Ultrasonic evaluation of anatomical abnormalities of heart in congenital and acquired heart diseases

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Attempts have been made to apply ultrasono-cardiotomography to patients with congenital and acquired heart diseases. Ultrasono-cardiotomography enables a clear cross-section picture of the heart and great vessels in patients with various heart diseases as well as in normal subjects. Abnormalities in anatomical structure such as hypertrophy of the myocardium, enlargement of the cardiac chambers, and septal defect at atrial or ventricular levels can also be seen.

The findings from the ultrasono-cardiotomograms are in good agreement with those found in the resected mitral valve. Changes in tissue, such as verrucae or degeneration, can be seen and the method is clinically useful in detecting morphological and anatomical abnormalities in various heart diseases.

Ultrasound cardiography is the clinical application of ultrasonic reflection technique (Edler and Hertz, 1954; Edler *et al.*, 1961; Edler, 1965; Effert, Erkens, and Grosse-Brockhoff, 1957), by which an echogram is obtained which is a one-dimensional record of the intracardiac structures. Thus only a difference in distance from the transducer to the heart structures is shown which produces the echo.

However, along the direction of ultrasonic propagation the movement of the intracardiac structures such as the valves, septum, or ventricular free wall, which are inaccessible to other diagnostic methods, can easily be seen in living subjects. This analytical method of cardiac movements has been employed almost exclusively for the diagnosis of mitral (Effert, 1959, 1967; Edler, 1967; Joyner, Reid, and Bond, 1963; Gustafson, 1966; Segal, Likoff, and Kingsley, 1966, 1967) and tricuspid valve diseases (Joyner *et al.*, 1967; Nimura *et al.*, 1967) and pericardial effusion (Feigenbaum, Zaky, and Grabhorn, 1966; Feigenbaum, Zaky, and Waldhausen, 1967).

Another application of the pulse reflection technique is ultrasono-cardiotomography which has been developed for practical use by the present authors (Tanaka, 1966; Tanaka

et al., 1966, 1970; Ebina *et al.*, 1967). With this method, a vertical or horizontal cross-sectional picture of the heart and great vessels in a living human subject can be recorded in two dimensions. Furthermore, visualization of the anatomical structures, and the measurement of the diameter of the cardiac chambers and of the thickness of the heart walls as well as the analysis of the cardiac movements become much easier (Tanaka *et al.*, 1970).

Since publication of the preliminary report on ultrasono-cardiotomography, the present authors have improved the apparatus for clinical diagnostic purposes (Kikuchi and Tanaka, 1966; Tanaka and Kikuchi, 1967; Tanaka *et al.*, 1967b, 1968a, b). In this paper, the clinical significance of ultrasono-cardiotomography as a method of seeing the intracardiac structures will be reported together with the demonstration of ultrasono-cardiotomograms of various heart diseases.

Method

Apparatus The ultrasonic transmitter receiver unit, and the synchronizer used for automatic control of the ultrasonic apparatus synchronized with cardiac movements, were the same as those used in previous reports (Tanaka, 1966, 1968a; Tanaka *et al.*, 1966, 1970; Ebina *et al.*, 1965, 1967). In

addition, a sensitivity time control circuit and a fast time constant circuit were built into the receiver unit, in order to increase the resolution of the ultrasono-cardiotomogram (Tanaka *et al.*, 1967b, 1968b).

By the application of the sensitivity time control circuit, the brightness of echoes from the cardiac areas at different distances from the transducer became almost of the same intensity and the echo from the heart could be differentiated clearly from that of the anterior chest wall. With the use of the fast time constant circuit, the echo pattern on the cathode ray screen became sharper and the width of the echo narrower. Accordingly, the apparent resolution of the ultrasono-cardiotomogram was remarkably improved by using both circuits.

Because of good penetrability and resolution, an ultrasonic pulse with a frequency of 2.25 MHz and a repetition rate of 1000/sec was used in this experiment. The transducer with a resonant frequency of 2.25 MHz was made of a concave disc of barium titanate. It had a diameter of 30 mm and a radius of curvature of 100 mm. This concave transducer was designed on the basis of the preliminary investigation (Tanaka and Kikuchi, 1967).

In transthoracic ultrasono-cardiotomography (Ebina *et al.*, 1967; Tanaka, 1968b), the sector motion of the transducer on the anterior chest surface was a prerequisite for the projection of the ultrasonic beam to the portion of the heart behind the sternum and to the lateral portion of

the heart enveloped by the lung. It was also necessary to set a plane of ultrasonic scanning at an inclination and at an azimuthal angle¹ to the chest surface as desired, in order to obtain the ultrasonic section pictures of the heart at various levels and in different directions. For this purpose, two new scanners were used for sector scan, linear scan, and compound scan which was a combination of the sector and linear scan.

