

Pulmonary compliance in sick low birthweight infants

How reliable is the measurement of oesophageal pressure?

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SUMMARY Measurements of dynamic lung compliance (C_{dyn}) were made on 42 occasions in a group of 15 intubated very low birthweight infants with respiratory distress syndrome, using an oesophageal balloon and pneumotachograph system. Values of C_{dyn} were compared with those of total respiratory system compliance (C_{rs}) using an occlusion technique. Ten very low birthweight infants with no respiratory disease were similarly studied while breathing through a facemask. The occlusion tests for oesophageal balloon assessment were unsatisfactory in 14 of 15 intubated infants, but in only 3 of the 10 normal infants. Values of C_{dyn} were poorly reproducible and correlated poorly with C_{rs}. We conclude that in sick intubated preterm infants oesophageal pressure (and hence C_{dyn}) cannot be reliably measured, but that C_{rs} may be a useful parameter of lung stiffness.

Infants under intensive care are extensively monitored but accurate information on the mechanical function of the lungs has been difficult to obtain. A number of workers have attempted to measure lung mechanics in infants with respiratory distress. The simplest and most commonly reported measurement has been the dynamic lung compliance (C_{dyn})—the relation between lung volume change and oesophageal pressure change (Δ Poes) during breathing. For this purpose, Δ Poes is assumed to be equal to the mean change in pleural pressure. Recent reports have suggested that the measurement of oesophageal pressure may itself provide information that will improve management of newborn babies.^{1–3} No attempt has been made, however, in any of these reports to validate oesophageal pressure measurements in sick infants.

Δ Poes, and hence C_{dyn} may be accurately and reproducibly measured in healthy babies.^{4–5} There is increasing evidence, however, that Δ Poes does not reflect mean pleural pressure changes (Δ Ppl) where there is chest wall distortion^{6–7}—a prevalent condition in sick or very preterm infants, in whom the chest wall is likely to be highly compliant^{8–9} and hence subject to distortion. Conversely, in the presence of a compliant chest wall, conditions are ideal for the measurement of the total respiratory system compliance (C_{rs}), which does not depend on

the measurement of Δ Poes and which is likely to be close in value to the lung compliance.

We aimed to determine the reliability of measurements of oesophageal pressure in sick, intubated newborn babies (and hence the accuracy of C_{dyn}) and to compare values of C_{dyn} with C_{rs}. We were seeking a reliable measurement of lung compliance which would provide clinically useful information in this group of babies.

Patients

The study population was a group of 15 infants weighing less than 1500 g (mean birthweight 1200 g, range 750–1500 g; mean gestational age 30 weeks, range 27–37 weeks), who were intubated and being ventilated for respiratory distress syndrome, but were able to breathe spontaneously through the endotracheal tube for short periods of time. Coles pattern 2.5–3 mm PVC endotracheal tubes (Portex) were used.

In addition, similar techniques were applied to a group of 10 healthy infants of birthweight less than 1500 g, four of whom had never had a respiratory problem and 6 of whom had fully recovered from their initial illness. The characteristics of this group were: mean gestational age 29.1 weeks, range 26–32 weeks; mean postconceptional age 31.7 weeks,

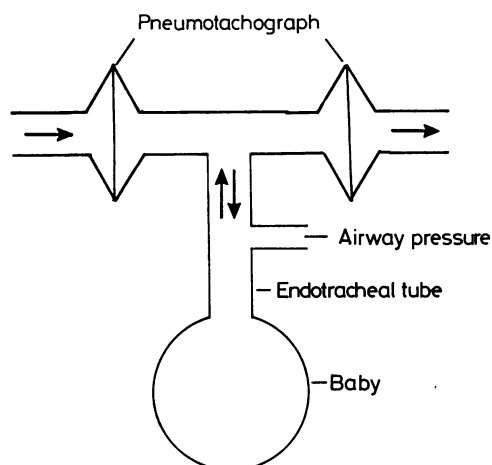


Fig. 1 Diagram of double pneumotachograph system. Flow pathways are indicated by arrows.

range 28–34 weeks; mean birthweight 1200 g, range 890–1470 g; mean weight at time of test 1230 g, range 940–1400 g.

