DEFORMATION OF THE TRANSPULMONARY PRESSURE PLATEAU IN EXPERIMENTAL EMPHYSEMA

F. F. Tetenev

UDC 612.212-087.2

Deformation of the transpulmonary pressure plateau obtained during interruption of the air flow for 0.5 sec in 8 healthy rabbits and in 9 rabbits with experimental emphysema caused by intravenous injection of lycopodium spores is described. Greatest deformation of the plateau was observed in healthy animals at inspiration (on average up to 20 mm water). In rabbits with emphysema the degree of deformation was reduced on average to 13 cm water. At expiration deformation of the plateau was equal in the healthy and emphysematous rabbits, with a mean value of about 7 cm water. The direction of the change in the effect of the respiratory muscles at inspiration or expiration during interruption of the air flow was monitored by recording the pressure in the bronchus, in which the amplitude of the respiratory fluctuations considerably exceeded that of the transpulmonary pressure. Deformation of the plateau at inspiration is regarded as the result of the active sucking action of the lungs, and at expiration, as their active contraction during interruption of the air flow.

KEY WORDS: transpulmonary pressure; emphysema of the lungs.

According to the generally accepted view of the mechanics of respiration, at a certain level of static extensibility of the lungs during interruption of the air flow, a plateau must be recorded on the transpulmonary pressure curve [6], indicating constancy of elastic strain of the lungs under static conditions.

In the investigation described below deformation of the transpulmonary pressure plateau in experimental emphysema was studied.

EXPERIMENTAL METHOD

Experiments were carried out on 8 healthy rabbits (group 1) and 9 rabbits with experimental emphysema caused by intravenous injection of lycopodium spores [1]. Four rabbits with moderate emphysema were investigated 4.5 months (group 2) and 5 rabbits with severe emphysema 9 months (group 3) after the beginning of the experiment. The mean body weight of the healthy and emphysematous animals was identical and it varied between 2.5 and 3 kg.

Tracheostomy was performed under intravenous thiopental anesthesia. The trachea was connected to a spirograph. The transpulmonary pressure (the difference between the pressure in the esophagus and in the trachea) was measured by a differential manometer. Meanwhile the spirogram, the transpulmonary pressure curve, and the intrabronchial pressure were recorded on a multichannel oscillograph. The work of respiration, its fractions, and the dynamic extensibility were calculated from the respiratory loop. The air flow was interrupted by means of a special valve. After investigation the lungs together with the trachea were fixed in a Donders' bell jar. Respiratory fluctuations of intrathoracic pressure in the bell jar were simulated by means of bellows. The transpulmonary pressure was the difference between the pressure in the bell jar and in the trachea. The results of the morphological investigations, of the measurement of pressure in the occluded bronchus, the esophagus, and the pleural cavity, and also the generally accepted indices of the mechanics of respiration, were published previously [3].

Department of Propedeutics of Internal Diseases, Central Research Laboratory, Tomsk Medical Institute. Department of Pathological Anatomy, Patrice Lumumba Peoples' Friendship University, Moscow.
(Presented by Academician of the Academy of Medical Sciences of the USSR D. D. Yablokov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 86, No. 9, pp. 264-267, September, 1978. Original article submitted December 13, 1977.

0007-4888/78/8609-1126$07.50

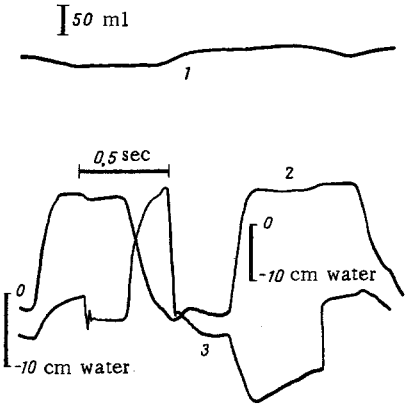

Fig. 1. Spirogram (1), curve of intrabronchial pressure (2), and curve of transpulmonary pressure (3) of rabbit with moderately severe emphysema during interruption of air flow. Explanation in text.

EXPERIMENTAL RESULTS

The static elastic pressure was measured in order to measure the static extensibility of the lungs as the most reliable indicator of the elasticity of the lungs in emphysema. However, in a spontaneously breathing rabbit it was impossible to interrupt the air flow twice at inspiration, for after closure of the valve the direction of the effort of the respiratory musculature was changed to expiration. Under these circumstances differences in the mechanical behavior of the lungs were noted which could not be explained in terms of the generally accepted notion of the lungs as a passive elastic organ.

The spirogram, intrabronchial pressure, and transpulmonary pressure curve for a rabbit of group 2 are illustrated in Fig. 1. At inspiration the spirogram rises but the pressure curves fall. During interruption of the airflow at the end of expiration a plateau appeared instantly on the transpulmonary pressure curve and persisted for 0.2 sec. During this period the efforts of the respiratory muscles were aimed at expiration (positive intrabronchial pressure). Later expiration changed to inspiration and the intrabronchial pressure began to fall rapidly. Deformation of the plateau into an upward pointed wave, due to the considerably greater decrease of the pressure in the alveoli and trachea than of the intrathoracic pressure, corresponded to this sharp drop of intrabronchial pressure for 0.3 sec. The next time the airflow was interrupted was at the beginning of expiration. Deformation of the plateau into the zone of negative pressure corresponded to a positive intrapulmonary pressure. In this case deformation of the plateau was so considerable that it went beyond the limits of respiratory fluctuations of transpulmonary pressure.

