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Shape changes in static V-P loops from children's lungs related to growth

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Fagan, D. G. (1977). *Thorax*, **32,** 198–202. **Shape changes in static V-P loops from children's lungs related to growth.** Sixty-eight sets of deflation data from the left lungs of children who had died from non-pulmonary causes were analysed by the exponential equation model to derive theoretical values of Pst(1) for 50, 60, and 90% of the observed maximum inflation volume. The resultant P_{50}, $_{60}$, and $_{90}$ values were compared to the same values measured from graphic displays of the V-P data. The graphically derived Pst(1) data at 50, 60, and 90% of TLC were then plotted against the crown-heel length to demonstrate a shape change related to physical growth.

It was found that the form of the deflation curve in preterm infants did not fit an exponential model as satisfactorily as did the deflation curve from older children. The exponential model should be used with caution in small infants where Pst(1) values below P_{90} are sought. A maximum inflation pressure of +30 cm H_2O was found to produce a V_{max} within 98% of the hypothetical V_{INF} value.

The question whether there is a growth-related shape change in static pulmonary volume pressure (V-P) deflation curves has to some extent been confused by the different methods of data presentation used in human postmortem data (Fagan, 1969; Stigol *et al.*, 1972; Fagan, 1976), animal experiments (Havránková and Kuncová, 1971), and clinical studies (Turner *et al.*, 1968; Zapletal *et al.*, 1971; Zapletal *et al.*, 1976), and differences in the level of inflation which was regarded as equivalent to *in-vivo* maximum lung capacity (TLC).

A method of V-P loop analysis, developed by Salazar and Knowles (1964), is finding increasing application in experimental animal and *in-vivo* human experiments (Turner *et al.*, 1968; Glaister *et al.*, 1973; Mansell *et al.*, 1977) because it does not depend on an arbitrary TLC.

This method involves a mathematical analysis to fit an exponential equation to the observed deflation data, and from this to predict the static elastic recoil pressure (Pst(1)), at given proportions of TLC.

In this paper the V-P data collected by the methods described in a previous communication (Fagan, 1976) from children's lungs obtained at necropsy, with body lengths ranging from 33 to 168 cm, are analysed by the exponential regression method described by Salazar and Knowles (1964). The results of this analysis are compared with the results from measurement of the same Pst(1) values from the same data displayed graphically. The graphically derived Pst(1) data are then analysed by linear regression to demonstrate a change in Pst(1) at 50%, 60%, and 90% TLC (P_{50}, P_{60}, and P_{90}) related to increasing physical stature.

This constitutes evidence for a growth-related deflation curve shape change where a shape change is defined as a change in Pst(1) at a given proportion of maximum inflation volume.

Material and methods

The left lung was reserved at necropsy in a series of infants and children who had died from non-pulmonary causes. The lungs were inflated and deflated in a stepped manner using fixed pressure intervals to obtain static V-P data. The full details of the methods, population, and controls are described in a previous communication (Fagan, 1976). The standard maximum inflation pressure was +30 cm H_2O. The deflation V-P data from each of the 74 lungs designated normal after subsequent histological examination were analysed to find a 'best fit' single exponential equation using an iterative procedure on a Hewlett-Packard 9810A computer.

The form of the equation used was $V = V_{INF}\ (1\text{-}e^{-KP})$, where V=the observed lung volume, V_{INF}=the volume asymptote, or the theoretical volume of the lung at infinitely high pressure, P=Pst(l) at the observed lung volume, and K=a constant.

Of the 74 lungs designated normal, three were excluded from the series because the computer failed to find a solution within 10 minutes, two were excluded because the solution found had a correlation coefficient value (r) of <0·97, and one was excluded because less than four values had been recorded during deflation. A further three values from each regression analysis were deleted as being unusually high or low.

The solution was then used to predict $P_{50},\ {}_{60},\ {}_{70},\ {}_{80}$, and ${}_{90}$, that is, Pst(l) at 50%, 60%, 70%, 80%, and 90% of the observed V_{max} of the left lung. In order to compare data obtained by the exponential and graphic methods, mean values of sets of grouped deflation data were plotted, and the $P_{50},\ {}_{60},\ {}_{70},\ {}_{80}$, and ${}_{90}$ were read off the resultant curve when the individual points were joined by a free-hand smoothed curve and by straight lines.

When these results were scrutinised, some of the preterm and full-term infant group results were re-computed with and without observed volume values at zero transpulmonary pressure (V_0).

Results

The mean correlation coefficient and standard deviation for all 68 deflation curves were analysed exponentially, r=0·995, SD=0·005.

The ratio $\frac{V_{max}}{V_{INF}}$ was calculated to ascertain whether the observed V_{max} using a transpulmonary pressure of +30 cm H_2O approached the asymptote, V_{INF}. The resultant mean was V_{max}= 0·993 V_{INF}, SD ±0·005. The individual results were plotted against body length, and linear regression analysis failed to show any change related to body length.

