An Experimental Study on the Phonocardiogram in Dogs

Yoshito WAKAO

*Department of Veterinary Surgery, Azabu Veterinary College,
Sagamihara-shi, Kanagawa 229*

(Received for publication October 12, 1974)

Abstract. The components of the central vibrations of the first heart sound on the phonocardiogram were studied in dogs. The results obtained are summarized as follows.

1. Although a clear time difference was found between the left and right isometric contraction phases at the beginning, no time difference in the occurrence time was clear between the left and right central vibrations of the first heart sound on the external phonocardiogram.

2. The appearance of the central vibrations of the first heart sound on the epicardial phonocardiogram was derived from the difference in the onset between the right and left isometric contraction phase. The central vibrations of the first heart sound occurred usually earlier on the left epicardial phonocardiogram than on the right epicardial phonocardiogram.

3. The central vibrations of the first heart sound on the epicardial phonocardiogram were the closing sounds of the atrioventricular valves. The central vibrations of the first right epicardial sound were originated from the tricuspid valve component and those of the first left epicardial sound from the mitral valve component mainly.

4. These results indicated that the central vibration of the first heart sound on the phonocardiogram in dogs were divided into two components. The mitral valve component occupied the first half of the central vibrations of the first heart sound, and a mixture of mitral and tricuspid valve components the second half.

Phonocardiography is used to express the change of physical sound in the heart and great vessels in graphs. Accordingly, when a disorder occurs to the heart sounds in the case of a heart disease, as revealed by phonocardiography, it may be possible to make a more reliable clinical diagnosis of the heart disease by this technique than by auscultation. In order to make a clinical diagnosis by phonocardiography, it is necessary to understand the relationship between the physical or mechanical function of the heart and the phonocardiogram. In order to understand this relationship, accurate analysis of the wave is required.

On the structure of the heart sounds,

many reports have been made by Dock [2], Luisada et al. [6], Bartolo et al. [1], Shah et al. [13], Spörri [14] and Rushmer [12]. Of these authors, Rushmer has attracted special interest recently. He described that the heart sounds were composed of many systolic sounds of the myocardium and blood vessels, the opening and closing sounds of the valves, blood-flow sounds, etc.

Many investigators have tried to analyze the waves shown by the phonocardiogram. There are two theories on the structure of the first sound. The first sound is considered to consist of the closing sounds of the atrioventricular valve, according to one theory (Reinhold and Rudhe [10], Leatham

[4]), or of two components, the closing sounds of the atrioventricular valve and the opening sounds of the semilunar valve, according to the other theory (Rushmer [11] and Luisada et al. [7]). However, if the relationship between the function of the heart and the heart sounds is understood correctly, the valvular sounds may be distinguished from one another on the phonocardiogram.

The analysis of the valvular sounds on the phonocardiogram is very important. On the other hand, the morphological change of the thorax in animals may affect the sounds which are transmitted from the heart to the chest wall. Therefore, in order to use the phonocardiogram for the clinical diagnosis of a heart disease in an animal, an attempt must be made to analyze the waves which are considered to be characteristic of the animal.

To use the phonocardiogram for the clinical diagnosis of a heart disease, the author studied the components of the first heart sound by phonocardiography. As a result, the central vibrations of the first heart sound in dogs were separated into two components. The mitral valve component may occupy the first half of the central vibrations of the first sound, and a mixture of the mitral and tricuspid valve components the second half.

Materials and Methods

Five experiments have been carried out, the first the external phonocardiogram in normal dogs, the second the epicardial phonocardiogram in normal dogs, the third the relationship of the intercardiac pressure and epicardial phonocardiogram, the fourth the disappearance test of heart sounds by partial perfusion and the fifth the relationship of the external phonocardiogram and intercardiac pressure.

1. External phonocardiogram: Twelve adult mongrel dogs 1–1.5 years of age weighing 10–15 kg and proved to be clinically healthy were used in

these experiments. Under pentobarbital anesthesia, they were subjected to multiple phonocardiography (type AS-21S). Their heart sounds were recorded from 22 points on the left and right chest wall, using the acceleration type microphone. The Q-I time was measured from the middle-area phonocardiogram with filter M.

2. Epicardial phonocardiogram: Eleven adult mongrel dogs which had been found normal in general clinical and electrocardiographical examinations were used in this examination. They were 1–1.5 years of age and weighed 15–30 kg. Under halothane anesthesia, they were subjected to bilateral incision of the thorax, and microphones (acceleration type) were attached to the left and right sides of the epicardium. The epicardial sounds were recorded by the visigraph and cathode oscillograph. The rate used was 100 mm/sec for the visigraph and 7×10 or 5×10 msec/cm for the cathode oscillograph.

