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Further Vectorcardiographical and Pathotopographical Studies on the Heart of Spontaneously Hypertensive Rats (SHR)

(hypertension/left ventricular hypertrophy/vectorcardiogram)

YUKIO YAMORI, MICHIYA OHTAKA, RYOICHI HORIE, YASUO NARA, and AKIRA OOSHIMA

Department of Pathology, Shimane Medical University ; Japan Stroke Prevention Center, Izumo 693, Japan

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Vectorcardiographical and electrocardiographical findings were comparatively studied in spontaneously hypertensive rats (SHR) and control Wistar-Kyoto rats (WK). The angle of maximum QRS vector in the frontal plane reflects in the electrical axis in electrocardiogram (ECG), and ST-T changes in vectorcardiogram (VCG) which were also observed as ST-T depression in X scalar ECG were related to the ST-T depression in left chest leads.

The topographical location of the heart was examined in the transverse section of the chest of 10-month-old stroke-prone SHR (SHRSP) immediately frozen in acetone-dry ice mixture and a comparison was made with age-matched WK. The clockwise rotation of the heart thus proven in SHRSP appeared to be related to such vectorcardiographical findings as the left superior deviation of major QRS portion.

From these results also, the heart of SHR was ascertained to be a good basic model for hypertensive cardiac diseases in humans.

Since "vectorcardiography for small animals" with a good reproducibility was established (1), various vector- or electrocardiographical features of spontaneously hypertensive rats (SHR) (2—6) or stroke-prone SHR (SHRSP) (7) have been revealed. Characteristic vectorcardiogram (VCG) in adult SHR was left superior deviation of major QRS portion usually with ST-T changes, which corresponded to pathological findings such as increased weights of the heart and the left ventricle, left ventricular wall thickening and also to high blood pressure. This vectorcardiographical feature was recognized as LVH (Left Ventricular Hypertrophy) pattern of SHR (Figs. 1 and 2) (1).

Our recent studies revealed that such an LVH pattern was evident even in prehypertensive 1-month-old SHR, particularly SHRSP and such observations suggested that "LVH", the change of the ventricular myocardium, might be evoked by genetic predisposition (8).

In old SHR particularly SHRSP, VCG often shows a deformity and deviation of QRS loop accompanied by prolonged QRS duration or predominantly increased magnitude of spatial maximum QRS vector, which might be the reflection of the organic changes of myocardium such as infarction-like

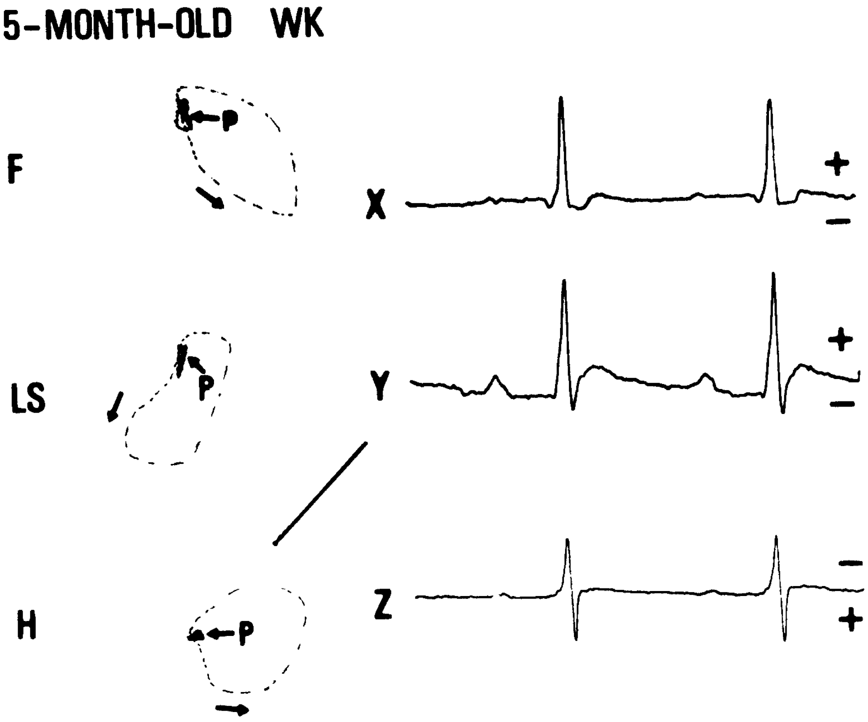

Fig. 1. Vectorcardiogram (VCG) of adult Wistar-Kyoto rats (WK). (Cal. 1 mV)

