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The influence of endotracheal tube leak on the assessment of respiratory function in ventilated children

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Abstract *Objective*: The use of respiratory mechanics to optimise ventilator settings has become more common since the integration of pressure and flow transducers into modern ventilators. However, values of respiratory resistance (R_{rs}) and compliance (C_{rs}) can be overestimated in the presence of tracheal tube leak and clinical decisions based on these figures would be misinformed. This study aimed to assess the influence of tracheal tube leak on measurements of C_{rs}, R_{rs} and expired tidal volume (V_{TE}) in ventilated children in order to establish when such measurements were reliable in this population.
Design: Respiratory function was monitored for at least five consecutive hours during which normal medical procedures were performed. The magnitude and variability of tracheal tube leak was assessed during these periods.
Setting: The paediatric and cardiac intensive care units at Great Ormond Street Hospital for Children, NHS Trust, London.
Patients: Seventy-five paralysed, fully ventilated infants and children.
Results: Ten children had a mean leak greater than 20 % (range: 22 %–65 %). Amongst this group there were wide fluctuations with respect to leak magnitude, V_{TE}, C_{rs} and R_{rs}. Leaks of less than 20 % appeared necessary to obtain reliable measurements of C_{rs} and R_{rs} and to ensure consistent and adequate ventilation.
Conclusions: Leaks larger than 20 % result in inconsistent tidal volume delivery and gross overestimation of C_{rs} and R_{rs} irrespective of ventilation mode. The magnitude of tracheal tube leak needs to be accurately displayed on all ventilatory equipment to verify reliable measures of respiratory function so that appropriate clinical decisions can be made and ventilatory management optimised.

Keywords Ventilators, mechanical · Respiration, artificial · Intubation, intratracheal · Respiratory function tests · Respiratory mechanics · Child

Introduction

In the last decade, several authors have noted the potential for respiratory measurements in ventilated patients to assist in optimising ventilation, by reducing iatrogenic lung damage from lung overdistension and hastening the clinician's response time to clinical changes. In addition, sheer stress on the lungs can be avoided by ventilating with appropriate tidal volumes and optimal levels of PEEP [1, 2, 3, 4, 5, 6]. The use of respiratory mechanics to guide clinical ventilatory management has become more common since the integration of pressure transducers into modern ventilator equipment and respiratory monitors. Many ventilators now display respiratory parameters such as resistance and compliance and intensivists therefore have on-line information about the respiratory function of their patients. If there is any intention to act on these readily displayed figures, it is essential to examine their accuracy and the conditions under which they might become unreliable. Data about the accuracy of measurement devices and the validity of calculated parameters are seldom given in specification manuals, and information about restricted applicability or conditions under which the measurement and calculation of the parameters may become erroneous are limited. One confounder, which has been identified in laboratory and animal studies and which is especially pertinent to paediatric ventilation, is the tracheal tube leak. Uncuffed tracheal tubes are commonly used to ventilate infants and children because of concerns about subglottic damage. However, there is relatively little information with regard to the effects of leak in the clinical environment or how much leak may be tolerable in ventilated children.

Tracheal tube leak can confound a number of parameters of interest, including metabolic gas exchange and functional residual capacity [7, 8]. Krauel et al. showed that patients with a tracheal tube leak needed higher FIO_2, MAP and respiratory frequency than those without such a leak [9]. Tracheal tube leak has been found to reduce the mean tracheal pressure with respect to the mean airway pressure by 15–21 % in rabbits [10]. The predictive value of MAP in guiding clinical decisions is thus reduced in the presence of leak. Furthermore, any increase in the magnitude of tracheal tube leak may result in a disproportionate decrease in oxygenation, by decreasing mean tracheal pressure, and a reduction in the efficiency of tidal ventilation and lung recruitment via PEEP. In the presence of lung disease and reduced compliance, gas shunting through the leak pathway is likely to increase, which may further compromise ventilatory support. In diseased lungs even small airway leaks lead to large reductions in lung recruitment at higher PEEP values, and errors in measuring resistance and compliance have been found to be relatively larger than in healthy lungs for all magnitudes of leak [11].

Several lung model or animal model studies have established that compliance and resistance measurements are overestimated and unreliable in the presence of leak [11, 12, 13]. While these are valuable in vitro results, caution should be exercised when extrapolating these findings to the clinical setting. Kuo et al. noted that while errors were proportionate to the size of the leak, they also depended on the method used to calculate respiratory mechanics [13]. The most commonly used techniques include Mead and Whittenberger's method, multiple linear regression analysis or the least squares method [14].

The aim of this study was to assess in vivo the influence of tracheal tube leak on expired tidal volume (V_{TE}), respiratory compliance (C_{rs}) and respiratory resistance (R_{rs}) in ventilated children and infants. In addition, the magnitude and within-subject variability of tracheal tube leak was assessed in order to establish when such measurements could be performed reliably in this population.

Materials and methods

The "CO_2SMO Plus" respiratory monitor (Novametrix Medical Systems, Wallingford, Conn.) was used to measure respiratory function continuously in 75 babies and children between May 1998 and August 1999. Inclusion criteria were that patients were muscle relaxed, fully ventilated and were unlikely to have changes in ventilatory parameters for the duration of measurement. A range of ventilators including the Bear Cub BP2001, Servo 300 and 900 and SLE 2000 were employed, with pressure pre-set modalities preferentially used in young babies and both volume and pressure pre-set modalities in older children. No patients were excluded from analysis and data from the entire measurement period were analysed for all patients.