One of the scanners was driven automatically by motors. Scanning speed of either 1 mm/sec or 0.5 mm/sec could be chosen for linear scan. For sector scan, the angular velocity of the sector motion could be controlled in proportion to the rate of cardiac pulsation. However, the angle of the sector scanning was fixed at 60°.

The other was operated manually without limitation on the angle of sector scanning. The

¹ See explanatory note at end of paper.

FIG. 2 X-ray tomogram of the excised human heart inflated with air and the ultrasono-cardiotomogram taken in the direction along the longitudinal axis of the left ventricle in a normal living human subject. Schematic cross-section of the human body in the same direction is also represented (right below). The azimuthal angle is about -45°.

FIG. 1 Block diagram of ultrasono-cardiotomography by the transthoracic method.

transducer, when attached to this scanner, could be easily fixed to the chest surface at any incidence angle which could be measured in three dimensions. Therefore, this scanner driven manually was more suitable for the combination of ultrasono-cardiotomography with the time position indication method (so-called ultrasound cardiography or echocardiography) (Tanaka *et al.*, 1967a, 1970; Tanaka, 1968b).

The transthoracic method was employed throughout this investigation. As shown in Fig. 1, a thin vinyl bag ($50 \times 30 \times 10$ cm) filled with warm degasified water was attached to the chest wall of a patient in a supine position, with olive oil as acoustic couplant. The ultrasonic beam travelled in the water through the chest wall to the heart and the heart was cross-sectioned by the ultrasonic beam as shown in Fig. 2, 3, and 4. The origin of scanning was set very close to the chest surface. This method was designated as 'the proximity-immersed method' (Tanaka *et al.*, 1966, 1970; Ebina *et al.*, 1967).

FIG. 3 X-ray tomogram of the excised human heart and ultrasono-cardiotomogram obtained by scanning in the horizontal direction of the human body. The azimuthal angle is about 0° .

When the ultrasonic apparatus was operated in synchronization with cardiac pulsation for recording a stationary ultrasono-cardiotomogram, the scanner made continuous sector swings without being in synchronization with pulsation. Only the indicator (cathode ray tube) was repeatedly put into operation for about 30 msec at a selected phase of every cardiac cycle by using the electrocardiogram current. The echo patterns obtained during 20 to 30 successive pulsations were accumulated on cathode ray screen or film. Thus a sheet of ultrasono-cardiotomogram in a stationary state at any instant of one cardiac phase could be obtained.

The origin of sector scanning was mainly at the left parasternal border in the 4th intercostal space. The azimuthal angle (Tanaka *et al.*, 1968a; Tanaka, 1968a) was varied from case to case. A plane with an azimuthal angle of 0° was on a horizontal plane through the human body. The minus sign of the angle indicates that the scanning plane is rotated clockwise. The ultrasonic

FIG. 4 Comparison between the x-ray tomogram of the excised human heart and the ultrasono-cardiotomogram obtained by scanning in the sagittal direction of the body. The azimuthal angle is about -90° .

examination was applied to patients with congenital heart diseases such as atrial septal defect, ventricular septal defect, and tetralogy of Fallot; and to those with acquired heart diseases such as mitral regurgitation and aortic regurgitation.

Results

Fig. 5 shows the ultrasono-cardiotomograms at systolic and diastolic phases in a normal subject. The direction of the scanning plane is parallel to the longitudinal axis of the left ventricle as indicated by a black line in the x-ray picture. The left atrium, the left ventricle, the aorta, the aortic valve, and the anterior and posterior mitral leaflets are represented clearly.

The ultrasono-cardiotomograms of atrial septal defect, ventricular septal defect, and tetralogy of Fallot are illustrated in Fig. 6, 7, and 8. In atrial septal defect, the right ventricle is dilated and the ventricular septum is parallel to the chest wall. A hatched arrow in the tomograms indicates the defect at a level of the atrial septum. The ultrasono-cardiotomogram of tetralogy of Fallot reveals dilatation of the right ventricle and thickening of the right ventricular wall. (The hatched arrow also shows ventricular septal defect.) In ventricular septal defect, the defect is shown also at a level of the ventricular septum, as indicated by the hatched arrow.