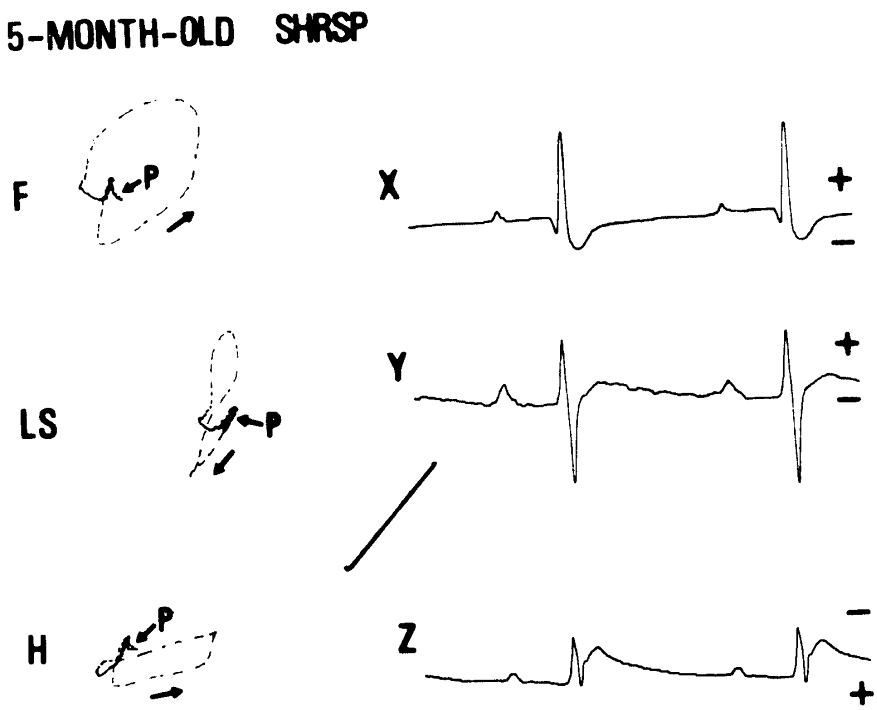

Fig. 2. VCG of adult stroke-prone SHR (SHRSP). Left superior deviation of major QRS portion usually with ST-T changes is recognized as LVH (Left Ventricular Hypertrophy) pattern of SHR. In this VCG, ST-T changes are noted as widely opened ST-T vector or ST-T depression in the X scalar electrocardiogram (ECG). (Cal. 1 mV)

myocardial fibrosis (Fig. 3) (9, 10) or dilated left ventricle (11).