The "CO_2SMO Plus" measures pressure, flow and capnography continuously via a disposable, fixed orifice differential pressure flow sensor connected between the tracheal tube and the ventilator circuit. The flow sensor was attached and taped firmly to the mouth of the tracheal tube, thereby avoiding the possibility of leak at this junction. A neonatal sensor (combined apparatus deadspace 0.8 ml) was used in children less than 2 years of age, whereas either a paediatric or adult sensor (deadspaces < 4 ml and 8 ml, respectively) was used in older children. Pressure and flow were measured instantaneously across the flow sensor with no time-lag. Data were electronically recorded by a 20-bit resolution, 100 Hz flow data sampling microprocessor and transferred to a portable PC running Analysis Plus software version 3.0 (Novametrix Medical Systems, Wallingford, Conn.). Repeated calibrations of the sensors over appropriate volume ranges (2–300 ml for neonatal sensors and 40–500 ml for the paediatric or adult sensors) demonstrated that, on average, the sensors were capable of measuring applied volume changes within 0.9 % (SD: 2.3 %) accuracy. Furthermore, these tests showed that, on average, inspired volumes differed by less than 2 % (SD: 2.3 %) against expired volumes when assessed in vitro (Table 1). This accuracy was maintained when calibration was repeated after connecting appropriately sized tracheal tubes (Table 1).

Similarly, pressure recordings by the "CO_2SMO Plus" monitor over a range of 2–60 cmH_2O were within ± 2 % of those displayed

Table 1 Volume accuracy of the flow sensors

	Mean % error (SD)[a]		% Difference V_{TI}–V_{TE} [mean (SD)][b]
	V_{TI}	V_{TE}	
Neonatal sensor (no tracheal tube)	0.5 (2.3)	0.5 (3.2)	0.01 (2.0)
Neonatal sensor with tracheal tube (sizes 3–6.5)	2.2 (1.6)	0.8 (2.9)	1.3 (1.9)
Paediatric sensor (no tracheal tube)	1.2 (1.2)	–3.2 (1.9)	4.4 (1.4)
Paediatric sensor with tracheal tube (sizes 3–6.5)	0.9 (2.1)	1.1 (4.0)	–0.3 (4.4)
Adult sensor (no tracheal tube)	3.3 (2.8)	–0.6 (1.9)	3.7 (2.1)
Adult sensor with tracheal tube (sizes 3.5–6.5)	3.2 (1.9)	0.5 (2.3)	2.5 (2.1)

[a] Mean percentage error calculated as [100×(measured–applied)/applied]
[b] Mean difference between inspired and expired volume calculated as: $[100 \times (V_{TI} - V_{TE})/V_{TI}]$

by an electronic manometer (Digitron – pressure manometer P200UL). Prior to use, the accuracy of individual sensors was checked by using a calibrated syringe (Hans Rudolf – calibrated volume syringe) to deliver a 10 ml (neonatal), 100 ml (paediatric) or 300 ml (adult) sensor signal. The least squares algorithms employed by the "CO_2SMO Plus" to calculate C_{rs} and R_{rs} were checked against linear regression of raw data points and found to be accurate to within 5%. In addition, C_{rs} measurements were checked against known values of C_{rs} on a Manley neonatal lung simulator and measurement errors were found to be less than 5% for the full clinical range of respiratory rates and peak inspiratory pressures (PIPs).

Written informed consent was obtained from the parents of all children included in the study. Subjects were monitored continuously for at least five consecutive hours, during which time nursing and medical procedures such as physiotherapy, postural changes and tracheal suction were performed as usual. These long periods of continuous measurement provided the opportunity to investigate the occurrence, magnitude and variability of tracheal tube leaks during a normal period of intensive care, as well as their consequences for the ventilated child. Only paralysed children were studied because those making spontaneous ventilatory efforts would have required additional oesophageal manometry to differentiate between chest wall and lung mechanics, which was not available from the "CO_2SMO Plus" [14]. All patients were paralysed, sedated and given pain relief by continuous infusion of vecuronium (2–4 μg/kg per min), midazolam (1–6 μg/kg per min) and morphine (10–40 μg/kg per h), in accordance with unit protocols.

V_{TE} volume was integrated from expiratory flow, while C_{rs} and R_{rs} were automatically computed by the "CO_2SMO Plus" throughout the breath cycle using the least squares regression method [14]. Inspiratory and expiratory R_{rs} were calculated using data from the inspiratory and expiratory portion of the respiratory cycle, respectively, whereas data throughout the whole breath was used to calculate C_{rs}.

Inspired (V_{TI}) and expired tidal volumes (V_{TE}), C_{rs}, and R_{rs} were continuously recorded and breath-by-breath values were averaged for each minute of recording. Tracheal tube leak was neither automatically calculated nor displayed by the "CO_2SMO Plus" or Analysis Plus software. For the purposes of this study, it was computed from on-line recordings as the difference between each minute's averaged values of inspired V_{TI} and V_{TE} using the equation:

$$\%\ \text{leak} = \frac{(V_{TI} - V_{TE})}{V_{TI}} \times 100$$

Changes in V_{TE}, R_{rs} and C_{rs} were related to simultaneous changes in leak during the monitoring period.