Fig. 9 shows the ultrasono-cardiotomograms of a case of mitral steno-insufficiency associated with aortic regurgitation, and Fig. 10 those of a case of pure mitral insufficiency caused by rheumatic fever. The direction of the scanning plane in both cases is almost the same as Fig. 5. Dilatation of the left atrium and ventricle, thickening of the left ventricular wall, and thickening and deformity of the mitral valve are observed.

Discussion

Anatomical consideration on ultrasono-cardiotomogram For precise diagnosis of heart diseases and for evaluation of the cardiac functions, exact information is required concerning the cardiovascular system before and/or after the treatment. This information should include abnormalities, if present, in the anatomical construction of the heart, the severity of organic lesions in heart muscle and valves, the size of the heart chambers, the thickness of the heart wall, etc. By practical application of ultrasono-cardiotomography, a cross-section picture of the heart and great vessels is shown in two dimensions without surgical technique. The anatomical construction and quantitative changes in tissue can also be shown by the detection of abnormal

FIG. 5 Ultrasono-cardiotomograms of a normal subject. The four ultrasono-cardiotomograms show a cross-section of the heart along the longitudinal axis of the left ventricle which goes through the centre of the right ventricle at four cardiac phases. Echo pattern on the left side of each tomogram represents the anterior and that on right side the posterior chest wall. Top of each tomogram represents right side of the patient, bottom represents left side.

echoes or echo defects. Therefore, in order to obtain necessary information for clinical diagnosis by a simple and safe technique, the application of the ultrasonic reflection method, especially that of ultrasono-cardiotomography, is considered most suitable. This unique technique to visualize the heart at a certain cardiac phase on an instantaneous static tomogram has been designated 'ultrasono-cardiotomography' by the present authors (Tanaka, 1966; Tanaka *et al.*, 1966).

For the precise interpretation of a cross-section picture of the heart obtained by this method, it is important that the correlation between the tomographic pattern and the anatomical construction is made clear. However, it is impossible to excise the heart of an examinee just after ultrasonic examination. In practice, comparison of the findings on an ultrasono-cardiotomogram with those on a plane of section of a freshly excised heart is impossible, because the size and form of the plane of section of the freshly excised heart change due to the release of blood from the cardiac chambers. Hence *x-ray* methods have been used for the interpretation of ultrasono-cardiotomograms in living subjects.

Immediately after ultrasonic examination, anteroposterior chest *x-rays* and right-to-left lateral *x-rays* were taken in the same position as in ultrasonic examination. The size of the heart on the *x-rays* was calculated by dividing it by a factor of enlargement and that on the ultrasono-cardiotomograms based on the velocity of propagation of the ultrasound passing through the blood.

The distance between the echo from the anterior chest wall and the exterior border of the largest arc form echo was identical to that between the shadow of the anterior chest wall and that of the exterior border of the left ventricular wall in right-to-left lateral projection (Fig. 11; distance between two dotted vertical lines). Thus it is evident that the arc-form echo is from the left ventricular free wall and that the echoes between the two dotted lines are from the intracardiac structures.

To facilitate exact interpretation of the correlation between the anatomical construction of the heart and ultrasono-cardiotomograms, some fundamental experiments were performed on an intact human heart excised at necropsy. After the chambers of an excised human heart were filled with air in place of blood, *x-rays* were taken at almost the same levels and directions as in ultrasonic scanning. Then the intracardiac structures on the ultrasono-cardiotomogram were compared with those on the *x-ray*.

Fig. 11 (left below) shows the results of

FIG. 6 Ultrasono-cardiotomograms in a case of atrial septal defect. The direction and level of the cross-section is indicated by a black arrow in the chest *x-ray* picture. The thick white hatched arrow shows the septal defect.

FIG. 7 Ultrasono-cardiotomograms in a case of ventricular septal defect.

a typical experiment. The right ventricle, ventricular septum, left atrium, left ventricle, mitral anterior and posterior leaflets, aorta, aortic valve, etc. on the ultrasono-cardiotomogram coincide with those on the *x*-ray, respectively.

Finally, after the excised human heart was treated with formalin, a sectional plane of the heart at the same level and direction as in ultrasono-cardiotomography and in *x*-ray tomography was compared with these two kinds of tomograms. As shown in Fig. 12, the cross-section picture agrees well with the ultrasono-cardiotomogram.