Methods

ΔP_{oes} was measured with a thin latex oesophageal balloon over a size 6 FG catheter connected to a Validyne MP45 transducer, using a standard technique.⁴ Airway pressure changes (ΔP_{aw}) were measured at the end of the endotracheal tube using

an SE Labs 1150 transducer. In vivo assessment of the oesophageal balloon was performed by briefly occluding the infant's airway and comparing $\Delta P_{oes}:\Delta P_{aw}$ during subsequent respiratory efforts. Under ideal circumstances, in the absence of airflow, there will be uniform intrathoracic pressure swings such that $\Delta P_{oes}:\Delta P_{aw}$ should be close to unity. Attempts were made to reach this ideal $\Delta P_{oes}:\Delta P_{aw}$ ratio of 1.0 and the balloon was sited in the position that gave the highest value of this ratio—a position that also gave the maximum oesophageal pressure swings.

To avoid adding dead space to intubated infants' breathing circuit, flow was measured using two identical heated pneumotachographs, linear to 12 litres/min placed in the bias flow pathway on either side of the endotracheal tube connection (Fig. 1).¹⁰ The pneumotachographs and their transducers (Validyne MP45) were carefully balanced electronically so that the difference of the signals (the output) was zero over a wide range of bias flows. The output signal during a test then represented the infant's tidal flow. The flow signal could be electronically integrated to volume and was also available for digital integration on computer. Digital conversion of the flow signals to volume (at 100 Hz) eliminated electronic drift and allowed any differential leak past the endotracheal tube to be easily seen. Expiratory volumes were used for calculations. The healthy infants were studied using a mask and simple heated pneumotachograph (dead-space 8 ml) but the same tubing, connectors, and transducers.

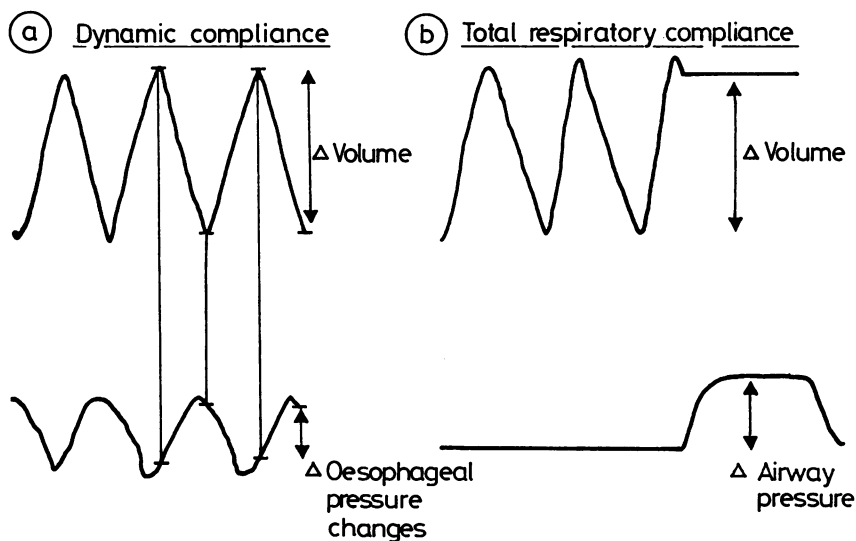


Fig. 2 Illustration of measurement of (a) dynamic compliance and (b) total respiratory compliance.

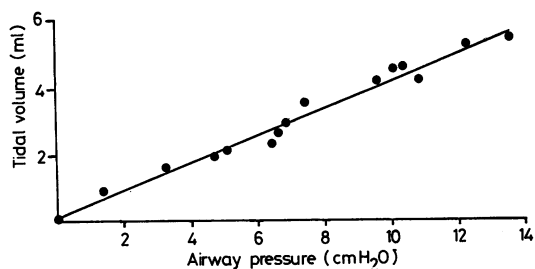


Fig. 3 Relation between airway pressure and tidal volume from multiple airway occlusions in a single infant. The slope of the regression line is the total respiratory compliance.

All transducers had a frequency response of >20 Hz when tested with a square wave (balloon burst). The signals were fed through an EMMA SE4001 amplifier and were recorded simultaneously on UV paper and in an Apple II microcomputer.

Dynamic compliance was calculated during tidal breathing using the method of Krieger¹¹ in which changes in Poes and volume are taken at points of zero flow (Fig. 2(a)). Each value was the mean of 8-10 breaths. Total respiratory system compliance was assessed using a method described by Olinsky.¹² Airway occlusion during tidal breathing (achieved by briefly occluding the tubing in series with the endotracheal tube, using a pair of artery forceps) resulted in a brief pause in the normal respiratory cycle. The airway pressure generated during this pause was then related to the volume occluded above functional residual capacity (Fig. 2(b)). Multiple occlusions at different volumes within the tidal range gave pairs of values of tidal volume and airway pressure, the slope of which, on regression analysis, represented the compliance of the total respiratory system (Fig. 3). The intercepts were all close to the origin.