Results

Of the 75 paralysed, ventilated children studied, 61 had pressure-controlled ventilation: median age 0.25 years (0.02–12.8 years) and weight 4.3 kg (2–87 kg) and 14 had volume-controlled ventilation: median age 4 years (0.02–10.5 years) and weight 15.8 kg (3–30 kg). Four children in each group had a cuffed tracheal tube: median age 8 years (4–16 years) weight 22 kg (13.9–87 kg), all of whom had tube leaks of less than 5%. Tracheal tube sizes ranged between 3.0 and 7.5 mm. Over half of the infants (43/75) were studied following corrective cardiac surgery for congenital defects: median age 8 weeks (3 days–16 years). The remaining children were studied in the paediatric intensive care unit following admission for a variety of reasons including head injury, gastric transposition surgery, respiratory or multi-organ failure: median age 22 months (1 week–16 years).

Ten children (13%) had a mean tracheal tube leak greater than 20% (21.9–65.1%), median age 0.12 years (0.02–1.3 years) and weight 2.95 kg (2.6–9.8 kg). In this group, there were particularly wide within- and between-subject fluctuations with respect to the magnitude of leak, V_{TE}, C_{rs} and R_{rs} during the monitoring period.

Figure 1 summarises data recorded over several hours in two infants in whom ventilatory settings remained constant during the monitoring period. The relationship between both V_{TI} and V_{TE} and changes in percentage of leak are displayed. In the first example, from a 16-month-old male infant on Servo 300 pressure pre-set ventilation (Fig. 1a), the leak varied between 10% and 70% over a 6-h period and was accompanied by a 30% increase in V_{TI} and a 60% reduction in V_{TE}. By contrast, but as expected, during volume-controlled ventilation (also via a Servo 300 ventilator), (Fig. 1b) inspired volume remained relatively constant in a 5-day-old (2.88 kg) infant over 7 h of monitoring. This was, however, accompanied by a marked reduction in expired volume as the leak increased, with V_{TE} halving when the leak was maximal. In this infant there was a strong negative correlation ($r^2 = 0.93$) between V_{TE} and the leak. There was also a strong positive correlation between the leak and C_{rs} ($r^2 = 0.68$) and inspiratory and expiratory resistance ($r^2 > 0.92$) (Figs. 2a–d). It can be

