

# Closing volume during normal pregnancy

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**Garrard, G S, Littler, W A, and Redman, C W G (1978). Thorax, 33, 488–492. Closing volume during normal pregnancy.** Serial lung function studies were performed in ten healthy, primiparous women aged 21–28. Measurements were made at two-monthly intervals during pregnancy and included functional residual capacity (FRC), total lung capacity (TLC), vital capacity (VC), specific conductance (SGaw) and closing volume (CV) on each occasion.

Closing volume expressed as  $\frac{CV}{VC} \%$  or as  $\frac{CV+RV}{TLC} \%$  ( $\frac{\text{closing capacity}}{TLC} \%$ ) showed a progressive rise during pregnancy in all subjects with a linear relationship to time ( $P < 0.001$ ,  $P > 0.01$ , respectively).

No consistent changes in lung volume could be shown during pregnancy over the study period.

It is suggested that the increase in closing volume during pregnancy might result in abnormalities of distribution of ventilation sufficient to explain the maternal blood gas disturbances of pregnancy.

The appearance of dyspnoea in early pregnancy (Cugell *et al*, 1953) in conjunction with blood gas changes (Lucius *et al*, 1970) has suggested the development of ventilation/perfusion mismatching in early pregnancy. In an attempt to define ventilation distribution abnormalities we have studied sequential changes in lung volumes and closing volumes throughout pregnancy in a small, closely defined, group of women.

## Methods

We have studied a group of 10 healthy, normotensive, non-smoking, primigravid women aged 21–28, all of whom gave their informed consent (table 1). Pulmonary and ventilatory function was measured in most subjects at two-monthly intervals from the 10th to 12th week up to term. These measurements included functional residual capacity (FRC), total lung capacity (TLC), residual volume (RV), vital capacity (VC) and specific conductance (SGaw) measured plethysmographically (DuBois *et al*, 1956). Measurements of FRC were made during resting tidal breathing and not during panting. Any error in shutter closure not coinciding with end-expiration

**Table 1** Characteristics of ten pregnant subjects. Lung volumes and specific conductance expressed as mean value of all estimations made on each subject

Subject	Age (years)	Height (cm)	FRC (l)	TLC (l)	VC (l)	SGaw (kPA <sup>-1</sup> s <sup>-1</sup> )
1	21	170	2.7	4.5	3.1	0.11
2	24	158	2.1	4.3	3.2	0.16
3	26	162	2.0	3.8	3.0	0.19
4	23	162.5	2.1	4.1	3.0	0.15
5	22	160	2.5	4.5	3.0	0.16
6	25	157.5	2.3	4.5	3.4	0.19
7	27	167.5	2.3	4.3	3.1	0.22
8	23	175	2.4	4.8	3.4	0.15
9	24	167.5	2.1	4.1	3.0	0.19
10	28	162.5	1.8	3.4	2.3	0.20

was corrected for by reference to a simultaneous record of the volume spirogram. Similarly, SGaw was measured during the tidal breathing of warm, moist air fulfilling BTPS conditions. The volume spirogram obtained from the flow signal integral of the body box pneumotachograph was used to measure inspiratory capacity (IC) and VC (for calculation of TLC and RV). Closing volume was measured by a nitrogen bolus technique (Anthonisen *et al*, 1969). Five measurements of closing volume were made on each subject at each attendance. Volume measurements were made using a wedge spirometer and recorded together with the expired nitrogen signal on an X-Y recorder. The first three measurements of CV to fall within a 10% coefficient

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of variation were used in data analysis. All the above measurements were made with the subjects in the upright seated position.

## Results

### LUNG VOLUMES

Lung volume changes in relationship to CV in case 1 can be seen as an example in fig 1. Although there appears to be a fall in lung volumes at 38 weeks in this subject, CV, expressed as  $\frac{CV}{VC}\%$  or  $\frac{CV+RV}{TLC}\%$  shows a progressive increase independent of lung volume ( $r=0.981$ ,  $P<0.02$ ). The lung volume regressed with time in seven subjects (those with best time span of investigations) (fig 2). Individual and group correlation coefficients (table 2) show both positive and negative correlations for the individual data so that the grouped data show no significant regression with time. Case 5, however, shows a significant fall in both FRC and TLC. Coefficient of variation of slopes of box pressure versus mouth pressure for derivation of FRC by body plethysmography on any one occasion was less than 3.4%.

