Proceedings of the Annual Scientific Meeting of the International Medical Society of Paraplegia held in Toronto from 4 to 6 August 1976 (Part III)

THE FLOW-VOLUME LOOP IN TETRAPLEGICS

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Abstract. The flow-volume curves and maximum flow-volume loop were studied in 20 tetraplegics and the results were compared with the predicted normal values.

Key word: Flow-volume loop.

Introduction

THE Forced Vital Capacity (FVC) manoeuvre recording the volume expired during the first second (FEV₁) is an important way of demonstrating an obstructive lung disease.

A strong relationship between maximum flow and lung elastic recoil was observed by Dayman (1951). As the lung elastic recoil is dependent on lung volume, it is clear that the maximum flow would also be dependent on lung volume.

The flow-volume curves were developed by Hyat, Schilder and Fry (1958).

Nowadays the maximum expiratory flow-volume (MEFV) curve is frequently used in which the maximum expiratory flow rate is plotted against volume, during the performance of a forced expiratory vital capacity (FEVC) manoeuvre.

The maximum inspiratory flow-volume (MIFV) curve is obtained in the same way during the performance of a forced inspiratory vital capacity (FIVC) manoeuvre but it is of considerably less clinical importance.

The MEFV curve (Fig. 1) rises steeply at high lung volumes reaching the peak expiratory flow (PEF) when 20-25 per cent of VC has been expired and then decreases more slowly reaching the zero flow at the end of the VC.

At high lung volumes (70-80 per cent of VC) the MEF is strongly effort-dependent and is altered by neuromuscular weakness, fatigue and lack of co-operation. It is also dependent on the cross-sectional area of large airways.

At lower lung volumes the maximum expiratory flow (MEF) depends primarily on the permeability of the lower airways and lung elastic recoil pressure, that is to say, of the physical conditions of the lung parenchyma.

The lung and airways behave like a Starling Resistor that consists of a collapsible tube enclosed in a chamber. When the pressure in the chamber increases above the pressure inside the tube, this becomes narrowed increasing the resistance to flow. The increased driving pressure meets with increased resistance and therefore above certain limits the flow cannot be further increased (Pride *et al.*, 1967).

Similarly when the pleural pressure increases during a strong expiratory effort the small airways become compressed and narrowed, limiting the flow.

According to Bass (1973) the flow-volume curve is a ventilatory test easy to demonstrate and with characteristic abnormalities in pulmonary diseases. It appears to be a sensitive indicator of early airways obstruction (Macklem, 1975).

FIG. 1

It is well known that the respiratory problems are the most important cause of death in the early stages of tetraplegics (Durbin, 1957; Norton, 1962; Tribe, 1963; Cheshire, 1964).

These respiratory disturbances are mainly due, if we exclude the pulmonary embolism, to the widespread paralysis of the respiratory muscles.

The expiratory muscles have lower segmental innervation than the inspiratory muscles and are almost all paralysed in cervical patients. Some auxiliary muscles like the sternocleidomastoideus, and trapezius are more active during inspiration than in normal condition.

The mechanics of ventilation are then altered: the inspiratory force impaired and the expiratory force almost exclusively due to the elasticity of the lung.

There are several previous papers on physiology of ventilation in tetraplegics demonstrating the reflex activity of intercostal muscles (Guttmann & Silver, 1965), the diminution of vital capacity and expiratory reserve volume and the postural variations of vital capacity (Gilliat *et al.*, 1948; Cameron *et al.*, 1955; Hemingway *et al.*, 1958; Forner, 1970; Silver, 1963), but there are few studies on flow rates apart from the work of Ohry *et al.* (1975) comparing the improvement of flow rates on admission and 6 months later.

We believe that it is important to study the maximum flow rates as the effectiveness of the cough is dependent on them. During the cough the flow rates reached are approximately within the limits of the MEFV curve. In fact, what is really important for eliminating the phlegms is the velocity of airflow that is directly proportional to alveolar pressure and inversely proportional to the cross-sectional area of the airways. Therefore for the same flow at any lung volume the velocity is higher when pleural pressure is high and some compression of airways has occurred.