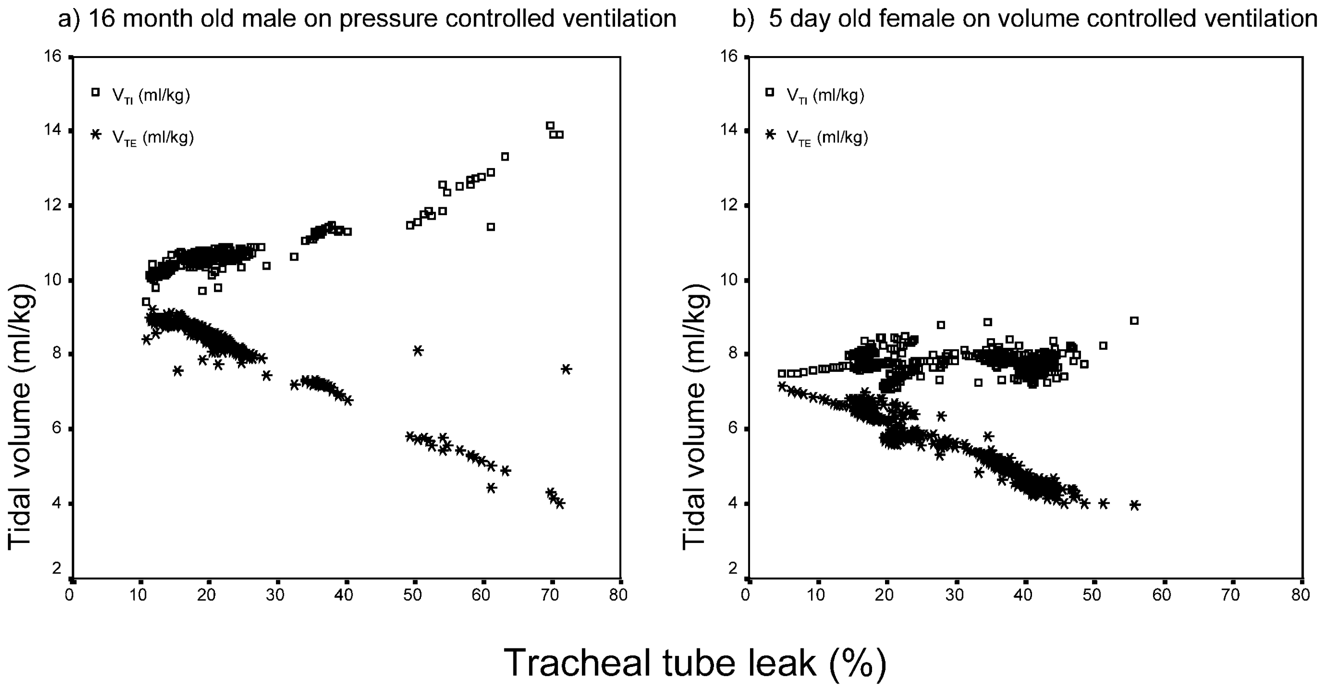

Fig. 1 a, b The relationship between inspired and expired tidal volume and percentage leak in **a** a 16-month-old infant on pressure pre-set ventilation (Servo 300) and **b** a 5-day-old infant on volume pre-set ventilation (Servo 300). Tracheal tube leak is calculated from the difference between inspiratory (V_{TI}) and expiratory (V_{TE}) tidal volume. Each data point represents the mean value from 1 min of recording

seen that, in the presence of a large leak, values of C_{rs} and R_{rs} in this neonate were distorted far beyond the range previously reported in ventilated newborns, i.e. 0.2–1 ml.cmH_2O^{-1}.kg^{-1} and 70–150 cmH_2O.l^{-1}.s [5, 14, 15, 16, 17].

The influence of the large tracheal tube leak on the shape of flow volume and pressure volume curves is illustrated in Fig. 3, which shows data from a 7-week-old (2.6 kg) baby who was on pressure pre-set ventilation (Bear Cub BP2001), both before and after the tracheal tube was changed from a size 3.0 mm to a size 4.0 mm. Data were collected for 7 h prior to, and 5 h after, the tube change; the results are summarised in Fig. 4. Clinical status was stable and ventilator settings not altered during this period, suggesting that the observed changes in tidal volume, compliance and resistance were attributable to the change of tracheal tube. It can be seen that the reduction in tracheal tube leak from over 80 % to an average of 16 % was accompanied by a marked reduction in both the magnitude and variability of compliance (Fig. 4b) and resistance (Figs.4c, d). While some of the reduction in R_{rs} can be attributed to the insertion of a larger tracheal tube [18], this cannot account for the magnitude of change observed or the reduction in variability. In addition, even within the smaller range of leak that occurred after the tracheal tube had been changed (11–23 %) there was still a significant correlation ($r^2 = 0.84$) between calculated values of R_{rs} and magnitude of leak (Fig 4c).

In an attempt to identify the magnitude of leak that would preclude accurate measurements, the median and interquartile range of all values of weight-corrected compliance for each of the 75 children studied were plotted against the mean leak in that child during the measurement period (Fig. 5). Tracheal tube leaks greater than 20 % were associated with a marked rise in both the absolute values and the variability of weight-corrected compliance. A similar pattern was obtained when resistance data were plotted in the same way.

Discussion

These results confirm in vivo those of previous in vitro lung model studies, which show that compliance and resistance values are overestimated in the presence of tracheal tube leak [11, 12, 13, 19]. The credibility of these findings is dependent both on the ability of the monitoring equipment to record volume and pressure changes accurately and the absence of various confounding issues, such as changes in ventilatory management and/or clinical status, that can occur when undertaking studies on the ICU.

Many of the potential confounders were avoided by limiting measurements to paralysed, fully ventilated

