8. STUDIES ON BODY COMPOSITION OF JUDOISTS

M. Ikai, T. Fukunaga and H. Toheda (University of Tokyo)

For better understanding of working capacity, it may be useful to know the relationship between the sizes of the tissue of the body (as a mass) and their function. The measurement of the subcutaneous fat by means of the skinfold caliper or x-ray photograph is often made for estimation of the body composition[4]. However, by this method, it is not possible to measure the cross-section of the tissue. Recently, the apparatus of ultrasonic photography was exploited, which makes it possible to observe directly the cross-section of the tissue.[6,7,8] On the other hand, a physical method which is called the "densitometory" has been used as a method to calculate the weight or ratio of the whole body compartments. The purpose of this study is to analyse the body composition of Judoists by these methods above mentioned.

METHOD OF INVESTIGATION

1. Measurement by means of ultrasonic method.

Ultrasonic apparatus is constituted transducer, scanner, observation equipment, water tank and a divice to fix the limb at a certain position. The whole view of arrangement is shown in Fig. 1. The schematic view of the equipment applied to the subject was shown in Fig. 2. The subject, keeping the lying position, extends his arm down to the bottom of the water tank. An equipment by Japan Radio Company U S I-2D was used for recording. The ultrasonic scanner circulates around the limb of the subject for 30 seconds. The pulse echoes reflect on the cathode ray screen by brightness modulation and recorded on the film. The frequency of ultrasonic wave was chosen to be 1, 2.25, 5, 10 MC (megacycle) per second to get clear shape of bone, muscle as well as subcutaneous fat tissue.

The cross-sectional pictures of the upper arm and the forearm were shown in Fig. 3 and 4. In this picture, the boundaries among subcutaneous fat, muscle, fascia and bone can be observed clearly. For estimation of size of the tissue size, several bakelite models with several diameters were employed

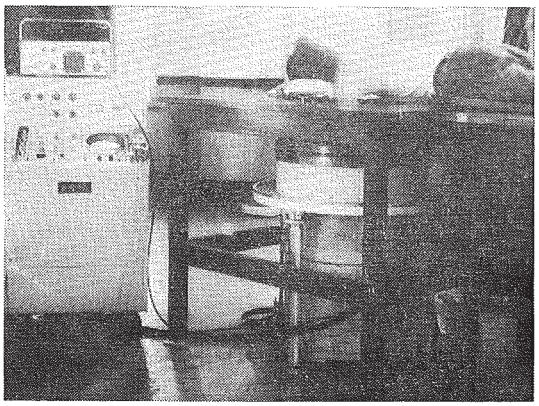

Fig. 1 Arrangement of the ultrasonic apparatas.

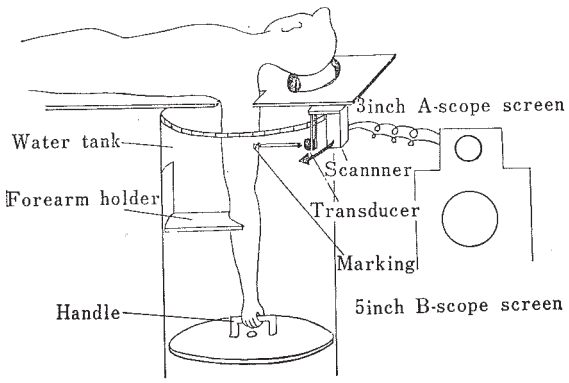

Fig. 2 Schematic presentation of ultrasonic equipment.

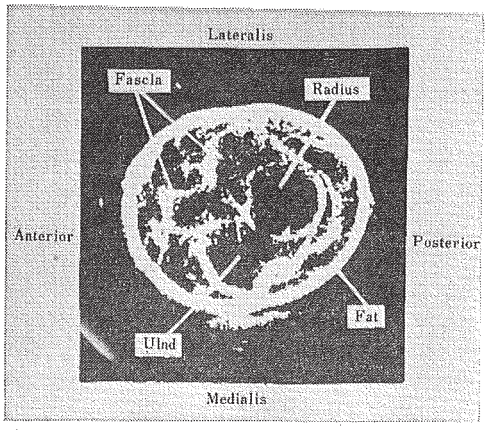

Fig. 3 Cross-sectional View of Human Forearm by Ultrasonic Method

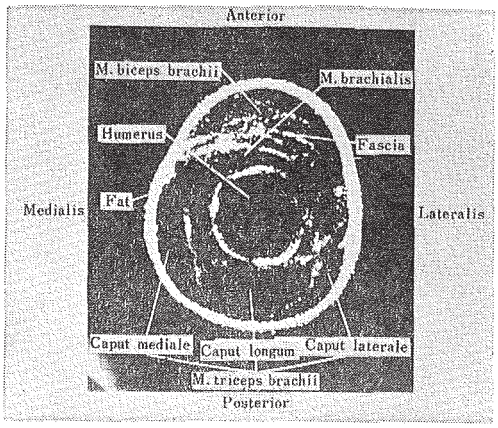

Fig. 4 Cross-sectional View of Humon Upper Arm by Uitrasonic Method

for the calibration. To discuss the acuracy of ultrasonic method, the pinch caliper method was examined on the carcass of pig and compared with the result obtained by the ultrasonic method. The mesurement was made at the section with the maximum girth of the right forearm and the upper arm in extended position. The area of the tissue was measured by an planimater on the photograph.