In Fig. 1 the deflation data from group A of Table 1 are plotted with ±1 SD. Since no significant difference between Pst(l) values from free-hand smoothing of the curve and straight line joining of the six points shown could be demonstrated (Table 2), the straight line is illustrated (Figs 1 and 2).

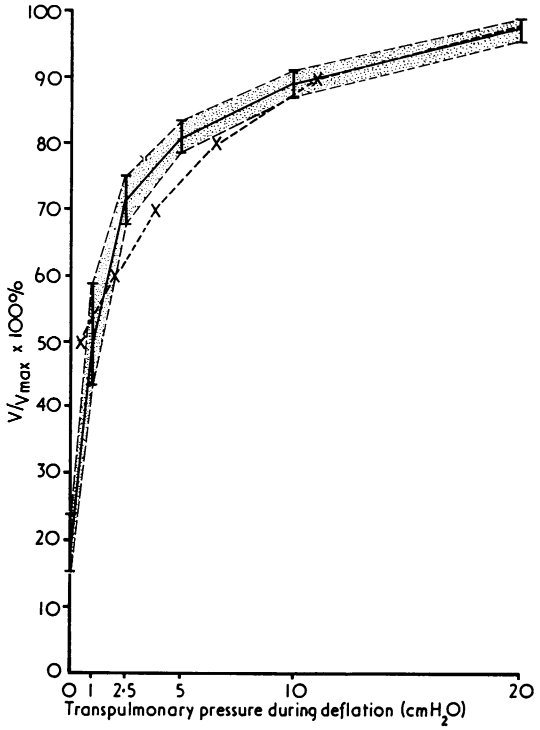

Fig. 1 *The mean deflation curve data from group A, Table 1, are plotted against the transpulmonary pressure. The shaded area indicates ±1 SD around each mean datum point. The datum points have been joined by straight lines. The second curve x - - - x results from finding the 'best fit' exponential regression equation and using that to predict the Pst(l) values shown at $V_{50},\ {}_{60},\ {}_{70},\ {}_{80}$, and ${}_{90}$. In this pooled example, correlation coefficient, r, =0·989.*

It can be seen that the mean expontial $P_{50}\ {}_{60}$, and ${}_{90}$ values all lie close to or within 1 standard deviation of the mean of the observed data, while the P_{70} and ${}_{80}$ values deviate beyond that limit. The results of the re-analysis of group A values without the V_0 data are shown in Table 2.

In Fig. 2 the mean data from group D, Table 1, are plotted in the same fashion as in Figure 1. All the exponential Pst(l) values now lie within 1 standard deviation about the mean observed values.

Figure 3 shows the graphic P_{90} values plotted against the body length (CH) in centimetres, with 95% confidence limits. The linear regression equation: P_{90}=0·067(CH)+8·14, SD±2·59, r=0·66, $p<0{\cdot}001$.

Figure 4 shows the P_{60} values plotted against the body length, again with 95% confidence limits. P_{60}=0·045(CH)+0·62, SD±1·43, r=0·79, $p<0{\cdot}001$.

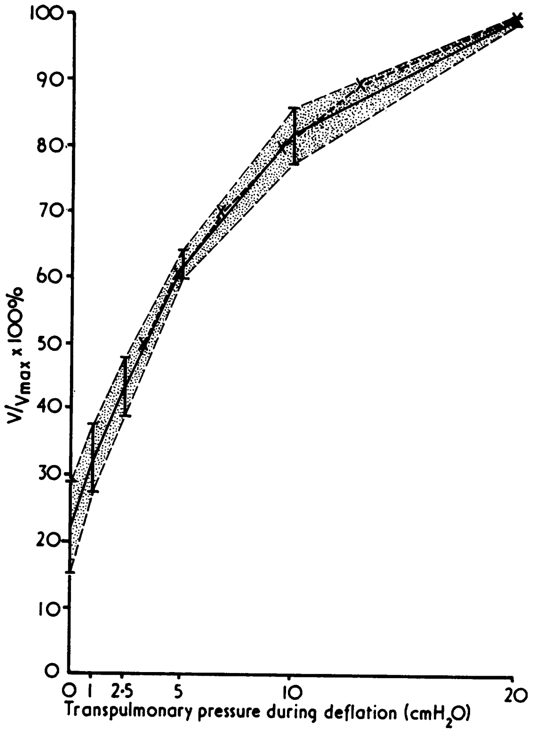

Fig. 2 *Shows the mean deflation curve data from group D, Table 1, plotted in the same manner as in Fig. 1, with the second curve x - - - x derived in the same manner as in Figure 1. In this example, r=0·999.*

Figure 5 shows the P_{50} values plotted against the body length with 95% confidence limits. $P_{50}=0{\cdot}032(CH)+0{\cdot}27$, $SD\pm0{\cdot}99$, $r=0{\cdot}82$, $P<0{\cdot}001$.