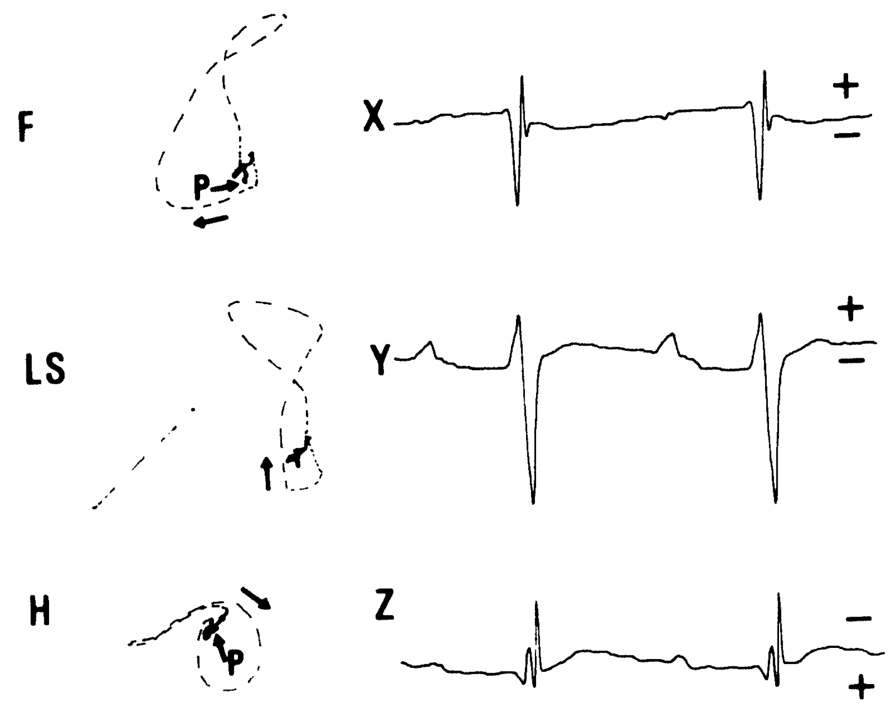

Fig. 3. VCG of old (1-year-old) SHRSP. Deformity and deviation of QRS loop with prolonged QRS duration, and ST-T changes are characteristically observed. (Cal. 1 mV)

In the present studies, we attempted to clarify the following 2 problems in SHR : 1) correlation between vectorcardiographical and electrocardiographical findings, and 2) the pathological topography of the heart and the ventricles in the transversed chest, in order to obtain the better understanding of vectorcardiographical findings in the heart of SHR and SHRSP.

MATERIALS AND METHODS

Experiment 1

Both vectorcardiogram (VCG) and electrocardiogram (ECG) were taken from each 5 of 5-month-old male stroke-prone SHR (SHRSP) and control Wistar-Kyoto rats (WK). The vectorcardiographical and electrocardiographical findings were examined regarding the following : 1. Relationship between the angle of maximum (max.) QRS vector in the frontal plane of VCG and the electrical axis of ECG. 2. Appearance of ST-T changes.

For this vectorcardiography, according to Takayasu lead system, 6 electrodes consisting of 2 small ones (placed at the head and the tail) and 4 large ones (placed at the front and back, right and left sides of the chest) were used, and orthogonal 3 axes of X, Y and Z configurated frontal, left sagittal and horizontal planes. VCG was recorded by the apparatus of S-3013 (Nihon Kohden). To facilitate a close attachment of the electrode plate to the skin, the hair of the rat was neatly cut, and a cotton wool wet with saline solution was placed between the skin and the plate. Rats under pentobarbital anesthesia

(30 mg/kg, i. p.), were placed in the prone position, and 4 transparent plastic walls with large electrode plates were fixed around the trunk (Fig. 4).

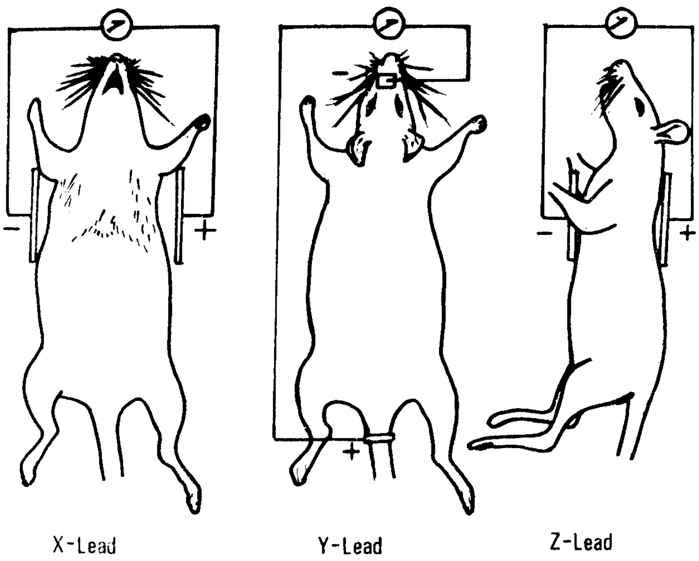

Fig. 4. "Vectorcardiography for small animals" according to the Takayasu lead system. Two small electrodes and 4 large ones make orthogonal 3 axes, namely, X-axis (from right to left), Y-axis (from up to down), and Z-axis (from front to back).

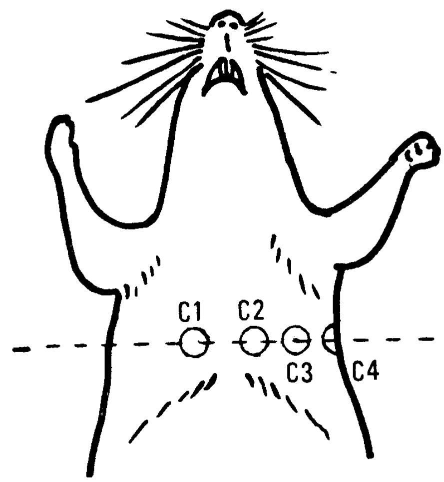

Fig. 5. Positions of the 4 chest leads in ECG of the rats. C1 on the right sternal border, C2 on the left sternal border, C3 on the apex, C4 on the left axillar line were, respectively, placed on the circumferential line at the height of the pulsating apex.