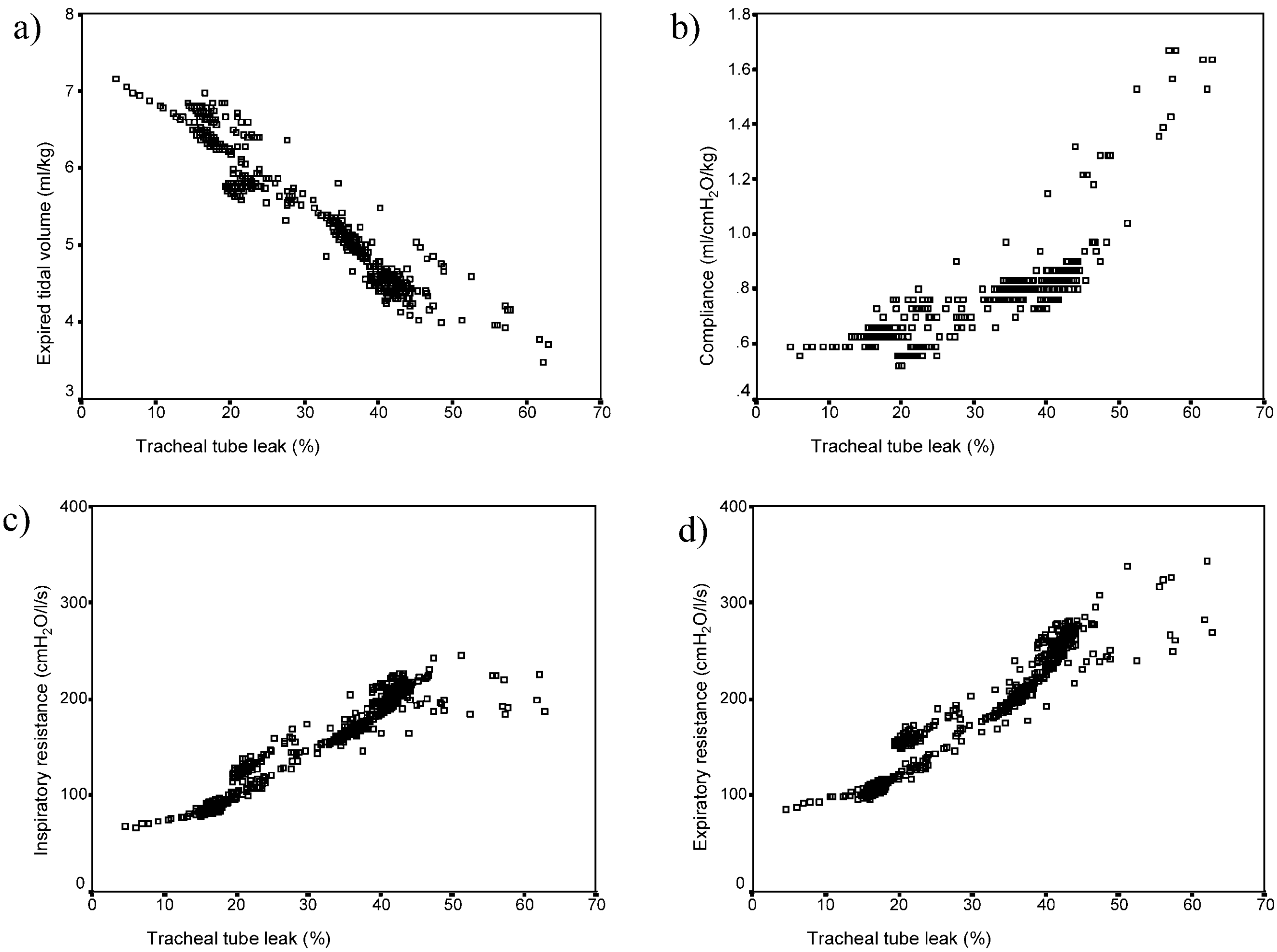

Fig. 2 a–d The relationship between tracheal tube leak and **a** tidal volume, **b** compliance, **c** inspiratory resistance and **d** expiratory resistance in a 5-day-old infant. Each data point represents the mean value from 1 min of recording

children in whom ventilatory settings remained unchanged during the period of monitoring. Since unit policy was to maintain a constant paralysis rather than intermittently reduce doses, the observations reported in this paper should not have been confounded by any changes in mechanics associated with waxing or waning of the muscle relaxant agent used.

Extensive bench testing to validate the accuracy of the "CO_2SMO Plus" sensors suggested that the observed discrepancies between V_{TI} and V_{TE} were indeed due to the presence of a tracheal tube leak rather than any equipment or software errors. The importance of assessing the accuracy of both the equipment and software used to assess respiratory function in infants has been stressed in several recent publications [20, 21, 22, 23, 24]. Magnitude of leak is conventionally assessed as the percentage difference between V_{TI} and V_{TE} and, as such, there will obviously be a strong negative relationship between percent leak and V_{TE}. However, the clinical significance of a calculated leak will to some extent depend on the type of ventilatory management.

During pressure-controlled ventilation, leak magnitude reflects both overestimation of V_{TI} (much of which, having passed through the flow-meter, will leak out around the tube before entering the child's lungs and the reduction in V_{TE}. In turn, the latter will primarily reflect a reduction in the actual volume delivered, although in the presence of a very loose fitting tube or any secretions within the tube some expired air may shunt through the leak pathway without passing through the flow-meter, thereby underestimating true expired volume. During pressure-controlled ventilation there will be some compensatory increase in delivered volume as the ventilator attempts to maintain a constant PIP, whereas this will be far less marked during volume-controlled ventilation, as shown in Fig. 1b. Consequently, the same magnitude of leak is likely to reflect a greater reduction in delivered tidal volume during vol-