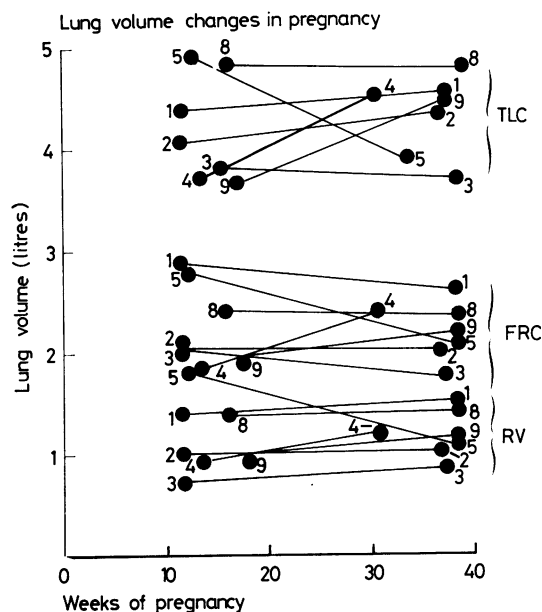


Fig 2 Regressions of lung volume with time (weeks of pregnancy) for seven of ten subjects.

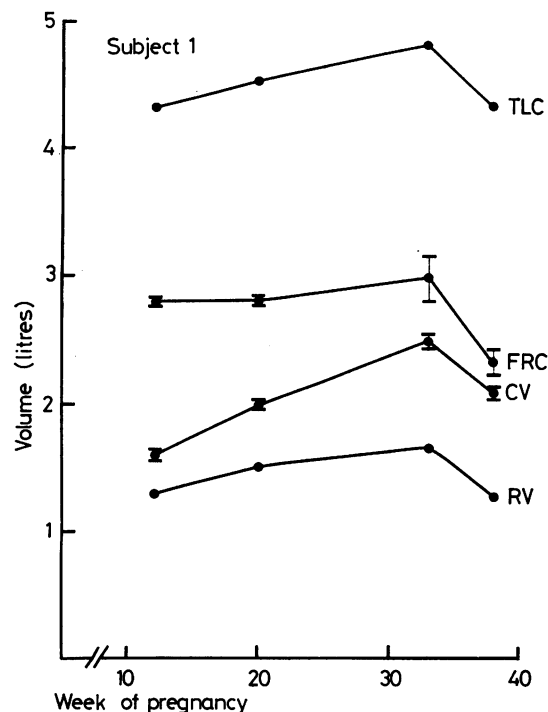


Fig 1 Relationship of closing volume to lung volumes in case 1. Bars indicate  $\pm 1$  SD.

### CLOSING VOLUMES

Closing volumes expressed as a percentage of vital capacity ( $\frac{CV}{VC}\%$ ) and closing capacity as a percentage of total lung capacity ( $\frac{CV+RV}{TLC}\%$ ) showed a progressive rise during pregnancy in all subjects (figs 3 and 4). Due to low degrees of freedom for individuals, only case 1 showed a significant regression for  $\frac{CV}{VC}\%$  with time ( $P<0.02$ ). Regressions for grouped data, however, show significant increases ( $\frac{CV}{VC}\%$   $P<0.001$ ;  $\frac{CV+RV}{TLC}\%$   $P<0.01$ ). Correlation coefficients for individual and grouped data are given in table 2. Ideally, to eliminate the heterogeneity of variance introduced by expressing data in the form of a percentage, an angular transform should have been performed on percentage data. However, after transforming data, regressions of CV with time remained significant—for example,  $r$  value for  $\frac{CV}{VC}\%$  against time fell from 0.686 to 0.600 after transform,  $P<0.001$ ;  $r$  value for  $\frac{CV+RV}{TLC}\%$  was unchanged. Data have, therefore, been left in the untransformed state. The mean coefficient of variation of CV

Table 2 Correlation coefficient of closing volumes and lung volumes with time (weeks of pregnancy)

Subject	CV/VC%	CV+RV %		FRC	TLC	RV	VC	SGaw	n
		TLC	VC						
1	+0.981*	+0.879	-0.450	+0.343	+0.301	+0.406	-0.977*		
2	+0.880	+0.550	-0.868	+0.659	+0.025	+0.451	+0.738		
3	+0.358	+0.611	-0.226	-0.369	+0.114	-0.897*	+0.656		
4	+0.566	+0.986	+0.931	+0.994	+0.978	+0.963	+0.814		
5	+0.665	+0.022	-0.970*	-0.999*	-0.806	-0.645	+0.244		
6	+0.711	+0.747	+0.152	+0.248	+0.524	-0.500	-0.581		
7	+0.965	+0.962	+0.713	+0.826	+0.937	-0.990			
8	+0.519	+0.431	-0.181	-0.220	+0.065	-0.188	-0.338		
9	+0.946	+0.928	+0.391	+0.836	+0.518	+0.896	+0.943		
10	+0.999	+0.883	-0.790	-0.681	+0.363	-0.979	-0.989		
Total	+0.686	+0.457	-0.089	+0.115	+0.052	+0.120	+0.327		
Significance	P < 0.001	P < 0.01	NS	NS	NS	NS	P < 0.05		

\*Indicates significant correlations in individuals.

