ULTRASONIC INVESTIGATION OF THE BLOOD FLOW IN DIFFERENT PARTS OF THE PULMONARY CIRCULATION IN CATS

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Few direct studies have been made of the pulsating blood flow in vessels of the pulmonary circulation. There are only isolated references of this kind in the Soviet literature, to clinical studies with cardiac catheterization [2]. Experimental investigations of this problem have been conducted on dogs; their aim has mainly been to study the blood flow in the main trunk of the pulmonary artery [10, 12]. Yet it is important to have information not only about the minute volume of the right heart, but also its distribution between the right and left lungs and between individual lobes of the lungs; it is also important to be able to compare the inflow of blood to a particular lobe of the lung with the outflow from it under different conditions (to judge retention of blood and other processes).

The object of this investigation was to study quantitative characteristics and particular features of the pulsating blood flow in different parts of the vascular bed of the lungs and also how the pulmonary blood flow depends on contractions of the heart and respiratory movements of the lungs. This investigation is a logical development of previous studies in the writers' laboratory, aimed at studying the physiology and pathology of the regional circulation [4, 5] and, in particular, of the pulmonary circulation [1, 8, 9].

EXPERIMENTAL METHOD

For various reasons vessels of the pulmonary circulation have difficult access for study [3, 11, 13]. Measurement of the blood flow in the pulmonary vessels of cats, on which these experiments were done, has some particular difficulties of its own, due to the small diameter and high compliance of the thin-walled pulmonary arteries and, in particular, veins. The low values of blood pressure in these vessels call for the use of very light transducers with flexible leads for their investigation. The low values of blood flow in the pulmonary circulation necessitate the use of a method of measurement with high sensitivity and free from zero drift. These demands are satisfied to a large extent by the ultrasonic method of blood flow measurement [6], based on recording the frequency of ultrasonic waves reflected from the blood cells. The frequency of the reflected ultrasound is proportional to the velocity of the blood flow, and for that reason transducers can be calibrated in units of linear and volume velocity of blood flow. Ultrasonic transducers are made in the form of a small dismantlable bandage, weighing not more than 2 g. The design of the transducers and the method used to calibrate them are similar to those for transducers used to study the coronary blood flow in dogs [7].

In acute experiments on 30 cats weighing 3-4 kg under open chest conditions with artificial ventilation of the lungs and under pentobarbital anesthesia (30 mg/kg) the blood flow was measured in different parts of the pulmonary vascular system: in the infundibulum, the branch of the pulmonary artery supplying the left lung (from anatomical considerations this is more easily accessible for investigation than the right branch), the branch supplying blood to the lower lobe of the left lung, and the vein leaving the lower lobe of the left lung.

To study the output of the right heart transducers measuring 5-6 mm were applied to the infundibulum. The blood flow in the artery and vein of the lower lobe was measured with trans-

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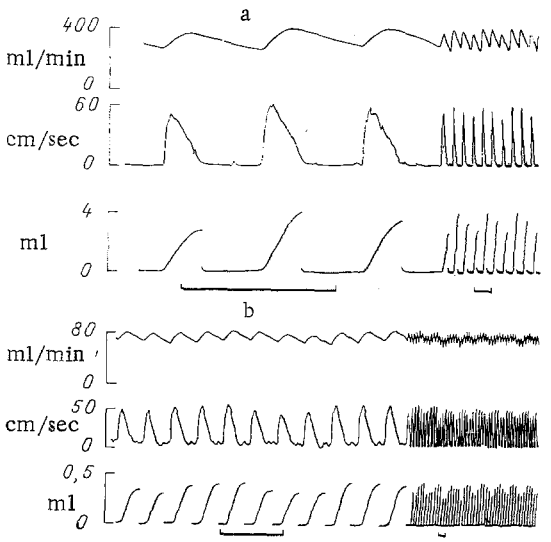

Fig. 1. Pulsating blood flow in infundibulum (a) and in artery of lower lobe of left lung (b). From top to bottom: for a) minute volume, shape of pulsating blood flow, stroke volume (readings of electronic integrator), time scale 1 sec; for b) mean values of flow in lower lobar pulmonary artery, shape of pulsating blood flow, systolic blood volume recorded in lobar artery, time scale 1 sec.

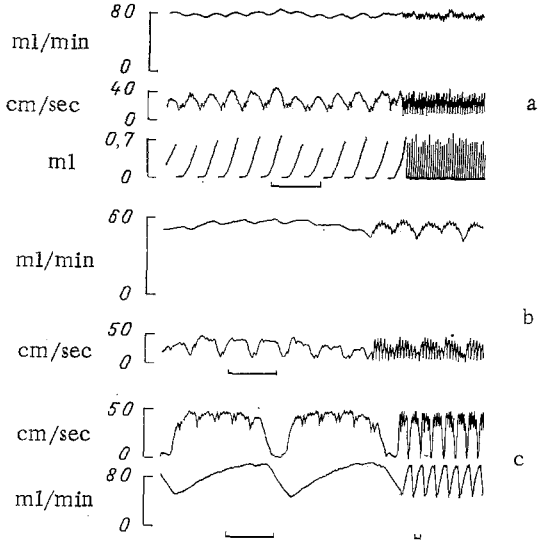

Fig. 2. Different types of blood flow recorded in pulmonary vein to lower lobe. From top to bottom: for a) mean values of blood flow along pulmonary vein, flow velocity, integrator of phasic blood flow, time scale 1 sec; for b) mean values of flow, flow velocity curve, time scale 1 sec; for c) curve of flow velocity, mean values of flow, time scale 1 sec.

ducers measuring 4, 3, and 2 mm. The following parameters were recorded: linear and volume velocity of the blood flow, minute and stroke volumes of the right heart, pulsating flow curve with a transmission band of up to 100 Hz, and mean values of the blood flow with an integration constant of 2.5 and 10 sec. The blood flow was recorded on magnetic tape. The N-338 and Mingograph-81 instruments were used as recorders.

