Crying vital capacity

Measurement of neonatal lung function

MALCOLM L. CHISWICK and R. D. G. MILNER

From the Department of Child Health, St. Mary's Hospital, Manchester

Chiswick, M. L., and Milner, R. D. G. (1976). *Archives of Disease in Childhood*, **51**, 22. **Crying vital capacity: measurement of neonatal lung function.** Serial measurements of crying vital capacity (CVC), expressed as ml/cm chest circumference, were made by reverse plethysmography during the first 2 weeks of life. Clinically normal babies born at term by elective caesarean section had a smaller mean CVC in the first 2 weeks of life compared with clinically normal term babies born vaginally. In contrast, no significant difference was shown between the mean CVC in term babies born vaginally and those born by urgent caesarean section. Clinically normal term babies born by caesarean section (elective and urgent) had a smaller mean percentage rise of CVC in the first 24 hours of life and a significant delayed rise of CVC from 24–48 hours compared with those born vaginally. Clinically normal preterm babies born vaginally had a smaller mean CVC in the first 2 weeks of life compared with term babies born vaginally, and were characterized by a significant rise of CVC from 5–10 days.

Babies with hyaline membrane disease (HMD) had a smaller CVC in the first 2 weeks of life compared with clinically normal preterm babies. Babies of various gestational ages with transient tachypnoea (TT) had a smaller mean CVC in the first 2 weeks of life compared with clinically normal term babies, but a similar mean CVC in the first 72 hours of life compared with clinically normal preterm babies. At each postnatal age the mean CVC of babies with HMD was less than the corresponding mean in babies with TT. All babies with TT had a rise in CVC from 24–48 hours, whereas CVC fell in all babies with HMD except one during this period.

CVC is a simple, safe, rapid, and noninvasive test of neonatal lung function, and is a valuable aid to other methods of assessing pulmonary function in the neonate with respiratory distress.

Measurement of arterial blood gas tension is the commonest indirect method of assessment of the neonate with respiratory distress. Direct measurements of lung function are usually precluded because the methods are time consuming and invasive. Crying vital capacity (CVC) is defined as the maximum volume of air expired in a single breath during a bout of crying. The significance of CVC measurements as an aid to assessment and management of babies with respiratory distress has received little attention in published reports (Sutherland and Ratcliff, 1961; Orzalesi *et al.*, 1966; Krauss *et al.*, 1973).

The role of serial CVC measurements as an

adjunct to clinical assessment, chest radiology, and measurement of blood gas tension in neonates with respiratory distress is reported here. The use of CVC measurements as a research tool to study the effect of caesarean section delivery on neonatal lung function is discussed.

Patients and methods

Measurements of CVC were made on babies born in hospital within 6 hours of birth (initial measurement), between 12 and 36 hours ('24 hours'), 36 and 60 hours ('48 hours'), 60 and 84 hours ('72 hours'), on the 5th day, and between 7 and 14 days ('10 days'). Gestational age was estimated from the date of the mother's last menstrual period and the birthweights of all babies were between 10th and 90th centile for gestational age (Thomson, Billewicz, and Hytten, 1968; Babson, Behrman, and

Lessel, 1970). Clinically normal term babies (37–42 weeks) were further divided into those born vaginally, those born by caesarean section before onset of labour (elective CS), and those born by caesarean section after onset of labour (urgent CS). Preterm babies (<37 weeks) were born vaginally. The following definitions were used in babies who suffered respiratory distress. (a) *Respiratory distress*: the presence of 2 or more of the following signs at the age of 4 hours, respiratory rate >60/min, expiratory grunt or whine, rib cage recession on inspiration. (b) *Hyaline membrane disease (HMD)*: respiratory distress associated with pulmonary radiological changes of diffuse granularity and air bronchograms. (c) *Transient tachypnoea (TT)*: respiratory distress with no obvious cause such as pneumothorax, meconium aspiration, cardiac failure, etc., occurring in the absence of radiological features of HMD. In all babies with respiratory distress the initial chest x-ray was taken between 4 and 12 hours, and clinical signs abated between the 3rd and 5th days of life.

CVC was measured by reverse plethysmography (Fig. 1) with the baby lying supine in the cot or incubator. The baby was stimulated to cry into a mask (Ambu International Ltd., Beswick) firmly applied over the nose and mouth, by gently flicking the soles of the feet. Pressure changes within the rebreathing chamber were

FIG. 1.—Diagram of apparatus for measuring crying vital capacity. The rubber tubing which connected the rebreathing chamber to the face mask and transducer was of low compliance and had an internal diameter of 0.92 cm and an external diameter of 1.39 cm.

measured with a micromanometer pressure transducer (Furness Controls Ltd., Bexhill). Recordings were made by pen on moving paper. The instrument was calibrated by injecting a known volume of air into the rebreathing chamber. The calibration factor was approximately 4 ml/mm pen deflection. 5 bursts of crying of about 20 seconds' duration were recorded in each baby and the maximum expiratory deflection was designated the CVC. The result was discarded if the difference between the two highest observations in a single record exceeded 4 ml. Before performing the test on babies with respiratory distress requiring oxygen therapy, the apparatus was filled with 90–100% oxygen.