Thus it is evident that all parts of intracardiac structures reflect ultrasound, and the anatomical construction of the heart can be represented clearly by ultrasono-cardiotomography. The ultrasono-cardiotomogram is a two-dimensional display of the heart which has a three-dimensional structure. Therefore, for the detection of anatomical abnormalities such as septal defect or stenosis of the valves by ultrasono-cardiotomography, the most suitable level, inclination, and/or azimuthal angle of a scanning plane for ultrasono-cardiotomogram, which gives as much information as possible of the target area of the heart, must be decided. In addition, it is necessary to confirm the validity of the ultrasono-cardiotomograms taken in various directions and at different inclinations by comparing them with the corresponding sectioned planes of the entire heart or of the target heart area. However, when only one formalin-treated heart or freshly-excised heart is used, it is very difficult to obtain the precise shape of the heart or that of an actual sectioned plane in various directions. Thus, the application of *x*-ray tomography was considered adequate.

X-rays of the excised human heart filled to the normal size with air were taken almost at the same levels and in the same direction as in transthoracic ultrasonic scanning in living subjects. The *x*-rays thus obtained were compared with ultrasono-tomographic patterns. Some of the results obtained can be seen in Fig. 2, 3, and 4.

In the *x*-rays, when a plane of tomogram was so selected that the left ventricle was cut longitudinally through the centre of the right ventricle and along the line between the basic part of the aorta (portion of the aortic bulb) and the apex of the heart as shown in Fig. 2, the left atrium and ventricle, mitral valve, aortic valve, and ascending aorta were clearly seen. Thus much information about the left heart can be obtained on such tomographic planes.

To get longitudinal section patterns as

FIG. 8 Ultrasono-cardiotomograms in a case of tetralogy of Fallot.

above in ultrasono-cardiotomography and in *x*-ray tomography, the origin of the scanning plane was set at the left parasternal border in the fourth intercostal space in the supine position, and an azimuthal angle of the scanning plane was within the range -35° and -50° .

Both the in- and outflow tracts of the left ventricle appear on the plane which crosses the chest surface at a right angle in spite of a difference in distance along the dorso-ventral direction between the in- and outflow tracts; thus giving useful information about the left heart. In normal cases, the left ventricle is visualized as a sonolucent elliptical structure. In addition the ventricular septum with an inclination of about 45° to the chest wall is clearly seen and the right ventricle attached to the chest wall appears triangular.

When the tomographic plane was rotated counterclockwise by about 30° to 45° from the

longitudinal axis of the left ventricle, tomograms of the excised heart as shown in Fig. 3 were obtained. The right atrium and ventricle, parts of the left atrium and ventricle, and the atrial and ventricular septum were clearly seen. Therefore, the tomogram obtained in this direction was considered to yield significant information concerning the right heart.

In order to obtain a pattern in ultrasonotomography which corresponds to one in *x*-ray tomography, it was necessary to set the origin of the sector scanning in the fourth to fifth intercostal space at the left sternal border and to set the direction of scanning plane at 0° to -15° of the azimuthal angle along the intercostal space.

When the right ventricle is looked at from the anterior chest surface, the direction of the outflow is almost perpendicular to that of the inflow. Therefore, the information on the right ventricular outflow tract and pulmonary artery in *x*-ray tomography of the excised heart is obtained by taking tomograms at 30° to 45° from the longitudinal direction. In ultrasono-cardiotomography, an equivalent section pattern will be obtained by scanning in the sagittal direction along the parasternal line (azimuthal angle is about $+90^\circ$; the origin of the sector scan is in the fourth intercostal space as shown in Fig. 4). Ultrasono-cardiotomograms taken in horizontal and sagittal planes of scanning will be enough to give diagnostic information on the right heart. While scanning on a horizontal plane and/or scanning with an azimuthal angle of about $+15^\circ$ to $+30^\circ$ at the third intercostal space, there should be ultrasono-cardiotomograms of the left and right atria, atrial septum, and basic portions of the aorta and of pulmonary artery.

Detection of morphological abnormalities In heart diseases, the size and form of the heart and the configuration of the valves and septum differ from normal subjects. In addition, the intensity of the echo varies depending upon the incidence angle of the ultrasonic beam to the target and on the degree of attenuation of ultrasound during propagation. Therefore, the direction suitable for ultrasonic scanning of the diseased heart is different from that for normal heart, and the echoes frequently fail to return to a receiver even from the portion from which the echo is expected in normal subjects. The heart has many curved interfaces and the attenuation during propagation may become more remarkable due to dilatation of the chambers or to hypertrophy of the walls. For the purpose of distin-

