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LUNG VOLUMES IN SCOLIOSIS BEFORE AND AFTER CORRECTION BY THE HARRINGTON INSTRUMENTATION METHOD

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The deleterious effect of structural scoliosis on lung volumes is well documented. A general survey of the influence of spinal deformities on cardiorespiratory function was reported by Bergofsky et al. (1959) and has been pointed out by, among others, Caro & DuBois (1961), Mankin et al. (1964), deCoster & Remacle (1967), Westgate (1967), Barois et al. (1972), Zorab (1973) and Bjure & Nachemson (1973). The reduction in lung volumes occurs at an early stage of the deformity and this reduction becomes more evident with the more severe curve. Since a severe spinal deformity is associated with cardiopulmonary symptoms and often failure, early diagnosis and treatment of scoliosis are imperative.

Reports of surgical techniques in the correction of scoliosis have often included their effects on lung function, but the results from this point of view are varying.

The purpose of this study is to evaluate, at the completion of treatment, the effect of Harrington instrumentation and fusion on lung volumes in scoliosis patients.

MATERIAL AND METHODS

Surgical procedure

The operative correction of the scoliosis was done with Harrington's distraction rod followed by spinal fusion with autogenous iliac bone. In the majority of patients, correction was done in two stages, with an interval of 2 weeks between operations. During this period the patient was kept supine in bed without external

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support. The second or fusion procedure was also followed by absolute recumbency for several weeks. At this second operation an average of 6 degrees of further correction of the scoliosis was achieved with the Harrington rod (Nordwall 1973). The patient was then allowed out of bed, fitted with a Milwaukee brace and could leave the hospital within a week. After 6 to 7 months of wearing a brace continuously, gradual weaning from the brace was carried out for another 6 to 9 months. Gradually increased activities were allowed until 18 months after surgery when the patients had no further restrictions placed on them.

Breathing program

During the stay at the hospital, the patient underwent a breathing program consisting of either conventional breathing exercises or the IPPB (intermittent positive pressure breathing).

Blowing up a balloon of 2– to 4–litre capacity was performed for unsupervised breathing training in both groups.

A. *Conventional breathing exercises*
   1. Deep breathing exercises with diaphragmatic, upper costal and lower costal breathing for general ventilation and expansion of the rib cage.
   2. Resistance added to the lower costal breathing for further expansion of the thorax.

B. *IPPB*

   The Bird respirator was used for intermittent positive pressure breathing to obtain deep inspiration with expansion of the chest.

   The two methods seemed to have the same effect, but the IPPB method has become the routine in training as it is the easiest for both the patient and the therapist.

Subjects

The study is based on measurements in 92 consecutive patients with scoliosis treated as above from 1967 to 1971: 87 patients had idiopathic scoliosis and five had paralytic scoliosis due to poliomyelitis. There were 83 females and nine males, aged 10 to 25 years (Table 1). Seventy-seven patients had dorsal curves, two had lumbar curves and 13 were operated for double major curves. The site and pre-operative degree of the curves and the degree at follow-up are also shown in Table 1. Cobb's method was used to measure the angle of the curves.

Lung volumes. Vital capacity, total lung capacity, functional residual capacity and residual volume were measured a week before surgery and during a reevaluation made at least 18 months postoperatively, i.e. when the patient had been brace-free for at least 3 months. The average time of follow-up was 2.9 years for patients with idiopathic scoliosis and 3.5 years for patients with paralytic scoliosis (Table1). Vital capacity was measured in the sitting positon using a Bernstein spirometer, and functional residual capacity was measured with the helium dilution technique.

Prediction of normal values. For this purpose a corrected height has been used. The diminished standing height in scoliosis patients makes it necessary to com-

pensate for the height loss when predicting normal values for lung volumes, to make possible a comparison between pre- and postoperative measurements.

Table 1. Physical characteristics of the patients before and after surgery.

