

6. ROENTGEN CINEFLUOROGRAPHIC STUDIES ON CHANGES IN HEART VOLUME OF JUDOISTS DURING PHYSICAL EXERCISE

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Since the Tokyo Olympic Games especial interest has been aroused in the cultivation of physical fitness in Judo, together with the cultivation of techniques. Several scientific papers dealing with the subject have been published, and among them there are quite a few papers dealing with the respiratory and circulatory systems^{2,3,4,6,9}. As it has already been reported^{5,12} the performance of Judo necessitates an aggressive attitude and in order to effect the techniques successfully a great deal of stamina is required, and consequently, there is no doubt that much load is imposed on the circulatory and respiratory systems.

In a previous paper⁶ the authors reported on a Judoist with a sport heart and it was thought to be of interest to investigate the heart of Judoists.

In the present study a Roentgen cinefluorographic investigation was made into the changes in cardiac volume of Judoists during physical exercise. In a previous report the authors published a paper regarding a Roentgen cinematographic study of changes in cardiac volume of middle distance running champions during physical exercise, however, similar studies dealing with Judoists have not yet been made. Roentgenographic observations on the heart was made by Ikai and associates² in their physiological study on the "Shime" in Judo.

Table 1. Physique and each index of resting cardiac silhouettes on a judoist and a non-trainee

	Judoist	Non-trainee
Name	H.S.	H.E.
Sex	Male	Male
Age	19	24
Body height (cm)	165.0	163.5
Body weight (kg)	67.7	51.6
Chest girth (cm)		
normal	95.1	81.4
max.	96.5	82.7
min.	94.5	79.7
Cardiac Silhouettes (cm)		
AR+AL	4.84	4.5
MR+ML	14.46	10.91
MR	5.99	3.12
ML	8.47	7.79
L	15.67	12.26
UQ+OQ	12.13	10.30
Area (cm ²)	152.6	107.0

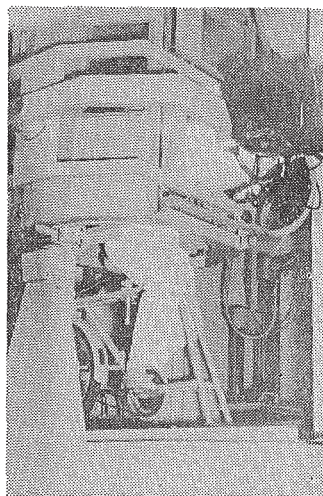


Fig. 1 A photograph of the experimental apparatus

METHOD OF INVESTIGATION

1. Experimental subject.

As the experimental subject a light weight university Judoist with 5 years of Judo experience was selected and a healthy young adult male of the same age was selected as the control. These two subjects were the same individuals as those used in a previous study: Physical Fitness of a Judoist (1) A Case Study from the View-Point of Cardio-vascular Function. Their basic physical fitness measurements are found in Table 1 and 2 of the same report.

The fundamental morphological measurements of the 2 experimental subjects are shown in Table 1.

2. Apparatuses used.

A Roentgen cinefluorograph and a bicycle ergometer were used (Fig. 1).

a) Bicycle ergometer.

An apparatus adapted to various kinds of physical exercise, especially to locomotic exercise, is desirable, however, it is not possible by present day Roentgenographic technical standard. Consequently, the bicycle ergometer with a few modifications in order to adapt Roentgenocinematography was used in the present experiment. The modifications were aimed at making the experimental subject take a posture as close as possible to that of running, and also at facilitating Roentgen cinefluorography. In order to fulfill these conditions the distance between the saddle and the crank was elongated. Although the position of the crank was fixed, that of the saddle was designed to move forward and backward and also vertically in order to regulate its position, thus overcoming differences due to discrepancies in bodily conditions.

b) Image intensifier, fixation of X-ray tube.

The device which fixes the image intensifier was made to withstand a weight of 50 kg. so that the image intensifier and the X-ray tube may be fixed at each end of the horizontal axis.