Chest circumference was measured at the nipple line with the baby lying supine and the arms extended alongside the baby. Several methods of expressing the results were explored (see Discussion). In clinically normal babies CVC measurements from 5 to 14 days were steady and their mean was calculated and correlated with chest circumference or birthweight. The following coefficients were observed: *CVC v. birthweight* 0.84 (linear regression), 0.86 (power curve), 0.85 (exponential curve), *CVC v. chest circumference* 0.87 (linear regression), 0.87 (power curve), 0.89 (exponential curve). The function CVC ml/cm chest circumference was chosen for the analysis of all results because it is a simple concept which is biologically meaningful and not significantly different from more complicated functions.

Results

The mean $\pm$ SD birthweight, gestational age, and chest circumference, and the number of babies studied in each group at each postnatal age is shown in the Table.

Clinically normal babies. A linear correlation was shown between the mean of the CVC (ml) measurements between 5 and 14 days and chest circumference (cm) in babies of various sizes

TABLE
Description of babies

	Postnatal age						Mean $\pm$ SD		
	Hours				Days		Birthweight (kg)	Gestational age (w)	Chest circumference (cm)
	0–6	24	48	72	5	10			
Clinically normal									
No. of infants	173	159	146	116	95	90			
Term vaginal	61	58	52	35	33	19	3.33 $\pm$ 0.41	39.7 $\pm$ 0.9	32.2 $\pm$ 3.2
Term elective CS	47	37	30	27	24	23	3.33 $\pm$ 0.45	39.1 $\pm$ 1.1	32.6 $\pm$ 1.6
Term urgent CS	25	21	24	20	17	15	3.26 $\pm$ 0.40	39.2 $\pm$ 1.2	31.9 $\pm$ 5.5
Preterm vaginal	40	43	40	34	21	33	1.89 $\pm$ 0.37	34.3 $\pm$ 1.8	26.5 $\pm$ 2.2
Respiratory distress									
No. of infants	21	23	23	18	19	25			
HMD	10	12	10	8	8	12	2.43 $\pm$ 0.55	35.1 $\pm$ 3.3	28.5 $\pm$ 2.6
TT	11	11	13	10	11	13	2.69 $\pm$ 0.63	37.2 $\pm$ 2.0	30.1 $\pm$ 2.6

CS, caesarean section; HMD, hyaline membrane disease; TT, transient tachypnoea.

($r = 0.85$, $P < 0.001$) (Fig. 2). Term babies born vaginally had a range of mean $\pm$ SEM CVC at different times in the first 2 weeks of life of 2.76 ± 0.07 to 3.47 ± 0.1 ml/cm. By comparison, the values in preterm babies (1.81 ± 0.08 to 2.26 ± 0.09 ml/cm) and in term babies born by elective CS (2.27 ± 0.07 to 3.00 ± 0.1 ml/cm) were

FIG. 2.—Crying vital capacity (ml) and chest circumference (cm) of term babies born vaginally $\circ$, small-for-dates babies of various gestational ages $\bullet$, and preterm babies born vaginally $\times$. Each point represents the mean of several CVC measurements made between 5 and 14 days in a single baby.

smaller ($P < 0.02$) (Fig. 3). The difference between the mean CVC in term babies born vaginally and those born by elective CS was particularly significant within the first 48 hours of life ($P < 0.001$). However, there was never a significant difference between the mean CVC in term babies born vaginally and those born by urgent CS. During the first 48 hours of life the mean $\pm$ SEM CVC in term babies born by elective CS (2.27 ± 0.08 to 2.67 ± 0.07 ml/cm) was smaller than the corresponding value in babies born by urgent CS (2.53 ± 0.1 to 3.07 ± 0.1 ml/cm; $P < 0.05$).

Mean CVC (%) rose significantly in the first 24 hours of life in each group of clinically normal babies ($P < 0.02$) (Fig. 4), the degree of the rise varying between different groups. Compared with term babies born vaginally who had a mean $\pm$ SEM percentage rise of $15.5 \pm 2.8\%$, the corresponding result in preterm babies ($5.9 \pm 2.9\%$) and term babies born by elective CS ($7.4 \pm 2.6\%$) was

FIG. 3.—Mean $\pm$ SEM crying vital capacity (ml/cm) at various postnatal ages in clinically normal babies born at term vaginally $\square$, or by urgent caesarean section $\blacktriangle$, or elective caesarean section $\triangle$, in clinically normal preterm babies born vaginally $\times$, and in babies with transient tachypnoea $\bullet$ or hyaline membrane disease $\circ$.

smaller ($P < 0.02$). Though term babies born by urgent CS also had a smaller mean $\pm$ SEM percentage rise CVC in the first 24 hours ($10.0 \pm 4.5\%$) this was not significantly different from the result in term babies born vaginally. The sequential changes of CVC after the first day were of a different pattern in the various groups of babies. Term babies born by urgent CS were characterized by a rise in CVC from 24–48 hours ($P < 0.025$), those born by elective CS had a rise in CVC from 48–72 hours ($P < 0.05$), and preterm babies were characterized by a rise in CVC from 5–10 days ($P < 0.005$).