The strength of the elbow flexor muscle was measured isometrically with an strain-gauge tensiometer. For this measurement, the subject pulled the belt attached to the wrist with maximum effort, keeping the elbow at right angle in siting position. The grip strength was also measured isometrically with a dynamometer. The highest value in three trials was adopted.

2. Densitometry

The underwater weighing was used to obtain the body volume. The water tank of 86×122 cm was used and subject was suggested not to touch the bottom or side wall of the water tank when he submarged in the water (Fig. 5).

Performing the maximal expiration, that is, in the condition of remaining only the residual volume in the lung, the subject hung on a balance scale suspended from iron beam. The underwater weight was measured when the oscilation of the indicator of the scale stoped. Then, in order to meausre the residual volume, the expiratory reserve volume was measured by a Aika-Benedict type respiro-

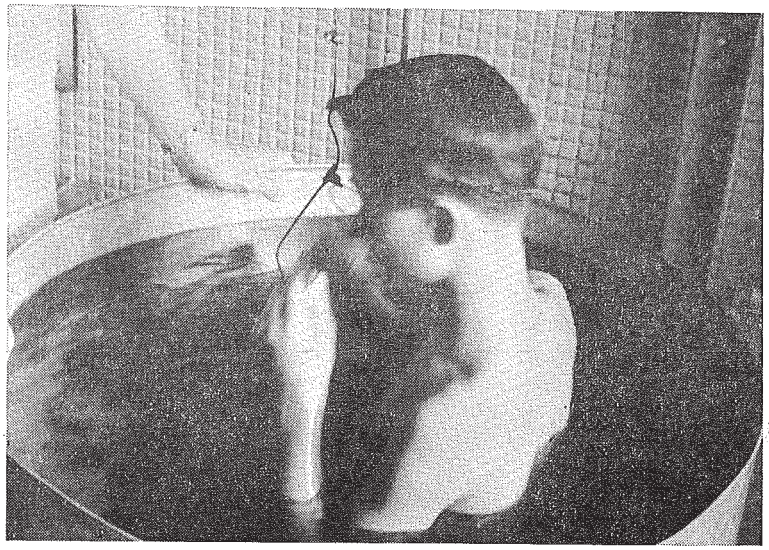

Fig. 5 The measurement of underwater weight.

meter of 13.5 L (Fig. 6). The functional residual capacity was measured by Cournand-Richards's nitrogen dilution method[3] (Fig. 7).

The water temperature in the tank was maintained at 35–37°C.

Body density was calculated as follows.

$$D_b = \frac{M_{ba}}{\frac{M_{ba}-M_{bw}}{D_w} - RV} \quad \cdots\cdots(1)$$

Where, D_b is body density, M_{ba}, M_{bw} is body weight in the air and in the water respectively. D_w is the density of the water, RV is residual volume.

Each body compartment was calculated as follows:

$$\text{Body fat mass}^{2)} = \left(\frac{4.570}{D_b} - 4.142\right) \times 100 \quad \cdots\cdots(2)$$

$$\text{Lean body mass} = \text{body weight} - \text{body fat mass} \quad \cdots\cdots(3)$$

$$\text{Total body water} = \text{lean body mass} \times 0.72 \quad \cdots\cdots(4)$$

$$\text{Solids} = \text{body weight} - (\text{body fat mass} + \text{total body water}) \quad \cdots\cdots(5)$$

