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How safe is non-bronchoscopic bronchoalveolar lavage in critically ill mechanically ventilated children?

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Abstract *Objective*: To assess the safety of non-bronchoscopic bronchoalveolar lavage (NB-BAL) in critically ill mechanically ventilated children.
Setting: Paediatric intensive care unit in a tertiary children's hospital.
Methods: The data from 60 consecutive critically ill mechanically ventilated children who underwent NB-BAL was reviewed from November 1997 to December 1999. PRISM score prior to NB-BAL, observations at the time of NB-BAL and arterial blood gases, oxygenation index (OI), ventilator settings, haemodynamic variables and temperature taken at 1 h before, and 1 and 6 h after NB-BAL, were retrieved from the archived computerised database.
Results: Median age was 7 months (IQR 2.8–43 months) and median weight was 5.5 kg (IQR 4–14 kg). Four (7%) patients exhibited significant immediate complications, requiring escalation of respiratory or haemodynamic support. Forty-two (70%) patients had complete data for calculation of OI; there was no significant change in median OI at 1 and 6 h after NB-BAL. However 5 (12%) of these patients experienced an increase in OI of between 10 and 45 at 1 h post NB-BAL, which returned to baseline at 6 h post NB-BAL. Complications did not correlate with any of the available variables: baseline OI, PRISM score or with deterioration at the time of the procedure, although it was observed that four out of the six patients with baseline OIs of greater than 20 experienced complications.
Conclusion: Non-bronchoscopic bronchoalveolar lavage in critically ill mechanically ventilated neonates and children is generally a well-tolerated procedure, but for some patients, in whom it was not possible to elucidate predictive factors, complications developed. All patients, particularly those with OIs of greater than 20, require careful monitoring during and after the procedure.

Key words Bronchoalveolar lavage · Non-bronchoscopic · Mechanical ventilation · Critical care

Introduction

Bronchoalveolar lavage has a prominent role in the evaluation of suspected lower respiratory tract infection in mechanically ventilated critically ill patients [1] and is also applied as a therapeutic procedure in the management of extensive multilobar atelectasis [2, 3]. Bronchoscopic bronchoalveolar lavage (B-BAL) has become a routine procedure for collection of a sample of bronchoalveolar lavage fluid (BALF) in both the adult and the paediatric population including children requiring mechanical ventilation due to severe lung disease [4]. However B-BAL is associated with deterioration of pulmonary mechanics and function [5, 6] as well as hypoten-

Table 1 Risk factors requiring correction pre non-bronchoscopic bronchoalveolar lavage *(NB-BAL)*

1. Arterial saturation < 95 % when manually ventilating with an FiO_2 of 1.0 (assuming no R-L cardiac shunt)
2. Cardiovascular instability despite inotropes or presence of arrhythmias
3. Severe electrolyte/metabolic disturbance
4. Platelet count < 40×10^9 per litre
5. Coagulopathy
6. Pulmonary hypertension (10μg/kg fentanyl bolus given pre NB-BAL)
7. Insufficient sedation

sion and pyrexia [7]. In addition, B-BAL is impossible in ventilated neonates and young infants, since the smallest paediatric bronchoscopes (2.2 mm) have no suction ports. At present the standard paediatric flexible bronchoscope has an external diameter of 3.6 mm so that its use is precluded in patients intubated with an endotracheal tube of less than 4.5 mm in diameter.

Alternatives include tracheal aspirate (TA) and non-bronchoscopic bronchoalveolar lavage (NB-BAL). Both are minimally invasive and relatively inexpensive techniques. NB-BAL involves administering larger aliquots of saline conducted through a catheter that is advanced further down the airway, hence obtaining fluid of more distal origin [8]. Several studies have shown that the diagnostic accuracy is similar to that of B-BAL [9, 10, 11, 12] and it has therefore been used as a simple and cheap alternative to B-BAL [8, 11, 13, 14]. Reports record that it is well-tolerated [10, 11, 15], though deterioration of cardiorespiratory parameters within a physiologically accepted range has been described in ventilated newborn infants during the procedure [16, 17]. Dargaville et al. [8] have also described transient arterial desaturation in neonates, but did not demonstrate a relationship with severity of lung disease.

Non-bronchoscopic bronchoalveolar lavage is increasingly being used on the Paediatric Intensive Care Unit in our hospital and we therefore carried out a retrospective survey to investigate the safety of this procedure on the patients in our unit. We specifically reviewed the procedure to find out whether NB-BAL causes significant cardiorespiratory compromise and, if so, whether such deterioration can be predicted.