	Idiopathic scoliosis 87 patients (M=7, F=80)				Paralytic scoliosis 5 patients (M=2, F=3)			
	Dorsal curve 73 Lumbar curve 2 Double major curve 12				Dorsal curve 4 Lumbar curve – Double major curve 1			
	Before surgery		After surgery		Before surgery		After surgery	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Age (years)	15.6				14.4			
Height (cm)	159.4	9.1	165.3	7.8	153.1	17.8	163.5	10.6
Height correction (cm)	5.1	2.7	2.1	1.5	10.1	5.0	4.5	2.2
Corrected height (cm)	164.4	9.1	167.4	7.9	163.2	18.3	168.0	12.1
Degree of scoliosis	72		38		99		67	
Follow-up time (range 1.5–5.0) years			2.9				3.5	

Using spine roentgenograms, the height reduction was quantitated by determining the difference in length of a wire superimposed on the actual roentgenographic curve as compared with actual vertical height of the spine (Bjure et al. 1968). The possible influence of kyphosis and lordosis was not taken into consideration but has been discussed since then by Bjure & Nachemson (1973). The logarithm of the trunk height loss (Y) was linearly correlated to the angulation of the curvature (X). $\text{Log } Y = 0.011\,X - 0.177$ (in the original paper the regression equation for this relation was given with an erroneous sign). For the 13 patients with double major scoliosis, both curves have been taken into consideration. The method is good in curves below 100°, but above this figure we overestimate the height loss and this error increases with increasing curvature. The reason for this might be that the regression line calculated from the logarithmic equation did not fit the individual values at the end of the curve. The original presentation of the method was based on 62 patients in whom most of the curves were below 100°. To make a more accurate correction of height loss in patients with severe curves, we have added another 13 patients with severe curves to the original number of 62, making a total number of 75 patients. A line is fitted by hand to the individual values of the relation between angulation of the curvature and trunk height loss. In this paper we have used the correction factors for different curvatures above 100°, taken from that relation and given in Figure 1 together with curves also below 100°. A table of the correction factor in centimetres for a given curvature is included in the figure. For practical use, however, the decimal has been rounded off to the closest 0.5.

Analysis of data. Measurements of vital capacity were made in all patients, but functional residual capacity and residual volume were not available in all cases. The results are presented in two ways: 1. In absolute values in litres. 2. In per cent

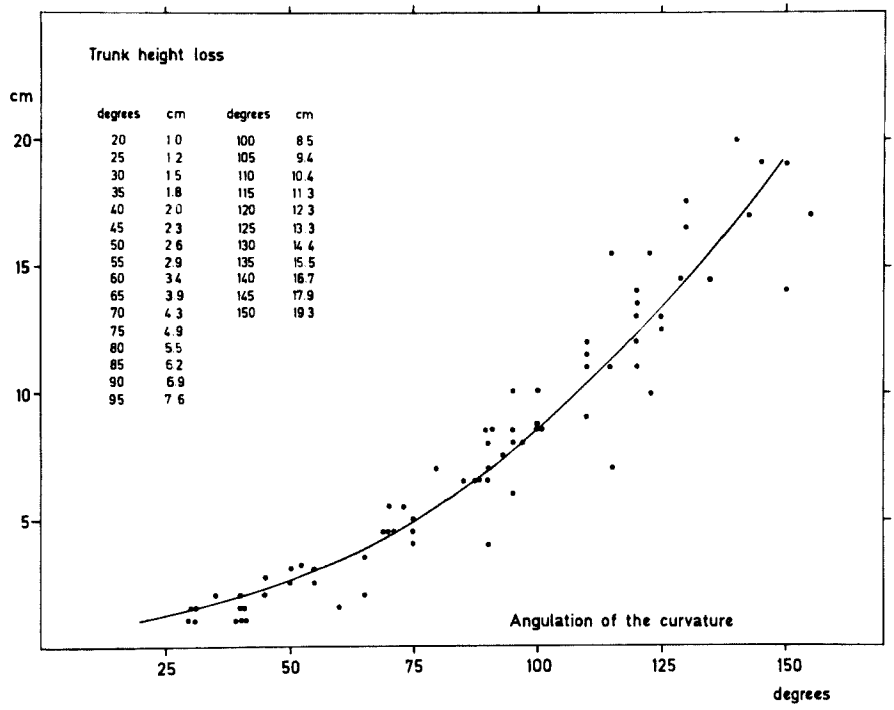

Figure 1. Correction factors in cm according to the degree of scoliosis.

of predicted normal values where the predictions are based on age and the corrected height using the correction factor presented above. The normal values were predicted according to the formulae given by Berglund et al. (1963), Grimby & Söderholm (1963) and for patients below 18 years of age according to the formula of Bjure (1963) for vital capacity and according to Helliesen et al. (1958) for other lung volumes.