Babies with respiratory distress. Throughout the study, babies with HMD had a smaller mean CVC compared with the corresponding mean in each group of clinically normal babies ($P < 0.001$). Babies with TT had a smaller mean CVC at each postnatal age compared with the result in clinically normal term babies ($P < 0.001$) but a similar mean CVC in the first 72 hours of life compared with clinically normal preterm babies. However, the gestational ages of babies with TT ranged from 32–40 weeks (mean $\pm$ SD, 37.2 ± 2.0 weeks), which was significantly higher than the mean gestational age of clinically normal preterm

FIG. 4.—The mean percentage change of crying vital capacity at various postnatal ages in clinically normal babies born at term vaginally $\square$, or by urgent caesarean section $\blacktriangle$, or elective caesarean section $\triangle$, in clinically normal preterm babies born vaginally $\times$, and in babies with transient tachypnoea $\bullet$ or hyaline membrane disease $\circ$.

babies, and significantly lower than the mean gestational age of clinically normal term babies (see Table). At each postnatal age the mean CVC of babies with HMD was smaller than the corresponding result in babies with TT ($P < 0.005$). In contrast to clinically normal babies, those with TT or HMD had a smaller mean CVC at 24 hours compared with the measurement at 0–12 hours. Babies with HMD were unique in having a smaller mean CVC at 48 hours than at 24 hours.

A study of sequential changes of CVC between consecutive time periods provided a more critical analysis. The cumulative percentage change in CVC at 48 hours in babies with TT was $+33.9\%$ whereas in babies with HMD the corresponding value was -19.5% . This large difference was mainly accounted for by the mean $\pm$ SEM percentage change in CVC which occurred from 24–48 hours which was $+29.9 \pm 9.1\%$ in babies with TT, and $-9.6 \pm 5.6\%$ in babies with HMD ($P < 0.005$). All babies with TT had a rise in CVC from 24 to 48 hours whereas all babies with HMD except one had a fall in CVC during this period (Fig. 5).

FIG. 5.—Crying vital capacity (ml) at 24 and 48 hours in individual babies with transient tachypnoea $\bullet$ or hyaline membrane disease $\circ$.

Discussion

Measurement of CVC by reverse plethysmography was technically simple to perform, rapid, and safe. Each measurement took 5–10 minutes. Out of approximately 1000 individual measurements, vomiting into the mask occurred on 3 occasions and deepening cyanosis on crying into the mask occurred on 4 occasions.

Expression of results. One of the problems of comparing CVC in babies of different sizes is choosing a suitable way to express the results. Vital capacity in childhood correlates well with body length (Polgar and Promadhat, 1971). However, our object was to study the role of CVC measurements as an aid to assessment of babies with respiratory distress, and accurate measurements of body length of sick babies nursed in incubators is technically difficult. The justification for expressing CVC as ml/cm chest circumference was that no alternative correlation was significantly greater than the linear correlation of CVC with chest circumference (see Patients and methods). It was considered that chest circumference rather than birth-weight as a reflection of lung size was biologically more meaningful.

Clinically normal babies. CVC is depressed in conditions of reduced lung volume. Krauss *et al.* (1973) showed that CVC measured by spirometry in normal neonates and those with HMD correlated linearly with functional residual capacity measured by the helium dilution method. The smaller mean CVC and later mean percent rise of

CVC in term babies born by caesarean section compared with those born vaginally (Figs. 3 and 4) is compatible with a situation of reduced lung volume due to delayed clearance of lung fluid after caesarean section. At vaginal delivery a considerable positive intrathoracic pressure develops during compression of the thorax within the birth canal (Adams, Karlberg, and Lind, 1958). The discharge of fluid from the nose and mouth of the fetus at delivery of the head confirms the role of thoracic compression in the clearance of lung fluid at birth.