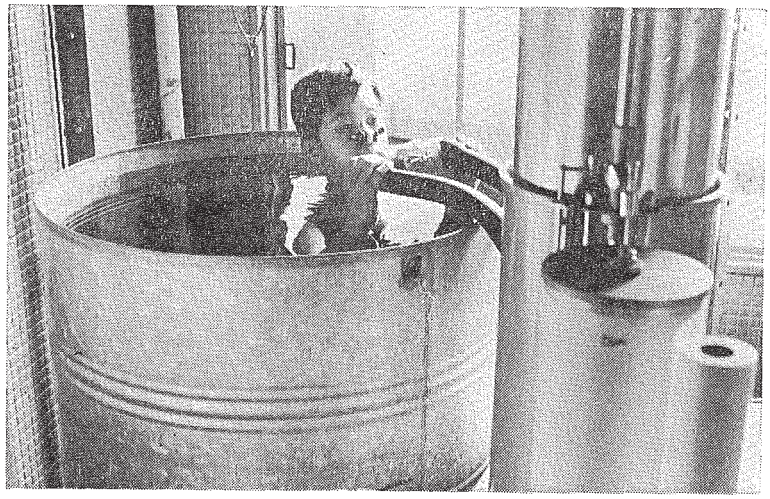

Fig. 6 The measurement of expiratory reserve volume

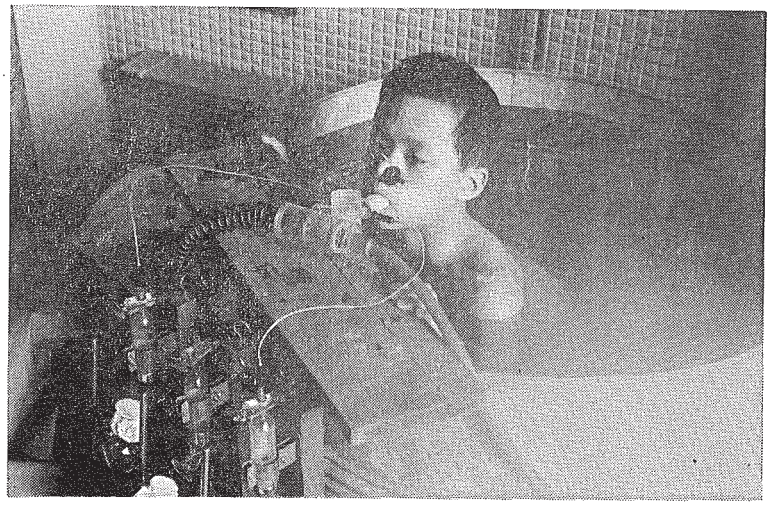

Fig. 7 The measurement of residual volume.

Table 1.

Subject	Age	No. of subject	
Judoists	18–21	10	Univ. Students holding of 2nd "Dan" of Judo
Non-trainees	21–29	14	Univ. students of ordinary

In order to estimate the subcutaneous fat mass, the skinfold was measured by using "Eiken" (National Institute of Nutrition) type skinfold caliper. The measurement of skinfold was made at the following 12 sites.

1) cheek ——— a lower margin of zygomaticum
2) neck ——— over the thyroid
3) chest ——— just ajacent to the nipple
4) side chest ——— at the level of xiphoid in the medial axillary line
5) abdomen ——— a right side of the umblicus
6) abdomen (lower part) ——— just above the spina iliaca anterior superior
7) upper arm ——— a midpoint between the acromion and the olecranon

Table 2. Cross-sectional

		Anthropometric measurement				Forearm						
						Cross-sectional area of tissue (cm^2)				Relative tissue area to total (%)		
Subject	Age	Height (cm)	Weight (kg)	Chest girth (cm)	Rohrer's index	Total	Fat	Muscle	Bone	Fat	Muscle	Bone
H.K.	19	168.7	64.3	90.8	1.34	52.9	3.8	45.3	3.8	7.2	85.6	7.2
T.H.	19	172.5	64.5	91.8	1.26	57.0	3.6	46.9	6.5	6.3	82.3	11.4
Y.Y.	18	168.3	65.9	88.6	1.38	55.8	6.8	46.6	2.4	12.2	83.5	4.3
H.O.	19	165.7	67.5	92.2	1.49	59.6	4.1	48.6	6.9	6.9	81.5	11.6
Y.H.	21	167.1	72.1	95.7	1.55	62.2	6.8	49.3	6.1	10.9	79.3	9.8
K.S.	19	170.3	74.0	100.7	1.49	60.6	6.8	48.9	4.9	11.2	80.7	8.1
T·O.	18	171.9	75.9	98.5	1.49	63.7	5.0	54.3	4.4	7.8	85.2	6.9
M.T.	19	175.3	78.1	93.0	1.44	62.0	7.3	50.1	4.6	11.8	80.8	7.4
K.O.	20	172.4	79.1	100.8	1.54	72.8	7.2	58.7	6.9	9.9	80.6	9.5
mean		170.7	71.3	94.7	1.43	60.7	5.7	49.9	5.2	9.4	82.2	8.5
Standard Deviation		3.0	5.2	4.0	0.09	5.4	1.4	4.0	1.6	2.2	2.1	2.2
non-trainees (12)	21 ~ 29	[1] 166.7	60.1	87.0	1.33	50.8	5.7	41.1	4.0	11.1	81.1	7.9
		[2] 3.5	11.5	9.4	0.12	8.6	2.2	6.5	1.5	3.0	3.8	1.9

1); mean, 2); standard diviation

8) back——— subscapula
9) knee—just above the patella
10) thigh (anterior) ——— a midpoint between the iliocristale and the patella
11) thigh (posterior) ——— back of thigh
12) calf ——— at the level of the maximal girth of the calf

The subcutaneous fat mass was calculated as follows:

$$\text{Subcutaneous fat mass} = \text{skinfold} \times \text{body surface area} \times 0.9000 \quad \cdots\cdots(6)$$

Subjects were listed in Table 1.

RESULTS

1. Cross-sectional area of the arm measured by ultrasonic method.

(1) Comparison of Judoists and non-trainees male subjects.

The cross-sectional area of the tissue, the muscle strength and the anthropometric indicies of subjects are presented in Table 2. The cross-sectional view of upper arm of judoists and non-trainees were shown in Fig. 8. In this figure, it is observed that the muscle and the bone area are larger in judoists than the non-trainees. As is shown in Fig. 9, the mean of the total areas in the forearm are 60.7 cm^2 in judoists and 50.8 cm^2 in non-trainees. Judoists show 8.8 cm^2 larger than non-trainees in the average. In the case of upper arm, 68.1 cm^2 judoists and 52.3 cm^2 in non-trainees. The difference is 14.5 cm^2 in the cross-sectional area. The sum of the muscle areas of forearm and upper arm is bigger in judoists than non-trainees ($P<0.01$). However, there is no significant difference in sub-