This fixing device was designed to allow horizontal and vertical movements and also diagonal up and down movements. The vertical shift permits fixing the conditions for measurements in compliance with the physical condition of the experimental subject. The distance of the vertical excursion

Table 2. X-ray experimental position

	Tube Voltage (KVP)	Tube current (mA)	Exposure dose (r/min)	Irradiation time (sec)	Total exposure dose (r)
Judoist	70	8.0	8.7	80	12.00
Non-trainee	90	6.0	11.2	50	8.750

was 16 cm.. An excursion of 45° rotation was allowed in the horizontal shift in order to facilitate observation of the heart in the right anterior oblique and left anterior oblique positions. Also, it was designed to make possible observations from a diagonally up and down direction. Manipulations of the apparatus was done by the push-button method. The distance between the X-ray tube and the fluorescent screen was 90 cm.

c) Image intensifier.

A 9 inch (230 mm.) Philips image intensifier was used. The reason for using this image intensifier was because with an intensifier with a diameter of less than 9 inches it is not possible to obtain a full image of the heart.

d) The X-ray tube used was the Toshiba DRX-90 A type.

3. Cinefluorographic conditions.

The main cinefluorographic conditions were as follows: Camera: Arriflex 16 mm.; lens: Arriflex Cinegon 35 mm., 39.5 mm.; film: Eastman Tri X, ASA 250; film speed: 24/sec., F stop: 2, 1.8.

4. Roentgenographic conditions.

During application of X-ray the following conditions are indispensable: tube voltage, tube amperage, and exposure time, and the objective was to obtain maximum results while limiting these conditions to a minimum. For this purpose many preliminary experiments were conducted, for example, a phantom similar in form to that of the experimental subject was placed in front of the fluorescent screen and the camera was cranked for a few seconds each after changing the tube voltage and tube amperage in order to determine optimum conditions.

Optimum conditions determined by preliminary experiments are shown in Table 2.

5. Measuring apparatuses.

Positive films were developed and each frame was measured by a motion analyzer (NAC). In order to minimize error, measurements were performed in a dark room in order to obtain a clear picture of the cardiac silhouette.

6. Parameters of measurement.

The following parameters were measured from the films: total transverse diameter, i.e., the distance between the right border of the cardiac shadow and the boundary between the heart and the blood vessel, and the distance between the right border of the cardiac shadow and the boundary between the heart and the diaphragm. The total transverse diameter is the longest transverse diameter of the cardiac shadow.

The measurements were those made by the motion analyzer and are not absolute values, however, they are not inconsistent, because changes in measurement relative to that during rest are to be considered.

7. Conditions of exercise.

a) Judoist

The Judoist was made to perform all-out exercise in the preliminary experiment, and after considering the all-out time and the exercise load, an exercise of 10 kg. m./sec. for 4 minutes was decided upon. As a pace-maker the metronome was used during exercise with a bicycle ergometer, and an exercise requiring peddling at the rate of 90—96 per minute and a work corresponding to 2400/kg. m. was decided upon.

b) Non-trainee.

The intensity of exercise and the peddling rate of the bicycle ergometer were the same as that of the Judoist, i.e., 10 kg. m./sec.. The exercise duration was 2 minutes, and consequently, the amount of work was 1200 kg.m.

8. Course of cinefluorography

Varying phases of interest were selected from rest, exercise, and recovery periods and filmed for 11 seconds each. The duration of exercise of the Judoist was 4 minutes, and observations were made at 1 minute intervals, i.e., filming during the exercise period was done immediately after inception of exercise, at 1 minute, 2 minutes, 3 minutes, and immediately before termination of exercise, and filming during the recovery period was done immediately following cessation of exercise, and at 1 minute of recovery. On the other hand, in the non-trainee the duration of exercise was 2 minutes, and similar phases as those of the Judoist was observed. After due consideration of the amount of X-ray to which the subjects may be exposed to without danger, a filming interval of 11 seconds was decided upon.

