GENETIC BASIS OF INDIVIDUAL DIFFERENCES IN TISSUE COMPOSITION

T. OHTSUKI, V. KLISSOURAS

Exercise Physiology Laboratory, University of Tokyo, Japan
Ergophysiology Laboratory, McGill University, Montreal, Canada

A total of 19 pairs of twin adolescent boys, 14 MZ and 5 DZ, were used to determine the relative contribution of the genotype to the individual differences observed in surface density of muscle, subcutaneous fat, and bone. The cross-sectional areas of these tissue components were calculated from photographs of the upper arm, taken by means of an ultrasonic apparatus. The respective mean percentage intrapair difference in MZ and DZ twins was 6.9 and 9.8 for total area, 6.6 and 7.8 for muscle, 13.9 and 32.0 for fat, and 6.7 and 31.3 for bone tissue. Interindividual variations in bone only could be ascribed to genetic differences.

Using the model of heredity plus environment, many attempts have been made to identify the genetic components in the interindividual variability of morphological characters, biochemical and hematological measures, endocrine variables, behavioral traits and pathological processes. We have also used this model to ascertain the extent to which human diversity in physiological function is genetically determined. We found that during maximal effort the mean intrapair difference between twin pairs in many components of the oxygen transport system and the neuromuscular apparatus, which is the mediator and the executor of the adaptive responses, was significant for nonidentical twins, but not for identical twins (Klissouras 1971, Klissouras et al. 1973, Komi et al. 1973). The two studies on which we are reporting in this congress were designed to further investigate the polygenic variation in man: (1) by making measurements in cross-sectional area of muscle, bone and subcutaneous fat tissue in MZ and DZ twins; (2) by comparing some ultrastructural components and the activities of some energy-transforming enzymes in the muscle cells of MZ twins; and (3) by making spirometric measurements in the same twins and finding out whether or not intrapair cellular differences can explain intrapair differences in maximal oxygen uptake, which represents the global capacity of the organism to transport and utilize oxygen. This presentation will deal with our observations on tissue composition only.

METHODS

Twins. Nineteen pairs of Japanese male twins (14 MZ and 5 DZ), whose physical characteristics are shown in Table 1, were tested for cross-sectional area of tissue components and muscular strength. Their zygosity was determined in a manner previously described (Inouye 1962). Some MZ twins were initially classified as DZ on the basis of similarities in physical appearance, but later reference to their antigens and blood grouping showed that their classification was wrong. For this reason the number of DZ pairs is smaller than initially planned. All tests were performed during the afternoon hours and all cotwins were tested in pairs in order to eliminate diurnal and environmental variation.

The cross-sectional area of the upper arm was determined by using an ultrasonic apparatus previously described (Ikai and Fukunaga 1969). The arrangement and a block diagram of the apparatus are shown in Fig. 1. The scanner, oscillating in a range of 60° circulates around the tank in about 30″ and produces an image of a cross-section of the arm on the specially designed Braun tube oscilloscope which is photographed by means of a 35 mm camera. Four to six pictures were taken with output intensity of ultrasonic wave gradually dimin-

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Tabella 1. *Physical characteristics of the MZ and DZ twins*

	Code	Age (yr)	Body weight (kg) A	Body weight (kg) B	Body weight (kg) Δ	Body height (cm) A	Body height (cm) B	Body height (cm) Δ
MZ Twins	2/1	12.7	59.5	58.5	1.0	174.3	173.4	0.9
	11/12	12.7	36.5	35.0	1.5	145.0	145.5	0.5
	18/17	12.9	37.5	38.0	0.5	151.7	149.4	2.3
	21/22	14.5	49.3	47.2	2.1	163.1	162.6	0.5
	26/25	14.6	51.4	48.4	3.0	155.5	154.5	1.0
	28/27	14.10	51.5	49.5	2.0	168.6	165.6	3.0
	30/29	15.1	52.4	55.0	2.6	165.2	164.2	1.0
	33/34	14.4	46.5	49.3	2.8	158.1	158.7	0.6
	35/36	14.11	53.0	53.5	0.5	163.2	164.8	1.6
	38/37	15.3	54.0	52.0	2.0	176.0	173.9	2.1
	39/40	14.7	43.5	42.5	1.0	165.6	160.6	5.0
	43/44	17.0	58.0	63.0	5.0	167.5	167.2	0.3
	45/46	16.8	75.0	—	—	168.3	—	—
	48/47	16.5	50.0	51.0	7.0	166.5	167.3	1.8
	X	14.67			2.38			1.58
	SD	1.40			1.84			1.31
	SE	0.39			0.53			0.38
DZ Twins	5/6	12.6	56.5	44.5	12.0	168.3	153.6	14.7
	9/10	12.8	36.5	39.0	3.0	152.5	158.8	6.3
	20/19	12.8	35.0	33.5	1.5	140.2	142.1	1.9
	42/41	16.8	59.0	61.0	2.0	165.7	163.0	2.7
	50/49	17.3	52.5	52.0	0.5	170.2	169.1	1.1
	X	14.46			3.80			5.34
	SD	2.37			4.67			5.60
	SE	1.19			2.34			2.80