area of tissue in judoists

Upper arm									Muscle strength (kg)		Strength per unit area of muscle (kg/cm^2)
Cross-sectional area of tissue (cm^2)				Relative tissue area to total (%)			Flexor area (cm^2)	Flexor area/ total muscle area (%)	Grip strength	Arm strength	
Total	Fat	Muscle	Bone	Fat	Muscle	Bone					
59.1	4.0	50.9	4.2	6.8	86.1	7.1	24.1	47.4	55.5	32.5	6.6
58.5	4.3	47.1	7.1	7.4	80.5	12.1	25.1	53.2	65.0	34.0	6.6
59.7	5.8	49.8	4.1	9.7	83.9	6.9	21.7	43.6	63.5	35.0	7.9
71.3	4.7	59.3	7.3	6.6	83.2	10.2	28.7	48.4		37.6	6.4
71.4	6.0	60.8	4.6	8.4	85.2	6.4	27.7	45.5	55.9	38.0	6.7
66.3	7.0	51.7	7.6	10.6	78.0	11.5	29.1	56.2	53.3	31.4	5.5
68.3	5.6	55.2	7.5	8.2	80.8	11.0	25.0	45.3	53.0	38.0	7.4
70.6	9.7	54.0	6.9	13.7	76.5	9.8	26.8	49.6	57.5	32.0	5.9
87.8	8.3	72.5	7.0	9.5	82.6	8.0	37.1	51.2	60.0	37.0	4.9
68.1	6.2	55.7	6.3	9.0	81.8	9.2	27.3	48.9	56.3	34.5	6.4
8.6	1.8	7.2	1.4	2.1	2.9	2.0	1.3	1.2	6.1	3.0	0.9
52.3	6.5	41.2	4.6	12.0	79.2	8.7	20.1	49.1	52.4	27.4	6.7
10.1	3.2	6.5	1.9	3.4	4.1	2.9	2.9	1.4	4.8	5.2	1.1

cutaneous fat of the forearm and the upper arm between both groups.

The percentage of each tissue to the total area was calculated (Fig. 10). The subcutaneous fat of the upper arm was 3.0% larger in judoists than that of non-trainees, and this difference is significant ($P<0.05$). But, as for the forearm, there is no significant difference between judoists and non-trainees.

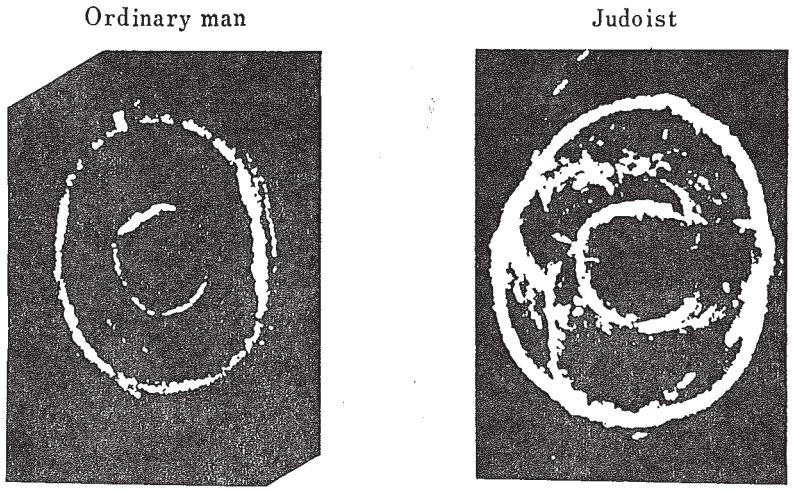

Fig. 8 Ultrasonic View of Human Upper Arm

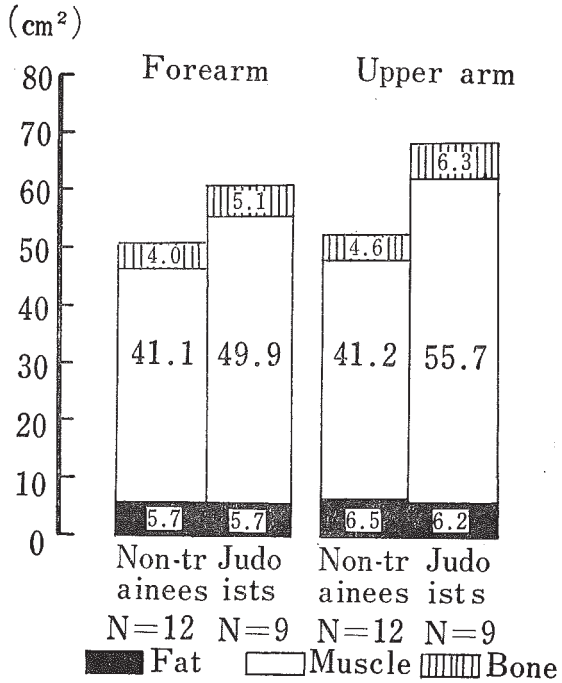

Fig. 9 Cross-sectional area of forearm and upper arm.

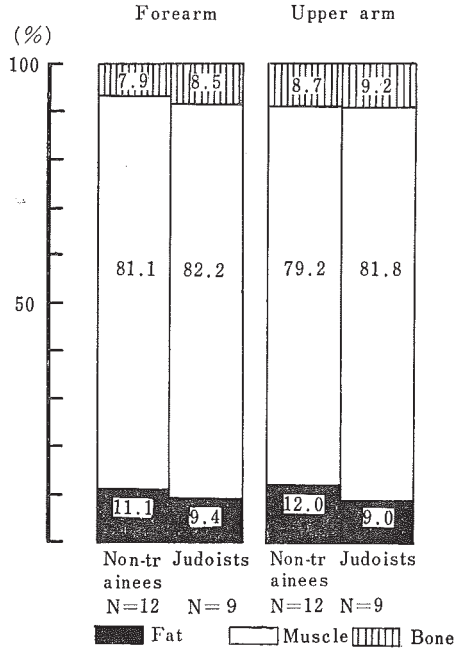

Fig. 10 Ratio of tissue areas to the total area.