To evaluate further the effect of the Harrington procedure of lung volumes, the idiopathic group was divided into three groups according to the preoperative curve, in order to discover if any possible correlation exists between changes in lung volumes after surgery and preoperative degree of curvature. Double major curves were classified with the thoracic curves. The three groups comprise patients with curves less than 60 degrees, from 60–89 degrees and more than 89 degrees (Table 2).

RESULTS

Effect of surgery on the curvature. The correction of the curvature by the Harrington procedure is seen in Table 1 for both idiopathic and paralytic scoliosis. The postoperative curves measured at follow-up show a reduction of 50 and 35 per cent respectively. The reduction with

Table 2. Characteristics of the patients with idiopathic scoliosis according to the degree of the curvature.

	< 60 ° 22 patients				60–89 ° 49 patients				> 89 ° 16 patients			
	Before surgery		After surgery		Before surgery		After surgery		Before surgery		After surgery	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Age (years)	14.4				15.8				16.8			
Height (cm)	160.4	5.1	165.7	4	159.8	10.5	165.3	9.3	156.7	9.0	164.6	7.1
Height correction (cm)	2.8	0.8	1.4	0.6	4.8	1.7	1.9	1.0	9.0	3.0	3.5	2.6
Corrected height (cm)	163.2	4.9	167.1	4.1	164.6	10.2	167.2	9.3	165.7	10.1	168.2	7.4
Degree of scoliosis	52		27		72		36		103		59	
Follow-up time (years)			3				2.6				3.2	

Table 3. Statistical results of the measurements of pulmonary function in the patients with idiopathic scoliosis.

	Before surgery		After surgery		*P*
	mean	s.d.	mean	s.d.	
VC in litres	2.7	0.64	3.2	0.59	< 0.001
VC in % normal "corrected"	67	14.5	77	12.4	< 0.001
TLC in litres	3.5	0.73	4.2	0.68	< 0.001
TLC in % normal "corrected"	71	12.7	81	10.7	< 0.001
FRC in litres	1.7	0.41	2.1	0.48	< 0.001
FRC in % normal "corrected"	70	13.6	80	14.5	< 0.001
RV in litres	0.8	0.27	1.0	0.33	< 0.001
RV in % normal "corrected"	79	24.8	89	26.6	< 0.005

VC = vital capacity
TLC = total lung capacity
FRC = functional residual capacity
RV = residual volume

respect to the preoperative angle of the curve is shown in Table 2 for idiopathic scoliosis, in which the severe group is to be compared with the paralytic group in Table 1.

The difference in corrected height before and after operation (Tables 1 and 2) gives a measure of the actual growth up to the time of follow-up. The mean correction factor for the idiopathic group all together (Table 1) was 5.1 cm before surgery and 2.1 cm after surgery. The cor-