For the reasons given above we expect to find in otherwise healthy tetraplegics

an important reduction of maximum flow rates at high lung volumes but less reduction at low lung volumes where the flow is mainly dependent on the physical conditions of lung parenchyma.

Material and Methods

We have studied the flow volume curves of 20 complete cervical patients (Table I). There were 16 men and four women of ages ranging between 21 and 57. The mean age being 33.

In 18 cases the spinal cord lesion was traumatic, in one it was due to transverse myelitis and in the remaining case it was due to arachnoiditis. None of the cases had any respiratory disturbance at the time of examination but during the acute stage six of them had a tracheostomy done for respiratory insufficiency. There was no sign of residual tracheal stenosis. Seven of them were smokers and thirteen non-smokers.

The level of the lesion in one case was below C₄, in four patients below C₅, in six patients below C₆, in eight patients below C₇ and in one patient below C₈.

All patients were already up and about and all ventilatory tests were done at least 5 months after the accident.

All patients had been carefully instructed to perform correctly the manoeuvre consisting of a maximal inspiration followed by a forced and complete expiration (FVC) and this immediately followed by a forced inspiration.

During the first day a standard spirometry was performed after the adequate instructions. The patients who did not co-operate sufficiently were discarded. In the following days the flow-volume loops were performed in three positions: sitting, supine and Trendelenburg (20° head down). Every curve was repeated until the manoeuvre was done correctly and we took the curve that showed higher values.

We have used a wire-mesh screen pneumotachograph that measures the flow with a linear response from 0.1-15 litres/sec. The volume is integrated from the flow (Pnevmotest Jaeger, Wurzburg, Germany). The flow-volume curves are directly recorded in a Hewlett-Packard XY Recorder 7.045-A.

From the maximum flow-volume loops we take following parameters: (a) Forced vital capacity (FVC); (b) Peak expiratory flow (PEF); (c) Maximum expiratory flow at 75 per cent of FVC (MEF 75); (d) Maximum expiratory flow at 50 per cent of FVC (MEF 50); (e) Maximum expiratory flow at 25 per cent of

TABLE I
Flow-volume curve in tetraplegics. Distribution of cases ($n = 20$)

Sex: Males 16	Level of lesion: C ₄ 1
Females 4	C ₅ 4
Age: Mean: 33 years	C ₆ 6
S.D.: 10.8 years	C ₇ 8
Range 21-57	C ₈ 1
Aetiology: Traumatic 18	
Transverse myelitis 1	
Arachnoiditis 1	

S.D. = Standard deviation.

FVC (MEF 25); (*f*) Peak inspiratory flow (PIF); (*g*) Maximum inspiratory flow at 50 per cent FVC (MIF 50).

All these parameters taken from the curves were compared with the normal predicted values obtained from the equations of Bass (1973) that take into account the sex, age, height, weight and body surface area of normal people.

Results

Table II shows the mean values and standard deviation of FVC and expiratory flows of the 20 patients in the three positions, measured in the flow-volume curve.

Table III shows the mean values and standard deviation of the inspiratory flows and the ratios PEF/PIF and MFF 50/MIF 50 in the three positions.

Table IV shows the percentages of all these values in the sitting position in relation with the predicted normal values.

We can see that the FVC is reduced to about half of the normal values.

Regarding the flow rates, the PEF, the MEF 75, and MEF 50 are also reduced in the same proportion at about half of the normal values. Nevertheless the MEF 25 is much less reduced (71.5 per cent).

The PIF is less reduced than the PEF but the difference is not statistically significant.

TABLE II

Flow-volume curve in tetraplegics. Data of the MEFVC in 20 cases

Position	Sitting		Supine		Trendelenburg	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
FVC ml	2195	950	2470	765	2485	780
PEF l/sec	4.13	1.62	3.94	1.40	3.87	1.21
MEF ₇₅ l/sec	3.92	1.52	3.63	1.38	3.66	1.20
MEF ₅₀ l/sec	2.73	1.17	2.47	0.96	2.57	0.98
MEF ₂₅ l/sec	1.38	0.64	1.27	0.50	1.25	0.49