FIG. 9 Ultrasono-cardiotomograms in a case of mitral steno-insufficiency associated with aortic regurgitation. Aortic and mitral valve echoes show abnormal nodular pattern and remarkable thickening of the left ventricular wall. The echo of the wall is demonstrated in a three-layer pattern.

guishing the echo defect caused by the genuine tissue defect from that caused by the above acoustic factors, and of detecting the abnormal echoes produced by the morphological changes of the intracardiac structures of three-dimensional construction, ultrasono-cardiotomograms should be taken from various directions by changing slightly the azimuthal angle or the inclination of the scanning plane as well as from the direction most suitable for the normal cases as shown in Fig. 13. It is evident that the echo defects and the abnor-

mal echoes can be confirmed, based on the findings of the ultrasono-cardiotomograms thus obtained.

Fig. 6, 7, 8, 9, and 10 show ultrasono-cardiotomograms of various heart diseases taken in the most suitable direction of scanning for the detection of specific findings.

Dilatation of the right ventricle and the septal defect at the atrial level in a case of ASD, right ventricular hypertrophy in a case of tetralogy of Fallot, and the septal defect at the ventricular level in a case of VSD and in tetralogy of Fallot are illustrated, respectively.

As understood from the above figures, ultrasono-cardiotomography is a new way of showing the anatomical changes of the cardiac structures such as dilatation of the atrium or ventricle, ventricular hypertrophy, and/or the septal defect at the atrial or ventricular levels without surgical technique.

Detection of changes in tissue character

Degeneration of the tissue occurs frequently in cardiovascular diseases such as arteriosclerosis, myocardial infarction, myocardiopathy, rheumatic heart disease, etc. When there is a change in tissue character, such as cicatrization, it is likely that there is also a change in acoustic character (a change in density of the tissue or in velocity of propagation through the tissue) in the degenerate tissues, and that the difference in acoustic impedance between the blood and endocardium or myocardium becomes larger than that in normal subjects.

In the ultrasonic pulse reflection technique, strong echoes are received whenever the beam encounters the interface between the tissues which show large differences in acoustic impedance. It is thus conceivable that the echo intensity or echo pattern on ultrasono-cardiotomograms in heart diseases associated with tissue degeneration as mentioned above changes also.

Fig. 9 shows the ultrasono-cardiotomograms in a patient with dominant mitral stenosis associated with aortic incompetence. The mitral and aortic valve echoes are more clearly seen than those of healthy subjects even in a range of low sensitivity of the apparatus. In the aortic valve, two considerably wide and bright echoes can be distinguished clearly from each other. On the mitral valve, particularly its anterior leaflet, nodular and large abnormal echoes are seen at the tip of the leaflet. Enlargement of the left atrium and ventricle, and thickening of the ventricular wall are represented also.

The brightness of the echo of the internal wall of the left ventricle exceeds that of nor-

FIG. 10 Ultrasono-cardiotomograms in a case of pure mitral regurgitation. Enlargement of the left atrium and ventricle. Abnormal nodular echo illustrated at the tip of the mitral anterior leaflet.

mal subjects. From these facts, it is assumed that the difference in acoustic impedance at the interface between blood and the internal surface of the ventricular wall or of the myocardium in this case is larger than in the normal cases due to degeneration or cicatrization of the endocardium or myocardium.

Fig. 10 demonstrates the ultrasono-cardiotomograms of a case of pure mitral regurgitation with similar ultrasonic findings to those in Fig. 9. The left atrium and ventricle are much enlarged. The nodular echo at the tip of the valve and the wide echo which seemed to be caused by the thickening and adhesion of chordae tendineae are particularly prominent.

Kikuchi (1968) has already mentioned that the method of sensitivity graded tomogram pairs is a great help in detecting tissue degeneration. The sensitivity graded tomogram pairs of the mitral valve (Fig. 14) were obtained by a slight change in the azimuthal angle of the ultrasonic scanning plane from that in Fig. 10. The nodular echoes at the tip of the valve are represented also.

From the findings of Fig. 13 and 14, it is assumed that the incompetence of the mitral valve in this case is due to extensive thickening at the edge of the mitral leaflets and to thickening or adhesion of the chordae tendineae. A prosthetic valve was implanted later at operation in this case.

The macroscopical findings of the valve resected at operation are shown in Fig. 15 and 16. Thickening at the tip of the anterior leaflet, and thickening and partial adhesion of chordae tendineae are remarkable. Similar findings are observed also in the posterior mitral leaflet.

Fig. 15 and 16 show verruca in association with cicatrization due to tissue degeneration. The appearance and pathological changes of the mitral valve coincide well with the ultrasono-cardiotomographic findings.