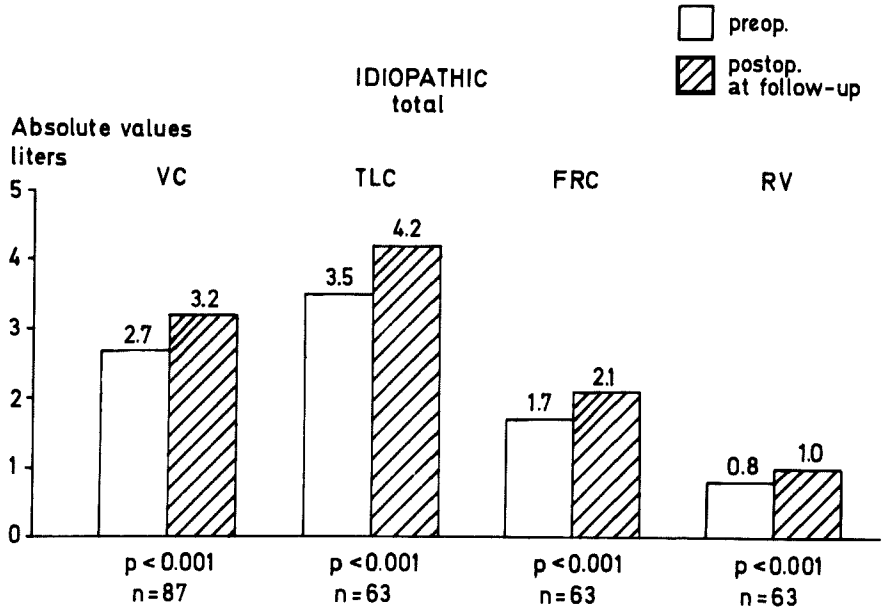

Figure 2. Lung volumes in litres pre- and postoperatively. Idiopathic scoliosis.

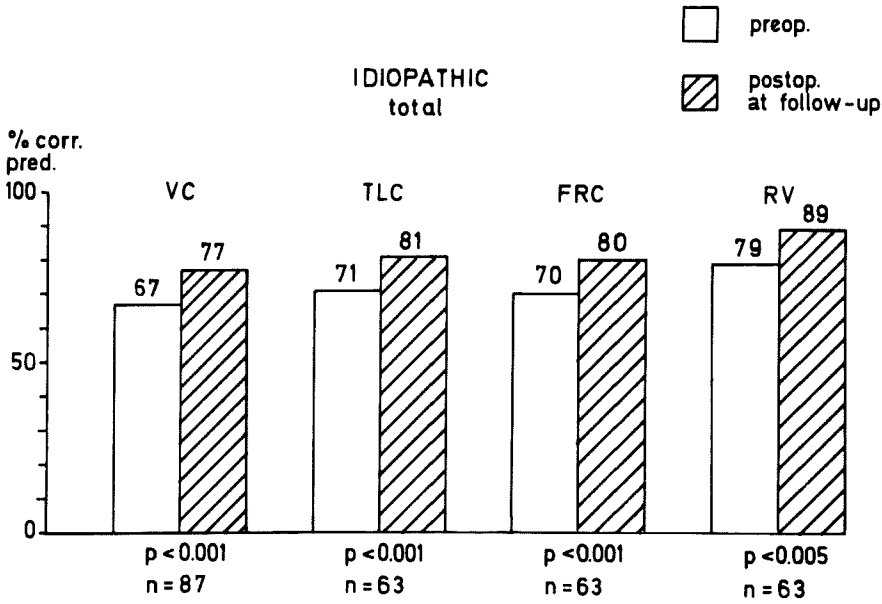

Figure 3. Lung volumes in per cent of predicted normal values pre- and postoperatively. Idiopathic scoliosis.

