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Respiratory work in relation to cardiopulmonary bypass[1]

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Twenty-four patients undergoing cardiopulmonary bypass have been studied and the work of respiration was measured (1) before the incision, (2) before bypass with the thorax open, (3) after bypass, and (4) after suturing of the incision. Our results indicate that moving the thoracic wall requires 10 to 14% of the respiratory work and that little change occurs as a consequence of cardiopulmonary bypass.

Cardiopulmonary bypass entails a thoracotomy and a severe reduction in pulmonary perfusion together with adverse effects of anaesthesia. We became interested in the extent to which cardiopulmonary bypass changes the respiratory work; and in studying this it became essential to know how much the chest wall normally contributes to the work of respiration and whether the subsequent suturing of the incision alters this contribution.

The patients studied were undergoing cardiopulmonary bypass for a variety of different cardiac conditions. In all instances the patient was being ventilated mechanically under the relaxation of general anaesthesia, and the mechanical work of inspiration was calculated. A determined effort was made to maintain steady conditions, since the respiratory work is changed by changes in rate or tidal volume.

The work before, during, and after thoracotomy was measured and the results were compared.

METHODS

Twenty-four anaesthetized patients aged from 3 to 72 years and undergoing cardiopulmonary bypass had a Fleisch pneumotachograph placed in the respiratory line. Airway pressure and flow were recorded on tape, and inspiratory work was computed on a TR 20 analogue computer by integrating the product of pressure and flow (Segger, Osborn, Elliott, and Gerbode, 1966). Tidal volume and rate were measured and the minute volume was calculated. Measurements were taken before incision, after suturing of the thorax, and before and after bypass.

Throughout bypass the lungs were gently ventilated. The lungs for all measurements were fully expanded and the measurements for 'open thorax' were at maximum thoracic retraction.

The measurements were then divided into four separate groups for comparison: (1) thorax closed versus thorax opened before bypass; (2) thorax opened before bypass versus thorax opened after bypass; (3) thorax opened after bypass versus thorax sutured; and (4) thorax closed versus thorax sutured. The components of these comparisons were comparable in rate and tidal volume. The results that were not comparable were discarded. This led to a randomization of the results in each comparison.

The thorax was opened by either a sternum-splitting incision or a lateral thoracotomy.

RESULTS

The figures that were exactly comparable were too few to allow a separate assessment of sternum-splitting and lateral thoracotomy incisions. The type of incision has been marked beside the appropriate result together with the patient's age.

The results for each group in a table have been summated and an average figure has been determined. The two have been subtracted and a percentage has been derived.

In Table I (thorax intact compared with thorax incised and widely retracted) there were five median sternotomies and four lateral thoracotomies, the patients' ages ranging from 3 to 56 years. The mean work of the two groups was

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TABLE I

THE WORK OF RESPIRATION (INSPIRATION ONLY) WITH AN INTACT CHEST COMPARED TO THAT WITH THE CHEST OPEN AND RETRACTED BEFORE BYPASS

Age (yrs)	Incision	Work (kg. m./min.)	
		Chest Intact	Chest Open
3	T[1]	0·60	0·53
3	S	0·69	0·69
4	T	0·50	0·38
5½	T	0·98	0·74
7	S	0·74	0·61
17	T	0·98	0·74
48	S	1·77	1·47
48	S	1·26	1·05
56	S	1·25	1·11
Total work (all cases)		8·12	6·92
Mean work		0·902	0·77
Difference between two figures		0·13	
Percentage of work contributed by chest wall		14%	

[1] In all tables S and T in the incision column stand for sternum-splitting incision and lateral thoracotomy respectively.

0·902 kg./m./min. and 0·77 kg./m./min., a difference of 14%, representing the amount of work required to move the thoracic wall.

Table II gives the results for 12 patients aged between 6½ and 70 years; there were nine median sternotomies and three thoracotomies. The work of respiration was compared before and after bypass with the thorax still open. The percentage change over the period of bypass was 1·7, which is not significant.