Degrees of freedom = n - 2.

measurements for all subjects was 6.7% with a range of 2.7% to 22.2%. Regression with time of each of the three estimations of CV (on each occasion) in the subjects with the poorest coefficients of variation (Cases 2 and 3) improved the correlations in these subjects.

Closing volumes measured before the 18th week of pregnancy were within normal (non-pregnant) predicted limits for age (Buist and Ross, 1973; Collins *et al*, 1973), thereafter rising to abnormal levels.

Although grouped data for SGaw show a significant increase, individual data show both positive and negative correlations with time (table 2). Case 1 was the only subject to show a significant change in SGaw (decrease), which was not in keeping with the overall trend.

## Discussion

In contrast to previous studies, we have failed to confirm significant changes in lung volumes during pregnancy. The vital capacity, which is one of the most convenient volumes to measure, has been reported by several workers as being increased, decreased, or unaltered (Alward, 1930; Anthony and Hansen, 1934; Thompson and Cohen, 1938; Gazioglu *et al*, 1970). Lung compliance would appear to remain unchanged throughout pregnancy (Gee *et al*, 1967), findings that would be consistent with an unchanging VC. Inspiratory capacity has been shown by many workers to increase while others have shown it to remain unchanged (Cugell *et al*, 1953). TLC appears to remain unaltered, but small reductions in FRC have been consistently reported (Cugell *et al*, 1953; Prowse and Gaensler, 1965; Gee *et al*, 1967). These changes, however, have been relatively small, in the region of 18%. Surprisingly,

diaphragmatic excursions do not seem to be adversely affected by the gravid uterus even late in pregnancy (McGinty, 1938; Stewart, 1951). Relaxation of abdominal musculature and the ligamentous attachments of the ribs may result in the lung volumes and chest mobility remaining unaltered (Bonica, 1967). Bearing in mind the small changes that have been shown and the large day-to-day and cyclical variations in lung volumes that have been reported in normal, non-pregnant women (Hlastala *et al*, 1973), such results as ours are perhaps not unexpected. Eng *et al* (1975) in studying a group of obese women failed to show a significant change in FRC during pregnancy. Their group mean values for FRC (2.061) are similar to our results (2.21). Many of the subjects we studied complained of difficulty in performing VC manoeuvres even in early pregnancy. This might explain the generally low values obtained for VC and TLC. We had intended to perform postpartum studies, but this plan had to be abandoned when four of the subjects became pregnant again before restudy.

Small alteration in lung mechanics, if present, would not be adequate to explain the dyspnoea that is present in up to 70% of women during pregnancy, often during the first and second trimesters (Thompson and Cohen, 1938; Cugell *et al*, 1953). Such dyspnoea is probably related to subjective awareness of the inappropriate hyperventilation, which is one of the most consistent changes seen during pregnancy (Root and Root, 1923; Plass and Oberst, 1938; Widlund, 1945). This finding in conjunction with the blood gas disturbances in pregnancy (Lucius *et al*, 1970) has led to the postulation of  $\dot{V}/\dot{Q}$  abnormalities in early pregnancy.

Bevan *et al* (1974) showed that closing volume, as a method of studying ventilation distribution, encroached on the tidal range of breathing during late pregnancy. However, this was assuming quite large