(2) Comparison of the muscle strength.

Grip strength of judoists was 56.3 kg and non-trainees 52.4 kg in the mean. But no significant difference was observed between both groups (Table 2). The arm strength of judoists (34.5 kg) was significantly higher ($P<0.01$) than that of non-trainees (27.4) in the average. The cross-sectional areas of the flexor of upper arm is 27.3 cm^2 in judoists and 20.1 cm^2 in non-trainees ($P<0.01$).

But judoists are slightly inferior to non-trainees in the relative flexor area to the total muscle area of the upper arm: 48.9% in judoists and 49.1% in non-trainees respectively.

The measured strength of the arm flexor was plotted against the cross-sectional area in Fig. 11 in which many other data collected from untrained male and female subjects besides judoists. The muscle strength per unit cross-sectional area (kg/cm^2) of the arm flexor was calculated.

Prior to this, x-ray photograph of the arm flexor was taken in the position of right angle at elbow, which was in the same position as in the strength measurment. As shown in Fig. 12, the ratio of "resistance arm" (OR) and "force arm" (OF) was measured as 4.90 in the average having the standard deviation of 0.29. Therefore, the strength by biceps brachii (A) was calculated as follows: $A=M\times4.90$, where M is the strength measured at the wrist.

The strength and the muscle area of judoists are larger than those of non-trainees, but the strength per unit cross-sectional area of muscle is almost same in both groups (6.4 ± 0.9 kg/cm^2 in judoists, 6.7 ± 1.1 kg/cm^2 in non-trainees) (Fig. 13).

2. The analysis of body compartments by the densitometry.

(1) Comparison of the body density and the body composition in judoists and non-trainees.

The anthropometric measures and the body density of 10 judoists and 14 non-trainees are shown

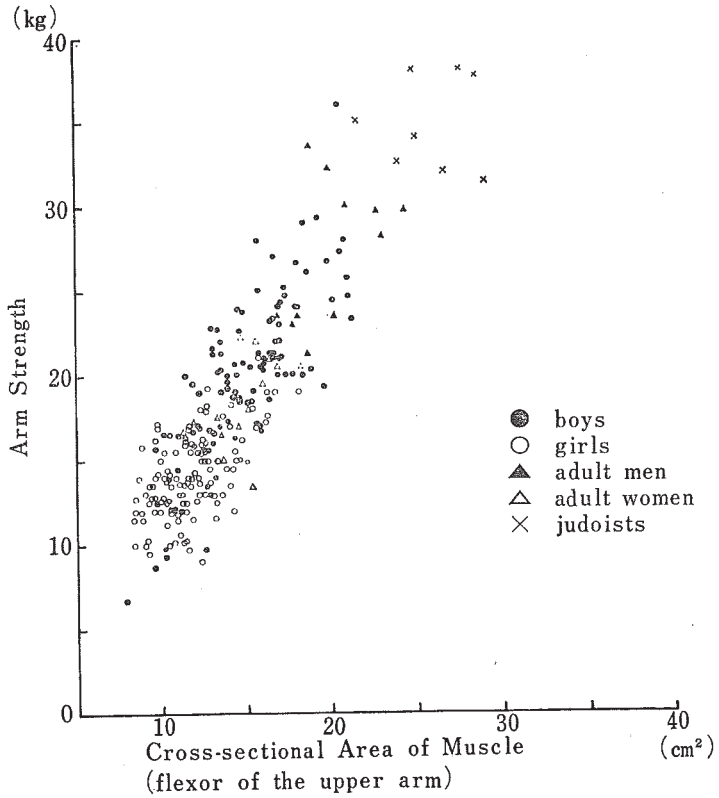

Fig. 11 Relationship between the muscle strength and muscle area.

Table 3. The ratio of each body compartment to the body weight calculated from body density are shown Table 3. The judoists are superior to non-trainees in height, weight, chest circumference found that the difference between them was significant ($P<0.01$).

The body density are to be 1.0733 in judoists and 1.0740 in non-trainees in the average. However, the difference between them is not significant ($P>0.1$). The weight of the body compartments and the ratio to the body weight are shown in Fig. 14. The fat mass, total body water and solids in judoists are 8.0 kg, 45.6 kg. and 17.7 kg respectively while in non-trainees are 6.8 kg, 38.5 kg and 15.0 kg respectively. Judoists should be larger values in all indicies than the adultmen. However, the ratio of each compartment to the body weight is very similar in both groups.

The lean body mass of judoists (63.3 kg) was 9.8 kg larger in the mean than the non-trainees (53.3 kg), but, the ratio of lean body mass to body weight was almost the same to.

(2) Comparison of the skinfold and subcutaneous fat mass.