Deformation of the transpulmonary pressure plateau is a paradoxical fact, contradictory to the generally accepted view that the elastic resistance of the lungs is constant under static conditions. Changes in the position of the transpulmonary pressure plateau have been observed by several workers [5, 7], but they considered it to be an artifact and did not analyze it specially. From the present writer's point of view this phenomenon cannot be explained as an artifact. The amplitudes of respiratory fluctuations of intrapleural and intraesophageal pressure were identical in the present investigation [3]. It is difficult also to imagine any possible effect of the pleural pressure gradient.

Displacement of the plateau at inspiration can be explained by the sucking action of the lungs, in addition to the action of the respiratory muscles, and at expiration to active contraction of the lungs. These efforts were aimed at overcoming the obstacle caused by interruption of the air flow. The results described above agree with those of comparison of the amplitudes of the respiratory fluctuations of pressure in the occluded bronchus with those in the pleural cavity and esophagus [3], the only difference being that predominance of the amplitude of pressure in the occluded bronchus reflected the mechanical activity of part of the lung, whereas deformation of the plateau reflected mechanical activity of the lung as a whole. In man deformation of the transpulmonary pressure plateau gave rise to a phenomenon of negative elastic hysteresis [4].

TABLE 1. Nonelastic Pressure Measured from Respiratory Loop and Peak of Deformation of Transpulmonary Pressure Plateau at Inspiration and Expiration in Rabbits of Groups 1, 2, and 3. Total Nonelastic and Alveolar Pressure Measured by Air Flow Interruption Method in Isolated Lungs

Group of animals	Number of animals	Statistical index	RMV,* liters/min	Inspiration, cm water (−)			Expiration, cm water (+)		
				nonelastic pressure	deformation of plateau	P	nonelastic pressure	deformation of plateau	P
1	8	M	1,6	0,12	19,7	$<0,001$	1,34	6,8	$<0,001$
		$\pm m$	0,208	0,049	0,876		0,510	0,543	
2	4	M	3,1	5,4	12,6	$<0,02$	6,10	7,4	
		$\pm m$	0,016	1,480	2,125		2,145	1,182	
		P_{1-2}	$<0,001$	$<0,001$	$<0,05$		$<0,05$		
3	5	M	2,5	11,0	12,9	$<0,2$	10,72	9,6	
		$\pm m$	0,484	2,302	1,701		3,286	1,490	
		P_{1-3}	$>0,05$	$<0,001$	$<0,001$		$<0,01$	$<0,2$	
		P_{2-3}	$<0,02$	$<0,05$			$>0,05$	$>0,05$	
Isolated lungs of animals of groups 1, 2, and 3									
	6	M	0,30	11,3	1,8	$<0,001$	15,3	1,3	$<0,001$
		$\pm m$	0,028	2,209	0,365		2,388	0,274	

*RMV – Respiratory minute volume.

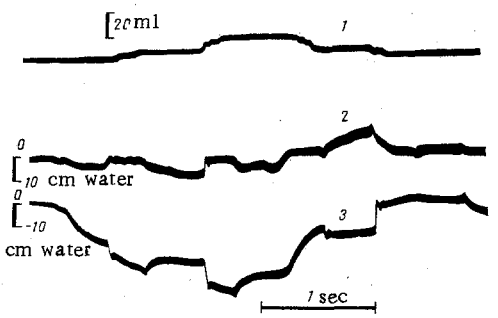

Fig. 2. Spirogram (1), intrabronchial pressure curve (2), and transpulmonary pressure curve (3) during ventilation of isolated lungs under Donders' bell jar and interruption of air flow (lungs of same rabbit as in Fig. 1). Explanation in text.

Since the degree of deformation of the plateau depends on the degree of predominance of the change in alveolar pressure over the pleural, it is logical to regard it as a reserve force of mechanical activity of the lungs. The dynamic component of the transpulmonary pressure, calculated from the respiratory loop (predominantly the alveolar pressure), however, represents the degree of utilization of the reserve. In each experiment respiratory cycles with the greatest degree of deformation of the plateau were chosen. The highest peaks of the deformed plateau were compared with the alveolar pressure measured from the respiratory loop at inspiration and expiration separately (Table 1). The greatest reserve of mechanical activity was present at inspiration. In healthy animals it averaged almost 20 cm water, compared with about 7 cm water at expiration. In experimental emphysema the reserve of mechanical activity of the lungs at inspiration fell to 13 cm water, but at expiration it was unchanged. During ordinary breathing by healthy rabbits the dynamic component of the transpulmonary pressure was very small, and in a pathological state it increased sharply. In the presence of moderate emphysema (group 2) the reduced reserve at inspiration was used up partly, but at expiration almost completely. In the presence of marked emphysema (group 3) the reserve was completely used up both at inspiration and at expiration.

In isolated lungs no signs of deformation of the transpulmonary pressure plateau were observed (Fig. 2), proof of the ability of the lungs to deform the transpulmonary pressure plateau only during life. The dynamic component of the transpulmonary pressure in all cases considerably exceeded the alveolar pressure measured under static conditions. The plateau obtained on stretching of the lungs was located in a zone of more negative pressure than the plateau obtained during their collapse at the same volume. This points to an increase in pulmonary elastic hysteresis, in agreement with data in the literature [3, 7].

LITERATURE CITED

1. V. K. Mavrin, Arkh. Patol., No. 3, 42 (1970).
2. F. F. Tetenev, Byull. Éksp. Biol. Med., No. 6, 21 (1974).
3. F. F. Tetenev, Byull. Eksp. Biol. Med., No. 1, 30 (1976).
4. F. F. Tetenev, Ter. Arkh., No. 2, 33 (1976).
5. G. Cavagna, F. Brandi, F. Saibene, et al., J. Appl. Physiol., 17, 51 (1962).
6. W. Stead, D. Fry, et al., J. Lab. Clin. Med., 40, 674 (1952).
7. M. E. B. Wohl, J. Turner, and J. Mead, J. Appl. Physiol., 24, 348 (1968).