RESULTS

1) Changes in cardiac shadow of the Judoist

Fig. 2 illustrates the pattern of 3 frames each that were randomly picked from Roentgen cine-fluorographic records taken at rest, during exercise, and during the recovery period. Measurements made on each frame was plotted in order to study the serial changes in the measurements (Fig. 4). The intervals between the black dots indicate 0.25 seconds, and 1 wave indicates 1 pulsation. As shown in Fig. 4 both the end-diastolic level (E.D.L.) and end-systolic level (E.S.L.) were increased when compared to the levels at rest. The solid line shows tracing of the pulse amplitude. When exercise was discontinued the E.D.L. and E.S.L. rapidly decreased to less than their respective levels at rest. In order to obtain a clearer picture the averages of the E.D.L. and E.S.L. of each phase was plotted against time (Fig. 6). The open circles indicate E.D.L. and the closed circles indicate E.S.L., and consequently the difference between the two is the pulse amplitude. The figures indicate the percentage of increase or decrease with regard to the E.D.L. or E.S.L. at rest.

The increase in E.D.L. and E.S.L. as compared to their respective levels at rest indicates increase in cardiac volume. Observations on the pulse amplitude during exercise and recovery period disclosed the following tendency: immediately after cessation of exercise > at 4 minutes of exercise > at 3 minutes of exercise = at rest > at 2 minutes of exercise > at 1 minutes of exercise > immediately following initiation of exercise. From this the following facts may be known: the cardiac volume is increased by exercise, and the pulse amplitude is smaller than that at rest during the early half of the exercise period and it later increases and approximates the amplitude at rest and is further increased at the time of termination of exercise. Consequently, the systolic discharge is definitely greater than that at rest. Also, from the fact that the cardiac volume is increased, the presence of a function which prevents lowering of the systolic discharge, at least during exercise, may be presumed.

2) Changes in the cardiac shadow of the non-trainee.

Fig. 3 illustrates the cardiac shadow patterns of the non-trainee at rest during exercise, and during the rest period and correspond to the patterns of the Judoist shown in Fig. 2. A similar plotting of measurements as shown in Fig. 4 was made by plotting the measurements of the non-trainee (Fig. 5). Also, the averages of the E.D.L. and E.S.L. of each phase were plotted against time as illustrated in Fig. 7. As also shown in the Figure, E.D.L. and E.S.L. were higher than the respective levels at rest, however, the rate of increase was only 1/3 that of the Judoist. As the exercise progressed there was marked tendency for the E.D.L. and E.S.L. to approximate the respective levels at rest. Consequently, from the results obtained from this non-trainee, the increase in cardiac output may be

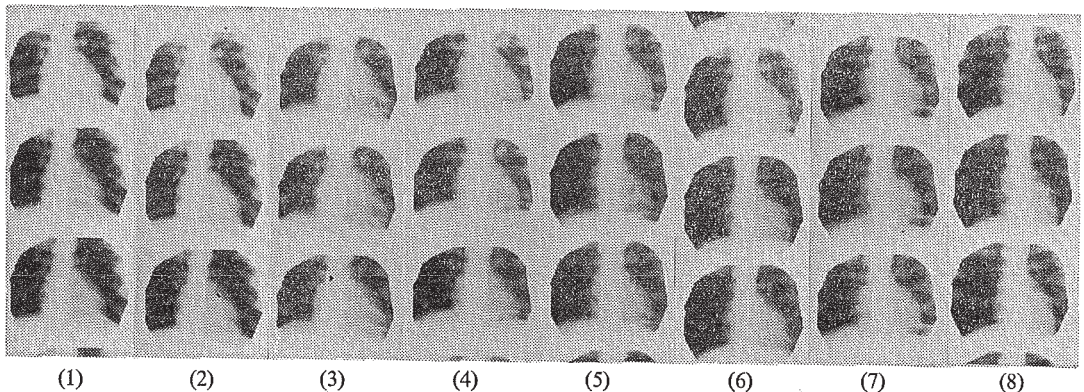


Fig. 2 Changes of cardiac silhouettes of a judoist before, during and after the all-out exercise. (1) Resting state, (2)-(6) During exercise (2) Immediately after the commencement of exercise (3) 1 min. after (4) 2 min. after (5) 3 min. after (6) 4 min. after (7)-(8) Recovery. (7) Immediately after the termination of exercise (8) 1 min. after.

