Monitoring alveolar derecruitment at bedside using functional residual capacity measurements in cardiac surgery patients

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Abstract

Background: Monitoring of functional residual capacity (FRC) may help detecting alveolar derecruitment and guiding countermeasures like recruitment maneuvers. The aim of this study was to detect the possible decrease of FRC after a suctioning procedure - indicating alveolar derecruitment - and the effect of a successful alveolar recruitment maneuver on pulmonary function.
Methods: We studied 20 postoperative mechanically ventilated cardiac surgery patients. FRC was assessed by oxygen washout using a sidestream O_2-analyser (LUFU system (Dräger Medical AG, Luebeck, Germany)). FRC, respiratory compliance, paO_2/FiO_2 (PF-ratio) and $paCO_2$ were recorded at baseline, after a standard suctioning procedure with disconnection of the ventilator (20 sec, 14 F catheter, 200 mmHg negative pressure) (post ETS), and after a standard recruitment manoeuvre (PEEP 15 mbar, PIP 35–40 mbar for 30 sec) (post RM).
Results: Mean FRC decreased post ETS (3.2 L ± 1.2) compared to baseline (3.4 L ± 1.1, p = 0.046) and increased post RM compared to post ETS (3.5 L ± 1.0, p=0.039). Mean respiratory compliance showed no significant changes. $paCO_2$ decreased and PF-ratio increased post RM compared to post ETS (p = 0.005, p = 0.026, respectively). Relative FRC changes post ETS correlated to changes of PF-ratio post RM (Pearson: -0.896, p<0.001).
Conclusion: In post cardiac surgery patients changes of FRC after alveolar de- and recruitment can be detected at bedside using the oxygen washout technique. There was a strong association of a FRC-decrease after open ETS with an improvement of oxygenation from a consecutive RM. A FRC decrease may help to identify those patients who profited from a RM in terms of increased oxygenation, even in absence of blood gas data.

Implications

In post cardiac surgery patients changes of FRC after alveolar de- and recruitment can be detected at bedside using the oxygen washout technique. Further studies are needed if a FRC decrease may help to identify those patients who profited from a RM in terms of increased oxygenation, even in the absence of blood gas data.

Introduction

Pulmonary dysfunction after cardiac surgery is quite common and contributes significantly to morbidity and mortality of the patients (1,2). One important clinical finding is atelectasis (3). Postoperative alveolar recruitment manoeuvres (RM) and ventilation with sufficiently high positive end-expiratory pressure (PEEP) as part of an open lung concept has been advocated to reduce atelectasis formation and improve oxygenation and pulmonary function (4,5). Disconnection of the ventilator and / or endotracheal suctioning may lead to alveolar derecruitment and could counteract this open lung approach. As there is a high inter-individual variability in the tendency for alveolar derecruitment (6), in some patients reconnection to the ventilator with unchanged ventilatory settings may be enough to restore lung volume, but others might need a RM. In clinical routine this is difficult to judge.

Many methods currently available for assessment of alveolar de- or recruitment are only used in research situations (7,8) or are not suitable at bedside in clinical routine (9). Changes of oxygenation or CO_2-removal are probably the most widely used criteria to monitor the effect of RM, but have the disadvantage of being labor intensive, as repeated blood gas analyses are necessary. In addition, oxygenation may change not only by alveolar de- or recruitment, but also by pulmonary hemodynamic changes (10). CO_2-removal is influenced by CO_2 production, which can be extremely variable in critically ill patients. Measures of lung mechanics have also been used for guiding therapy and respiratory compliance has been shown to correlate with changes in lung aeration in an experimental study in pigs (11), but is difficult to assess in patients, especially during spontaneous breathing.

Recently, direct measurements of lung volume have gained more interest, because functional residual capacity (FRC) is independently affected by alveolar de- or recruitment (12). Routine FRC measurement using the oxygen washout technique is now applicable at bed-side and has been introduced into clinical practice (13,14). A decrease in FRC after disconnection and / or endotracheal suctioning indicates alveolar derecruitment and may identify patients who need a RM to restore lung volume.

