

Research Article

Predictors of Severity and Nocturnal Nadir of Postoperative Oxygenation Impairment after Shoulder Surgery in the Older Population

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- Nocturnal
- Survival

Abstract

Aim: Pain following shoulder surgery can be severe; interscalene brachial plexus blockade (ISB) and high dose opioid analgesia are commonly used management options, however both impair oxygenation by multiple mechanisms. We aimed to quantify the extent of, and explore the factors influencing, the largest decline/ nocturnal peak onset of postoperative oxygenation impairment.

Methods: 114 shoulder surgery patients over the age of 50 were included. Binary logistic regression analysis was used to identify factors predisposing to a significant fall in patient's partial pressure of arterial oxygen: fraction inspired oxygen ($\text{PaO}_2:\text{FiO}_2$) ratios. Survival analysis was used to elucidate time to nocturnal $\text{PaO}_2:\text{FiO}_2$ nadir.

Results: 67 patients received ISB. Greatest postoperative reduction in $\text{PaO}_2:\text{FiO}_2$ ratio per patient was [mean (SD)] (179 [102]); in 22% of patients this occurred nocturnally. Only higher preoperative SpO_2 (OR 3.9) was associated with a significant fall in $\text{PaO}_2:\text{FiO}_2$ ratio in the multivariate logistic regression model; opioid usage, use of ISB and all other factors were not. ISB was however strongly associated with much earlier time to greatest nocturnal fall in $\text{PaO}_2:\text{FiO}_2$ ratio (median survival time 205 minutes vs. 635 minutes, hazard ratio 24.3, $p < 0.0001$ by Kaplan-Meier survival curve). Higher preoperative SpO_2 was also strongly correlated to fall in $\text{PaO}_2:\text{FiO}_2$ ratio (Pearson's $R = 0.7$, $p < 0.0001$), but not absolute lowest $\text{PaO}_2:\text{FiO}_2$ ratio per patient (Pearson's $R = 0.15$, $p = 0.12$).

Conclusion: Whilst choice of analgesic technique does not influence the likelihood of profound impairment of oxygenation after shoulder surgery, use of ISB significantly shortens the time to onset of a nocturnal oxygenation nadir. Knowledge of this timing of peak respiratory impairment should be used to focus postoperative observation. As patients with normal preoperative room air SpO_2 may still suffer a significant nadir in postoperative $\text{PaO}_2:\text{FiO}_2$ ratio, postoperative monitoring should be managed accordingly.

INTRODUCTION

Shoulder surgery is well known to be associated with moderate to severe pain in the postoperative period [1]. Most commonly interscalene brachial plexus blockade (ISB) or a multimodal systemic analgesic regime is used for postoperative pain relief. Arthroscopic shoulder surgery, the least invasive surgical approach, typically requires an opioid analgesic component of up to 20mg of intravenous morphine [2]. The majority of published studies rank thoraco-abdominal surgery

as the highest risk for perioperative hypoxaemia [3,4]. However postoperative oxygenation impairment in this context, with or without the use of ISB, has not been examined.

Opioids can induce postoperative hypoxia in a complex fashion via sedation, centrally mediated hypoventilation, and loss of pharyngeal tone with partial airway obstruction [5]. Respiratory depression and significant postoperative desaturation has occurred with use of patient controlled IV opioid analgesia with an incidence of 1.2% and 11.5% [6] respectively.

Interscalene brachial plexus blockade is also associated with phrenic nerve palsy in the majority of cases [7]; unilateral phrenic nerve palsy induces global impairment of mechanical lung function by 20-40% [8]. As the orthopaedic surgical population continues to age and present with a greater burden of comorbid cardio-respiratory disease, there will be a greater propensity for significant postoperative hypoxia. Even in the healthy population, but particularly in those with obstructive sleep apnea (OSA) and related syndromes [9], there is an increased risk of exacerbation of this hypoxia nocturnally as respiration is further depressed during sleep. The severity, timing, and risk factors pertaining to this event in this context remain unquantified; however, the implications for delayed nocturnal hypoxia are profound as it is well known that recognition of patient deterioration can be delayed during times of reduced numbers of nursing staff. We aimed to quantify the extent of postoperative oxygenation impairment and explore the influence of clinical risk factors on oxygenation impairment and its nocturnal onset after shoulder surgery with the use of ISB and opioid analgesia.