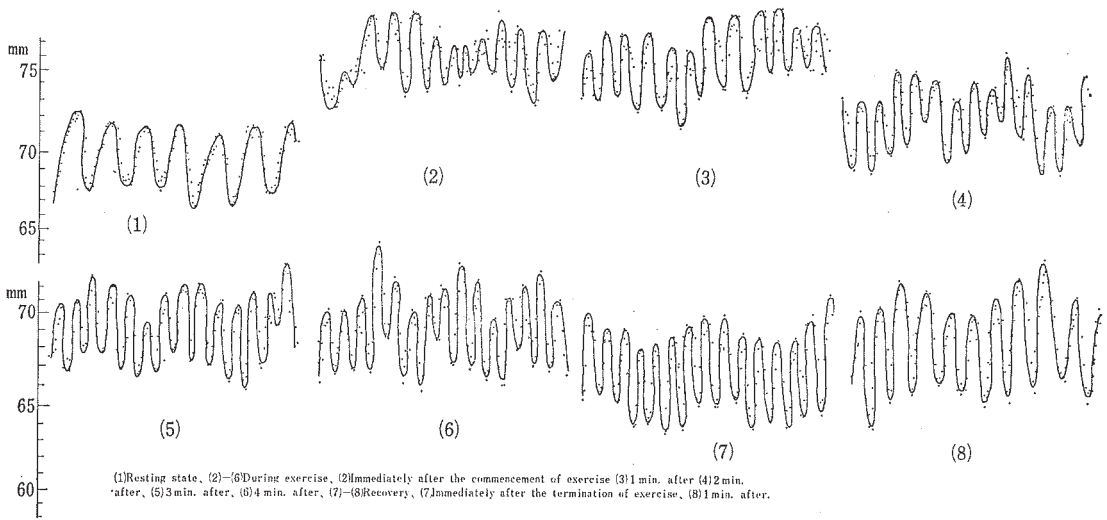


Fig. 4 Changes of the transverse width in cardiac silhouettes of a Judoist before, during and after the exercise

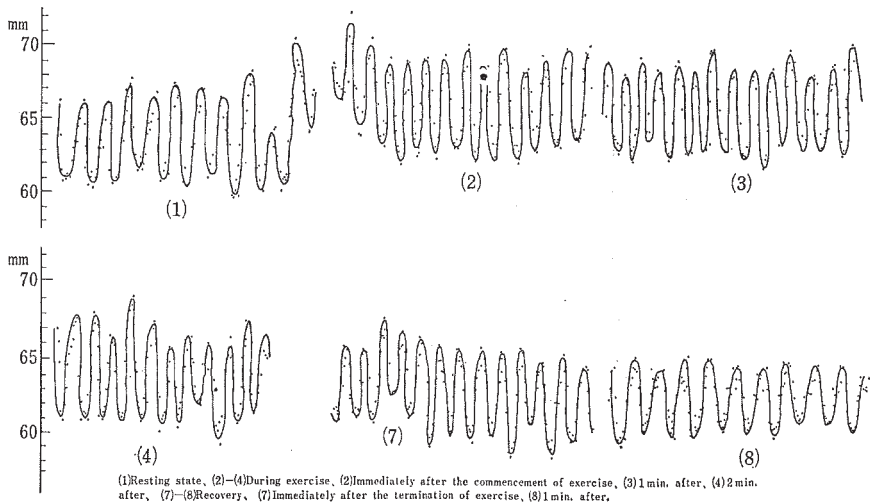


Fig. 5 Changes of the transverse width in cardiac silhouettes of a non-trainee before, during and after the exercise.

met with by an increase in pulse amplitude.

From an analysis of the above mentioned results it has been confirmed that in both the Judoist and the non-trainee during exercise, the cardiac shadow is increased, i.e., the E.D.L. and E.S.L. are increased. However, since there were fluctuations in the measurements of the individual films the averages of the measurements of each phase during exercise were computed without differentiating between diastole and systole, and an analysis of the increase and decrease in cardiac shadow was made, results of which are illustrated in Fig. 8. In this illustration the measurements during the rest period was considered to be zero, and the rate of increase or decrease with regard to the values at rest of the maximum changes due to exercise were plotted against time. The unbroken line indicates results of the Judoist and the dotted line those of the non-trainee. Figures indicate the rate of increase or decrease with regard to the values at rest.