The aim of this study was to detect the possible decrease of FRC after a suctioning procedure - indicating alveolar derecruitment - and the effect of a successful alveolar recruitment manoeuvre on pulmonary function.

Methods

After approval by the local ethics committee and written informed consent we studied 20 postoperative cardiac surgery patients during 6 hours after surgery. Patients were excluded if they needed major inotropic support because of haemodynamic instability, i.e. adrenaline > 0.05 µg kg^{-1} min^{-1}, dobutamine > 5 µg kg^{-1} min^{-1}, or milrinone > 0.3 µg kg^{-1} min^{-1}. In addition, patients ventilated withfraction of inspired oxygen (FiO_2) > 0.4 were excluded.

All patients underwent standard open heart surgery with non-pulsatile cardiopulmonary bypass (CPB) in moderate hypothermia (nasopharyngeal temperature: 32°C). Patients were equipped with standard monitoring (three-lead electrocardiogram, a transcutaneous oxygen sensor, a radial arterial and a central venous line).

After surgery all patients were transmitted to the intensive care unit for postoperative therapy. All patients were mechanically ventilated with biphasic positive airway pressure. Airway pressures were adjusted to deliver a tidal volume of 6 - 8 ml kg^{-1} predicted body weight, PEEP was set to 10 mbar and respiratory rate was adjusted to achieve normocapnia. Patients were sedated with continuous infusion of propofol and intermittent boli of piritramid or pethidin. No further muscle relaxing agents were administered. Fluids, catecholamines and blood products were administered according to the routine practice in the department.

FRC measurement

The LUFU system (Dräger Medical, Luebeck, Germany) estimates FRC by oxygen washout, a variant of multiple breath nitrogen washout. The exact technical and mathematical description has been published before (14). Briefly, a sidestream O_2-analyser calculates FRC from the end-inspired and end-expired concentrations of O_2 during a step change of the inspired O_2-concentration.

The O_2-wash-in was started by increasing the fraction of inspiratory oxygen (FiO_2) by 0.2. FRC measurement was terminated automatically when the accumulated net ventilated volume was greater than eight times the calculated FRC (approximately 5 – 7 minutes). After that the next measurement -a washout- was started by decreasing the FiO_2 again by 0.2. The mean of one wash-in and one washout was calculated.

Study protocol

Before start of the study protocol a standardized recruitment manoeuvre was applied to the patients` lung (PEEP 15 mbar, PIP 35 - 40 mbar for 30 sec) (15,16) and the patients allowed stabilizing haemodynamically for 10 minutes.

After that FRC was measured and after termination of one wash-in and washout an open endotracheal suctioning (ETS) manoeuvre was conducted. The patients were disconnected from the ventilator and a 14F suctioning catheter was inserted into the endotracheal tube, advanced until resistance was met and withdrawn 2-3 cm. A negative pressure of 200 cm H_2O was applied for 20 seconds, during which the catheter was gently rotated and withdrawn. The patients were then reconnected to the ventilator. After ETS each patient was allowed to stabilize for a period of 2 minutes before FRC was measured again. 20 minutes after ETS the patients´ lungs were recruited using the same RM as before. Again FRC was measured after a 2 minute stabilization period.

Static compliance of the respiratory system (C_{RS}) (expiratory tidal volume divided by the pressure difference between end-inspiratory plateau pressure and end-expiratory pressure; mean of 10 breaths), arterial blood gases (arterial partial oxygen pressure (paO_2) and arterial partial carbon dioxide pressure ($paCO_2$)), and global haemodynamics (heart rate (HR), mean arterial pressure (MAP), and central venous pressure (CVP)) were obtained right before the ETS (baseline), 20 minutes after ETS (post ETS), and again at the end of the study protocol 20 minutes after RM.