3. Intracardiac pressure and epicardial phonocardiogram: Three adult mongrel dogs which had been found normal in the clinical examination were used in this experiment. Under halothane anesthesia, a bilateral incision of the thorax was performed to fix microphones of acceleration type on the left and right sides of the atrioventricular area, and a small incision was made on the left and right sides of the ventricles. Cardiac catheteres were inserted through this incision. These phenomena were recorded simultaneously.

4. Disappearance test of heart sounds by partial perfusion: Five adult mongrel dogs which had been found normal by many clinical tests were used in this experiment. Under halothane anesthesia, a bilateral thoracic incision was made through the fourth intercostal space. Partial perfusion was done through the left and right heart bypass by the aid of a pump-oxygenator. A venous drainage cannula was inserted into the anterior or posterior vena cava and an arterial infusion cannula into the main pulmonary artery for the right heart bypass. Venous drainage and arterial infusion for the left heart bypass were conducted from the left atrium to the aortic arch. A cardiac catheter was inserted into both ventricles through the myocardium to record intracardiac pressure. The heart sound was recorded in the same manner as mentioned in the previous section.

In this experiment, the valve serving as control had been measured before venous drainage. In contrast to this value, changes in the first epicardial sound and depression of blood pressure by venous drainage were observed.

5. External phonocardiogram and intracardiac pressure: Four adult mongrel dogs found in normal health conditions by routine clinical examination were used in this experiment. Under pentobarbital anesthesia, an external phonocardiogram and intracardiac pressure were recorded simultaneously from the left and right body surface and ventricles.

Results

1. In the examination of the external phonocardiogram of the twelve dogs (Fig. 1), it was found that the first heart sounds were divided into three phases, initial, central and final. The Q-I time of the left external phonocardiogram was about 0.039–0.062 seconds and that of the right external phonocardiogram about 0.046–0.077 seconds. The left Q-I times were a little shorter than the right ones. The time difference between the left and right Q-I times, however, was very small. Accordingly, the author assumed that the time difference between both Q-I time on the external phonocardiogram might not be clear on account of the measurement error.

2. The first epicardial sounds were separated into about three phases, initial, central and final. The Q-I time was about 0.050–0.126 seconds (mean: about 0.067 seconds) on the left epicardial phonocardiogram and about 0.060–0.135 seconds (mean: about 0.073 seconds) on the right epicardial phonocardiogram.

These results indicate the extension of the Q-I time on the right epicardial phonocardiogram. It was also elucidated that the central vibrations of the left epicardial sounds occurred usually earlier than those of the right epicardial sounds (Fig. 2).

3. Studies were made on the relationship between the left and right epicardial phonocardiogram and the intracardiac pressure. Their results revealed that the central vibrations of the first heart sound on the left epicardial phonocardiogram had

occurred at the same time with the onset of the left isometric contraction phase. The central vibrations of the first heart sound on the right epicardial phonocardiogram occurred about 0.010–0.020 seconds later than the onset of the right isometric contraction phase (Fig. 3). These results revealed that the time difference in the central vibrations between the left and right first heart sounds on the epicardial phonocardiogram was derived from the difference in the onset of the isometric contraction phase.

4. A remarkable decline, in disappearance test of the first heart sound by right heart bypass, was found in the epicardial sounds with depression in the right ventricular pressure (RVP) caused by venous drainage. Namely, at five seconds of venous drainage, the RVP was reduced by about one-third, as compare with the control, and a decline was observed in the first and second sounds on the right epicardial phonocardiogram. At seven seconds, the RVP was reduced by about one-seventh, as compared with the control, and a more remarkable decline was observed in the right epicardial sound. At ten seconds, the RVP was reduced to 0 mmHg and the most remarkable decline was observed in this sound. Few remarkable changes, however, were found in the left epicardial sound (Fig. 4).

A remarkable decline, in disappearance test of the heart sounds by left heart bypass, was observed in the left epicardial sound with depression of the left ventricular pressure (LVP). These results were similar to those obtained in the case of the right heart bypass. When recorded simultaneously, the right epicardial sound was not affected in spite of depression of the LVP (Fig. 5).

As mentioned above, the rapid rise of the ventricular pressure played an important role in the occurrence of the first

sound. The central vibrations of the first right epicardial sound were derived mainly from the tricuspid valvular component and those of the first left epicardial sound from the mitral valvular component.

5. In the examination of the between external phonocardiogram and intracardiac pressure, it is indicated that there was no time difference between the left and right Q-I times. A clear time difference, however, was found between the left and right isometric contraction phases at the beginning in two cases, Nos. 1 and 3. There was no clear time difference in the occurrence time between the left and right central vibrations (Fig. 6).