Methods

Patients

The notes and archived computerised databases (Carevue, Hewlett Packard) of 60 consecutive critically ill mechanically ventilated neonates and children who had undergone NB-BAL on the Paediatric Intensive Care Unit were reviewed over a period of 25 months, from November 1997 to December 1999. These patients had risk factors corrected before NB-BAL according to unit guidelines, as described in Table 1.

Technique

Non-bronchoscopic bronchoalveolar lavage is performed by the two senior respiratory physiotherapists on our unit using a standard protocol that delivers aspirate via a closed circuit to a sterile container. Additional sedation or relaxation may be required if the patient is coughing or interbreathing, and fractional inspired oxygen (FiO_2) is increased to 1.0 on the ventilator (no other ventilator changes are made). During the procedure ventilation is provided by a T-Ayres bagging circuit delivering an FiO_2 of 1.0. The patient is supine with the head turned to the left or right for access to right or left main bronchus, respectively. The technique involves wedging a size 6F or 8F end hole suction catheter in children under 3 years old and a longer, funnel-tipped catheter in older children through the angled connector (swivel elbow, Intersurgical) of the endotracheal tube using a sealed access port adapter (suction port, SLE). 1 ml/kg (to a maximum of 10ml per instillation) of sterile physiological saline at room temperature is injected through the catheter, the syringe is detached and replaced by a sputum trap. The lungs are inflated and the chest wall is then vibrated during expiration as mechanical suction is applied, collecting the return fluid into the sputum trap, and the catheter is removed. This procedure is repeated 3 times unless the patient becomes clinically unstable. The three sputum traps with aspirate are immediately sent to the microbiology department for analysis.

Measurements

Paediatric risk of mortality (PRISM) score and the presence of inotropic support, sedation and muscle relaxation were retrieved from both patient notes and the database. The occurrence of any complications such as arterial oxygen desaturations, arrhythmias, pneumothoraces, wheeze, pulmonary haemorrhage or death was noted. Arterial blood gases, ventilator settings, haemodynamic variables (heart rate, systolic and diastolic blood pressure) and temperature taken at 1 h before (baseline), and 1 and 6 h after NB-BAL were retrieved from the archived computerised database. The arterial oxygenation status of the patient, represented by oxygenation index (OI), where OI = (mean airway pressure × $FiO_2 \times 100)/PaO_2$ (mmHg), was calculated for these times. These variables were calculated for sub-groups of patients with different respiratory diseases, and for those who had received surfactant (Survanta/Beractant, Abbott Labs).

Analysis of results

Differences in haemodynamic variables, temperature and $PaCO_2$ were compared using the Student's paired *t*-test for dependent variables. This data is presented as mean and 95 % confidence interval (CI). Where the distribution was skewed, as with PRISM scores and OI, the data are presented as median and interquartile ranges (IQR). The Wilcoxon matched-pairs test was applied for differences in OI. Least-squares linear regression was used to predict changes in OI from pre NB-BAL values and PRISM scores. The significance level for all statistical hypothesis tests was set at 5 %.

Table 2 Patient characteristics, $n = 60$ (*HFOV* high frequency oscillatory ventilation, *PRISM* paediatric risk of mortality, *ICU* intensive care unit, *ARDS* acute respiratory distress syndrome, *CMV* cytomegalovirus infection, *PCP Pneumocystis carinii* pneumonia)

Age (months), median(IQR)		7.6 (2.8–43.0)
Male/female		36/24
Weight (kg), median (IQR)		5.5 (4–14)
HFOV/conventional ventilation		14/46
PRISM score, median (IQR)		11 (7–17)
Reason for admission to ICU		
ARDS		19
Atypical pneumonias	*Pneumocystis carinii*	10* (2 also had CMV)
	Cytomegalovirus (CMV)	3 (+2 with PCP)
	Others	11*
Bronchiolitis		13***
Meconium aspiration syndrome		2*
Asthma + pneumococcal pneumonia		1
Pulmonary haemosiderosis		1

* represents each patient who received surfactant immediately after NB-BAL

Results

Sixty patients underwent NB-BAL during the study period. The median age was 7.6 months (IQR 2.8–43 months) and median weight was 5.5 kg (IQR 4–14 kg). Patient characteristics are shown in Table 2. Patients with bronchiolitis underwent NB-BAL as part of a separate study (and for this reason some of them received surfactant). All other patients underwent NB-BAL for diagnostic or therapeutic reasons.

At the time of the procedure 51 patients were already on infusions of morphine and/or midazolam, 23 were on vecuronium infusions and 12 were receiving inotropic support. These infusions were continued throughout the study period. Median aspirate returned was 40 % of the volume instilled (IQR 31–53) of which 13 aspirates were recorded as being blood-stained.