In Table III the work of respiration at the end of bypass is compared with the work after the thorax had been sutured. There were seven patients in this group and their ages ranged from 5½ to 65 years. There were four median sternotomies and three thoracotomies. The mean work in these groups was 0·84 kg./m./min. and 0·96 kg./m./min. By closing the thoracic incision the work of respiration was increased by 12·5%.

In Table IV the respiratory work is compared before incision and after suturing of the thorax. There were five patients, their ages ranging from 3 to 56 years, four with median sternotomies and one with a thoracotomy. The mean work for these groups was 0·991 kg./m./min. and 0·992 kg./m./min., showing no significant difference.

TABLE II

A COMPARISON OF THE WORK OF INSPIRATION BEFORE AND AFTER BYPASS WITH THE CHEST OPEN

Age (yrs)	Incision	Work (kg./m./min.)	
		Chest Open before Bypass	Chest Open after Bypass
6½	T	0·564	0·588
6½	S	0·47	0·36
7	S	0·61	0·42
17	T	0·74	0·89
22	S	0·90	1·24
45	S	1·38	1·05
48	S	1·47	1·51
52	S	1·28	1·97
62	T	1·56	1·15
65	S	0·936	1·38
68	S	1·10	1·20
70	S	2·44	1·96
Total work (all cases)		13·45	13·72
Mean work		1·12	1·14
Difference between two figures		0·02	
Percentage change in work over period of bypass		1·7% increase	

TABLE III

A COMPARISON OF THE WORK OF RESPIRATION AT THE END OF BYPASS AND AFTER SUTURING

Age (yrs)	Incision	Work (kg. m./min.)	
		Chest Open after Bypass	Chest Closed after Bypass
5½	T	0·65	0·61
6	S	0·47	0·47
6½	T	0·59	0·66
7	S	0·42	0·67
17	T	0·89	1·35
48	S	1·51	1·61
65	S	1·38	1·36
Total work (all cases)		5·91	6·73
Mean work		0·84	0·96
Difference between two figures		0·12	
Percentage increase in work by closing the chest wall		12·5% increase	

TABLE IV

WORK CONTRIBUTED BY THE CHEST WALL BEFORE INCISION AND AFTER SUTURING

Age (yrs)	Incision	Work (kg. m. min.)	
		Chest Closed before Incision	Chest Sutured
3	S	0·69	0·90
4	T	0·512	0·67
7	S	0·74	0·67
48	S	1·76	1·61
56	S	1·25	1·11
Total work (all cases)		4·95	4·96
Mean work		0·991	0·992
Difference between two figures		0·001	
Percentage change		Not significant	

DISCUSSION

The normal work of respiration in adults has been given as 0·5 kg./m./min. (Comroe, Forster, DuBois, Briscoe, and Carlsen, 1962), although figures as low as 0·37 kg./m./min. have been noted (Fletcher and Barber, 1966). Essentially all

of this is work of inspiration. We have not tried to obtain our measurements under conditions of the greatest respiratory efficiency; most of our patients were somewhat hyperventilated under anaesthesia, which probably explains our higher average values for work.

The results in Tables I and III indicate that moving the thoracic wall (and diaphragm) requires between 10 and 15% of the inspiratory work. The data in Table IV show that the difference between respiratory work with the thorax intact and after suturing is 0·001 kg./m./min.; the work of moving the 'chest box' is not significantly changed by the incision and subsequent suturing. This result supports by inference the conclusions drawn from Tables I and II. These measurements were made immediately after closure and do not take into account any subsequent tissue swelling or haematoma formation which might add considerably to the component of work later in the post-operative period. The figures in Table II show little change (1.7%) over the perfusion period and suggest that perfusion makes little immediate difference in the work required to inflate the lungs. Decreases in compliance following perfusion have been reported by others (Ellison and Ellison, 1966) and a fall in compliance would increase the respiratory work. However, such changes have been noted some time after surgery. All our measurements were made while the patient was still in the operating room.

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