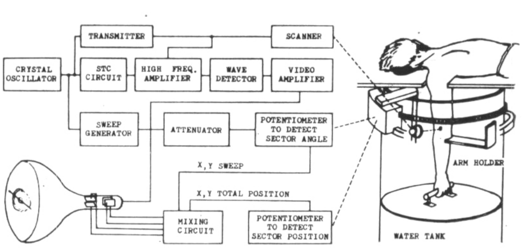

Fig. 1. Arrangement and block diagram of the ultrasonic apparatus.

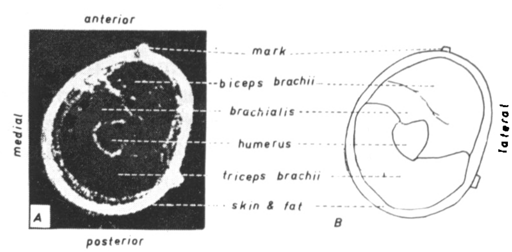

Fig. 2. A typical ultrasonic photograph of the upper arm.

ishing. High intensity was used to define the bone outline and low intensity to define precisely the boundaries of muscle and fat. The frequency of the ultrasonic wave was chosen to be 5 MC/sec. A typical ultrasonic photograph of the upper is presented in Fig. 2. The photograph was traced and planimetric values were obtained for the three tissues which were then converted into actual cross-sectional area (A_t) by the formula: $A_t = A_p\,(a_t b_t)/(a_p b_p)$, where A_p is the planimetric value, a_p and b_p are the major and minor axes of each oval area (it is assumed that the photographic shape of the cross-section is an ellipse), and a_t and b_t are the actual lengths obtained from a calibration graph. Since different diameters were found to have a different magnification ratio, pakelite tubes of various diameters (2 to 12 cm) were photographed for the construction of the calibration graph.

Table 2. *Cross-sectional area of tissue component of the upper arm in MZ and DZ twins*

	Code	Total				Muscle				Fat				Bone			
		A	B	Δ	Δ%	A	B	Δ	Δ%	A	B	Δ	Δ%	A	B	Δ	Δ%
MZ Twins	2/1	44.75	45.37	0.62	1.39	33.22	34.05	0.83	2.50	7.95	7.59	0.36	4.74	3.58	3.73	0.15	4.19
	11/12	30.23	29.50	0.73	2.47	22.70	22.44	0.26	1.16	4.87	4.38	0.49	11.19	2.66	2.68	0.02	0.75
	18/17	29.98	30.06	0.08	0.27	21.17	21.99	0.82	3.87	5.49	5.56	0.07	1.28	3.32	2.51	0.81	32.27
	21/22	42.96	42.39	0.57	1.34	32.79	33.61	0.82	2.50	7.28	6.00	1.28	21.33	2.89	2.78	0.11	3.96
	26/25	47.04	41.72	5.32	12.75	36.24	31.40	4.84	15.41	7.56	6.91	0.65	9.41	3.24	3.41	0.17	5.25
	28/27	41.69	42.99	1.30	3.12	32.47	33.13	0.66	2.03	5.95	6.45	0.50	8.40	3.27	3.41	0.14	4.28
	30/29	38.15	45.42	7.27	19.06	28.43	33.05	4.62	16.25	5.21	7.86	2.65	50.86	4.51	4.51	0.00	0.00
	33/34	42.53	42.86	0.33	0.78	32.18	33.75	1.57	4.88	7.20	5.88	1.32	22.45	3.15	3.23	0.08	2.54
	35/36	47.37	48.69	1.32	2.79	36.55	37.34	0.79	2.16	7.30	7.65	0.28	3.80	3.45	3.70	0.25	7.25
	38/37	34.59	34.53	0.06	0.17	25.44	26.50	1.06	4.16	6.32	5.29	1.03	19.47	2.73	2.74	0.01	0.37
	39/40	29.94	27.41	2.53	9.23	22.73	21.28	1.45	6.81	4.52	3.74	0.78	20.86	2.69	2.39	0.30	12.55
	43/44	51.90	56.21	4.31	8.30	39.01	42.50	3.49	8.95	9.82	10.93	1.11	11.30	3.07	2.78	0.29	10.43
	45/46	66.57	59.18	7.39	11.10	51.94	46.81	5.13	10.96	11.36	9.33	2.03	21.76	3.27	3.04	0.23	7.57
	48/47	41.17	36.67	4.50	12.28	31.41	28.25	3.16	10.06	6.37	5.11	1.26	24.67	3.39	3.31	0.08	2.42
	X				6.08				6.55				16.54				6.70
	SD				5.98				5.02				12.60				8.23
	SE				1.66				1.39				3.49				2.28
DZ Twins	5/6	35.64	44.36	8.72	24.47	27.48	31.75	4.27	15.54	5.69	9.60	3.91	68.72	2.47	3.01	0.54	21.86
	9/10	28.35	31.77	3.42	12.06	22.65	24.75	2.10	9.27	4.24	5.46	1.22	28.77	1.46	1.56	0.10	6.85
	20/19	30.28	27.97	2.31	8.26	21.16	21.43	0.27	1.28	6.77	4.48	2.29	51.12	2.35	2.06	0.29	14.08
	42/41	51.43	49.53	1.90	3.84	40.65	38.15	2.50	6.55	8.71	8.40	0.31	3.69	2.07	2.98	0.91	43.96
	50/49	37.44	37.63	0.19	0.51	28.22	30.04	1.82	6.45	4.44	4.77	0.33	7.43	4.78	2.82	1.96	69.50
	X				9.83				7.82				31.95				31.25
	SD				9.28				5.20				27.97				25.51
	SE				4.64				2.60				13.99				12.75