Discussion

Despite the high degree of mathematical correlation between the Pst(1) values in the pre-term (and some full-term) neonates, the theoretical curve is not a good fit (Fig. 1) as the predicted values go in runs above and below the observed data curve.

It is unfortunate that much of the information required from this form of analysis is in the area of maximum deviation. In the pre-term group (group A, Table 1), the Pst(1) values P_{70} and $_{80}$ deviate widely from the observed values while the P_{50}, $_{60}$, and $_{90}$ values lie on or within ±1 SD of the observed mean.

In addition to this problem, the amount of low pressure inflation data (Table 2) required to produce the 'best fit' exponential predictions of P_{50} and $_{60}$ must raise serious questions about the application of this method of V-P analysis in small infants.

The two valuable points about this method are that the predicted P_{90} values seem to lie very close to the graphically derived P_{90} values whether extended low-pressure data are available or not, and that the arbitrarily selected $P_{max}+30$ cm H_2O gives a V_{max} close to the asymptote.

It is also noteworthy that the exponential data from the older infants and children conform closely to the graphically derived data.

The P_{50} and $_{60}$ values (Figs 4 and 5) show the same high degree of correlation ($P<0{\cdot}001$), with body length as the P_{90}, although scrutiny of the slope of the regression lines suggests that the rate of change with growth of the P_{50} and $_{60}$ is different from that of the P_{90} values. At the present time it is uncertain if this is an artefact due to the mode of analysis or whether it suggests that the growth-related determinants of the P_{50} and $_{60}$ are different from those of the P_{90}.

The failure of the Salazar and Knowles form of equation to fit the small infant deflation curve adequately with progressive improvement of the 'adequacy of fit' with increasing stature suggests that a growth-related modification of the equation is possible, and this of itself in conjunction with the differences of slope of the P_{50}, $_{60}$, and $_{90}$ regression equation suggests that more complex

Table 1 *Data from the 68 cases grouped according to body length*

	Group A	Group B	Group C	Group D	Group E
Body length (cm)	30–45	46–55	56–65	66–90	91–168
Number of cases	8	26	13	13	8
Mean V_{20} (%)	97·0 ±1·5	96·20±1·36	96·0 ±1·4	96·3±1·5	96·2±0·95
Mean V_{10}	89·30±2·1	87·60±2·5	82·0 ±4·1	81·8±4·0	79·4±6·59
Mean V_5	81·0 ±2·2	77·40±4·1	65·30±3·8	62·8±2·4	59·1±5·89
Mean $V_{2\cdot5}$	71·40±3·7	61·10±8·4	48·30±5·2	43·7±4·3	43·6±9·1
Mean $V_{1\cdot0}$	50·90±7·8	41·10±7·4	32·10±6·6	32·9±5·0	—
Mean V_0	19·70±4·4	23·60±9·1	18·70±7·3	22·2±7·0	—

The mean V values are presented as percentages of the V_{max}, ±1 standard deviation at pulmonary pressure in cm H_2O, indicated by the suffix. Thus V_5=volume at + 5 cm H_2O during deflation maximum inflation volume, × 100%.

Table 2 *Pst(1) values at 50, 60, and 90% of V_{max} estimated by exponential function and graphic analysis for three groups shown in Table 1*

Mean values of	*Group A*			*Group B*			*Group D*		
	P_{50}	P_{60}	P_{90}	P_{50}	P_{60}	P_{90}	P_{50}	P_{60}	P_{90}
Exponential with V_0 data	0·61	2·06	10·98	1·48	3·06	12·62	3·17	4·74	14·13
Exponential without V_0 data	−0·85	0·84	11·09	0·72	2·39	12·46	3·17	4·73	14·10
Graphic smooth mean curve	0·99	1·50	10·95	1·55	2·3	12·2	3·30	4·8	14·85
Graphic straight line mean curve	0·99	1·70	11·05	1·65	2·4	13·1	3·35	4·8	15·73

All pressures are in cm H_2O.
The exponential values of P_{50}, P_{60}, and P_{90} using V_0 data lie close to or within the range of the mean of the observed values, ± 1 SD (see Fig. 1). The exponential values derived without the V_0 data at P_{50} and P_{60} of group A, and P_{50} of group B, lie well outwith the range of ± 1 SD about the observed means.
There seems to be little difference in the estimates derived by the different graphic analyses.