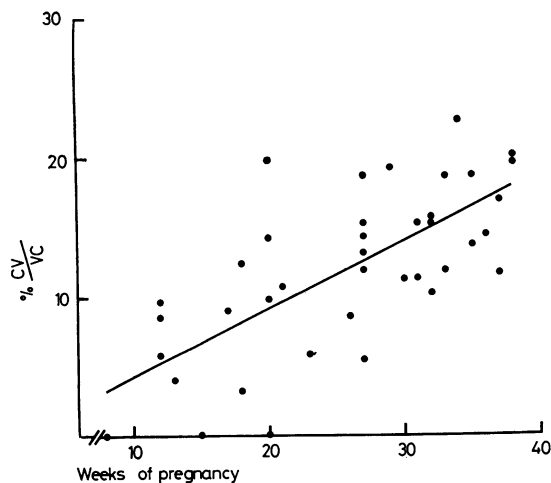
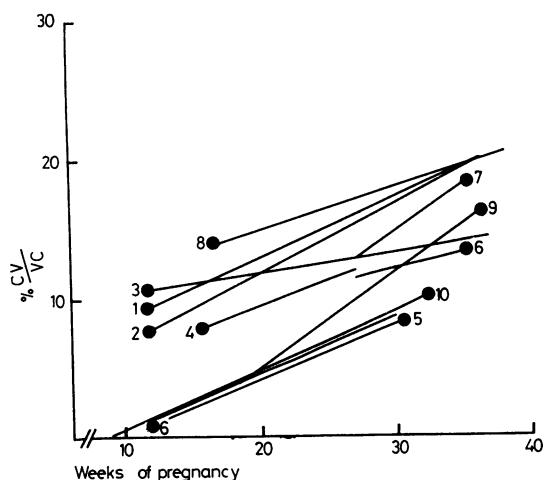


Fig 3 Regressions of closing volume as a percentage of vital capacity ( $CV/VC\%$ ) with time (weeks of pregnancy). Individual regression lines for ten subjects (top) and common regression for grouped data (bottom)  $P < 0.001$ . Values for  $r$  are given in table 2.

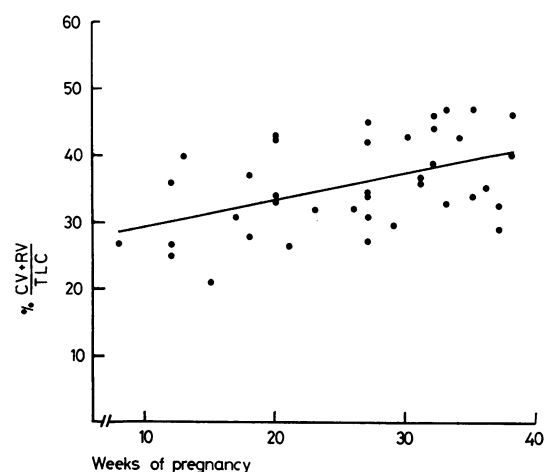
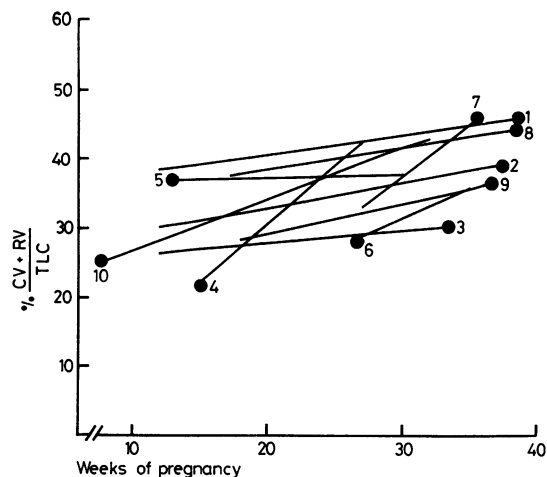


Fig 4 Regression of closing capacity as a percentage of total lung capacity ( $CV+RV/TLC\%$ ) with time (week of pregnancy). Individual regression lines for ten subjects (top) and common regression for grouped data (bottom)  $P < 0.01$ . Values for  $r$  are given in table 2.

falls in FRC. Their subjects were a somewhat heterogeneous group including both normotensive and hypertensive subjects. In contrast, Craig and Toole (1975) showed closing capacity ( $CV+RV$ ) to remain unchanged during pregnancy. Using a helium dilution technique they measured fall in RV sufficient to cancel out increases in CV. We have shown significant increases in closing capacity in a small group of pregnant subjects. All were normotensive and primiparous and none were smokers.

Interpretation of closing volume data must be made with care. Such measurements in normal

subjects can be extremely variable (Burki *et al*, 1975), and other factors, such as volume history and smoking (Malo and Leblanc, 1975), may greatly influence results. Careful repeated and controlled measurements made serially in normal subjects, however, are probably valid, and we have shown a significant change in closing volume. Although closing volume changes are not large enough to encroach on the tidal range of breathing, they do indicate some abnormality in ventilation distribution within the lung during pregnancy. We can speculate only as to the cause of the increasing closing volume. An increase in lung

water of pulmonary circulating volume or a change in the elastic properties of the lung might explain the changes we have shown. Clearly, further studies are required to clarify these disturbances.