Immediate complications

Fifteen immediate complications were described, most of which were transient and easily treatable, but four (7 %) were significant and necessitated escalation of respiratory or haemodynamic support. Two of these patients experienced prolonged arterial oxygen desaturation that did not respond readily to manual ventilation, their saturations only returning to the low 90s after more aggressive manual ventilation. Both had acute respiratory distress syndrome (ARDS). As a result only one and two saline instillations were carried out respectively, and conventional ventilation was replaced by high frequency oscillatory ventilation (HFOV) in each case. The remaining two patients required significant escalation of inotropic support (from 5 to 20 μg/kg/min of dopamine infusion). One patient had ARDS and the other had *Pneumocystis carinii* pneumonia (PCP), blood pressure returning to baseline levels by 12 h in the former, and only after 36 h in the latter. The median PRISM score for the four patients was 13.5, which was marginally higher than the median of 11 in the entire patient group. Only one of these patients proceeded to experience a late complication.

Two other patients required premature termination of the procedure. One post-operative (spinal fusion) patient who had developed ARDS had increasingly blood stained aspirate despite normal coagulation screen and platelet count, resulting in the last instillation being withheld. Endotracheal suction 8 h later yielded moderate creamy secretions. The other patient began to cough after the second instillation despite receiving morphine (30 μg/kg/hr) and midazolam (3 μg/kg/min) infusions. Four patients (10 %) experienced transient arterial oxygen desaturation to a minimum of 60 %, which was easily resolvable with manual ventilation and with no resulting prolonged compromise of gas exchange. Transient wheeze was recorded immediately after NB-BAL in one patient with respiratory syncytial virus (RSV) positive bronchiolitis and one patient with atypical pneumonia. Finally, there was one patient episode of transient bradycardia that corrected with manual ventilation.

Late complications (at 1 and 6 h post NB-BAL)

Haemodynamic variables and temperature remained stable at 1 and 6 h after the procedure for all 60 patients. Calculation of OI was not possible for 18 patients since arterial blood gases were unavailable at the times required for the study. The subsequent analysis is therefore with 42 datasets.

There was no significant difference in $PaCO_2$ before and after NB-BAL: mean $PaCO_2$ decreased from 6.1 kPa (95 % CI 5.6–6.6) to 5.9 kPa (95 % CI 5.3–6.5) 1 h and 5.7 kPa (95 % CI 5.4–6.2) 6 h post NB-BAL. Similarly, arterial oxygenation, as expressed by median