Table 4 shows the values in skinfold and subcutaneous fat mass. The total of skinfolds measurement was found to be larger 4.8 mm in judoists than non-trainees. Non-trainees showed the larger skinfolds than judoists in chest and abdomen. The comparison of the mean of the 12 skinfolds, subcutaneous fat mass and the ratio to body weight are shown in Fig. 15. The skinfold, subcutaneous fat mass, and their percentage to the body weight are 7.3 mm, 4.1 kg and 6.8 % in judoists and 7.7 mm, 4.6 kg and 6.4% in non-trainees respectively. No significant difference was found between two groups. The comparison of the ratio between the internal fat and exteranl fat (subcutaneous fat) of the body are shown in Fig. 16. The internal fat means the mass which is obtained by subtracting the subcutaneous fat mass from the total body fat.

The ratio of subcutaneous fat to total body fat is 56.2% in judoists and 57.6% in non-trainees. There was no significant difference.

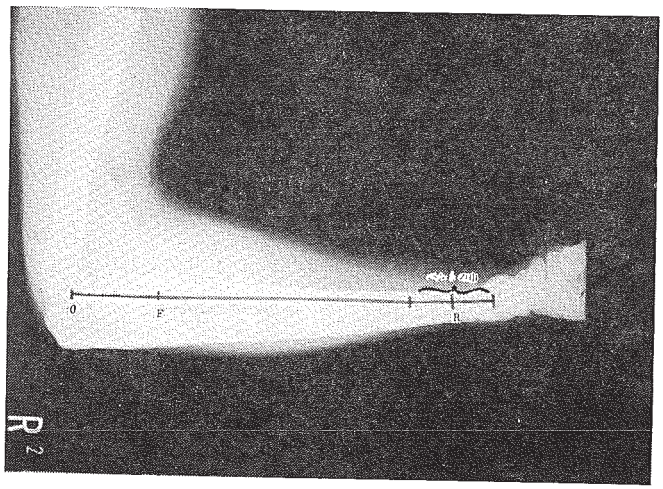

Fig. 12 Determination of fulcrum (0), force point (F) and resistance point (R) by means of X-ray photograph.

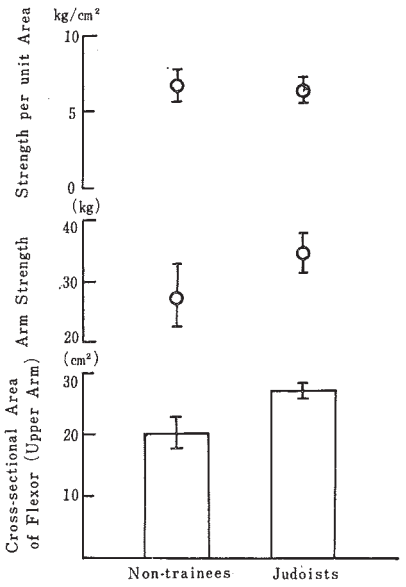

Fig. 13 Comparison of the muscle strength, muscle area and strength per unit muscle area between judoists and non-trainees.

DISCUSSION

(1) Comparison of the body composition.

The muscle area and the total area of forearm and upperarm are larger in judoists than non-trainees (Fig. 9). However the relative areas are same in judoists and non-trainees. The same tendencies were observed in subcutaneous fat of upper arm (Fig. 10). Furthermore, the areas between forearm and upper arm were compared in judoists. The muscle of upper arm was larger than that of forearm. The ratio of flexor and extensor in the upper arm was 49/51=0.96. and this ratio was same in judoists and in non-trainees.

Sakai[12] (1962) reported that the body density of Sumõ athletes was higher than that of non-trainees male subjects. Behnke[1] (1942) reported that the average of body density was 1.080 in 25 foot-ball players. Novak[10] (1966) reported 1.082 in basket ball and foot-ball players of high school. They found that body density of athletes were higher than those of non-trainees. In the present research, no significant difference was observed in the body density and the ratio of tissue per body weight in both groups.

The arm strength of judoists showed higher value than that of non-trainees and cross-sectional area of the upper arm flexor also appeared to be higher than non-trainees (Fig. 13). This result show that an increase of the muscle strength depend upon the muscle area.

In the subject of 245 healthy male and female ordinary Japanese, there was found the individual variation of strength per unit area in a range from 4kg to 8kg as shown in Fig. 17[7]. The strength per unit area of the subjects of Judoists in this test is distributed in the same range as ordinary people. Based on the experiment of training, it is supposed that these Judoists could be improved in their strength per unit area of the muscle after intensive strength training.