Table 3. *Relative contribution of different tissues to the total area of MZ and DZ twins*

	Code	Muscle A	Muscle B	Muscle Δ	Muscle Δ%	Fat A	Fat B	Fat Δ	Fat Δ%	Bone A	Bone B	Bone Δ	Bone Δ%
MZ Twins	2/1	74.23	75.05	0.82	1.10	17.77	16.73	1.04	6.22	8.00	8.22	0.22	2.75
	11/12	75.09	76.07	0.98	1.31	16.11	14.85	1.26	8.48	8.80	9.08	0.28	3.18
	18/17	70.61	73.15	2.54	3.60	18.31	18.50	0.19	1.04	11.07	8.35	2.72	32.57
	21/22	76/33	79.28	2.95	3.86	16.95	14.15	2.80	19.79	6.73	6.56	0.17	2.59
	26/25	77.04	75.26	1.78	2.37	16.07	16.56	0.49	3.05	6.89	8.17	1.28	18.58
	28/27	77/88	77.06	0.82	1.06	14.27	15.00	0.73	5.12	7.84	7.93	0.09	1.15
	30/29	74.52	72.77	1.75	2.40	13.66	17.31	3.65	26.72	11.82	9.93	1.89	19.03
	33/34	75.66	78.74	3.08	4.07	16.93	13.72	3.21	23.40	7.41	7.54	0.13	1.75
	35/36	77.16	76.69	0.47	6.61	15.56	15.71	0.15	6.96	7.28	7.60	0.38	4.40
	38/37	73.84	77.15	3.31	4.48	18.27	15.32	2.95	19.25	7.89	7.94	0.05	6.63
	39/40	75.92	77.64	1.72	2.27	15.10	13.64	1.46	10.70	8.98	8.72	0.26	2.98
	43/44	75.16	75.61	0.45	0.60	18.92	19.44	0.52	2.75	5.92	4.95	0.97	19.60
	45/46	78.02	79.10	1.08	1.38	17.06	15.77	1.29	8.18	4.91	5.14	0.23	4.68
	48/47	76.29	77.04	0.75	0.98	15.47	13.94	1.80	12.91	8.23	9.02	0.79	9.60
	X				2.58				11.04				9.25
	SD				1.73				8.17				9.49
	SE				0.48				2.27				2.63
DZ Twins	5/6	77.10	71.57	5.53	7.73	15.97	21.64	5.67	35.50	6.93	6.79	0.14	2.06
	9/10	79.89	77.90	1.99	2.55	14.96	17.19	2.23	14.91	5.15	4.91	0.24	4.89
	20/19	69.88	76.61	6.74	9.65	22.36	16.02	6.34	39.58	7.76	7.37	0.39	5.29
	42/41	79.04	77.02	2.02	2.62	16.94	16.96	0.02	0.12	4.02	6.02	2.00	49.75
	50/49	75.37	79.83	4.46	5.92	11.86	12.65	0.79	6.66	11.86	7.49	4.37	58.34
	X				5.69				19.35				24.07
	SD				3.13				17.47				27.56
	SE				1.56				8.73				13.78

