.46)	0.12
Age (continuous)	49.2 (18.0)	50.4 (18.4)	1.00 (0.98-1.02)	0.71
Gender				
Female	31	51	1	
Male	40	13	0.19 (0.09-0.42)	< 0.0001
Urgency				
Non-urgent	50	47	1	
Urgent	18	17	1.00 (0.46-2.18)	0.99
ASA				
I	17	13	1	
II	23	26	1.56 (0.63-3.94)	0.33
III	9	12	1.74 (0.61-5.80)	0.28
IV	1	0	--	
History of COPD/ Asthma				
No	60	48	1	
Yes	11	16	1.81 (0.78-4.37)	0.17
History of smoking				
No	41	44	1	
Yes	26	18	0.65 (0.31-1.34)	0.24
Surgical specialty				
General	17	12	1	
Lap General	4	4	1.42 (0.28-7.11)	0.66
Gynecology	15	16	1.51 (0.55-4.26)	0.42
Lap Gynecology	0	3	--	
ENT/MaxFax	16	11	0.97 (0.33-2.84)	0.96
Neurosurgery	8	8	1.41 (0.41-4.92)	0.58
Ophthalmology	3	4	1.88 (0.36-11.1)	0.46
Orthopedic	6	5	1.18 (0.28-4.83)	0.82
Vascular	2	1	0.71 (0.03-8.24)	0.79
Ventilator mode				
Pressure control	12	7	1	
Volume control	36	33	0.63 (0.21-1.78)	0.40
Volume AutoFlow	13	8	0.67 (0.24-1.80)	0.44
Pressure support	2	5	2.72 (0.55-19.9)	0.25
Length of surgery (continuous)	93.6 (83.4)	86 (55.8)	1.00 (0.99-1.00)	0.54

by expert consensus in intraoperative LPV being published after data collection, and the initial lack of a clear national guideline/protocol on this [9]. In the excessive TV cohort, tidal volumes of over 12 ml/kg IBW were identified. Historically, TVs of greater than 10 ml/kg were used in mechanically ventilated patients, following a study by Bendixen et al. in 1963 that

Table 3. Findings of the multivariable regression analyses for factors associated with excess TV ventilation

	Odds ratio (95% CI)	*P*-value
Obese	5.25 (1.91-15.41)	0.002
Male gender	0.19 (0.08-0.42)	< 0.001

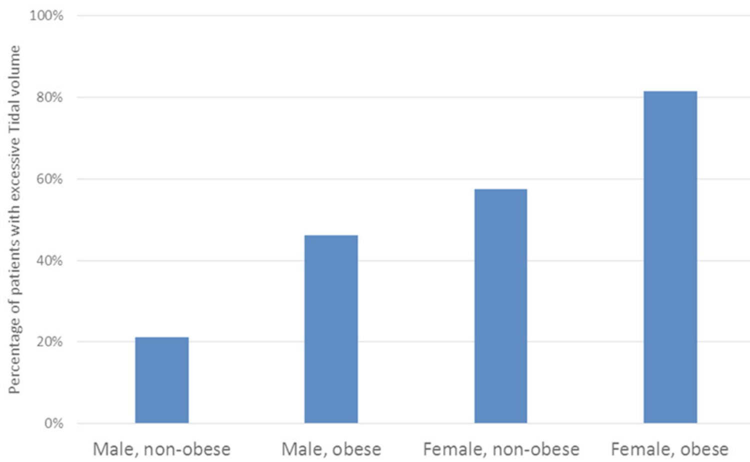

Figure 1. Patient characteristics and incidence of excess TV ventilation.

linked higher rates of atelectasis with patients ventilated with lower TVs [23]. Following publication of formal recommendations on intraoperative ventilation strategies, it would be beneficial to compare and contrast clinical practice in light of this.

Obesity was strongly associated with receiving excessive TVs, whereas being overweight/of a normal BMI was not. In clinical practice, ideal bodyweight is often estimated by the clinician based on the 'end-of-the-bed' impression, which is prone to errors and biases. It is likely that the pattern of ventilation practice seen in this study represents a tendency towards overestimating the IBW in obese patients, possibly due to anchoring and adjustment bias. Alternatively, this may be due to patients' actual body weight being used to determine TVs delivered, as has been previously postulated by Yang and Gong [11]. Obese patients are at a higher risk of developing PPCs, with obesity classes II and III independently associated with this [24]. Additionally, expert consensus has identified BMI > 40 as one of the eight factors posing the greatest risk for PPCs [9]. Obesity has a number of sequelae including: obstructive sleep apnoea and the metabolic syndrome [25], and is associated with greater perioperative risk [26]. With the growing prevalence of obesity worldwide resulting in increasing numbers of obese surgical patients to whom safe peri/intraoperative care must be delivered, greater focus should be drawn to the anaesthetic management of this patient group [27].

From the data, it is apparent that female patient gender is linked with receiving excessive TVs. We hypothesise that the IBW of female patients is overestimated by attending clinicians, resulting in greater TVs set on the ventilator. Of note, previous studies have similarly shown that the female gender, BMI ≥ 30, and short stature is associated with receiving greater TVs intraoperatively [19, 21]. Further awareness on patient height and the use of IBW to determine TVs should be reinforced, in order to improve clinical practice.

Increased length of surgery, ASA status, smoking and respiratory comorbidities are all risk factors for developing PPCs [28]. In our study, they had no association with excessive TVs being delivered to patients. In addition, we did not identify any significant association between surgical specialties and the risk of excess TVs. This was particularly unexpected for patients undergoing Neurosurgery whereby greater delivered TVs may be expected, due to the need for a relatively tighter control of partial pressures of Oxygen and Carbon Dioxide in order to maintain cerebral perfusion and prevent excessive cerebral vasodilation. This could however be due to the small number of patients in each subset, and the resultant lack of statistical power. Emergency surgery is also associated with higher risks of PPC development [28] , and it may be argued that Anaesthetists are more inclined to implement LPV strategies in this patient subgroup, especially those presenting with higher Early Warning Scores (EWS) and significant underlying pathology (such as sepsis). In our study however, we did not observe a significant association between urgency of surgery and risk of delivering excess TVs. This may be due to a variety of reasons including: small sample size, or patients' initial EWS not being elevated despite their urgent need for surgery. Unfortunately, data regarding the specifics of these patient details and the operation findings were not available to confirm the latter.

This study was limited due to it being a retrospective, *post hoc* analysis of a clinical audit, and while a strong association exists between excess TV, obesity and female gender, causation cannot be reliably established. There were also other clinical parameters such gas exchange status (oximetry, end-tidal Carbon Dioxide) which may affect decisions made regarding tidal volumes delivered, these were however not available for analysis. For instance, there may be instances whereby the risk of hypoxia outweighs the risk of subsequent PPC development. Finally, there were no data available on the incidence of PPCs in patients who received excess TVs.

Conclusion

Our study has identified female gender and obesity as strong risk factors for receiving excessive intraoperative TVs, possibly due to overestimation of patients' IBW by clinicians. With a strategy for the intraoperative implementation of LPV formalised in the international consensus by Young et al [9], the authors are optimistic that a change in practice is to be anticipated. We strongly recommend the appropriate use of calculated IBW to determine TVs for all patients undergoing general anaesthesia - facilitated by methods such as visual reminders and teaching sessions - with the aim of improving the delivery of LPV and minimising the attendant risk of PPCs, especially in high-risk cohorts as identified from this analysis.

Disclosure of conflict of interest

None.

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