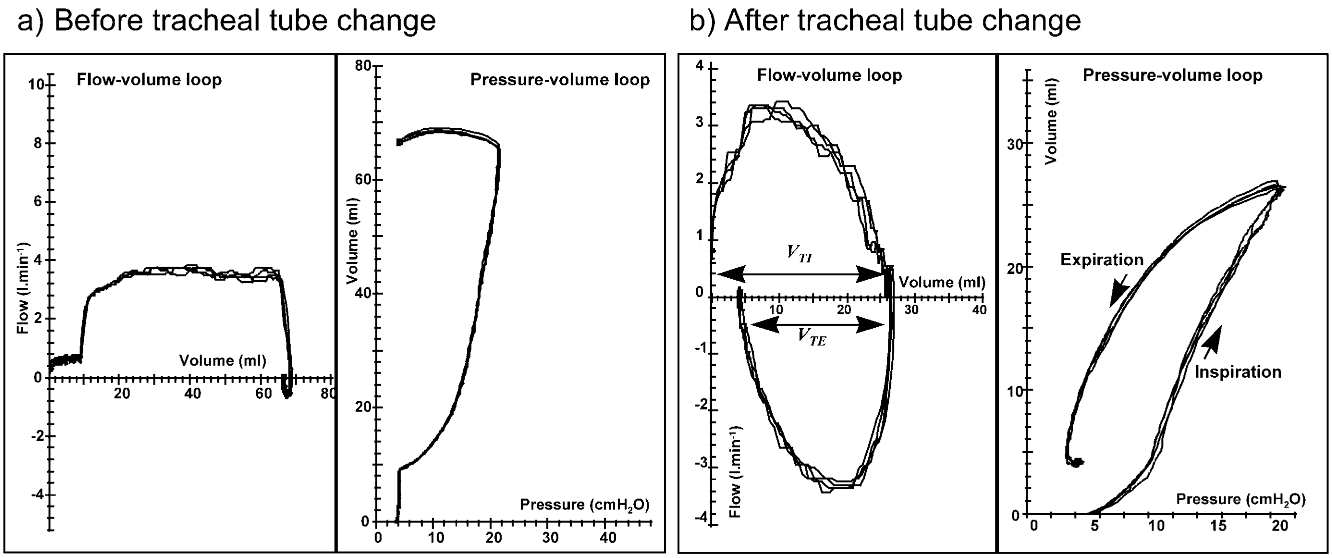

Fig. 3 a, b Flow/volume and pressure/volume loops **a** before and **b** after tube change from 3.0 mm to 4.0 mm in a 7-week-old infant. Loops generated from a 7-week-old infant receiving pressure-controlled ventilation

ume- than during pressure-controlled ventilation [25]. Theoretically, during pressure-controlled ventilation in the presence of a very large leak and/or a low bias flow, the time to reach peak inflation pressure could be prolonged thereby rendering inspired volume artificially larger relative to expired volume. In such circumstances the clinical significance of the observed leak would only be obviated if expired volume remained constant. In this study, however, increasing magnitude of leak was always associated with a reduction in V_{TE}.

Changes in tracheal tube leak, therefore, do not simply confound the calculation of respiratory function parameters, but may be associated with significant clinical consequences if there is inconsistent ventilatory delivery. For example, inadequate ventilation may occur if the leak increases following a change in patient position, whereas, unless appropriate modifications of ventilator settings are made, excessive ventilation with the attendant risks of volutrauma or barotrauma can occur if the leak suddenly decreases. This study has illustrated the magnitude and variability of leak during routine intensive care. In general, the larger the mean leak, the greater the variability both in delivered tidal volume and in the values calculated for compliance and resistance. In the presence of tracheal tube leak, apparent changes in compliance or resistance may not reflect real clinical changes, but simply a change in the magnitude of leak due, for example, to physiotherapy or alterations in head, neck or body position. Whether such changes have a beneficial or deleterious clinical effect will depend on the adequacy of ventilation prior to the intervention and the magnitude of leak change. Confusingly, the clinician will see an apparent "improvement" in compliance but "deterioration" in resistance as the leak gets larger, since both are increasingly overestimated as leak increases, whereas the opposite is true if a reduction in tracheal tube leak occurs. Clinical decisions based on these data would be unsound and any attempt to optimise ventilatory management in order to achieve optimal blood gases while minimising the risk of lung injury is not possible in the presence of such within-subject variability.

Clinical interpretation may be further confounded by the fact that changes in the clinical status of the child may also cause changes in leak magnitude. Thus, a reduction in C_{rs} may result in an increased leak, which could, in turn, exacerbate further clinical deterioration due to inadequate ventilatory delivery. Conversely, any improvement in C_{rs} could lessen the leak and further increase ventilation delivery, potentially leading to overinflation. This is in some ways analogous to the situation that seemed to occur during the early trials of surfactant, when failure to adjust ventilator settings following surfactant therapy led to overinflation of the lungs thereby masking any improvement in dynamic lung compliance due to the therapeutic intervention [14, 16, 17, 26, 27].

Establishing how much leak is acceptable in a ventilated child depends very much on the clinical status of the child. The results from this study suggest that attempts to optimise ventilatory management in the clinical situation are impossible in the presence of tube leaks greater than 15–20 %. For satisfactory clinical management and to avoid exposure of the child to sudden changes in tidal volume delivery and gas exchange, a maximum leak should not exceed 20 % and variability of the