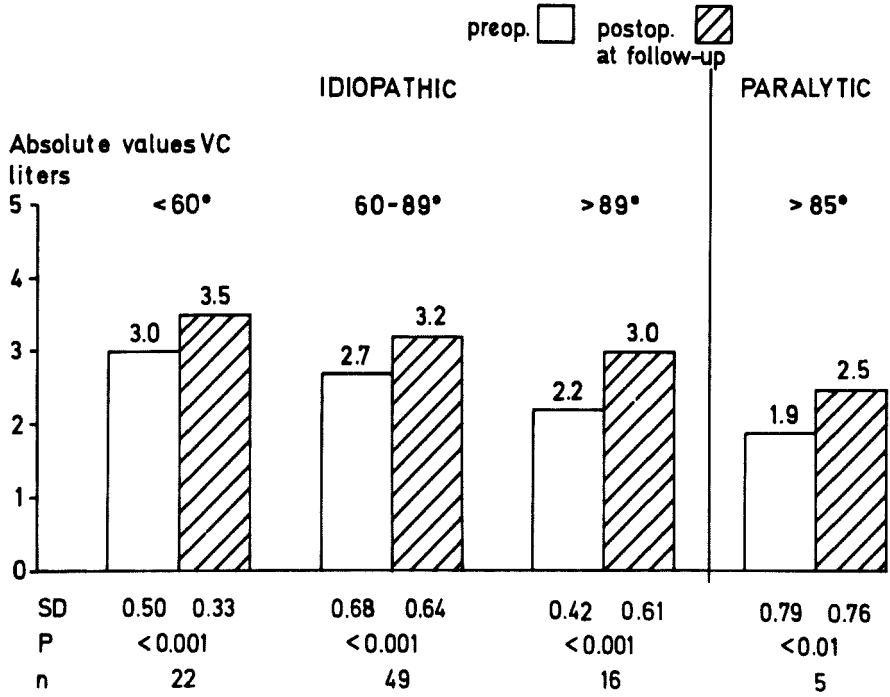

Figure 4. Vital capacity in litres pre- and postoperatively according to the preoperative degree of scoliosis. Idiopathic and paralytic scoliosis.

rected height averaged 164.4 cm and 167.4 cm respectively. According to the degree of the preoperative curvature (Table 2), the correction factor for idiopathic scoliosis less than 60 degrees was 2.8 cm before surgery and 1.4 cm after surgery, for the group of 60 to 89 degrees 4.8 cm and 1.9 cm, for more than 89 degrees 9 cm and 3.5 cm. The latter is to be compared with the severe paralytic group of 10.1 cm and 4.5 cm respectively (Table 1).

Effect of surgery on lung volume. The results are shown in absolute values in litres as well as in per cent of predicted normal values. Absolute values in litres alone will not give an accurate result of the effect of the surgery itself, since they do not take into account the natural increase in volumes due to growth. A comparison of predicted normal values according to corrected height gives a better evaluation of the operation procedure itself, excluding the growth factor. Figure 2 gives the result for the total idiopathic group in absolute values in litres. There were significant increases in vital capacity, total lung

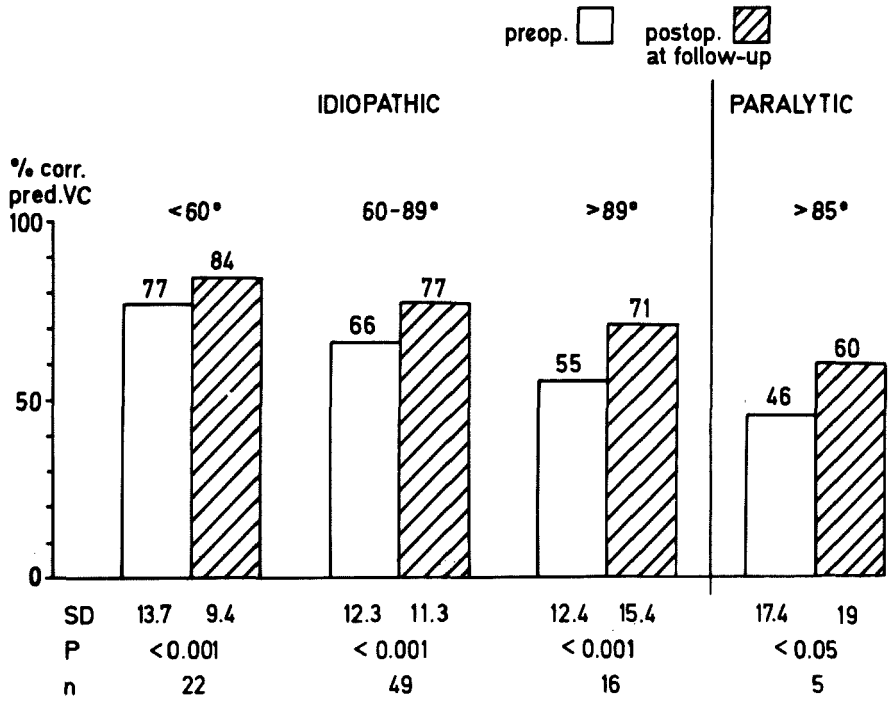

Figure 5. Vital capacity in per cent of predicted normal values pre- and post-operatively according to the preoperative degree of scoliosis. Idiopathic and paralytic scoliosis.

capacity, functional residual capacity and residual volume averaging 0.5, 0.7, 0.4 and 0.2 litres respectively. Figure 3 gives the result in per cent of corrected predicted normal values. For all volumes there was an increase of 10 per cent, which is highly significant.