MATERIALS AND METHODS

We reviewed 114 patients over the age of 50 who had undergone elective shoulder surgery within the last 3 years in a tertiary referral centre. All patients were opioid naïve and had received volatile agent based general anaesthesia, were intubated for the procedure and received nondepolarising neuromuscular blockade. All received intravenous morphine and oral oxycodone (slow and immediate release) and/ or ISB for postoperative analgesia.

The largest decline and absolute nadir in partial pressure of arterial oxygen - to - fraction inspired oxygen ($\text{PaO}_2:\text{FiO}_2$) ratio per patient was calculated from the preoperative oxygen saturations (SpO_2) on room air and the documented postoperative SpO_2 and fraction inspired oxygen (FiO_2). FiO_2 was derived by predetermined conversion from flows of oxygen as per the manufacturer's specifications ("Hudson" mask, Thermofisher Scientific Australia, Victoria, Australia) given by our industry standard delivery device. PaO_2 was derived from the documented SpO_2 with the Severinghaus formula [10]. Analysis of pre-to-postoperative $\text{PaO}_2:\text{FiO}_2$ ratios rather than SpO_2 removes the confounding effect of supplemental oxygen and is considered to be the most reliable index in estimating the impairment of gas exchange in clinical scenarios [11].

Information concerning patient factors (demographic, anthropomorphic, preoperative room air SpO_2 , cardio-respiratory co-morbidities, abnormal preoperative investigations), surgical factors (operation type, duration, AM or PM session) and analgesia factors (use of ISB, IV morphine opioid equivalent usage) was included into the final analysis. "24 hour postoperative period" was defined as 24 hours from the surgical end time documented in the surgical scrub sheet records. "Time to nocturnal $\text{PaO}_2:\text{FiO}_2$ ratio nadir" was defined as time from surgical end and peak decline in $\text{PaO}_2:\text{FiO}_2$ ratio occurring between 2000-0800 hours. Preoperative SpO_2 was taken on room air with the same pulse oximeter in the single room used for pre-admission anaesthesia assessment consultations. Any abnormality in lung fields documented in the radiologist's report of a preoperative CXR was defined as "abnormal CXR" and any abnormality documented

in the cardiologist's report of a preoperative transthoracic echocardiogram (TTE) was defined as "abnormal TTE". All intraoperative and postoperative opioid doses were converted to intravenous morphine equivalents as described by McIntyre [12] and Hildegaard [13] and compared on a per-kg basis.

STATISTICAL ANALYSES

All calculations were performed using SPSS V21 ((IBM, New York, USA) statistical software; graphs were prepared with Graph Pad Prism 5 (Graph Pad Software, California, USA). Continuous data was assessed for normality by histogram frequency distribution analysis and the Kolgomorov-Smirnoff normality test. A multivariate logistic regression model was used to establish covariates having significant effect on the likelihood of developing a peak decline in $\text{PaO}_2:\text{FiO}_2$ ratio of >136 , and also analysed by Cox regression/ proportional hazards to determine covariate influence on time to peak decline in $\text{PaO}_2:\text{FiO}_2$ ratio between the hours of 2000-0800. The peak decline in $\text{PaO}_2:\text{FiO}_2$ ratio cut-off of 136 was derived from the mean fall in $\text{PaO}_2:\text{FiO}_2$ ratio required to qualify for mild adult respiratory distress syndrome (ARDS) [14] ie. An absolute $\text{PaO}_2:\text{FiO}_2$ ratio of <300 . Kaplan-Meier survival curves were used to establish the effect of ISB on survival probability to the earliest time of greatest decline in patient's $\text{PaO}_2:\text{FiO}_2$ ratio between the hours of 2000-0800. *A-priori* sample size was determined conservatively by the requirement for 10 samples for each covariate used in logistic and cox regression [15], with the planned inclusion of a maximum of 10 covariates.