Statistics

Statistics were calculated using SPSS 15.0 (SPSS Inc., Chicago, Illinois, USA). We used the Kolmogorov-Smirnow test to check for normality. All data were normally distributed. The paired sample t-test was used to calculate differences between consecutive time-points. Correlations were assessed by calculating Pearson's coefficient. All data are presented as mean ± SD, unless stated otherwise.

Due to the small sample size and multiple comparisons the data analysis is descriptive (17). According to this, the term "significant" (used for $p < 0.05$) is given as a description of differences over time.

Results

Twenty postoperative cardiac surgery patients were studied. Patients` characteristics are summarized in table 1.

Mean FRC decreased post ETS ($p = 0.046$) and increased post RM ($p = 0.039$). Mean C_{RS} showed no significant differences between time-points. Mean $paCO_2$ decreased and the mean PF-ratio increased post RM ($p = 0.005$, $p = 0.026$, respectively) (all table 2).

Table 1: Demographic and perioperative data
Data are presented as n (gender, type of surgery) or mean ± standard deviation.

Gender (female / male)	4 / 16
Age (years)	70 ± 7
Hight (cm)	172 ± 7
Weight (kg)	84 ± 10
Leftventricular ejection fraction (%)	60 ± 14
EuroScore	4.6 ± 2.7
Coronary artery disease (n)	17
Valve disease (n)	16
COPD (n)	6
Surgical procedure	
Coronary artery bypass grafting (n)	10
Valve surgery (n)	2
Combination (n)	8

Table 2. FRC, static respiratory compliance, and blood-gas changes after de- and recruitment

	basal	post ETS	post RM
FRC (L)	3.4 ± 1.1	3.2 ± 1.2 *	3.5 ± 1.0 #
Compliance (mL $mbar^{-1}$)	48 ± 11	46 ± 14	47 ± 11
$paCO_2$ (mmHg)	39.5 ± 6.1	40.4 ± 6.1	38.9 ± 5.2 #
PF-ratio (mmHg)	370 ± 101	348 ± 110	407 ± 109 #

Baseline, before endotracheal suctioning (ETS); post ETS, after endotracheal suctioning; post RM, after recruitment maneuver; $paCO_2$, arterial partial pressure of CO_2; PF-ratio, ratio of arterial partial pressure of oxygen and inspiratory oxygen fraction.
Data are presented as mean ± standard deviation. *, $p<0.05$ compared to baseline; #, $p < 0.05$ compared to post ETS.

Correlation analysis showed significant associations of relative FRC changes, relative PR-ratio changes, and relative C_{RS} changes post ETS compared to baseline with absolute changes of PF-ratio post RM. No significant correlation could be detected between relative changes of pCO_2 post ETS with changes of PF-ratio post RM (see fig. 1).

Global haemodynamics remained stable over time (HR: 89 ± 10 (basal), 89 ± 10 (post ETS), 89 ± 10 (post RM), p = n.s.; MAP: 79 ± 11 (basal), 76 ± 10 (post ETS), 78 ± 09 (post RM), p = n.s.; CVP: 15 ± 4 (basal), 15 ± 5 (post ETS), 15 ± 4 (post RM), p = n.s.).