After VCG was recorded, ECGs of extremity and chest leads were taken with the animal in the supine position. ECG was recorded by ECG-4103 (Nihon Kohden). Round electrode plates, 9 mm in diameter, were used as indicated in Fig. 5. C1 lead on the right sternal border, C2 on the left sternal border, C3 on the apex, and C4 on the middle axillar line were, respectively, placed on the circumferential line at the height of the pulsating apex.

Experiment 2

After VCG was taken, 4 and 5 10-month-old female WK and SHRSP, respectively, were immediately frozen in acetone-dry ice mixture. Cross-sectioned blocks of the chest portion including the heart were prepared, and transversely cut into serial slices by an apparatus for whole body autoradiography, PMV-cryomicrotome 450 MP. The location and direction of the heart and the ventricles were examined in the transversed plane of the chest. The angle between the sagittal line of the trunk, namely the line from the sternum to the spinal cord, and the long axis of the oval left ventricular cavity was measured and tentatively termed α angle (Fig. 8).

RESULTS

Characteristic VCG and ECG of adult WK and SHRSP, respectively, are shown in Figs. 1, 2, 6 and 7.

As for VCG, max. QRS vector in the frontal plane was oriented toward the left inferior (the positive angle) in all WK, and contrarily toward the left superior (the negative angle) in all SHRSP (Figs. 1 and 2). In the ECG, the angle of the electrical axis was positive in all WK and negative in all SHRSP (Figs. 6 and 7). ST-T changes, characteristic in SHR, were observed in VCG to be widely opened ST-T loops and also ST-T depression in X scalar ECG. The corresponding findings in ECG were ST-T depression in leads of I, aVL, C3 and C4 (Figs. 2 and 7, and Table I).

The results of Experiment 2 are shown on Table II and in Fig. 8. The α angle was significantly larger in SHRSP than in WK. That is, the heart of SHRSP appeared to be rotated clockwise, compared with that of WK. VCG indicated a non-LVH pattern in all WK, and an LVH pattern in all SHRSP.

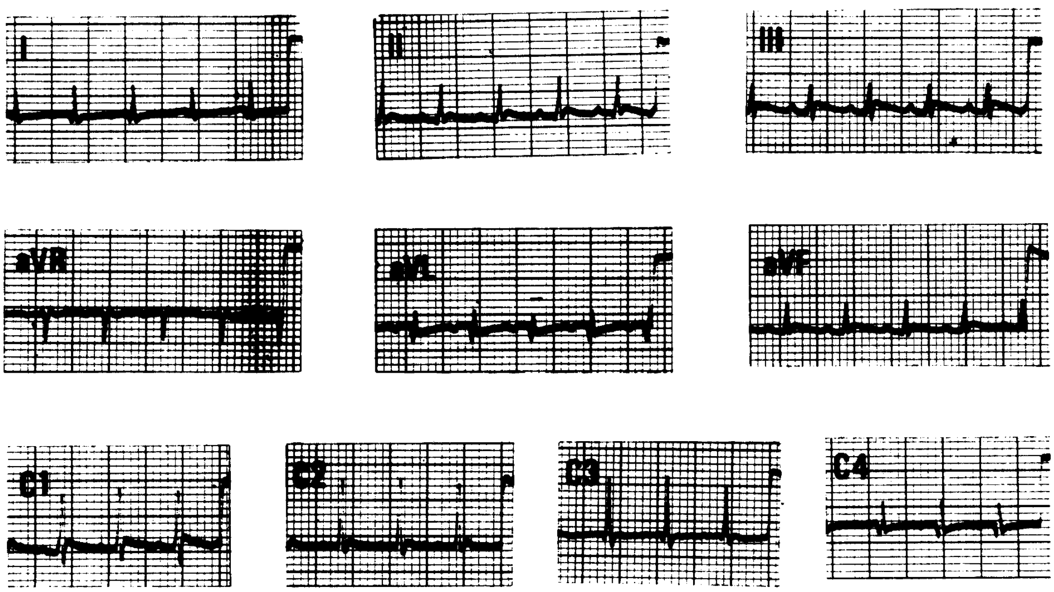

Fig. 6. ECG of the same WK as in Fig. 1.