When dividing the idiopathic group into three groups according to the preoperative degree of the curvature, the increase in litres for vital capacity was 0.5 litres for curves less than 60 degrees, 0.5 for curves 60 to 89 degrees and 0.8 litres for the more severe group with curves above 89 degrees. The last group can be compared with the severe paralytic group with a curve of more than 85 degrees, showing an increase of 0.6 litres (Figure 4). Figure 5 shows the increase in per cent of corrected predicted normal values. For the idiopathic subgroups the increase was 7, 11 and 16 per cent respectively and the paralytic group showed an increase of 14 per cent, all changes in volumes being highly significant.

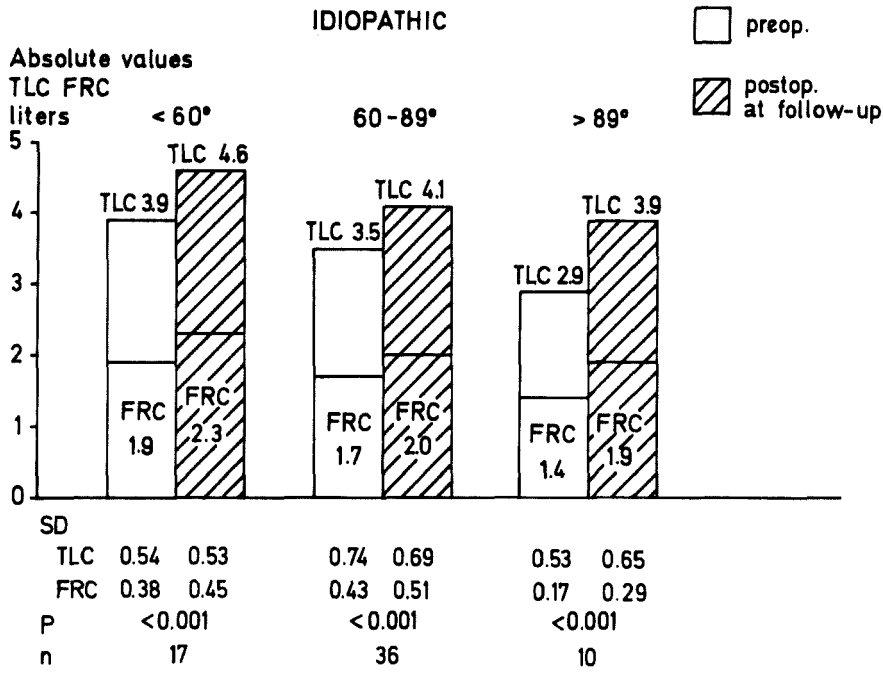

Figure 6. Total lung capacity and functional residual capacity in litres pre- and postoperatively according to the preoperative degree of scoliosis. Idiopathic scoliosis.

Absolute values for total lung capacity in the different subgroups of idiopathic scoliosis showed an increase of 0.7, 0.6 and 1.0 litres respectively (Figure 6). The increase of functional residual capacity in the same groups was 0.4, 0.3 and 0.5 litres. Figure 7 gives the data in per cent predicted to corrected height. For total lung capacity there were increases of 8, 9 and 16 per cent respectively, and for functional residual capacity the increases were 12, 7 and 18 per cent respectively, all increases being highly significant. Table 3 gives the results for the idiopathic group in total. The increase in residual volume was significant when counted up in a large number of patients. In smaller groups, however, the increase became less or not significant.

Thus for the idiopathic group an average 10 per cent increase in vital capacity, total lung capacity and functional residual capacity was obtained after surgery. When this increase was correlated with the preoperative angle of scoliosis, the increase turned out to be most obvious in the severe cases of scoliosis.