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## References

- Alward, H C (1930). Observations on the vital capacity during the last month of pregnancy and the puerperium. *American Journal of Obstetrics and Gynecology*, **20**, 373–382.
- Anthonisen, N R, Danson, J J, Robertson, P C, and Ross, W (1969). Airway closure as a function of age. *Respiration Physiology*, **8**, 58–65.
- Anthony, A J, and Hansen, R (1934). Lungenventilation und Atmung in der Schwangerschaft. *Zeitschrift für Geburtshilfe und Gynäkologie*, **107**, 186–202.
- Bevan, D R, Holdcroft, A, Loh, L, MacGregor, W G, O'Sullivan, J C, and Sykes, M K (1974). Closing volume and pregnancy. *British Medical Journal*, **1**, 13–15.
- Bonica, J J (1967). *Principles and Practice of Obstetric Analgesia and Anesthesia*. F A Davis Company, Philadelphia.
- Buist, A S, and Ross, B B (1973). Closing volume as a simple, sensitive test for the detection of peripheral airways disease. Fifteenth Aspen Conference Proceedings, *Chest*, **63** (supplement), 295–305.
- Burki, N K, Barker, D B, and Nicholson, D P (1975). Variability of the closing volume measurement in normal subjects. *American Review of Respiratory Disease*, **112**, 209–212.
- Collins, J V, Clark, T J H, McHardy-Young, S, Cochrane, G M, and Crawley, J (1973). Closing volume in healthy non-smokers. *British Journal of Diseases of the Chest*, **67**, 19–27.
- Craig, D B, and Toole, M A (1975). Airway closure in pregnancy. *Canadian Anaesthetists' Society Journal*, **22**, 665–672.
- Cugell, D W, Frank, N R, Gaensler, A, and Badger, T L (1953). Pulmonary function in pregnancy. I Serial observations in normal women. *American Review of Tuberculosis*, **67**, 568–596.
- DuBois, A B, Botelho, S Y, Bedell, G N, Marshall, R, and Comroe, J H jun (1956). A rapid plethysmographic method for measuring thoracic gas volume: a comparison with a nitrogen washout method for measuring functional residual capacity in normal subjects. *Journal of Clinical Investigation*, **35**, 322–326.
- Eng, M, Butler, J, and Bonica, J J (1975). Respiratory function in pregnant obese women. *American Journal of Obstetrics and Gynecology*, **123**, 241–245.
- Gazioglu, K, Kaltreider, N L, Rosen, M, and Yu, P N (1970). Pulmonary function during pregnancy in normal women and in patients with cardiopulmonary disease. *Thorax*, **25**, 445–450.
- Gee, J B L, Packer, B S, Millen, J E, and Robin, E D (1967). Pulmonary mechanics during pregnancy. *Journal of Clinical Investigation*, **46**, 945–952.
- Hlastala, M P, Wranne, B, and Lenfant, C J (1973). Cyclical variations in FRC and other respiratory variables in resting man. *Journal of Applied Physiology*, **34**, 670–676.
- Lucius, H, Gahlenbeck, H, Kleine, H O, Fabel, H, and Bartels, H (1970). Respiratory functions, buffer system and electrolyte concentrations of blood during human pregnancy. *Respiration Physiology*, **9**, 311–317.
- Malo, J L, and Leblanc, P (1975). Functional abnormalities in young asymptomatic smokers with special reference to flow volume curves breathing various gases. *American Review of Respiratory Disease*, **111**, 623–629.
- McGinty, A P (1938). Comparative effects of pregnancy and phrenic nerve interruption on the diaphragm and their relation to pulmonary tuberculosis. *American Journal of Obstetrics and Gynecology*, **35**, 237–248.
- Plass, E D, and Oberst, F W (1938). Respiration and pulmonary ventilation in normal and non-pregnant pregnant, and puerperal women. *American Journal of Obstetrics and Gynecology*, **35**, 441–449.
- Prowse, C M, and Gaensler, E A (1965). Respiratory and acid-base changes during pregnancy. *Anesthesiology*, **26**, 381–392.
- Root, H F, and Root, H K (1923). The basal metabolism during pregnancy and the puerperium. *Archives of Internal Medicine*, **32**, 411–417.
- Stewart, C J (1951). The diaphragm in pregnancy. *Tubercle*, **32**, 40–43.
- Thomson, K J, and Cohen, M K (1938). Studies on the circulation in pregnancy. II Vital capacity observations in normal pregnant women. *Surgery, Gynaecology and Obstetrics*, **66**, 591–603.
- Widlund, G (1945). The cardiopulmonary function during pregnancy. A clinical experimental study with particular respect to ventilation and oxygen consumption among cases at rest and after work tests. *Acta obstetrica et gynecologica Scandinavica*, **25**, supplement 1.

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