RESULTS AND DISCUSSION

Results

114 patients were included in the final analysis. Patient demographics and preoperative details are listed in Table 1.

No patients required respiratory support beyond high flow oxygen and no patients required unplanned high dependency unit (HDU), or intensive care unit (ICU) admission. Greatest

Age (years)	67 (50 - 90)	
Male Sex	49 (43%)	
BMI (kg/ m ²)	29 (18 - 46)	
Preoperative SpO_2 , room air (%)	96 (91 - 99)	
ASA	1	10 (9%)
	2	63 (56%)
	3	39 (34%)
Diagnosis of any Respiratory Disease	39 (36%)	
Diagnosis of CCF	5 (4%)	
Diagnosis of Hypertension	64 (56%)	
Abnormal Preoperative CXR	20 (18%)	
Abnormal Preoperative TTE	14 (11%)	
Data are expressed as median (range), mean (SD) or number (proportion). Abbreviations: BMI: Body Mass Index; CCF: Congestive Cardiac Failure; CXR: Chest x-ray, TTE: Transthoracic Echocardiogram		

postoperative reduction in PaO₂:FiO₂ ratio per patient was [mean (SD)] (179 [102]); in those who had received ISB the PaO₂: FiO₂ ratio decline was ([172, (145 - 198)]. Those who had not showed a PaO₂:FiO₂ ratio decline of [183, (142 - 224)]. Patient's surgical and postoperative oxygenation profiles are shown in Table 2.

Higher preoperative room air SpO₂ was the only factor which increased the likelihood of a postoperative fall in PaO₂:FiO₂ ratio of >136 in the logistic regression model (OR 3.9, [95% CI] 1.9 - 5.3, p<0.0001). No other patient risk factors or analgesia factors, including use of ISB, achieved statistical significance. Higher preoperative room air SpO₂ was strongly related to greatest fall in PaO₂: FiO₂ ratio (Pearson's R = 0.7, p<0.0001, linear regression; Figure 1), however was not associated with absolute lowest PaO₂:FiO₂ ratio per patient (Pearson's R = 0.15, p = 0.12; Figure 2).

25 patients (22%) experienced their greatest fall in PaO₂:FiO₂ ratio during the period of 2000 - 0800 hours. Patients who had received ISB were much more likely to suffer this nocturnal fall in PaO₂: FiO₂ ratio sooner after their procedure (Kaplan-Meier survival curve, hazard ratio 24.3, median survival time 205

Interscalene Block	68 (61%)
Interscalene Block LA dose (Ropivacaine, mg)	150 (50 - 200)
Open Surgery	47 (42%)
PM operating session	29 (26%)
Surgical Duration (minutes)	151 (61)
Lowest postoperative absolute PaO ₂ :FiO ₂ ratio	270 (71)
Greatest fall in perioperative PaO ₂ :FiO ₂ ratio	179 (102)
Lowest PaO ₂ :FiO ₂ ratio occurring 2000-0800 hrs (# patients)	25 (22%)
Opioid Requirements in 24 hour postoperative period (IV morphine equivalents, mg/ kg)	0.42 (0.39)
Data are expressed as median (range), mean (SD) or number (proportion).	

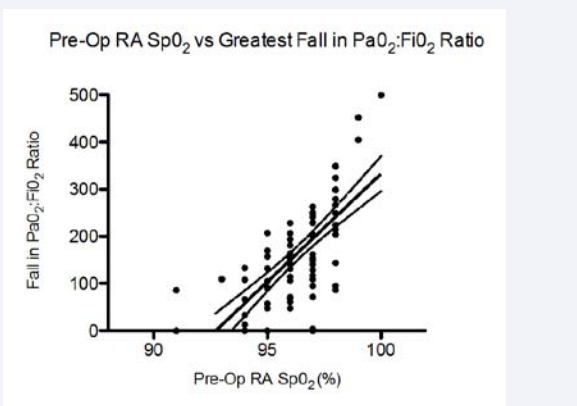


Figure 1 Linear regression of subject's preoperative room air spo₂ vs. largest decline in pao₂:fio₂ ratio.