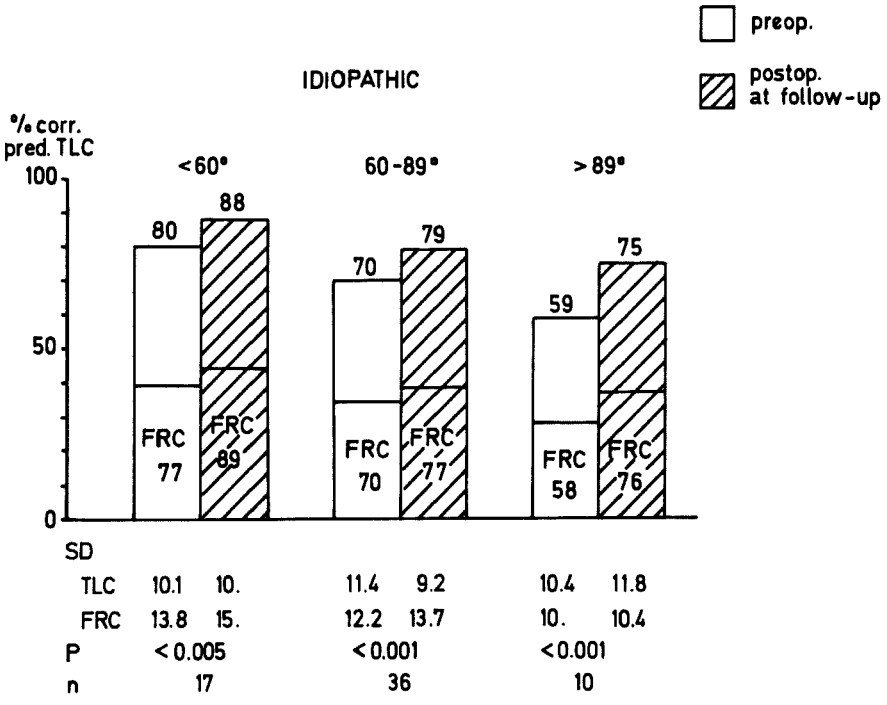

Figure 7. Total lung capacity and functional residual capacity in per cent of predicted normal values pre- and postoperatively according to the preoperative degree of scoliosis. Idiopathic scoliosis.

DISCUSSION

Scoliosis causes reduction in lung volumes, and the degree of the reduction varies with the severity of the curve. The paralytic subgroup is small but illustrates that with involvement of the respiratory muscles, the reduction in lung volumes is more marked than one would expect for idiopathic scoliosis of the same degree of severity.

When comparing lung function in scoliosis patients with lung function in normal persons, it is important to take into consideration the loss of height due to the spinal deformity. Various parameters have been used in predicting normal values for lung volumes in patients with scoliosis (Zorab & Prime 1963, Hepper et al. 1965, Vallbona et al. 1969, Johnson & Westgate 1970). The method described by Bjure et al. (1968), with its modification, is an easy way of correcting height for scoliosis and is valid in practice. The correction of height makes it

possible to compare pre- and postoperative values without influence of the natural increase in lung volumes due to growth.

One would expect, excluding any possible defects in the lung tissue, that a correction of the spinal curvature would increase the thoracic cavity, improve the rib movements on the concave side and thus make an increase of lung volumes possible. Cotrel (1965) found an improvement in vital capacity of 30–40 per cent with the EDF (Elongation Derotation Flexion) method and fusion, but this improvement was not calculated with a corrected height. Makley et al. (1968) demonstrated no significant improvement of pulmonary function following spine fusion. The application of a preoperative corrective device reduced lung volumes except when the halo apparatus was used. Cook et al. (1960) and Gucker (1962) had similar experiences and even showed a tendency for further decrease in lung volumes after fusion.