The ability to reproduce both Cdyn and Crs was assessed from repeated pairs of measurements over periods of up to 90 minutes while the infants were stable. During this time no changes were made in ventilation, the infants were undisturbed, and the oesophageal balloon was left in situ. Repeated assessments of both compliance measurements were made on a daily basis in several infants during recovery from respiratory distress syndrome.

For pairs of observations of Crs or Cdyn, the coefficient of variation was calculated as the standard deviation of the log of the ratio of the two observations.

Results

Despite careful and time consuming adjustment of

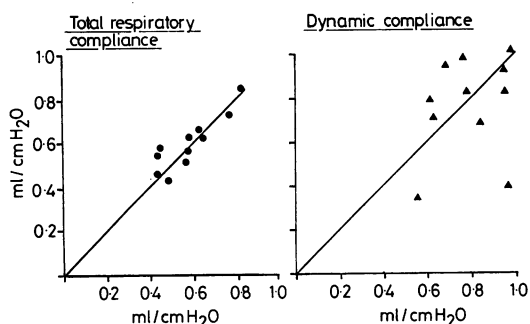


Fig. 4 Data from 11 infants showing pairs of measurements of both total respiratory compliance and dynamic compliance. Lines of identity are shown.

balloon position and volume we found it impossible to achieve the ideal $\Delta Poes:\Delta Paw$ ratio of 1.0 during the occlusion test in the study group undergoing mechanical ventilation. The balloon was sited in the position that gave maximum oesophageal pressure swings and maximum $\Delta Poes:\Delta Paw$ ratio, but in only four of the 51 tests did this ratio exceed 0.9, and in 24 tests the ratio was <0.75.

On 11 occasions repeated pairs of measurement of both Cdyn and Crs were made in the same intubated infants while they were undisturbed (Fig. 4). The values of Crs lay close to the line of identity (coefficient of variation 14%) and no

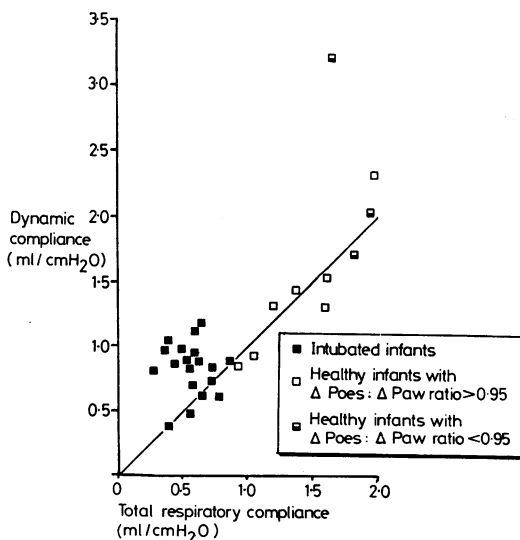


Fig. 5 Paired values of dynamic compliance and total respiratory compliance from intubated infants, healthy infants with $\Delta Poes:\Delta Paw$ ratio >0.95, and healthy infants with $\Delta Poes:\Delta Paw$ ratio <0.95. Line of identity shown.

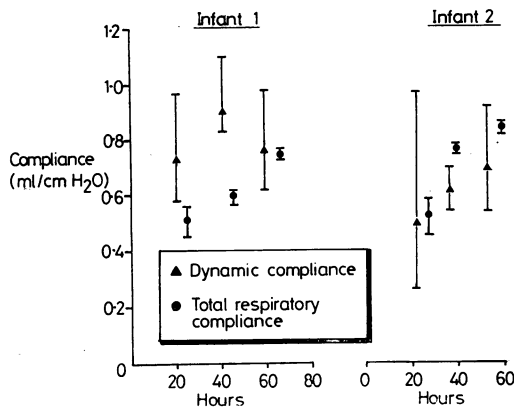


Fig. 6 Data from two infants showing mean and range of dynamic compliance, and total respiratory compliance measurements made over the first three days of life. Lines of identity shown.

individual differences were statistically significant. Six of the 11 pairs of C_{dyn} measurements were statistically significantly different and the coefficient of variation was 42%. The small changes in the frequency of breathing between measurements had no consistent effect on compliance measurements.