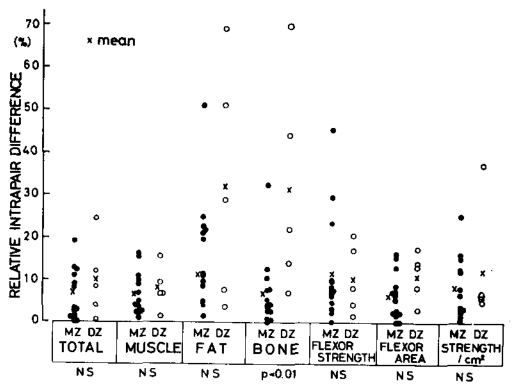

Fig. 3. The relative intrapair differences of cross-sectional area of tissue components and muscle strength of the upper arm in MZ and DZ twins. ←

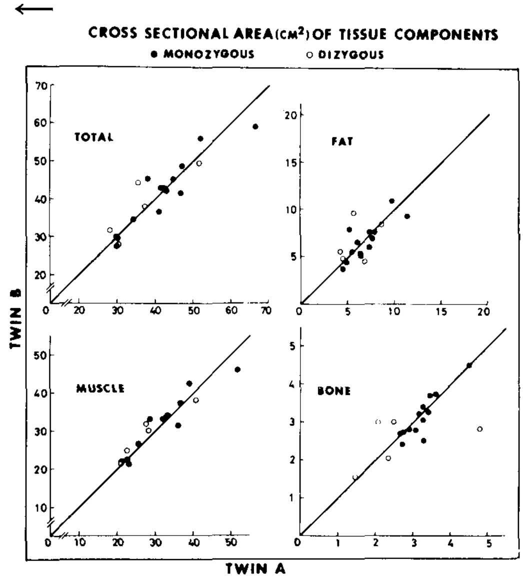

Fig. 4. Cross-sectional area (cm²) of tissue components in MZ (filled circles) and DZ (unfilled circles) twins.

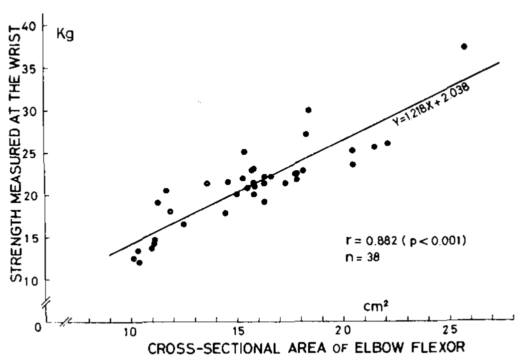

Fig. 5. Strength measured at wrist as a function of cross-sectional area of elbow flexor. ←

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The subject, lying prone on the table, immerses his arm perpendicularly on the central axis of a water tank. There are several stabilizers to keep the arm immovable during the measurement.

The maximum isometric strength of both arm flexors was measured by means of strain gauge force transducers, connected to a 45 mm wide belt fixed to the subject's wrist. The subject was seated in a specially designed iron chair with the elbows flexed at 90° and forearms prone on a horizontal platform adjustable to his somatotype. His knees were extended horizontally on the chair to avoid any possible mechanical contribution of lower limbs to the force production.
Three trials of maximal effort of about 5″ duration each were given for each arm with 3′ rest intervals between trials. The highest value was used for further analysis. The force exerted by the elbow flexors at the point of their insertion was estimated from the force measured at the wrist and the resistance arm to force arm ratio, which is shown from radiological measurements to have a value of 4.90 (Ikai and Fukunaga 1968). The absolute strength thus obtained was divided by the cross-sectional area of the flexors to derive the maximum muscle strength per unit cross-sectional area.

RESULTS

The cross-sectional area of tissue components of the upper arm in MZ and DZ twins is given in Table 2. The respective percent intrapair differences in MZ and DZ twins for the total area, the muscle, the fat, the bone tissue, and flexor strength, are presented in Fig. 3. Only the difference in bone between MZ and DZ twins was significant at 0.01 level of confidence. The intrapair differences of the cross-sectional area of the different tissues are also plotted in Fig. 4, so that the scatter of individual values around the line of identity may be seen.
The relative contribution of the three tissues to the total area is shown in Table 3. Only the difference in the relative muscle cross-sectional area appears to be wider between nonidentical than identical twins, resulting in a significant interzygotic difference at $p > 0.05$. The differences between MZ and DZ twins in fat and bone tissues did not reach a significant level. The data on muscle strength are presented in Table 4. There was no significant difference between MZ and DZ twins in muscle strength expressed either per kilogram or per unit muscle area. However, the dependence of muscle strength on the cross-sectional area of the contracting muscle was confirmed (Fig. 5). The derived coefficient of correlation is 0.88 and the relation is expressed with the equation: $Y = 1.218\,X + 2.038$, where Y = cross-sectional area of elbow flexor in cm², and X = strength measured at the wrist, in kg.
These findings are in good agreement with earlier observations made in the same laboratory (Ikai and Fukunaga 1968).