It is unlikely that developmental impairment of pulmonary surfactant properties account for the abnormal CVC results in babies born by caesarean section as these babies were born at term. The effect of maternally administered anaesthetic agents, sedatives, or analgesic drugs on CVC was not studied. Demonstrable neurological abnormalities were not present in any baby and all cried lustily into the mask. It is unlikely that maternally administered drugs influenced the ability to achieve a maximum cry in the second week of life when overt signs of neurological depression were not observed earlier. Furthermore, babies born by urgent caesarean section, rather than those born by elective caesarean section, would be expected to be particularly vulnerable to neurological depression as a result of analgesic drugs administered to mothers during labour and the occurrence of fetal asphyxia. However, the results showed that babies born by urgent caesarean section had a larger mean CVC in the first 48 hours of life, and did not have a significant late rise of CVC from 48–72 hours compared with babies born by elective caesarean section. Many babies born by urgent caesarean section were intubated immediately after birth and given intermittent positive pressure ventilation. Artificial expansion of the lungs after birth may aid in the clearance of lung fluid and mitigate the problem of establishing normal lung volume in those babies who are denied the benefit of thoracic compression within the birth canal. The possible beneficial effect of labour itself in preparing the lung for extrauterine life warrants further study.

Preterm babies born vaginally had a smaller mean CVC from 0–10 days compared with term babies born vaginally. It is unlikely that this finding was solely a reflection of lung size. Small-for-dates babies born at term who have a similar mean chest circumference to preterm babies of appropriate weight for gestational age have a larger mean CVC/chest circumference in the first 72 hours of life (personal observations). That the present findings reflect a functional difference in the lungs of preterm babies compared with term babies is

supported by the fact that preterm babies had a smaller mean percent rise in CVC in the first 24 hours and were characterized by a significant rise of CVC from 5–10 days.

Babies with respiratory distress. Babies with respiratory distress had a lower mean CVC within 12 hours of birth and had no significant rise of CVC from 0–24 hours compared with clinically normal babies of an equivalent gestational age. Approximately half of the babies with transient tachypnoea, a condition thought to be associated with delayed clearance of lung fluid after birth (Avery, Gatewood, and Brumley, 1966) were born by elective caesarean section. Fletcher, Sachs, and Kotas (1970) suggested that serial chest *x*-rays in newborn lambs born by caesarean section showed the presence of lung liquid which gradually cleared several hours after the onset of breathing. Progressive aeration of the lungs was associated with decreasing respiratory rates. Lung weight/body weight ratios measured post mortem were inversely related to pulmonary aeration assessed radiologically just before death. Chest *x*-rays in babies with transient tachypnoea in the present study were similar to those described by Kuhn, Fletcher, and DeLemos (1969). In spite of a cumulative mean percent rise in CVC from 24 hours to 10 days of more than 100%, babies with transient tachypnoea still had a smaller mean CVC at 10 days when they were symptom free compared with clinically normal term babies born vaginally. Delayed clearance of lung fluid after caesarean delivery may occur in varying degrees of severity and when encroachment on lung volume reaches a critical level clinical signs of respiratory distress follow.

An abnormally low CVC in babies with hyaline membrane disease was noted by other investigators (Sutherland and Ratcliffe, 1961; Orzalesi *et al.*, 1966; Krauss *et al.*, 1973) and may be attributed to the widespread atelectasis which is a prominent feature of this disease. In the present study, though the mean CVC within 6 hours of birth was significantly smaller in babies with HMD compared to babies with TT, a single measurement in an individual baby within 6 hours of birth did not permit these conditions to be distinguished because of a wide scatter of results. In contrast, the percentage change in CVC from 24–48 hours in individual babies with signs of respiratory distress distinguished those babies with HMD from those with TT. The 2 babies with HMD who died on the third day had the greatest percent fall in CVC from 24–48 hours. In spite of clinical recovery the mean CVC at 10 days in babies with HMD

was smaller compared with clinically normal preterm babies at 10 days. Orzalesi *et al.* (1966) showed that babies with HMD disease had abnormally small CVC's at 1 month despite complete clinical and radiological recovery.

The measurement of CVC is a rapid 'bedside' test of neonatal lung function. As the technique is noninvasive and detects differences in lung function between groups of clinically normal babies it is useful for the study of perinatal influences on the establishment of lung volume after birth. In babies with respiratory distress it is an adjunct to clinical assessment, chest radiology, and measurement of blood gases. One difficulty in assessing the efficacy of various therapeutic regimens for HMD is the problem of early prediction of the severity of the disease. The present preliminary findings suggest that serial measurements of CVC during the second day of life are valuable for distinguishing TT from HMD. Whether similar measurements in the first 6 hours of life will be of value in predicting the severity of HMD in order to justify the early use of continuous positive airways pressure remains to be seen.

We are grateful to Professor J. A. Davis for encouragement, and to Miss S. Westcott and Miss M. Cassie for devoted technical assistance. Financial support from

the Research Grants Committee of the United Manchester Hospitals is gratefully acknowledged.

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Correspondence to Dr. M. L. Chiswick, Special Care Baby Unit, St. Mary's Hospital, Hathersage Road, Manchester M13 0JH.