3) Changes in heart rate.

Heart rate was determined from the R spike of the ECG (chest lead) taken simultaneously with Roentgen cinematography. The maximum rate in the Judoist was 127 and that in the non-trainee was 110, i.e., the rate of increase with regard to the heart rate at rest in the Judoist was 115%, and that in the non-trainee was 52.8%.

DISCUSSION

The results of this experiment indicates that the E.D.L. and E.S.L. of the cardiac shadow are increased by exercise, i.e., the cardiac volume is increased. Also, the measurements disclosed that the increase in the cardiac volume was more pronounced in the Judoist than in the non-trainee. In other words, when an exercise load is imposed on the heart, it responds by increasing cardiac output, and the higher the adaptability the greater the cardiac volume, i.e., the heart is capable of increasing the reserve diastolic volume. In the Judoist, the pulse amplitude is small during exercise, and approaches the amplitude at rest as the course of the exercise progresses. This fact suggests the existence of a mechanism which at least prevents lowering of the stroke volume by increasing diastolic blood volume and by decreasing pulse amplitude.

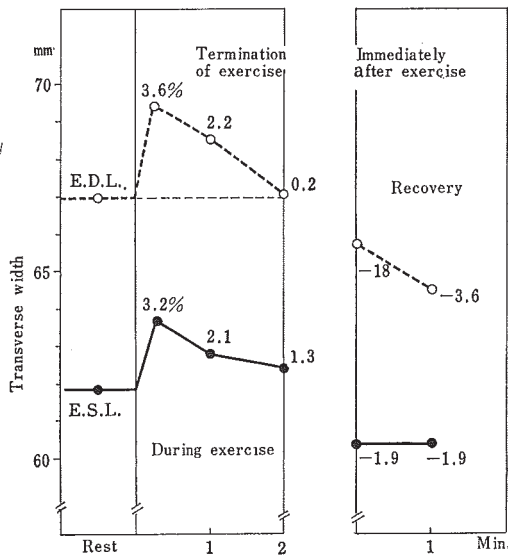


Fig. 6. Changes of the end-diastolic (E.D.L.) and end-systolic (E.S.L.) transverse widths of heart silhouettes in a judoist before, during and after the exercise.

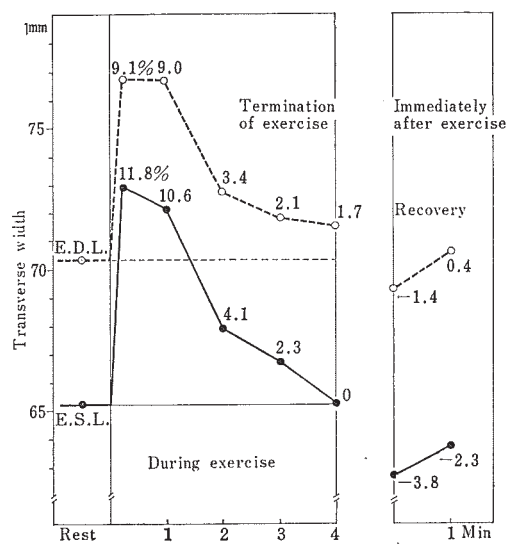


Fig. 7. Changes of the end-diastolic (E.D.L.) and end-systolic (E.S.L.) transverse widths of heart silhouettes in a non-trainee before, during and after the exercise.