From these results, it can be stated that the ragged edge of the mitral valve due to thickening or cicatrization produces more intense echoes than those in normal subjects, and that the structural changes of the valve tissue can also be represented.

Thus the sensitivity graded tomogram pair method was found to be very useful for the evaluation of the nature of degeneration.

When careful examinations are performed by changing the direction and inclination of the scanning plane, the pathological changes in the valve can be examined in three dimensions as shown in Fig. 13. Therefore, the evaluation of the extent and severity of the mitral valve lesion can easily be performed by

FIG. 11 Correlation between the findings of the x-ray examination and ultrasonic examination. The figure (left below) shows a tomogram of an intact human heart excised at necropsy. The level and direction of the tomogram is almost the same as in ultrasono-cardiotomogram. The sector enclosed by white lines on the tomogram corresponds to that on the ultrasono-cardiotomogram.

FIG. 12 Comparison between an ultrasono-cardiotomogram and the cross-section picture of the excised human heart treated with formalin (a normal case).

ultrasono-cardiotomography before and/or after treatment.

In the case of myocardial damage such as myocardial infarction, an increase in brightness of the echo or changes in echo character in a localized area of the heart wall are observed occasionally as shown in Fig. 9.

However, to confirm the presence of myocardial damage in living subjects, further investigations are necessary for the following reasons.

1 It is difficult to excise the heart just after the detection of abnormal echoes by ultrasono-cardiotomography and to investigate the correlation between the tomographic findings and the pathological changes in myocardium, and the intensity of the echo changes when there is a difference in direction of the muscle fibre even in normal subjects.

2 The results of the preliminary experiments on excised dog hearts indicate that the tissue structure of the myocardium can be demonstrated (Ebina *et al.*, 1965). However, some technical problems still remain to be solved in order to represent a very small difference in myocardial echoes.

Conclusions

A comparison between the ultrasono-cardiotomograms obtained in living human subjects by the transthoracic method and the x-rays of the excised human heart or the sectioned plane of the heart fixed with formalin revealed that the anatomical structure of the heart could be represented clearly by means of ultrasono-cardiotomography. The directions and inclinations of the ultrasonic scanning plane most suitable for obtaining useful diagnostic information of a target heart area were shown.

Enlargement of the atrium and ventricle, thickening of the heart wall or valves, septal defect, etc., were clearly seen by this method. In addition, changes in tissue character or structure, such as thickening or deformity of the valve due to cicatrization, could be detected. From these facts, the authors have emphasized the clinical value of ultrasono-cardiotomography in differentiation and identification of the congenital and acquired heart diseases.

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FIG. 13 Differences in ultrasono-cardiotomographic pattern obtained by changing the azimuthal angle of the scanning plane. When the scanning plane is changed in direction from (1) to (3), structural changes on the left side of the mitral valve including chordae tendineae can be demonstrated. In directions (6) and (7), structural changes on the right side of the mitral valve can also be seen as shown in the schematic figure. The numbers on each ultrasono-cardiotomogram correspond to those on the x-ray and the schematic figure. These tomograms were taken at the maximal systolic phase.

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FIG. 14 Sensitivity graded tomogram pairs of the ultrasono-cardiotomograms in a case of mitral insufficiency. The mitral valve echoes are shown in a range of low sensitivity of the receiver.

FIG. 15 The mitral valve resected from the case of Fig. 13. The ultrasono-cardiotomograms in this figure are taken in the direction of (4) in Fig. 13. From the consideration on azimuthal angle of scanning, the ultrasonic section picture of the mitral valve obtained corresponds to that of the part of the black arrow on the photograph of the resected valve. Histological findings (shown in the figure right below) show verruca and thickening of chorda tendineae.

FIG. 16 Ultrasonic section picture of the mitral valve. Figure obtained by clockwise rotation of the azimuthal angle about 10° from that in Fig. 13. The section pattern of this picture represents the area indicated by the black arrow on the photograph of the resected valve. The microscopical findings at this part of the valve are shown in the figure right below. Ultrasono-cardiotomographic findings clearly reflect the structural changes of the valve. Verrucae and deformity of the valve are also clearly represented.

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Note: The azimuthal angle in this paper indicates the angle between the horizontal plane and the ultrasonic scanning plane on chest surface.

When the scanning plane is on the horizontal plane, the azimuthal angle becomes 0° . When the scanning plane is on the sagittal plane, the azimuthal angle becomes -90° .