Previous reports of the actual effect of the posterior fusion with the Harrington instrumentation on lung volume have shown various results. Gazioglu et al. (1968) obtained a gain of 17 per cent in vital capacity for idiopathic scoliosis 1 year after surgery. A follow-up several years later did not change the results. The preoperative degree of the curvature did not influence the result. Predictions of normal values for vital capacity were made from measurements of arm span in normals. Meznik et al. (1972) showed, in the majority of cases, a mean increase of about 10 per cent with no information of the way of predicting lung volumes to normal. Westgate & Moe (1969) found a decrease in vital capacity 1 year after surgery as well as 5 years postoperatively. The preoperative height of the patient was used when predicting normal values of lung volumes. Meister & Heine (1973) reported no change in vital capacity 1 year after surgery and his predictions of vital capacity were calculated from pre- and postoperative heights. Vallbona et al. (1969) used a corrected height for predicting vital capacity and reported no significant change in lung volumes 1 year after surgery. Henche et al. (1971), using predicted height, showed a decrease in vital capacity 1 year after surgery for both idiopathic and paralytic scoliosis. A 2-year control, however, showed a 12 per cent increase in vital capacity for the idiopathic group, but for the paralytic scoliosis there was still a decrease compared to preoperative values.

This study showed an average increase of 10 per cent in idiopathic scoliosis that was highly significant. There was an obvious trend for patients with the worst curves before surgery to have the better lung function results after surgery. The increase in lung volumes was highly

significant even in the paralytic group, but this group is too small for further discussion.

Since the time of follow-up varied from 18 months to 5 years, we looked for any differences between the groups of patients followed for less than 2 years and the group followed for more than 2 years after surgery. Postoperative development of vital capacity related to average age at operation was also evaluated. There was a trend for better results the longer the time of follow-up and the younger the patient, i.e. younger than 16 years of age. Statistically, however, the variations were not significant.

As the results concerning changes in lung volumes after the Harrington operation technique for scoliosis vary with reports of deterioration as well as of improvement of lung volumes, the pre- and postoperative treatment routine may be of importance for the result. Lindh & Nachemson (1970) showed that breathing exercises are important for obtaining quicker return to preoperative vital capacities after the decrease that occurs immediately after surgery. That study further showed that, 6 weeks after surgery, the average increase in vital capacity for a trained group of patients was 12 per cent compared to 3–4 per cent for an untrained group. However, this difference decreased gradually and in this long-term follow-up the difference was no longer significant. For early improvement in lung function, breathing treatment is routinely given with the IPPB method recently described by Sinha & Bergofsky (1972).

The most important part in the postoperative routine for the early recovery of the lung function is probably that no external support of plaster body jackets is used, restricting the chest expansion. The patient is mobilized using a Milwaukee brace, which makes it possible for the patient to breathe deeply and expand the chest fully, which is not possible to the same extent in a plaster of Paris. Makley et al. (1968), among others, noticed the negative effects of the Risser cast in this respect. Experimental studies of the effects of restriction of chest cage expansion on pulmonary function are described by Caro et al. (1960) and show the importance of satisfactory chest expansion for pulmonary function. The Milwaukee brace in the postoperative treatment for scoliosis has been reported by Blount (1958), but is not widely used in the surgical procedure. When the patient becomes familiar with the brace, vital capacity measured in the brace will not differ much from a test without the brace.

SUMMARY

Studies of static lung volumes were performed before and after surgery in 92 scoliotic patients, aged 10 to 25 years. The majority of the patients had idiopathic dorsal curves. Vital capacity, total lung capacity, functional residual capacity and residual volume were measured at least 18 months after surgery. A significant increase was observed in all static volumes, averaging 10 per cent; the pre- and postoperative values were expressed in per cent of predicted normal values according to age and height. Correction of body height was taken into consideration in the prediction of normal values. Patients with the more advanced scoliosis had the greatest improvement in lung volumes. The patients were treated postoperatively with a Milwaukee brace for an average of 15 months. The use of this brace, which allows for chest expansion, might account for the improved lung function compared to previous series where plaster body jackets were used.

Thus the correction of idiopathic scoliosis by the standard posterior fusion with Harrington instrumentation together with our postoperative routine provides a lasting reduction of the spinal deformity, prevents progression of respiratory impairment and, in fact, increases the lung volumes, vital capacity, total lung capacity and functional residual capacity by an average of 10 per cent.

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