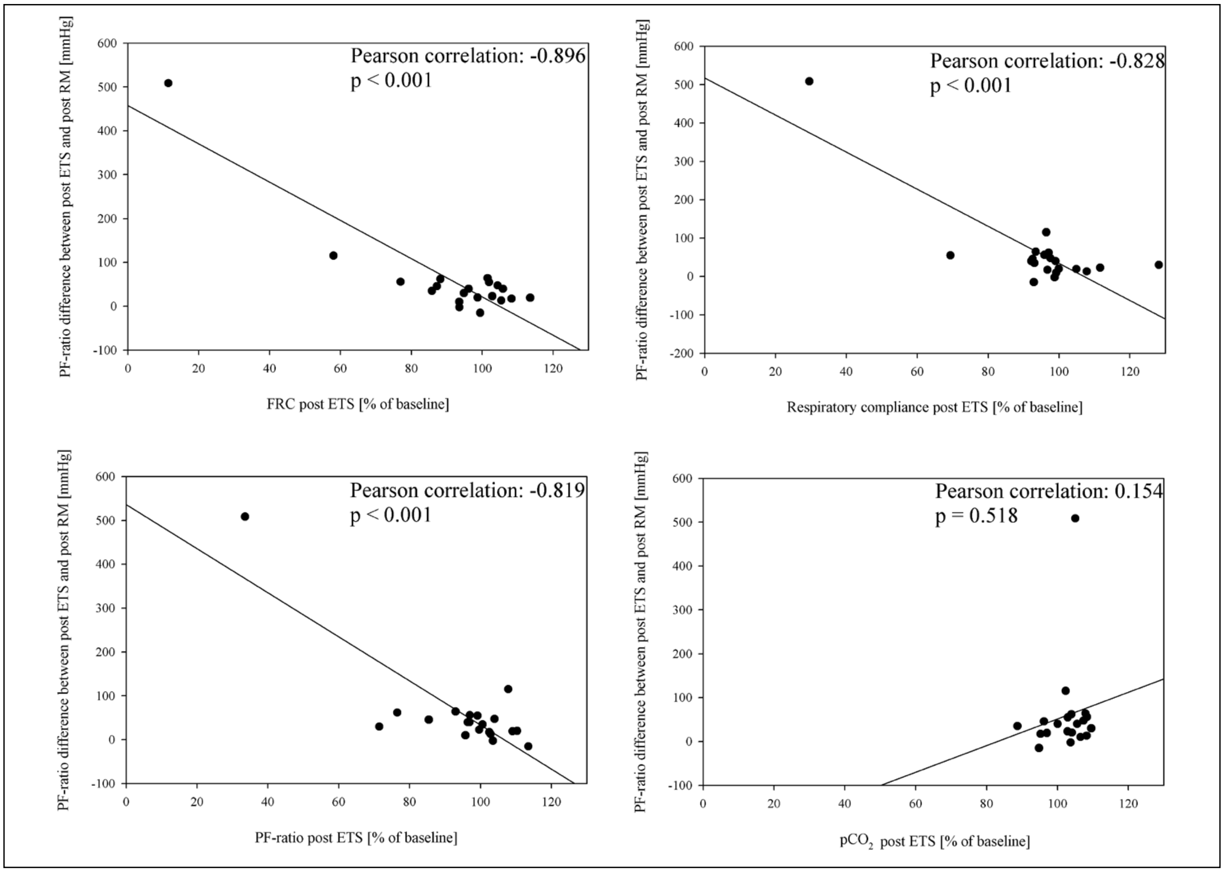

Figure 1. Correlation between relative changes of FRC, respiratory compliance, PF-ratio, and pCO_2 after ETS and changes of PF-ratio post RM
FRC, functional residual capacity; post ETS, after endotracheal suctioning; post RM, after recruitment maneuver; PF-ratio, ratio of arterial partial pressure of oxygen and inspiratory oxygen fraction.

Discussion

This pilot study shows that changes of FRC after alveolar de-recruitment and recruitment can be measured at bedside using the oxygen washout technique and that there is a strong association of a FRC-decrease after open ETS with improvement of oxygenation from a consecutive RM.

Methodological considerations

We measured FRC using the oxygen washout technique. It was first described by Fretschner and coworkers (18) and has recently been introduced into clinical practice (13). We used an advancement of this method with a side stream oxygen sensor, which further improved the clinical feasibility. In a bench study, this device measured FRC reliably under laboratory conditions with a lung simulator (19) and showed clinically acceptable accuracy compared to standard methods for FRC evaluation in healthy spontaneous breathing volunteers (14). In addition, we showed clinical acceptable repeatability in ventilated patients (20).

In line with published data on lung volume changes (21,22) we could show reduced FRC after an open ETS maneuver. Although we did not directly measure atelectasis with CT scans, the most likely explanation for the reduced FRC after ETS is alveolar derecruitment. FRC improved again in our patient group after a RM. Parallel with this we observed an increase of oxygenation, and a decrease of $paCO_2$, in line with alveolar recruitment with reduced shunt and improved alveolar ventilation.