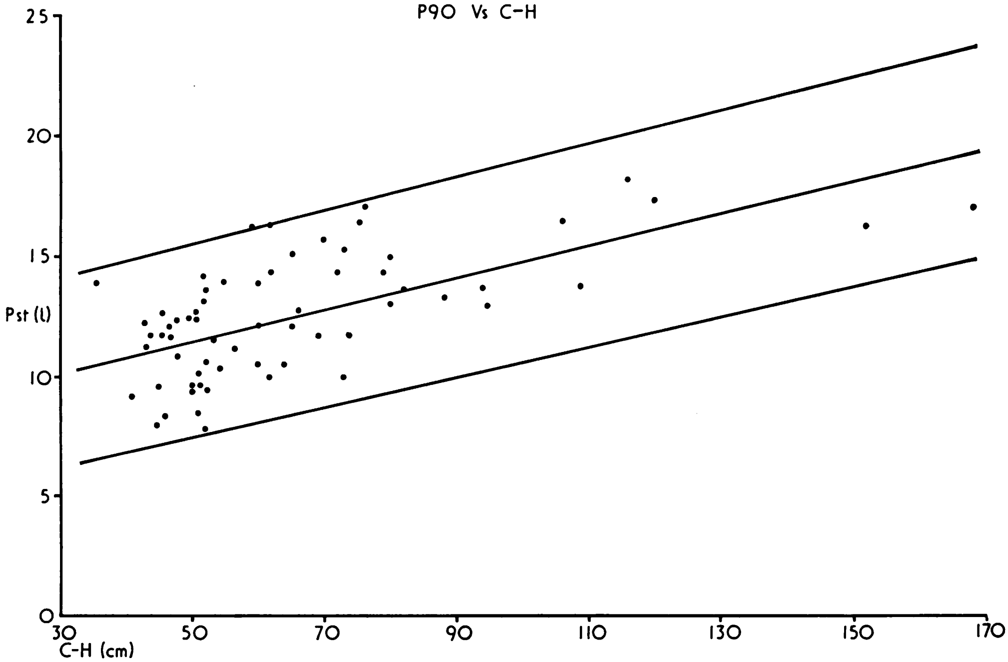

Fig. 3 *Shows the linear regression equation from plotting the individual P_{90} values obtained by graphic analysis against the crown-heel length: $Y=0{\cdot}067X+8{\cdot}14$, $\pm 2{\cdot}59$, $r=0{\cdot}66$, $P<0{\cdot}001$.*

changes of shape or form of the deflation V-P curve may be occurring in this period as well as the basic fact of a growth-related increase in static recoil at the inflation levels described.

This analysis shows that the changes seen in V-P loop shape when plotted in the proportional manner (Fagan, 1969; Havránková and Kuncová, 1971; Fagan, 1976) are quite consistent with the changes reported by Turner *et al.* (1968), Zapletal *et al.* (1971), and Zapletal *et al.* (1976), whether the index of development chosen is body length, maximum inflation volume, or body weight over the whole of the growth range studied.

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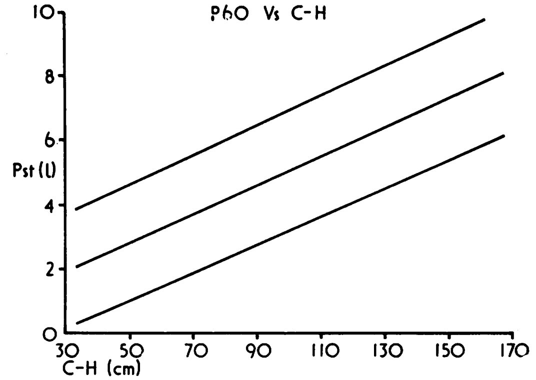

Fig. 4 *Shows the linear regression equation from plotting the individual P_{60} values obtained by graphic analysis against the crown-heel length: $Y=0{\cdot}045X+0{\cdot}62$, $\pm 1{\cdot}43$, $r=0{\cdot}79$, $P<0{\cdot}001$.*

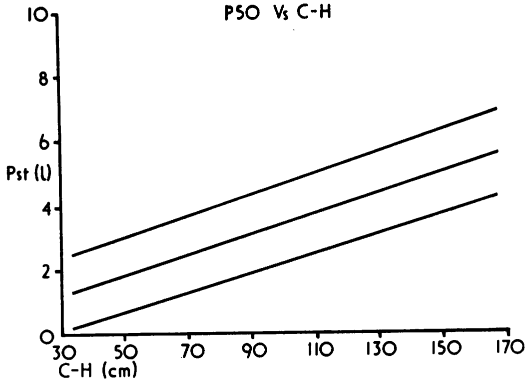

Fig. 5 *Shows the linear regression equation from plotting the individual P_{50} values obtained by graphic analysis against the crown-heel length: $Y=0{\cdot}032X+0{\cdot}27$, $\pm 0{\cdot}99$, $r=0{\cdot}82$, $P<0{\cdot}001$.*

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