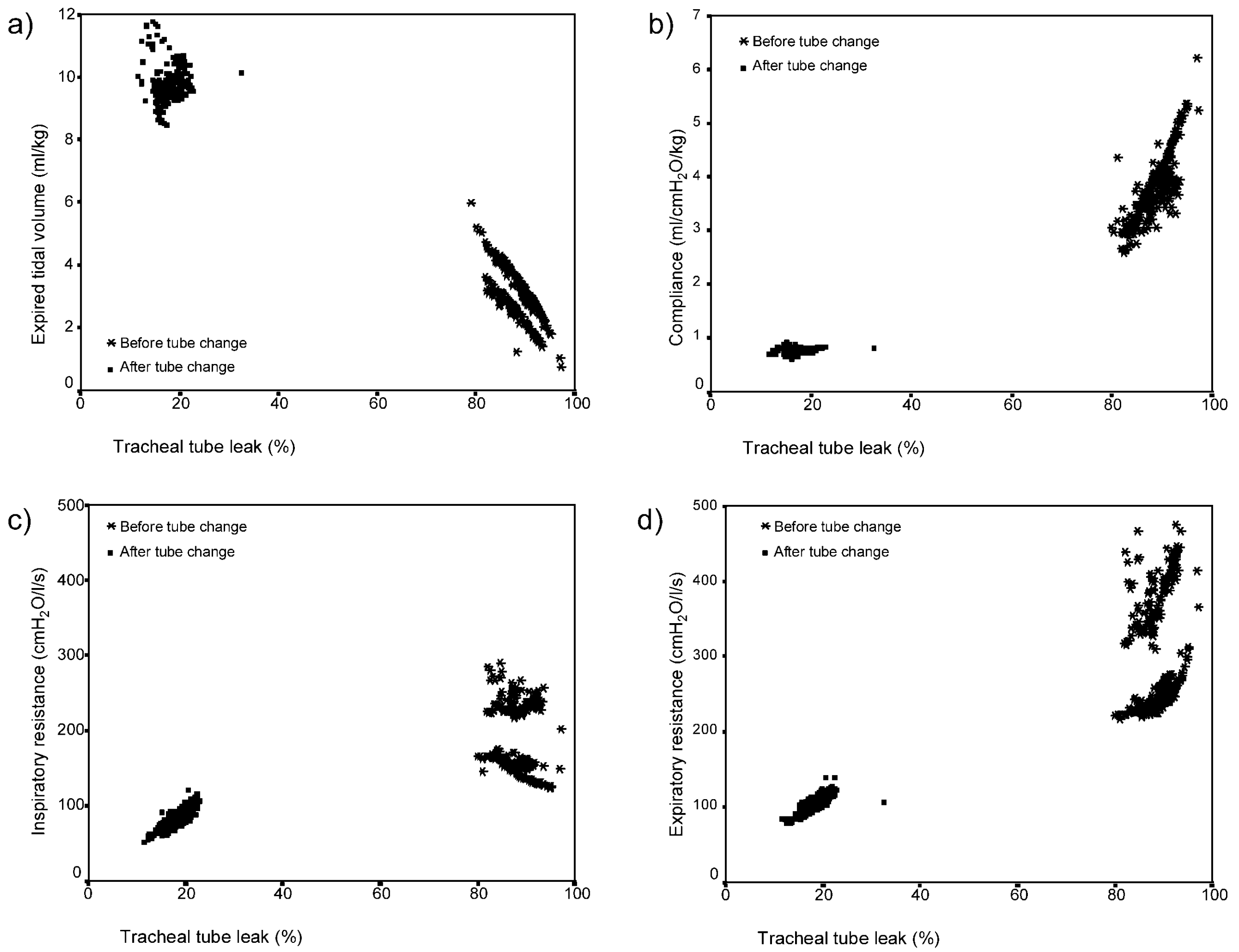

Fig. 4 a–d Influence of tracheal tube change from 3.0 mm to 4.0 mm on **a** tidal volume, **b** compliance, **c** inspiratory resistance and **d** expiratory resistance in a 7-week-old infant. Each data point represents the mean value from 1 min of recording from a 7-week-old infant receiving pressure-controlled ventilation (Bear Cub BP2001). Effective expired tidal volume was 3 times higher following tube change and reduction of leak. Note the gross overestimation and greater variability of calculated compliance and resistance in the presence of a large leak

leak should be below 10%. Whereas measurements of C_{rs} appear to be more robust, any attempt to use resistance as an outcome variable to evaluate therapeutic interventions such as steroid or bronchodilator therapy would require negligible leak throughout the entire period of study. Such a condition may not be attainable unless a cuffed tube is in situ [1].

Sly et al. suggested that the use of the expiratory portion of each breath to calculate respiratory mechanics might reduce the confounding effect of a leak but cautioned that this method has not yet been thoroughly validated [14]. A lung model study by Kondo et al. suggested that resistance could be reported reliably provided only the expiratory portion of the breath was used, when airway pressure was lower and hence the leak smaller [12]. This is in contrast to the results from this in vivo study, which found that both inspiratory and expiratory resistance were overestimated and unreliable in the presence of tracheal tube leak greater than 10%. The discrepancy in results between in vivo and in vitro studies may be explained by the difficulty of designing lung models to approximate the clinical situation, where the presence of lung disease may exaggerate the effect of leak, and indicates that results from in vitro studies should be interpreted with caution. In addition, in the presence of a large leak, changes in time constant and introduction of phase lags between flow and pressure signals are likely to invalidate the data collected and the algorithms applied, irrespective of phase of the respiratory cycle. When interpreting measurements of resistance in ventilated infants, it should be noted that, in addition to the presence of any leak, measurements may be confounded by the resistance of the tracheal tube, which may represent the largest component of