Table 3. The anthoropometric value and body density of judoists and non-trainees

subject	age	height (cm)	weight (kg)	chest circumference (cm)	abdominal circumference (cm)	difference	relative weight	rohrer's index	body surface area (m^2)	underwater weight (kg)	residual volume (ml)	body volume	body density
H.K.	19	168.7	64.3	90.8	70.9	19.9	38.1	1.34	1.73	4.20	1220	59.2	1.0861
T.H.	19	172.5	64.5	91.8	71.6	20.2	37.4	1.26	1.76	4.05	910	59.9	1.0768
Y.Y.	18	168.3	65.9	88.6	68.3	20.3	39.2	1.38	1.74	4.35	740	6.12	1.0768
H.O.	19	165.7	67.5	92.2	76.0	16.2	40.7	1.49	1.77	4.00	1390	62.5	1.0800
N.K.	18	174.3	71.6	94.7	76.5	18.2	41 1	1.35	1.86	4.15	1330	66.5	1.0767
Y.H.	21	167.1	72.1	95.7	83.5	12.2	43.1	1.55	1.81	3.65	1360	67.5	1.0681
K.S.	19	170.3	74.0	100.7	83.1	17.6	43.5	1.49	1.87	3.75	660	70.0	1.0571
T.O.	18	171.9	75.9	98.5	76.7	21.8	44.2	1.49	1.88	5.25	670	70.4	1.0781
M.T.	19	175.3	78.1	93.0	87.1	6.9	44.6	1.44	1.94	3.55	900	74.1	1.0540
K.O.	20	172.4	79.1	100.8	80.5	20.3	45.9	1.54	1.92	4.55	1680	73.3	1.0791
mean		170.7	71.3	94.7	77.4	17.3	41.8	1.43	1.83	4.15	1090	66.5	1.0733
S.D.		3.2	5.2	4.2	6.1	4.6	2.9	0.09	0.07	0.19	360	5.4	0.0093
non-trainees	21–29	165.6	60.3	88.3	74.8	13.5	36.4	1.33	1.66	3.26	1170	56.1	1.0740
		4.4	6.6	3.2	4.6	3.1	3.5	0.12	0.12	0.42	300	6.3	0.0071

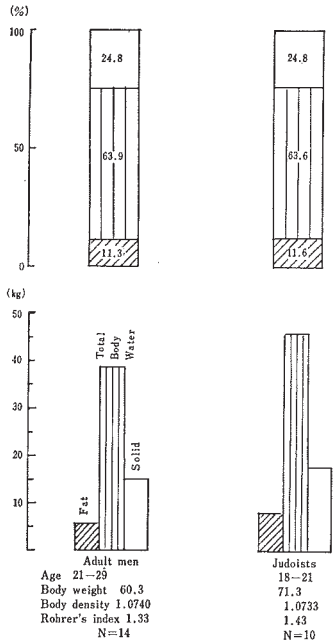

Fig. 14 Body composition of judoists and non-trainees.

Table 4. Body composition of judoists and non-trainees

subject	fat (%)	total body water (%)	solid (%)	L.B.M. (%)
H.K.	6.6	67.3	26.1	93.4
T.H.	10.1	64.8	25.1	89.9
Y.Y.	10.1	64.6	25.3	89.9
H.O.	8.9	65.6	25.5	91.1
N.K.	10.1	64.8	25.1	89.9
Y.H.	13.7	62.1	24.2	86.3
K.S.	18.2	58.9	22.9	81.8
T O.	9.7	65.0	25.3	90.3
M.T.	19.4	58.0	22.6	80.6
K.O.	9.3	65.2	25.5	90.7
mean	11.6	63.6	24.8	88.4
S.D.	4.2	3.0	1.2	4.2
non-trainees	11.3	63.9	24.8	88.7
	2.8	2.0	0.8	2.8

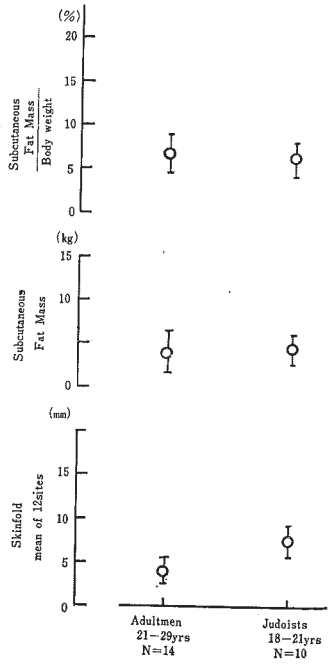

Fig. 15 The comparison of skinfold, Subcutaneous fat mass and that to the weight between judoists and non-trainees.

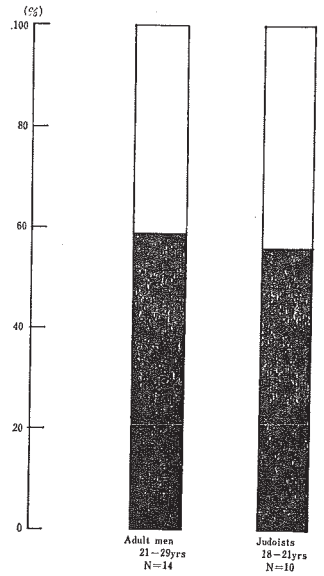

Fig. 16 The ratio of subcutaneous fat mass to the total fat mass.