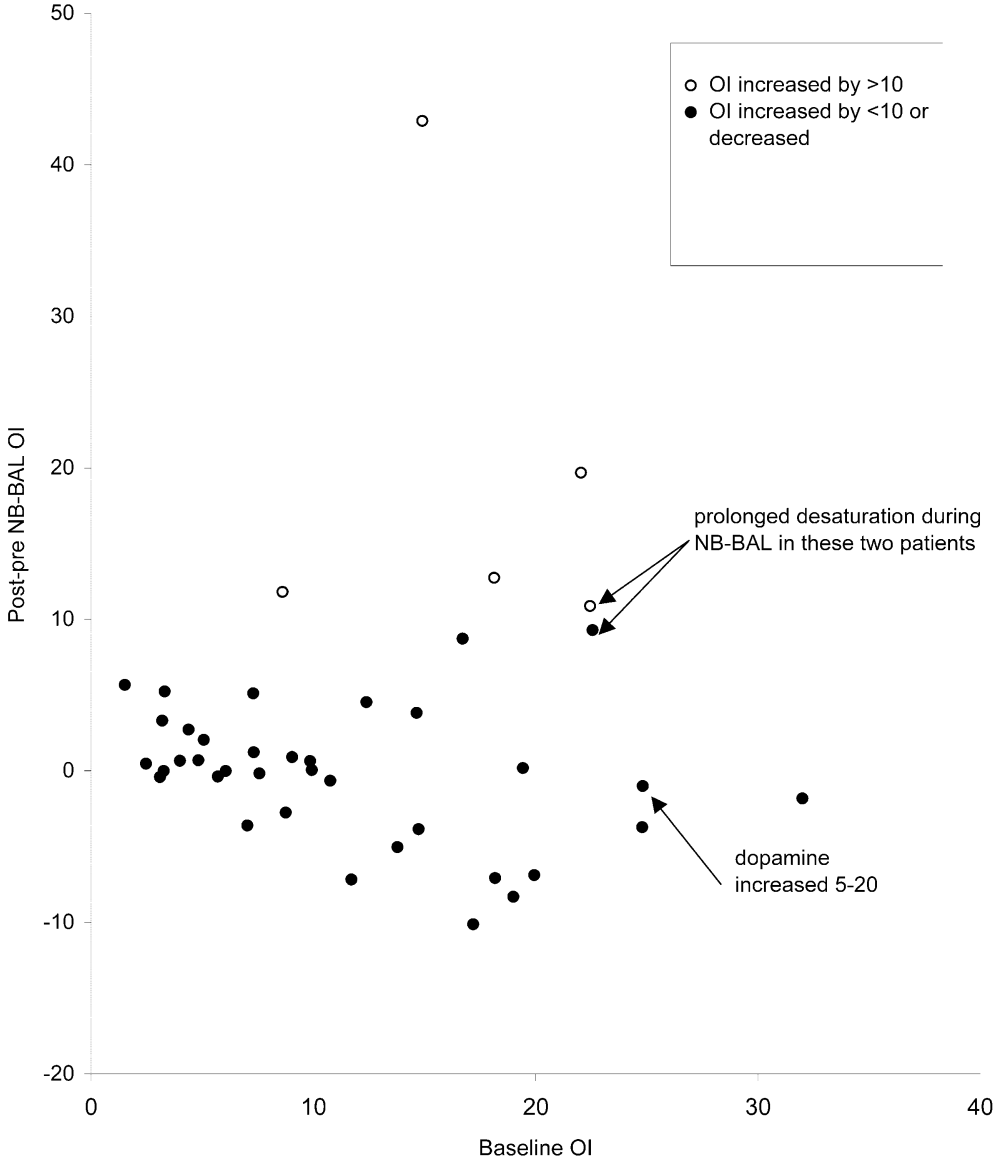

Fig. 1 Change in oxygenation index (OI) at 1 h post non-bronchoscopic bronchoalveolar lavage as a function of baseline OI ($n = 42$)

OI, showed no significant change at 1 and 6 h after NB-BAL. However, five patients (12 %) experienced a substantial increase in OI of between 10 and 45 at 1 h after NB-BAL. One of these patients had experienced an immediate significant complication (prolonged arterial oxygen desaturation), two had transient arterial oxygen desaturation, the remaining patients had been stable at the time of NB-BAL. The patient with the greatest increase in OI was on HFOV and had received surfactant concurrently. Anticipating that these five patients might have had poorer oxygenation to begin with, we compared the change in OI at 1 h after NB-BAL to the baseline OI (Fig. 1). There was no correlation ($r^2 = 0.0019$). Further analyses showed that there was no correlation with other clinical variables including PRISM score ($r^2 = 0.01$) sex, age, percentage aspirate or ventilation mode at the time of NB-BAL. The only observable association was that four out of the six patients who had baseline OIs of over 20 experienced significant immediate and/or late complications. At 6 h post NB-BAL, OI did not increase by more than 10 compared to baseline for any patient, including those who had experienced a substantial increase at 1 h (Fig. 2).

The two largest groups of patients with respiratory diseases were those with ARDS and atypical pneumonia, and these were analysed separately to see if these patients behaved differently in response to NB-BAL. There was no significant change in median OI in 24 patients with atypical pneumonia (2 of whom received surfactant) and 19 patients with ARDS. We also analysed