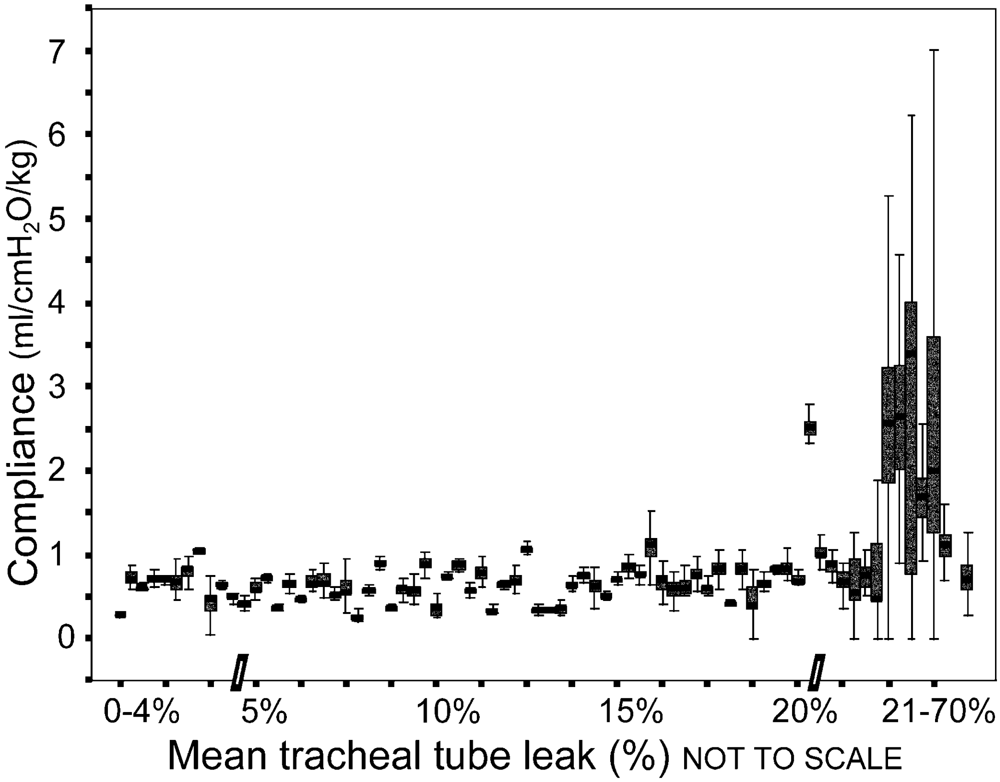

Fig. 5 Median and interquartile range of compliance at different tracheal tube leaks. Each data point represents the data set from one child over at least 5 h of monitoring. With leaks greater than 20% there is a significant rise in the calculated values and variability of compliance

the total resistance, especially in neonates with small tubes [18, 28]. In addition, variations in calculated resistance may occur according to both the equipment and algorithms used [29] and the age and size of the child. Whilst there are limited data available for 'healthy' ventilated children, a recent study by Lanteri et al. in 51 anaesthetised, intubated children ranging from 3 weeks to 15 years, showed that resistance fell from around 130 to 15 $cmH_2O.l^{-1}.s$ during this period of growth and development [30].

The results from the current study suggest that it is essential that a leak is no greater than 5–10% if parameters of respiratory function are to be used as objective outcome measures, particularly if such measures are required to detect within-subject changes in response to therapeutic interventions. Unfortunately significant leaks are not always audible or clinically obvious and their magnitude is not always accurately displayed on the ventilator or monitoring equipment, if at all. Indeed, no automatic display of the magnitude of leak was available when using the "CO_2SMO Plus", although it was possible to calculate these values for the purposes of this study. Leaks present in the circuit between the ventilator and tracheal tube would not have been recorded by the "CO_2SMO Plus" flow sensor and so should not have introduced error into measurements of tidal volume or C_{rs} and R_{rs} made at the airway opening. However, such leaks would affect parameters displayed on ventilators which measure flow at some distance from the airway opening and could contribute to known errors associated with these measurements [31].

Tracheal tube leaks would be less clinically relevant if cuffed tracheal tubes were more widely used in the paediatric ICU. Although an increasing number of centres in America and Europe are now using cuffed tubes, anxieties about the possibility of tracheal damage from cuffed tracheal tubes remain, despite the lack of firm evidence to support these concerns. In contrast there are studies that suggest that cuffed tubes are safe in children [32, 33, 34, 35]. Deakers et al. found no association between cuffed tracheal tube intubation in children and post-extubation stridor or long-term tracheal sequelae [32]. They emphasised that infants with decreased compliance may require high PEEP and relatively high PIP to maintain adequate tidal volumes. In such patients a cuffed tracheal tube will provide optimal and consistent levels of ventilation and PEEP, whereas a significant tracheal tube leak may hamper these two goals of ventilation. The use of a cuffed tube, however, normally requires a smaller internal diameter and hence higher resistance, which may limit its application in neonates.

In conclusion, the magnitude of tracheal tube leak is not stable in individual children and, in general, the larger the leak, the greater the variability of respiratory function measurements obtained. Leaks larger than 20% result in gross overestimations of compliance and resistance irrespective of mode of ventilation. Even when a leak is less than 20 %, a significant correlation between its magnitude and measures of respiratory mechanics remains. Consequently, measures of respiratory function cannot be used to optimise ventilatory management in the presence of moderate-to-large leaks and it may become clinically difficult to ensure consistent and adequate ventilation. If changes in mechanics are to be used as reliable outcome measures in ventilated children, it is probably advisable to ensure that the leak is less than 5–10 % and the variability is small.

The magnitude of leak needs to be displayed accurately on all ventilatory equipment to facilitate appropriate clinical decisions. Further work is required to establish the significance of clinical changes (including blood gases) which accompany any change in tracheal tube leak in specific groups of ventilated children.

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