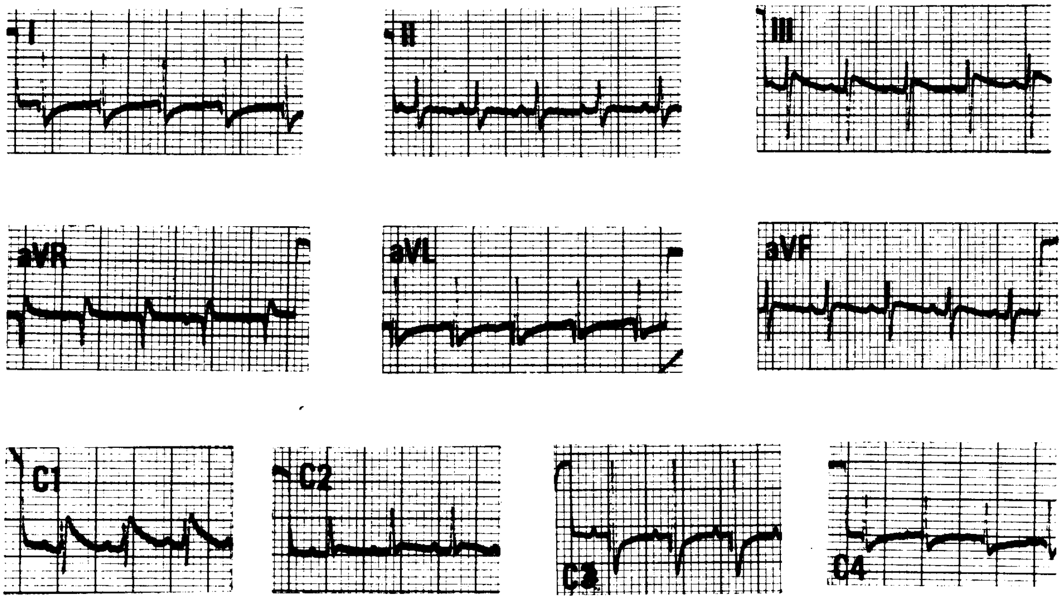

Fig. 7. ECG of the same SHRSP as in Fig. 2. Left axis deviation and predominant ST-T changes in leads of I, aVL, C3 and C4 are noted as characteristic features.

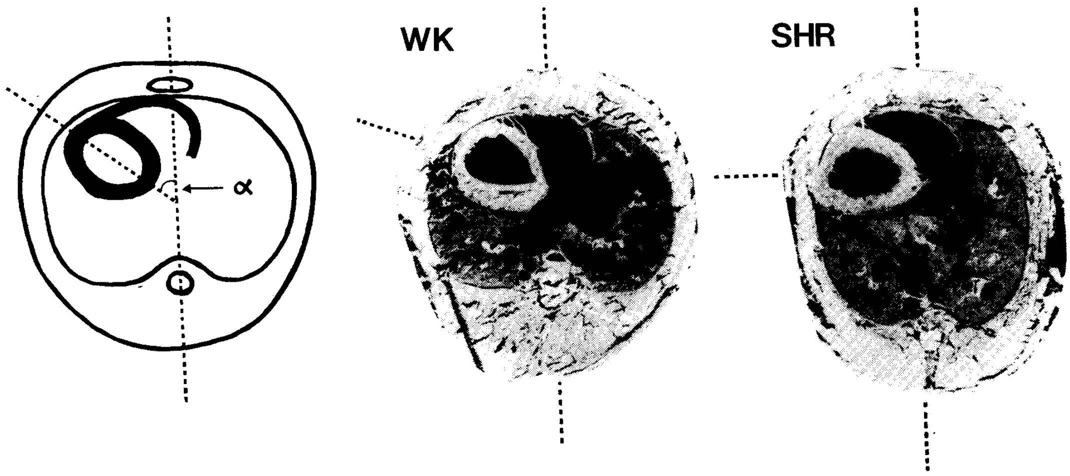

Fig. 8. Location and direction of the heart and the ventricles in 10-month-old WK and SHRSP. In SHRSP the α angle is larger and the heart seems to be clockwise rotated.