Discussion

1. Occurrence of the first sound in the dog

There have been many theories on the occurrence of the first heart sound in the central vibrations. In most of the theories at present, this sound is regarded as the closing sound of the atrioventricular valves. Dock [2] reported that the main factor for the occurrence of the first sound might not be the contracting sound of these valves. Luisada et al. [6], Bartoro et al. [1], Rushmer [12], Spörri [14] and Shah et al. [13] mentioned that the central vibrations of the first sound might be derived from the closing sound of each valve, judging from the phonocardiogram and intracardiac pressure simultaneously recorded. Luisada et al. [6] and Spörri [14] found a small time difference between the left and right isometric contraction phases at the beginning. Luisada et al. [6] ascribed this difference to the respiration, since he observed that the onset of the left isometric contraction phase occurred a little earlier than that of the right isometric contraction phase.

Luisada et al. [6] and Shah et al. [13] reported that the central vibrations of the

first sound had occurred a little later than the onset of the isometric contraction phase, as was clear from the endocardial phonocardiogram and intracardiac pressure simultaneously recorded. They presumed that the central vibrations of the first sound might have been induced by the rapid tension of the atrioventricular valves.

In this investigation, the author found a regular relationship between the first sound on the epicardial phonocardiogram and the isometric contraction phase. Namely, the central vibrations of the first sound usually appeared on the epicardial phonocardiogram at the same time with, or a little later than, the onset of the left and right isometric contraction phase. The author also pointed out that the time difference in these central vibrations was derived from the difference in the onset between the left and right isometric contraction phases.

These results indicate that the central vibrations of the first sound on the epicardial phonocardiogram were induced by the rapid tension of the atrioventricular valves. It is presumed that the time difference in the central vibrations between the left and right first sound recorded on the epicardial phonocardiogram, as mentioned in the previous section, may have been originated from the difference in the onset between the left and right isometric contraction phases. These results agree almost completely with those reported by Luisada et al. [6].

2. Components of the central vibrations of the first heart sound on the epicardial phonocardiogram in the dog

The central vibrations of the first heart sound on the epicardial phonocardiogram in the dog are derived from the tension sound of the atrioventricular valves, although they contain some components originated from the mitral and tricuspid

valves. It is necessary to distinguish these valvular components from each other.

Many reports have been published on the valvular components analyzed by the phonocardiogram, but no common interpretation has been found among them. Rappaport and Sprague [9] demonstrated that the first heart sound was often composed of three types of vibration, muscular, valvular and vascular. Luisada et al. [5], Rushmer [12] and Shah et al. [13] described that the first heart sound had three or four components, the first, second, third and fourth vibrations.

Luisada et al. [6] reported that the central phase was composed of four types of vibration which corresponded to the motions of the four valves, respectively; that is, closure of the mitral valve (first vibration) and the tricuspid valve (second vibration), and opening of the pulmonary valve (third vibration) and the aortic valve (fourth vibration). Rushmer [12] found that the central vibration was composed of two types of vibrations, or the components of the atrioventricular and semilunar valves, and that the tricuspid component had little effect on these types of vibrations. Later, Luisada [8] lent support to Rushmer's theory [11]. It was reported [3] that the component of the semilunar valve was not affected at all.

In the previous section, studied were made on the component of the central vibrations of the first heart sound on the epicardial phonocardiogram. The following results were obtained from them. The central vibrations of the first heart sound on the left epicardial phonocardiogram were composed mainly of the mitral valvular vibration, and those on the right epicardial phonocardiogram of the tricuspid valvular vibration. Few reports have been made on the components of the central vibrations of

the first heart sound on the epicardial phonocardiogram in the dog.

From the results maintained in this and the previous sections, it was clarified that the central vibrations of the first heart sound on the epicardial phonocardiogram were composed of two vibrations, and that the tentation sound of the mitral valve appeared a little earlier than that of the tricuspid valve.

3. Components of the central vibrations of the first heart sound on the external phonocardiogram in the dog

The present experiment made it possible to some extent to analyze the components of the central vibrations of the first heart sound on the epicardial phonocardiogram. It is presumed, however, that these components may be different in many points from those of the central vibrations of the first heart sound on the external phonocardiogram, as revealed by the results mentioned in the previous sections. Namely, a difference was found clearly in the time of onset between the left and right central vibrations of the first heart sound on the epicardial phonocardiogram. Such time difference, however, was not found clearly on the external phonocardiogram. It is assumed that the time difference between the sounds may be transmitted from the epicardium to the chest wall.