Abbreviations: Pre-Op RA SpO₂: Preoperative Room Air Oxygen Saturation; PaO₂:FiO₂ ratio: Partial Pressure of Arterial Oxygen Content: Fraction of Oxygen in Inspired Gas Ratio

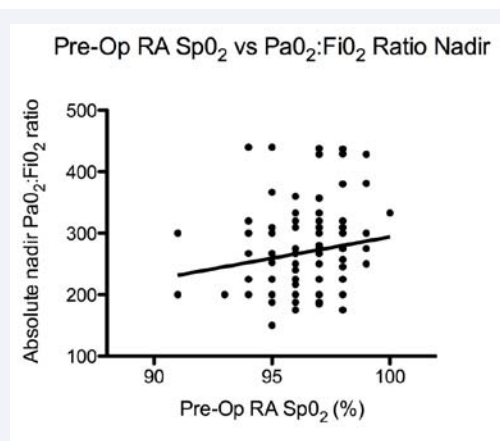


Figure 2 Linear regression of subject's preoperative room air spo₂ vs. absolute pao₂:fio₂ ratio nadir.

Abbreviations: Pre-Op RA SpO₂: Preoperative Room Air Oxygen Saturation; PaO₂:FiO₂ ratio: Partial Pressure of Arterial Oxygen Content: Fraction of Oxygen in Inspired Gas Ratio

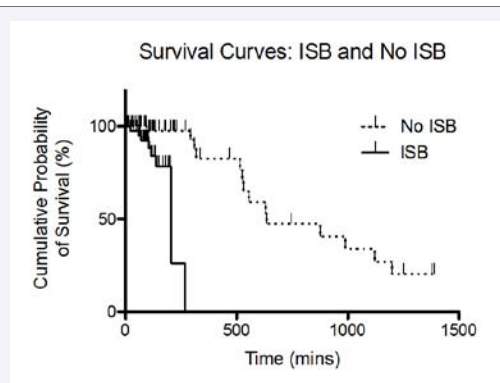


Figure 3 Kaplan-meier survival curve: time to greatest nocturnal fall in pao₂:fio₂ ratio.

Abbreviations: ISB: Inter-Scalene Brachial Plexus Blockade

minutes vs. 635 minutes, p < 0.0001; Figure 3). On Cox regression hazard ratio analysis for nocturnal occurrence of greatest fall in PaO₂:FiO₂ ratio, no other patient or analgesia factors (age, respiratory risk, BMI, preoperative SpO₂, ASA, open surgical procedure, or opioid usage) achieved statistical significance.

Discussion

We present findings of respiratory impairment in the 24 hour postoperative period from a retrospective study of patients over the age of 50 presenting for elective shoulder surgery. There is to our knowledge no published data quantifying the impact of analgesic techniques and patient factors on change in oxygenation impairment in this patient population and context. Opioid analgesia impairs oxygenation by several means: centrally induced hypoventilation together with partial airway obstruction caused by loss of pharyngeal tone causes small airway collapse, reducing V/Q ratio [5]. The phrenic nerve palsy associated with ISB also induces global impairment of mechanical lung function by affecting 1st-second forced expiratory volume (FEV₁) and forced vital capacity (FVC), causing basal lung collapse and V/Q

mismatch on the affected side. These effects may be compounded as block regression ensues and acute opioid loading is initiated to maintain patients' analgesia. Although administration of supplemental oxygen meant that no patients required escalation of care from the ward environment, we observed a profound nadir of oxygenation - a decline equivalent to that of a diagnosis of mild ARDS. In keeping with our finding that choice of primary analgesic technique did not affect likelihood of developing this degree of V/Q mismatch, it is clear that both use of ISB and high dose opioid analgesia have a significant impact on gas exchange. ISB use also resulted in a much higher likelihood of earlier onset to nocturnal PaO₂:FiO₂ ratio nadir. We propose that the almost immediate onset of phrenic nerve palsy together with sleep related hypoventilation and opioid loading with block regression contributed to this finding. The median survival time of approximately 2.5 hours for patients receiving ISB - almost 4 times earlier than those who had not - should alert those involved with patients' postoperative care within these times to increase their frequency of observations, ensure availability of high dependency or intensive care support, and have supportive respiratory facilities and equipment readily available.