Different RM to recruit collapsed lung tissue have been studied. We used a RM-strategy similar to that proposed by Tusman et al. (16) and Claxton et al. (15), which has shown to improve oxygenation in different patient groups.

Clinical considerations

More important than the mean FRC changes of the whole patient group may be the fact that for some patients restitution of ventilation with the set PEEP of 10 mbar was enough to restore baseline FRC values. These patients did not show any improvement of oxygenation after RM, in contrast to those with a reduced FRC after ETS. Therefore FRC measurement may be helpful in deciding which patient may need a RM, even in the absence of blood gas data. The possible negative side effects of such a manoeuvre (23,24) could be avoided in others. Further studies should address this issue.

Limitations of the study

An important limitation of our study is the fact, that we did not compare the FRC data with the best available technique to detect alveolar recruitment, i.e. computed lung tomography. Since CT scanning cannot be performed repeatedly under clinical conditions, we decided to use improvement of oxygenation to define a positive RM. Although there are some disadvantages by using changes of arterial oxygenation, as stated above, it is the most widely used parameter to guide alveolar recruitment in clinical practice. Our data support the work of Rylander et al. who demonstrated FRC being a good marker of aeration and consolidation in an experimental model of lung injury. They concluded that FRC may be a useful adjunct to oxygenation monitoring (12).

As an alternative technique to CT scanning electric impedance tomography (EIT) could be used to detect changes of lung volume breath by breath (8). Further studies should address this issue.

A drawback of any oxygen or nitrogen wash-in / wash-out is the requirement for stable circulatory conditions. Any manoeuvre influencing cardiac output, and therefore the oxygen content of the venous blood, may influence the result. Measurement should therefore not be performed immediately after any manoeuvre that could alter the haemodynamic status. As we did not measure continuous beat-by-beat CO, we cannot rule out that our results are influenced by this mechanism. After the RM the patients were allowed to stabilize for 10 minutes, and after ETS we waited 2 minutes before the oxygen wash-out was started. In this way, we hoped to minimize the influence of altered haemodynamics on FRC measurement.

We did not rule out the possible influence of active inspiratory muscles contraction, as we did not paralyze the patients. But muscle relaxation has been accused for promoting postoperative pulmonary complications by reducing FRC and increasing the risk for silent aspiration after extubation and routine administration is therefore not recommended (25). In addition, different levels of sedation may have influenced the results. We administered continuous sedation with propofol with intermittent boli of piritramid and pethidin, allowing some patients to cough during suctioning mimicking clinical routine practice.

This study was performed in cardiac surgery patients with nearly normal lung functions. We cannot say if the results would have been the same in patients with ALI / ARDS. More studies are needed.

FRC monitoring in clinical routine practice may indicate alveolar derecruitment and help decide whether to conduct a RM or not. But if the “optimal” FRC is not known, this measure alone may be misleading as it cannot differentiate between hyperinflation and recruitment. For example higher PEEP-levels will increase FRC values, but this may only be due to hyperinflation. In our pilot study we had the assumption that baseline values of FRC were near “optimal” and should be restored after derecruitment. But some patients showed higher FRC and oxygenation values post RM compared to baseline indicating more recruited lung volume, but we cannot rule out hyperinflated lung tissue. Therefore FRC values alone cannot be recommended for optimization of PEEP.

In conclusion we have shown that in post cardiac surgery patients FRC is reduced after alveolar derecruitment, i.e. ETS, and is increased after a RM. Both changes can be measured at bedside with the oxygen washout technique. There was a strong association of a FRC-decrease after open ETS with an improvement of oxygenation from a consecutive RM, i.e. a FRC decrease identified those patients who profited from a RM in terms of increased oxygenation. Further investigations should study if a FRC guided recruitment strategy could have an impact on patient’s condition.

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