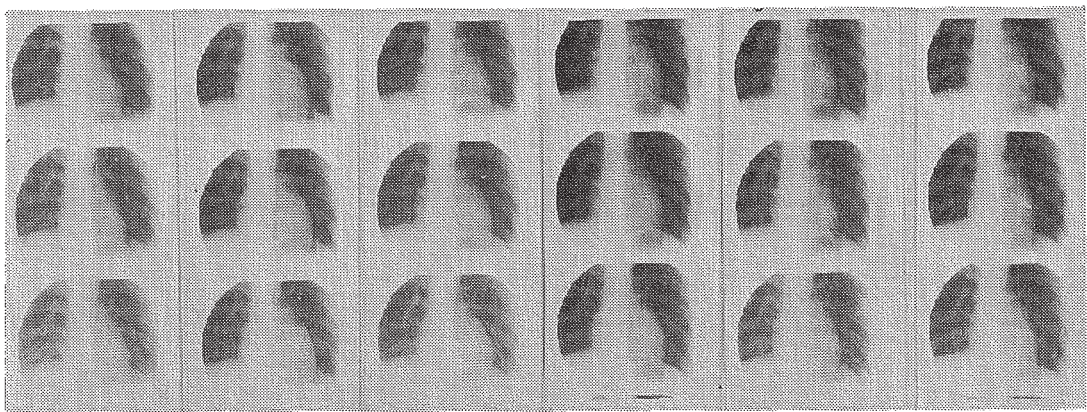
It is widely recognized that the increase in heart rate is the main factor contributing to the increase in cardiac output. For example, there is a report which states that even in strenuous exercise in which heart rate reaches 200, it is possible to maintain an ample stroke volume, and that in well-trained athletes the filling pressure into the left ventricle reaches twice that at rest, and consequently the stroke volume does not drop even when the inflow time is very short. Also, according to Starling's law of the heart, the stretching of the heart muscles, due to enlarged volume during diastole, enables the heart to maintain a comparatively large stroke volume by slight contraction of the heart muscles. Consequently, the maintenance of cardiac output by the increase in cardiac volume and the decrease in pulse amplitude may be considered physiologically expedient. In the Judoist, the heart volume immediately prior to termination of exercise nears that at rest, however, the pulse amplitude increases in order to meet with the situation. On the other hand, in the non-trainee, although the increase in heart volume during exercise is comparatively little, it is compensated by the increase in pulse amplitude.

Cardiac output is determined by two factors, viz., the diastolic volume and the degree of contraction of the heart muscles. Results of this experiment indicate that the increase in the cardiac volume was the determining factor in the Judoist, and the contraction of the heart muscle was the determining factor in the non-trainee.

The increase in heart volume occurs rapidly immediately after initiation of exercise. Since the cardiac output increases it is natural that the venous circulation increases, however, the mechanism of this rapid inflow of blood has not been clarified. However, the increase in venous circulation due to the pump action of the muscles, and also the difference in distribution of the blood in the viscera due to exercise may be thought to be contributing factors.

As the exercise progresses the pulse amplitude nears that at rest, and consequently, the stroke volume may be said to be greater than that at rest. There are many reports^{8,13} stating that stroke volume increases during exercise in man and animals, however, there are a few reports^{10,11} which state to the contrary, i.e., that stroke volume decreases during exercise. In the present experiment, from the fact that pulse amplitude maintained regularity, it is in agreement with other reports which state that the regularity of stroke volume is maintained.

The above results regarding cardiac volume of the Judoist contradicts those obtained by Rushmer and associates using their direct method, however, the discrepancy is thought to be due to the difference in the experimental animal, and also to the fact that in the present experiment it was not possible to investigate the volume of the left ventricle alone.



(1) (2) (3) (4) (7) (8)
 Fig. 3 Changes of cardiac Silhouettes of a non-trainee before, during and after the all-out exercise.

SUMMARY

Changes in cardiac volume during exercise was studied Roentgeno cinefluorographically in a Judoist. The experimental subjects used were a light weight Judoist with a sport heart and a healthy young male adult non-trainee.

The required exercise was performed by a bicycle ergometer.

A few modifications were added to the bicycle ergometer and the Roentgen cinefluorograph in order to adapt to the use of this experiment.

Roentgen cinefluorography was performed at the rate of 24 frames per minute. Measurements were made on each frame by a motion analyzer. Measurement of the cardiac shadow was made on its transverse diameter.

Results were as follows:

- 1) Exercise caused E.D.L. and E.S.L. to increase in both the Judoist and non-trainee. In other words, cardiac volume was increased by exercise.
- 2) This increase in cardiac shadow was more pronounced in the Judoist than in the non-trainee.