The heart is hung in the thoracic cavity. Therefore, when transmitted to the chest wall, the epicardial sounds are interfered acoustically with each other. The mitral and tricuspid sounds are separated on the epicardium. If they are produced in one closed cavity, they will be fused into one sound in that cavity. According to this theory, it is assumed that the mitral and tricuspid components may be contained in the central vibrations of the first heart sound on the left and right external phono-

cardiogram. In the central vibrations, the mitral valvular component usually appears earlier than the tricuspid valvular component. It is presumed that the mitral valvular component may occupy the first half of the central vibrations of the first heart sound, and a mixture of the mitral and tricuspid valvular components the second half. It is unknown where the tricuspid valvular component occurs. This component may appear about 0.010–0.020 seconds later than the mitral valvular component.

As mentioned above, phonocardiography revealed the components of the first heart sound in dogs distinctly. It is believed that it will be useful for the clinical diagnosis of a heart disease which is caused by the functional disturbance of the atrioventricular valves in dogs.

Acknowledgments: The author wishes to thank Professor T. Kita, Associate Professors M. Takahashi and T. Suzuki, and Lecturer T. Suganuma, of the Department of Surgery, Azabu Veterinary College, for their encouragement and valuable advice.

References

- [1] Bartolo, G., Nunez-Day, D., Muiesan, G., Macanon, D. M., and Luisada, A. A. (1961). Hemodynamic correlates of the first heart sound. *Am. J. Physiol.*, **201**, 888–892.
- [2] Dock, W. (1933). Mode of production of the first heart sound. *Arch. int. Med.*, **51**, 737–746.
- [3] Kelly, J. J., Jr. (1957). Origin of the heart sounds. Symposium on cardiovascular sounds. *Circulation*, **16**, 273–276.
- [4] Leatham, A. (1954). Splitting of the first and second heart sounds. *Lancet*, **2**, 607–614.
- [5] Luisada, A. A., Mendoza, F., and Alimurung, M. M. (1949). The duration of normal heart sounds. *Brit. Heart J.*, **11**, 41–47.
- [6] Luisada, A. A., Alimurung, M. M., and Lewis, A. L. (1952). Mechanism of production of the first heart sound. *Amer. J. Physiol.*, **168**, 226–233.
- [7] Luisada, A. A., Liu, C. K., Aravanis, C., Testelli, M., and Morris, J. (1958). On the mechanism of production of the heart sound. *Amer. Heart J.*, **55**, 383–39.
- [8] Luisada, A. A. (1965). *In From Auscultation to Phonocardiography*, C. V. Mosby Co., Saint Louis, 12–18.
- [9] Rappaport, M. B., and Sprague, H. B. (1942). The graphic registration of the normal heart sounds. A graphic analysis of the normal heart sounds. *Amer. Heart J.*, **23**, 591–623.
- [10] Reinhold, J., and Rudhe, V. (1957). Relation of the first and second heart sounds to events in the cardiac cycle. *Brit. Heart J.*, **19**, 473–485.
- [11] Rushmer, R. F. (1956). The initial phase of ventricular systole: Asynchronous myocardial contraction. *Amer. J. Physiol.*, **184**, 188–194.
- [12] Rushmer, R. F. (1961). *In Cardiovascular Dynamics*, 2nd ed., W. B. Saunders Co., Philadelphia & London, 300–328.
- [13] Shah, P. M., Mori, M., Sacanon, M., and Luisada, A. A. (1963). Hemodynamic correlates of the various components of the first heart sound. *Circulat. Res.*, **17**, 386–392.
- [14] Spörri, H. (1962). The study of cardiac dynamics and its clinical significance. *Advanc. vet. Sci.*, **7**, 1–41.

Explanation of Figures

Fig. 1. External Phonocardiogram (case No. 9).

A: Right. B: Left.

Fig. 2. Time relationship between the left and right first epicardial heart sounds (case No. 6).

R: Right epicardial sound.

L: Left epicardial sound.

Fig. 3. Relationship between the left and right epicardial sounds and intraventricular pressure (case No. 3).

A: Left. B: Right.

a: Beginning of the central vibrations of the left first heart sound.

b: Onset of the left isometric contraction phase.

c: Onset of the right isometric contraction phase.

d: Beginning of the central vibrations of the right first heart sound.

Fig. 4. Relationship between the left and right epicardial sounds and right intraventricular

pressure in right heart bypass (case No. 3).

A: Control. B: 10 second after the disappearance of the right epicardial sound.

Fig. 5. Relationship between the left and right epicardial sounds and left intraventricular pressure in left heart bypass (case No. 2).

A: Control. B: 7 seconds after the disappearance of the left epicardial sound.

Fig. 6. Relationship between the right and left external heart sounds and left and right intraventricular pressure (case No. 3).

A: Right. B: Left.

a: Beginning of the central vibrations of the left first heart sound.

b: Onset of the left isometric contraction phase.

c: Onset of the right isometric contraction phase.

d: Beginning of the central vibrations of the right first heart sound.

6