Our results showing strong correlation between higher preoperative room air SpO₂ and greater postoperative fall in PaO₂:FiO₂ ratios were unexpected; however, this seemingly counter-intuitive observation did not have a statistically significant influence on *absolute* postoperative PaO₂:FiO₂ nadirs. These findings can be reconciled with similar scenarios in thoracic anaesthesia and one-lung ventilation. It is well known that patients whose lungs do not have impaired ventilation-perfusion matching (V/Q ratios) suffer a greater fall, and in some cases a greater nadir, in SpO₂ on onset of one-lung ventilation [16]. We postulate that a similar mechanism may occur in those patients with a high preoperative room air SpO₂ (implying little baseline respiratory disease) and effects of ISB and/ or high dose opioid analgesia on V/Q ratios; hence gas exchange may unpredictably fall in lower risk patients. The degree of this fall may be proportionally higher than that observed in patients with lower preoperative room air SpO₂; however, conversely, we do not propose that this mechanism is necessarily protective for those with poor preoperative room air SpO₂. Unlike the scenario of one-lung anaesthesia where invasive respiratory support has been established, a patient with pre-existing lung disease in this postoperative setting may still require escalation of care as a small deterioration in oxygenation may be enough to exhaust their reserve. Our findings should also be qualified by the fact that the lowest preoperative room air SpO₂ value in our sample was 91%; hence inferences beyond this range cannot be made. With regards to planning for postoperative care, as higher preoperative room air SpO₂ is not necessarily a guarantee against significant postoperative oxygenation impairment, patients with little co-morbid disease preoperatively should still be treated with caution.

Our study is limited by its retrospective design and single centre sample; however the opioid requirements and oxygenation impairment in the patients receiving ISB in our study are in concordance with results of prospective studies [17]. There is also unavoidable error involved in conversion of oxygen flows in spontaneously ventilating patients to a fraction inspired oxygen

value, as it is known that the true FiO₂ varies with extremes of the patient's minute ventilation. Similarly, a derivation of PaO₂ by the Severinghaus formula will not account for shifts in the oxygen-haemoglobin dissociation curve. However, the application of these conversions was applied identically to all patients, and the narrow confidence intervals around the point estimates of fall in the PaO₂:FiO₂ ratios support our methodology. We do not believe that our findings are confounded by the conversion of SpO₂ to PaO₂:FiO₂ ratio; this ratio has been considered to be the most reliable in estimating the impairment of gas exchange in clinical scenarios [11] particularly when attempting to compare changes in oxygenation with SpO₂ alone when supplemental oxygen is administered. Similarly, our range of preoperative SpO₂ values fall within the linear portion of the haemoglobin-oxygen dissociation curve, hence a conversion artefact from SpO₂-to-PaO₂ is unlikely. It is possible that that our study was underpowered to detect small effect sizes of covariates; this may explain the unexpected finding that no patient risk factors appeared to influence the likelihood of a greater fall in postoperative gas exchange. Our sample size-to-covariate ratio used in the final analysis however was, however, conservative [15], making this unlikely.

CONCLUSIONS

Impairment of oxygenation after shoulder surgery is profound and does not appear to be associated with the use of ISB where opioid analgesia is utilized as the alternative analgesic technique; however use of ISB does result in a strong likelihood of a 4-fold earlier onset of nocturnal oxygenation nadir. In patients with preoperative room air SpO₂ values above 90% a higher preoperative room air SpO₂ is not necessarily protective against a significant nadir in PaO₂: FiO₂ ratio. Availability of high dependency/ intensive care services and respiratory support must be considered for patients in this age group even if little co-morbid disease is present, and accessibility of these services made a priority during the earlier nocturnal high risk period for oxygenation impairment after ISB.

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