TABLE III

Flow-volume curve in tetraplegics. Data of the MIFVC in 20 cases

Position	Sitting		Supine		Trendelenburg	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
PIF l/sec	2.93	1.23	2.87	1.18	2.82	1.15
MIF ₅₀ l/sec	2.61	0.98	2.48	1.11	2.61	1.08
PEF/PIF	1.47	0.42	1.50	0.71	1.50	0.64
MEF ₅₀ /MIF ₅₀	1.07	0.31	1.07	0.36	1.05	0.38

TABLE IV

Flow-volume curve in tetraplegics. Percentage of the predicted values ($n = 20$)

	Mean	S.D.	S. Error
% FVC	49.9	16.7	3.74
% PEF	54.8	17.2	3.86
% MEF ₇₅	55.0	17.8	3.99
% MEF ₅₀	51.2	19.1	4.28
% MEF ₂₅	71.5	29.3	6.55
% PIF	58.8	24.0	5.37
% MIF ₅₀	48.0	16.6	3.71

TABLE V

Flow-volume curve in tetraplegics. FVC in different positions. Paired t test

	Mean	S.D.	Dif.	S.E. dif.	t	P
Sitting	2.195	950	276	109	2.52	< 0.01
Supine	2.470	765				
Trendelenburg	2.485	780	287	109	2.63	< 0.01

Table V shows the paired t test between the mean values of the FVC in the three studied positions. In the sitting position the FVC is lower than in supine and Trendelenburg, being the difference statistically significant $P < 0.01$.

Discussion

The mean values of the forced vital capacity of the 20 tetraplegics studied were reduced in the sitting position to approximately 50 per cent of the predicted normal values.

In supine and Trendelenburg positions the mean values of the FVC were significantly higher than in the sitting position (mean value 300 ml higher). This is due to the more cranial rest position of the diaphragm that allows a higher inspiratory excursion and therefore a higher inspiratory reserve volume.

The widespread paralysis of the expiratory muscles allows a lower PEF, MEF 75, and MEF 50 in the first part of the curve that is effort dependent. (They are reduced at approximately 50 per cent of normal predicted values.)

Figure 2 shows a smaller reduction of the MEF 25 (71.5 per cent) and the last part of the curve is more abrupt. This could be due to the paralysis of expiratory muscles that would lead to a smaller pleural pressure during expiration and lack of dynamic compression of small airways on which the flow is strongly dependent at low lung volumes.

The ratios $PEF/PIF = 1.47$ and $MEF_{50}/MIF_{50} = 1.07$, are slightly

FIG. 2

higher than the values given by Jordanoglou and Pride (1968) for subjects of similar age. (These values are 1.18 and 0.76 respectively for young and 1.43 and 0.81 for middle-aged people.)

This would mean that the maximal inspiratory flow is proportionally more diminished than maximal expiratory flow in spite of the fact that in tetraplegics some inspiratory muscles have been spared.

SUMMARY

We have studied the FVC and maximum flow-volume loop in 20 tetraplegics and the results have been compared with the predicted normal values.

The FVC in sitting position is reduced at approximately half the normal predicted values and is significantly lower than in supine and Trendelenburg. At high lung volumes the flows are reduced at half the normal values.

At low lung volumes the reduction is smaller (71.5 per cent).

RÉSUMÉ

Nous avons étudié le FVC et la boucle maximum de débit-volume chez 20 tétraplégiques et les résultats ont été comparés avec les valeurs normales prévues.

Le FVC en position assise est réduit à environ la moitié des valeurs normales prévues et est beaucoup plus faible qu'en position couchée ou en position de Trendelenburg. Pour des volumes pulmonaires élevés, les débits sont réduits à la moitié des valeurs normales.

Pour des volumes pulmonaires faibles, la réduction est moins importante (71.5 per cent).

ZUSAMMENFASSUNG

FWC und maximaler Strom-Volumen-Schleife wurden in 20 Tetraplegikern untersucht und die Resultate mit dem erwarteten normalen Werten verglichen.

FWC ist in sitzender Position reduziert ungefähr zur Hälfte der erwarteten Normalwerte und ist bedeutend geringer in Trendelenburg Supination. Bei hohen Lungenvolumen war die Strömung zur Hälfte der Normalwerte reduziert. Bei geringen Volumen ist die Reduktion geringer.

Acknowledgement. We are very grateful to Professor V. Lopez Merino of Valencia for his guidance and advice.

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