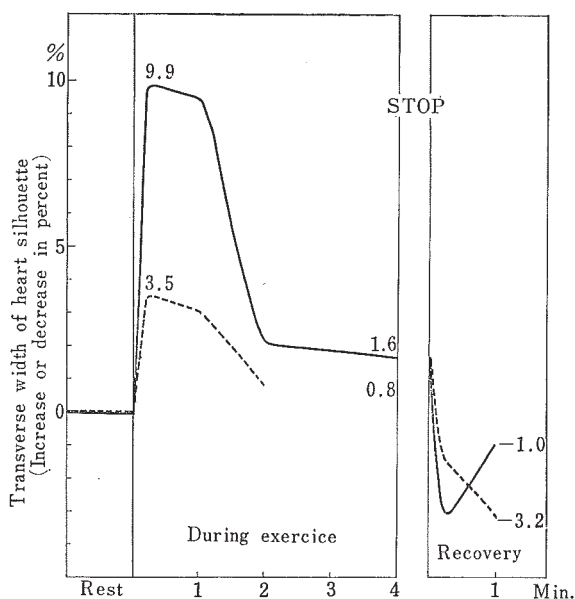


Fig8. An experimental diagram of the changes of human heart silhouettes before, during and after the exercise.

Solid line :Judoist

Dotted line :Non-trainee

- 3) The pulse amplitude which accompany the course of the exercise was smaller in the Judoist than in the non-trainee.
- 4) In the Judoist the pulse amplitude until immediately before termination of exercise was smaller than that at rest, and in the non-trainee it was larger than that at rest.
- 5) It is presumed that the systolic discharge during exercise is greater than that at rest.
- 6) The cardiac shadow decreased after termination of exercise in both the Judoist and the non-trainee.
- 7) From the aforementioned it is inferred that in the Judoist, the diastolic volume is increased, the degree of contraction of the cardiac muscle is decreased, and the stroke volume is increased or at least not decreased in order to meet with the demand of increasing the cardiac output during

exercise. In the non-trainee, it is presumed that since the diastolic volume is not so much increased as in the Judoist, it is compensated by an increase in the degree of contraction of the cardiac muscles.

REFERENCES

- 1) Benegard, S., et al (1963): Circulatory studies in well trained athletes at rest and during exercise, with special reference to stroke volume and the influence of body position, *Acta Physiol. Scand.*, 57, 26—50.
- 2) Ikai, M., et al (1958): Physiological studies on “Shime” (choking) in judo. Report II. Roentgenographic observation on the heart. *Bul. Ass. Sc. St. Judo*, 1, 13—21
- 3) Ikai, M. (1958): The effect of judo on blood pressure. *Bul. Ass. Sc. St. Judo*, 1, 85—91.
- 4) Ikai, M., et al (1966): Changes in pulse rate during judo practice. *Judo*, 37 (4), 25—60.
- 5) Association for the Scientific Studies in Judo (1966): Studies on stamina in judoists, *Judo*, 37 (7), 49—55.
- 6) Masuda, M., et al (1966): Physical fitness of a judoist (1) a case study from the viewpoint of cardiovascular function. *Tairyoku Kenkyu*, No. 9, 20—30.
- 7) Masuda, M., et al (1967): Study on human heart volume changes all-out and moderate exercise by cinefluorography, *Bulletin of Physical Fitness Research Institute*, No. 13, 1—19.
- 8) Meek, W.J., et al (1923): Cardiac size and output in man during rest and moderate exercise, *Am. J. Physiol.* 63, 400—401.
- 9) Ogawa, S., et al (1963): Studies on “Kanesetsu-waza” (4) with special reference to the circulatory and respiratory systems. *Bul. Ass. Sc. St. Judo*, II, 87—97.
- 10) Reindell, H. (1956): Regulative und myogene Dilatation des Herzens, *Fortschr. Gebiete Roentgenstratrol. Nuklearmedizin*, 85 (4), 385—409.
- 11) Ruosteenoja, R., et al (1958): Heart Volume changes at rest and during exercise, *Acta Med. Scand.* 162, 263—275.
- 12) Sasa, T. (1963): Studies on stamina in judoists. *Bulletin of the Committee for Sports Science*, 11—16.
- 13) Williamson, C.B., et al (1915): The effects of exercise on normal and pathological heart; Based upon the study of one hundred cases, *Am. J.M.Sc.* 149, 492—502.