TABLE I. *Correspondence between the Vectorcardiographical and Electrocardiographical Findings of SHR*

Characteristic findings in VCG	Corresponding findings in ECG
Left superior deviation of max. QRS vector	Left axis deviation
ST-T changes noted in X scalar ECG	ST-T changes in extremity leads of I, aVL and in left chest leads of C3 and C4

TABLE II. *The Angle between the Sagittal Line of the Trunk and the Long Axis of the Left Ventricular Cavity*

Group	No. of animals	Mean of the angle (degree)
WK	4	57±4
SHRSP	5	79±6*

WK : Wistar-Kyoto rats, SHRSP : Stroke-prone SHR, statistically significant difference from WK (* : $0.01 < p < 0.05$))

DISCUSSION

Relationship between VCG and ECG findings was examined in SHR and normotensive WK. Of course, there are differences in the recording system between VCG and ECG ; VCG was recorded using a X-Y recorder equipped with an oscilloscopic related memory system, while ECG was recorded using a heated pen and recording paper.

Vectorcardiographical features of LVH pattern of SHR, the left superior deviation of max. QRS vector and ST-T changes as also noted in the X scalar ECG corresponded well to the electrocardiographical findings of left axis deviation and ST-T changes of left chest leads, respectively. This confirmed the reliability of VCG in relation to ECG, although it was also considered that there might be some discrepancy between VCG and ECG, for example between the angles of max. QRS vector in the frontal plane and electrical axis of ECG, as suspected by the variety in the configuration of QRS vector.

VCG is known to be clinically much more effective in detecting LVH or myocardial organic or functional changes than ECG. Such seems to be the case in small animals also and other merits are as follows : 1) Accuracy and reproducibility particularly in the horizontal plane, compared with ECG of the chest leads. 2) Can be taken in the prone position which is natural to the rat.

These vector- or electrocardiographical findings of SHR and SHRSP also correspond to those in humans with essential hypertension, although the increased magnitude of spatial QRS vector and the posterior deviation of QRS vector (or decreased R/S ratio in the Z scalar ECG), both incidences of which seemed to be higher in SHR particularly in old SHR, were not necessarily good indices of LVH as in humans.

In Experiment 2, the topographical location of the heart in rats was ascertained to be basically similar to that in humans (Fig. 8) (12). The clockwise rotation may be related to the vectorcardiographical LVH pattern of SHR. Such direct morphological evidence is almost impossible to obtain in humans and may provide further insight into the roentgenographical cardiac silhouette in the posteroanterior projection in SHR. That is, the left ventricular silhouette may be a reflection of not only hypertrophy but also of rotation of the heart (Fig. 9). It may possibly be the case in humans with

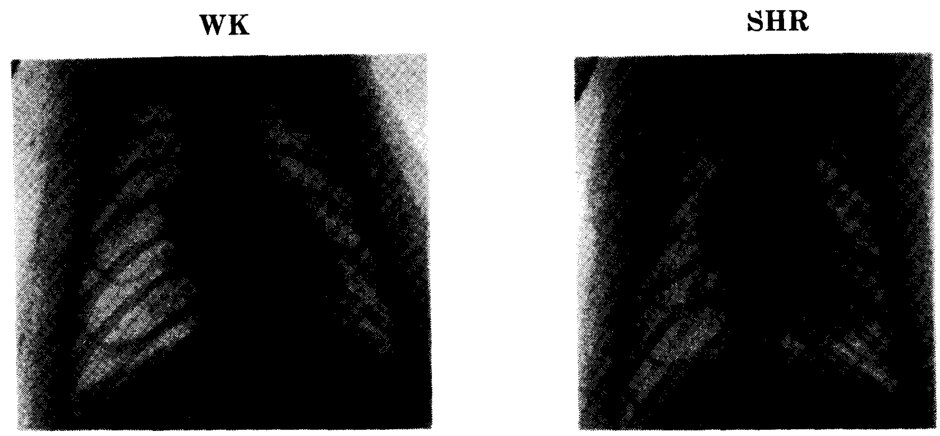

Fig. 9. Chest roentgenogram of adult WK and SHR. Cardiothoracic ratio is increased and the left ventricular silhouette is protruded in SHR.

essential or genetically related hypertension (13).

These vectorcardiographical and pathotopographical studies have further confirmed that the heart of SHR is a good model for studying hypertensive cardiac diseases in humans.

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