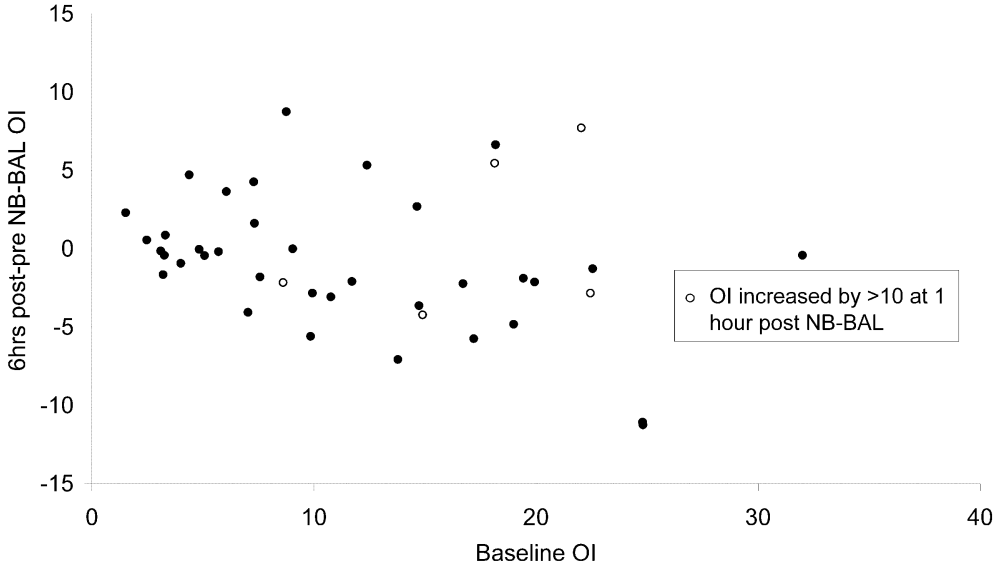

Fig. 2 Change in oxygenation index (OI) at 6 h post non-bronchoscopic bronchoalveolar lavage as a function of baseline OI ($n = 42$)

those patients who had received surfactant immediately after NB-BAL, anticipating an improvement in oxygenation variables. Median OI significantly decreased overall in six patients who received surfactant immediately after NB-BAL, from 15 (IQR 12–17) at baseline to 11 (IQR 10–14) at 6 h post NB-BAL ($p = 0.046$). However, there was a non-significant increase in median OI at 1 h after the procedure to 16 (IQR 9–26), which reflected the one patient who had experienced the greatest rise in OI.

No arrhythmias, clinically significant pulmonary haemorrhage or pneumothoraces occurred from the procedure and no patient deaths were directly attributable to NB-BAL.

Discussion

Our results indicate that a small proportion of patients have significant cardiorespiratory compromise both during and at 1 h after NB-BAL, though it is well-tolerated in the majority of critically ill mechanically ventilated infants and children. As far as we know this is not the published experience in infants and adults. Despite identifying and correcting risk factors in the patients, there was a higher than expected rate of significant immediate complications. Two patients required escalation of respiratory support and two patients experiencing significant hypotension required escalation of haemodynamic support. The latter observation is in contrast to that of Belai et al. [16], who reported a transient increase in systolic blood pressure in neonates. Our cohort represents a different case mix of patients from the population described in Belai's paper. The patients were heterogeneous with a median age of 7 months ranging from 9 days to 15.3 years old, although there was no association between age and adverse effects. It is possible that our cohort of patients was sicker at the time of the NB-BAL, but unfortunately neither PRISM score nor OI predicted these patients exhibiting significant immediate complications. Transient arterial oxygen desaturation that readily resolves also occurred and has been described in babies by Dargaville [8] and Grigg [17], and the ERS Task Force [3] corroborates this observation. One patient in our group had transient bradycardia (presumably due to a vasovagal response to catheter insertion), as has also been reported by Belai et al. [16].

Because of the retrospective nature of this study it was not possible to assess continuous changes in parameters during NB-BAL and transient episodes of deterioration in cardiorespiratory parameters may have been missed. Overall, arterial oxygenation, as expressed by median OI, showed no significant change after NB-BAL and the mean $PaCO_2$ dropped slightly. However, five patients experienced an increase in OI of more than 10 (one of 45) at 1 h after NB-BAL, although none had a sustained increase at 6 h post NB-BAL, indicating that this was an effect of the procedure rather than due to worsening of the underlying disease process. Unfortunately our data did not indicate any predictive factors for deteriorating OI at 1 h after NB-BAL. The only observable relationship to baseline conditions was that more than half of all patients with baseline OIs of greater than 20 experienced either significant immediate or late (at 1 h) complications.

An important limitation of this study is that the small number of patients may have masked any statistical difference, adverse outcome and predictive values. For the present it is advisable to be vigilant for all patients

within the 1st h after NB-BAL, anticipating possible deterioration in oxygenation regardless of OI and general stability during the procedure.

Patients who had concomitantly received surfactant experienced a significant improvement in median OI by 6 h after NB-BAL (despite a slight increase at 1 h). It is possible that the greater volume instilled may have led to the initial deterioration. The later improvement may be due to replacement of surfactant removed by NB-BAL or replacement of surfactant depleted by the underlying disease process. It is not at present routine practice on our unit to instil surfactant following NB-BAL, unless it has been shown to be of benefit to the underlying disease process (e.g. PCP and meconium aspiration syndrome). It may therefore be useful to perform a study to see if surfactant post NB-BAL may improve subsequent oxygenation and lead to less respiratory deterioration.

In conclusion, this review indicates that NB-BAL is generally well-tolerated by critically ill mechanically ventilated infants and children. However, a small proportion of patients developed complications, despite correction of risk factors, and more than half of these were observed to have had baseline OIs of greater than 20. At present it is not possible to predict patients who develop complications and therefore all patients, particularly those with baseline OIs of greater than 20, must be carefully monitored during and after NB-BAL.

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