There was no correlation ($r = -0.1$) between values obtained for C_{dyn} and C_{rs} in intubated infants, even when the $\Delta P_{oes}:\Delta P_{aw}$ ratio was greater than 0.8 (Fig. 5). In contrast, the results from the 7 healthy infants in whom $\Delta P_{oes}:\Delta P_{aw}$ was close to unity (0.95–1.05), were similar ($r = 0.92$).

The repeated assessments of both compliance measurements on a daily basis gave values of C_{rs} which were consistent with the clinical course, but C_{dyn} measurements that were poorly reproducible and often at variance with the clinical course (Fig. 6).

Discussion

These results show that C_{dyn} is a poorly reproducible and inaccurate measurement in sick intubated infants, as a result of inaccuracies in oesophageal pressure measurements. In contrast, a simpler and more reliable method for measuring C_{rs} provides reproducible information on lung mechanics which has great potential for monitoring sick infants.

Respiratory compliance is the ratio of tidal volume to pressure changes. For the measurement of both C_{rs} and C_{dyn} we used an identical volume measurement (but different sources of pressure measurement). In the intubated infants the double pneumotachograph system used has a 5% accuracy for volumes as small as 2 ml *in vitro*, and gives identical results to those obtained with a single

pneumotachograph placed in series with the endotracheal tube. This system overcomes the problem of adding deadspace to the infant's breathing circuit and allows measurements to be made over long periods of time without the need to handle the endotracheal tube directly.

With any system measuring flow through an endotracheal tube, leaks past the endotracheal tube cannot be measured. When the volume signal is derived by continuous electronic integration of flow, the presence of 'drift' cannot be taken to represent only leaks at the endotracheal tube, since both electronic factors and physiological factors, in addition to leaks, may produce some drift. The temptation to 'correct' all these electronically by eliminating all signal drift will cause major errors in tidal volume measurement. By digital conversion of flow to volume, however, any differential leaks between inspiration and expiration can be easily seen. When the infants were breathing spontaneously through the endotracheal tube there was rarely any differential leak. If a leak around the tube had existed, however, then the volume measurements would be too small and the values for both C_{rs} and C_{dyn} would have been less than expected. This would not account for any discrepancy between C_{rs} and C_{dyn} .

The pressure used for C_{rs} is airway pressure measured at the end of the endotracheal tube during brief periods of apnoea induced by artificial obstruction of airflow. During these pauses the pressure throughout the airways and airspaces of the lungs should be uniform (and therefore P_{aw} should equal alveolar pressure), provided there is no airway closure. This is a reasonable assumption for occlusions made high in the tidal volume range especially when multiple occlusions lead to a linear relation between volume and pressure (Fig. 3). The airway pressure measured during occlusion results not only from the recoil of the lung (lung compliance) but also from the state of the chest wall (which includes the respiratory muscles). It is assumed that during the plateau P_{aw} after airway occlusion the respiratory muscles are relaxed, and therefore C_{rs} is directly proportional to the static compliance of the lung itself. Plateau pressures were well maintained during occlusion suggesting both that there was no endotracheal leak and that the infant was relaxed. Although no difficulty was experienced in the patients reported here, it is not always possible to obtain reliable values for C_{rs} by this method.

The calculation of C_{dyn} is dependent on the accurate measurement of ΔP_{oes} . This involves two basic assumptions—firstly that the oesophageal

balloon is accurately recording Δ Poes, and secondly that Δ Poes is accurately reflecting mean pleural pressure swings. The technique and apparatus used have been validated in healthy infants^{4,5} using the occlusion test for checking balloon function.^{4,13} It has been a routine requirement in this laboratory since 1980 to have a Δ Poes: Δ Paw ratio between 0.95 and 1.05 before making measurements of Cdyn or pulmonary resistance. The difficulty in obtaining this ideal was the first indication of a problem with oesophageal pressure measurements. The problem in intubated infants could not have been caused by leakage past the endotracheal tube, as this would result in a decreased Δ Paw and therefore a Δ Poes: Δ Paw ratio of greater than 1.0. In adults with lung disease it has recently been pointed out that shunting of air between the lungs and a compliant upper airway during occluded respiratory efforts can result in low values of Δ Paw.¹⁴ In our infants the upper airway was replaced with a non-compliant endotracheal tube eliminating this potential error. Finally, the possibility that airway closure during the occlusion test could render Δ Paw inaccurate when Δ Poes was reliable, is made unlikely by the consistent values of Crs (dependent on Δ Paw) in individual infants repeatedly measured over the whole range of their tidal volume.