It is worth noting that no such investigations have hitherto been conducted on cats. We chose this object to ensure comparability of our results with those of other investigations of regulation of respiration and the regional circulation conducted in our laboratory.

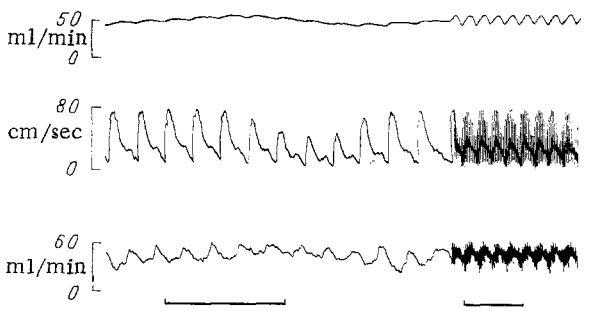

Fig. 3. Simultaneous recording of blood flow in pulmonary artery and vein of lower lobe. From top to bottom: mean arterial blood flow, phasic blood flow in artery, trace of venous flow, time scale 1 and 10 sec. It will be noted that the phases of the arterial and venous flows do not coincide.

EXPERIMENTAL RESULTS

Quantitative data on the blood flow in different parts of the vascular bed of the cat's lungs were obtained. The minute volume of the right heart was shown to average 293 ml/min (variation from 200 to 400 ml/min in different animals), and the mean stroke volume was 1.7 ml (variation from 1.3 to 2.3 ml). The linear velocity of the blood flow in the infundibulum averaged 60 cm/sec (minimal 35 cm/sec, maximal 80 cm/sec). The inflow of blood to the left lung was 40-45% of the volume of blood ejected by the right ventricle into the infundibulum. These observations suggest that 55-60% of the cardiac output goes to the right lung. This fact can be explained on the grounds that the volume of the right lung is somewhat greater than the volume of the left lung. The volume of blood entering the lower lobe of the left lung is 20-25% of the cardiac output.

Besides quantitative results, data reflecting the character of the pulsating flow of blood in different parts of the vascular bed of the lungs also were obtained (in the infundibulum, the artery and vein of the lower lobe).

When the blood flow was recorded in the pulmonary vessels, fluctuations synchronized with the phases of respiration and the cardiac contractions were clearly visible. During artificial inflation of the lungs (inspiration) a definite decrease in the blood flow was observed in the infundibulum and lobar artery, whereas during collapse of the lungs (expiration) the blood flow increased (Fig. 1a, b). According to data in the literature [10], during natural respiration, with the chest closed, changes in the blood flow along the pulmonary vessels during inspiration and expiration are opposite in direction. Reversal of the direction of the respiratory waves of blood flow in the present experiments was evidently due to the use of artificial positive-pressure respiration.

The blood flow in different parts of the vascular bed of the lungs had a well-marked pulsating character associated with cardiac contractions. Meanwhile analysis of curves of the pulsating blood flow shows that the blood flow in each section of the pulmonary vessels has its own special features. In the infundibulum (Fig. 1a) a sharp increase in blood flow was observed during systole. During diastole the blood flow fell to the zero line. The character of the blood flow in the left main branch of the pulmonary artery was similar to that observed in the infundibulum.

The volume velocity of the blood flow in the artery to the lower lobe of the lung averaged 58 ml/min (with variations from 35 to 80 ml/min in different experiments). Just as in the infundibulum, in the lobar pulmonary artery the blood flow rose sharply during systole. Meanwhile, in healthy animals, in the artery running directly to the lobe of the lung, the blood flow during diastole never fell to zero — there was always a more or less well-marked constant component of the blood flow, i.e., systolic ejection was observed against the background of a constant blood flow (Fig. 1b). Quantitative changes in the blood flow in the lobar artery under different experimental conditions arose, it will be noted, because of changes in the value of this constant component.

The volume velocity of the blood flow in the vein from the lower lobe normally corresponded to the blood flow velocity in the artery. The linear velocity of blood flow was lower than in the artery — mean 41 cm/sec (variations from 30 to 50 cm/sec). This is reflected in the fact that the constant component of the blood flow in the vein was even more marked than

in the artery carrying blood to the lower lobe. The character of the blood flow in the pulmonary veins was most variable. Several main types of blood flow could be distinguished in this case: a) distinct changes of blood flow synchronized with cardiac contractions were seen against the background of a continuous flow (Fig. 2a), and in some experiments these changes in the blood flow along the vein did not coincide in phase with changes in blood flow in the artery (Fig. 3); b) besides a continuous flow and pulsating fluctuations of blood flow, changes synchronized with the respiratory movements of the lungs also were well marked (Fig. 2b); c) in some experiments a blood flow with very distinct respiratory waves was observed (Fig. 2c); d) blood flowed continuously along the vein, without any distinct pulsating or respiratory oscillations (this type of venous blood flow was normally the one most rarely observed). The character of the blood flow along the pulmonary veins, it should be pointed out, could differ not only in different experiments, but also in the course of the same experiment. It can be tentatively suggested that this variability in character of the blood flow along the pulmonary veins is to a certain extent due to phenomena taking place in the intramural vascular bed of the lungs and it also reflects changes in pressure in the left atrium, into which the pulmonary veins empty [14, 15].

Quantitative data on the blood flow in different parts of the vascular bed of the cat lungs were thus obtained in the course of this investigation and particular features of the pulsating blood flow in the infundibulum, and lobar artery and vein were studied.

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