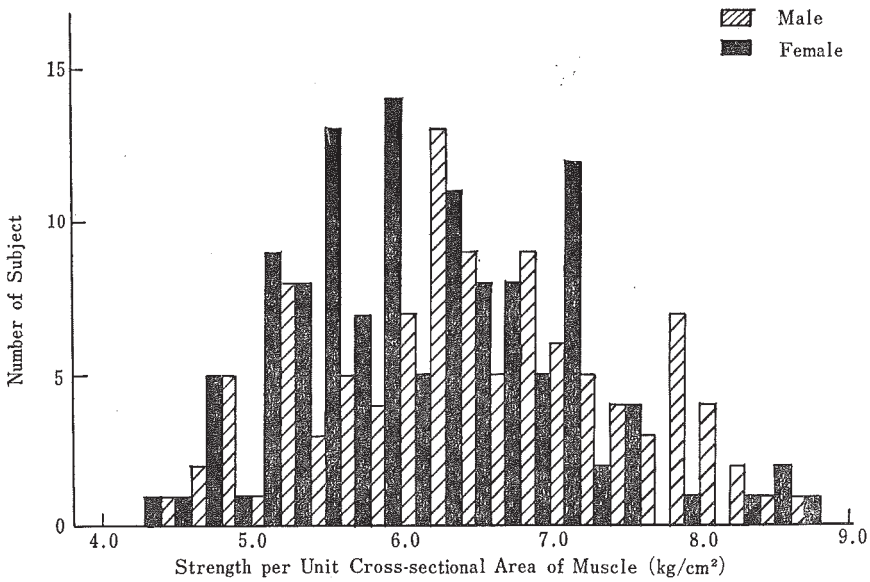

Fig. 17 The individual variation of the strength per unit cros-sectional area of the flexor muscle.

Table 5. Skinfold of judoists and non-trainees

subject	cheek (mm)	neck (mm)	chest (mm)	side chest (mm)	abdomen (mm)	inferior abdomen (mm)	upper arm (mm)	back (mm)
judoists	13.4	3.1	6.1	6.2	7.6	5.1	6.7	10.2
	2.7	1.8	2.1	3.8	3.1	1.3	3.4	2.2
non-trainees	13.1	2.8	7.0	6.1	8.5	4.5	6.9	10.2
	3.1	0.6	2.4	1.8	3.0	1.1	2.1	3.1
subject	knee (mm)	calf (mm)	thigh anterior (mm)	thigh posterior (mm)	total (mm)	mean (mm)	subcu-taneous fat mass (kg)	
judoists	6.5	9.2	8.9	10.2	92.9	7.7	4.6	
	1.5	4.1	2.6	3.4	30.4	1.8	1.7	
non-trainees	5.0	7.0	8.2	8.9	88.1	7.3	4.1	
	0.9	1.9	2.3	3.3	20.5	1.7	1.5	

CONCLUSION

The body composition was analysed in judoists (age 18–21) compared with non-trainees of same age group together with the measurement of physical perforemance capacity. In this paper the compartments of the body was reported on the body fat, solids and water related to the training effect of judo practice. On the other hand, the muscle mass was measured by means of ultrasonic photography related to the maximum strength of the muscle. We following results were obtained at this moment.

1) The cross-sectional area of the upper and forearm was photographed by means of ultrasonic radiation. The body compartment was analysed by means of densitometry.
2) The maximum muscle strength of the arm flexor was observed about 26% higher in judoists. No significant difference, however, was observed in strength per unit cross-sectional area of the arm flexor between both groups: 6.4 ± 0.9 kg/cm^2 in judoists, 6.7 ± 1.1 kg/cm^2 in non-trainees.
   The strength per unit cross-sectional area of these Judoists could be improved by 30 percent through intensive strength training.
3) The total mass of body fat, solid and body water were about 18% higher in judoists. No significant difference, however, was observed in the ratio of body compartment between both groups.

REFERENCES

1) *Behnke, A. R., Feen, B. G.*, and *Welham, W. C.:* The specific gravity of healthy men. J.A.M.A., 118, (7), 495–498, 1942.
2) *Brozek, J., Grande, F., Anderson, J. T.*, and *Keys, A.*: Densitometric analysis of body composition: Redision of some quantitative assumption. Annals New York Academy of Sciences, 110, 113–140, 1955.
3) *Cournand, A., Baldin, E.D., Darling, R.C.*, and *Richards, D.W.:* Studies on intrapulmonary mixture of gases, 3. The significance of the pulmonary empting rate and a simplified open circuit measurement of residual air. J. Clin. Invest., 20, 681–689, 1941.
4) *Garn, S.M.:* Fat patterning and fat intercorrelations in the adult male. Hum. Biol., 26, 59–69, 1954.
5) *Hettinger, Th.:* Physiology of strength. Charles C. Thomas. Publisher. 1961.
6) *Howry, D.H.*, and *Bliss, W.R.,:* Ultrasonic visualization of soft tissue structures of the body. J. Lab. Clin. Med., 40, 579–585, 1952.
7) *Ikai, M.*, and *Fukunaga, T.:* Calculation of muscle strength per unit cross-sectional area of human muscle by means of ultrasonic measurement. Int. Z. angew. Physiol. einschl. Arbeitsphysiol., 26, 26–32, 1968.
8) *Katsuki, S., H. Shibayama, M. Ikai,*, and *S. Kondo,:* An ultrasonic apparatus for measurement of body composition. Bulletin of the physical fitness research institute, 34–41, 1966.
9) *Kikuchi, K.*, and *Z. Kaneko,:* Medical Ultrasonic. Igaku-shoin, 1966.
10) *Morris, C.B.:* The measurment of the strength of muscle relative to the cross-section. Res. Qurt., 19, 295–303, 1948.
11) *Novak, L.P.:* Physical activity and body composition of adolescent boys. J.A.M.A., 197, 891–893, 1966.
12) *Suzuki, S.*, and *S. Nagamine,:* Study on subcutaneous fat and body density. Japanese Journa. of Physical Fitness, 7 (1), 185, 1962.
13) *Takenaka, T.*, and *T. Sakai,:* Measurement of body density. Research Journal of Physical Education. 7(1), 185, 1962.