Eight of our intubated infants were studied again in convalescence and in each case the Δ Poes: Δ Paw ratio had improved. In our group of healthy preterm infants Δ Poes: Δ Paw ratio of 0.95–1.05 was easily obtained in 7 of 10. Since Crs (and hence Δ Paw) measurements were consistent in our patients the unsatisfactory occlusion tests suggest a major error in the measurement of Δ Poes.

In healthy preterm infants, when the Δ Poes: Δ Paw ratio was close to unity under occlusion there was a good correlation between the values of Crs and Cdyn. Le Souef *et al.*⁸ have shown, however, that even in healthy preterm infants Δ Poes may change (for the same volume change) with increasing chest wall distortion, and we would not rely solely on oesophageal pressure measurement in any preterm infant.

D'Angelo *et al.*⁷ have shown in dogs that pleural pressure gradients can be created by abnormal activity of the respiratory muscles. The pleural space is a potential space with the properties of an ultrathin fluid layer. As such it has the capability of supporting a pressure gradient under conditions of distortion. Δ Poes may then be reflecting local pressure swings dependent on the muscle groups being used. Recently Heaf *et al.*¹⁵ have produced evidence that oesophageal pressure measurements are inaccurate in older intubated infants with lung disease.

The reliability of Δ Poes has been 'proved' by making comparisons with changes in pleural pressure in the presence of a pneumothorax.^{16,17} A pneumothorax with air, fluid, or a catheter in the pleural space will destroy the potential for uneven pressure distribution and indeed pneumothorax may be the only condition in which Δ Poes is accurate. Measurements made in infants with a pneumothorax cannot be used to validate oesophageal pressure measurements in infants with an intact pleural space.

The total compliance of the respiratory system is the sum of the chest wall compliance and the compliance of the lungs in series. In newborn infants the chest wall is highly compliant and so total compliance approaches the value of lung compliance. Dynamic compliance is, by definition, measured during breathing, and as such is not a pure measurement of lung compliance but has a small resistive component. This is minimised by making measurements of points of zero flow, but nevertheless Cdyn values might be expected to be slightly less than static lung compliance.

The values for Crs obtained in this study are similar to those of Simbruner *et al.*¹⁸ who studied infants in the first few hours after birth. They used a similar occlusion technique in the unintubated infants but a method dependent on an injection of a known volume in the intubated infants. The mean values of static compliance were 1.29 ml/cmH₂O in infants with mild respiratory distress syndrome, 0.8 ml/cmH₂O in infants who were ventilated and survived, and 0.46 ml/cmH₂O in ventilated infants who subsequently died.

There is a wide range of reported values for dynamic compliance in infancy,^{19–22} while several reports^{20–22} use measurements of Cdyn to show significant changes in lung mechanics during treatment manoeuvres. In our study more than half the infants showed significant changes in Cdyn (by Student's *t* test) over short periods of time while they were undisturbed. In addition, we found that the variability of Cdyn measurements resulted in discrepancies between the trend in Cdyn and the infants' clinical course. To rely on Cdyn results for clinical management decisions would have been dangerous. It would seem that for populations of preterm infants, as well as individual patients, values of Cdyn are variable and unreliable.

Conclusions

We found measurements of dynamic compliance in intubated infants weighing less than 1500 g to be poorly reproducible and inaccurate. The failure to

obtain a good Δ Poes: Δ Paw ratio during the occlusion test supports the conclusion that oesophageal pressure measurements do not reflect mean pleural pressure changes in these infants. Sick preterm infants have very obvious chest wall distortion and under such conditions oesophageal pressure may reflect a local pressure rather than the mean pleural pressure. On the other hand, the measurement of a total respiratory system compliance by an occlusion technique was simple to perform and gave reproducible and reliable results. This measurement would seem to have a useful clinical role in assessing the mechanical function of the lungs of small sick infants under intensive care.

This project was supported by Action Research—The National Fund for Research into Crippling Diseases and the University of London Central Research Fund. We would like to thank Mr Norman Levy of the Royal Postgraduate Medical School Workshop for building the double pneumotachograph system, Professor Healy for statistical advice, and Dr Janet Stocks for helpful comments.

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Received 22 July 1983