DISCUSSION

Most observers of body composition hold the view that constitutional differences result from genetic differences (Sheldon et al. 1954, Tanner 1964, Petersen 1968). Sheldon, in particular, has argued that an individual's body build is gene-determined and environmental influences cannot alter it. He identified three components in physique, i.e., the endomorphic, mesomorphic and ectomorphic, and noted that there is always a relative preponderance of one component, while the other two are manifested to smaller and varying degrees. We used Sheldon's taxonomy of constitutional variation in another twin study (unpublished observations), where each component was determined metrically and by visual inspection of photographs, which were then compared with photographs of established standard somatotypes (Heath 1963, Heirnaux 1963). The position of each somatotype was charted on a two-dimensional diagram, on the basis of the strength of its components. There was a tendency for nonidentical twins to show a greater intrapair difference than identical twins. However, in these observations, the potency of environmental modes on diversity could not be evaluated. We know, for example, that special training induces muscular hypertrophy which invariably modifies the somatotype rating of the individual (Tanner 1952, Wells et al. 1963).

The data of the present study suggest that human physique shows a stability as far as bone tissue

Table 4. *Forearm flexor strength of MZ and DZ twins*

	Code	Forearm flexor strength (kg)				Cross sectional area of forearm flexors (cm^2)				Forearm flexory strength per unit muscle area (kg/cm^2)				Arm used (dominance)	
		A	B	Δ	Δ%	A	B	Δ	Δ%	A	B	Δ	Δ%	A	B
MZ Twins	2/1	21.3	20.7	0.60	2.90	16.31	15.50	0.81	5.23	6.40	6.54	0.14	2.19	R (d)	L (nd)
	11/12	18.0	14.6	3.40	23.29	11.86	11.14	0.72	6.46	7.44	6.42	1.02	15.89	L (nd)	R (d)
	18/17	13.3	14.3	1.00	7.52	10.36	11.09	0.73	7.05	6.29	6.32	0.03	0.48	L (nd)	L (nd)
	21/22	22.6	21.3	1.30	6.10	17.76	17.30	0.46	2.66	6.24	6.03	0.21	3.48	R (d)	R (d)
	26/25	27.2	21.0	6.20	29.52	18.27	15.86	2.41	15.20	7.30	6.49	0.81	12.48	R (d)	R (d)
	28/27	21.4	20.1	1.30	6.47	15.80	15.80	0.00	0.00	6.64	6.23	0.41	6.58	L (nd)	R (d)
	30/29	23.2	22.7	0.50	2.20	15.79	17.81	2.02	12.79	7.20	6.25	0.95	15.30	R (d)	R (d)
	33/34	20.3	22.3	2.00	9.85	15.02	16.29	1.27	8.46	6.62	6.71	0.09	1.36	R (d)	L (nd)
	35/36	22.7	21.7	1.00	4.60	18.08	17.79	0.29	1.63	6.15	5.98	0.17	2.84	L (nd)	R (d)
	38/37	21.4	21.4	0.00	0.00	14.59	13.62	0.97	7.12	7.19	7.70	0.51	7.09	L (nd)	L (nd)
	39/40	20.5	19.1	1.40	7.33	11.72	11.27	0.45	3.99	8.57	8.30	0.27	3.25	L (nd)	R (d)
	43/44	23.4	25.2	1.80	7.69	20.46	20.44	0.02	0.10	5.60	6.04	0.44	7.86	R (d)	L (nd)
	45/46	37.8	26.0	11.80	45.38	25.72	22.10	3.62	16.38	7.20	5.76	1.44	25.00	L (d)	L (nd)
	48/47	22.9	25.1	2.20	9.60	15.76	15.40	0.36	2.28	7.12	7.99	0.87	12.22	R (d)	L (nd)
	X				11.60				6.38				8.29		
	SD				12.59				5.30				7.06		
	SE				3.49				1.47				1.96		
DZ Twins	5/6	17.8	19.2	1.40	7.87	14.47	16.33	1.86	12.85	6.03	5.76	0.27	4.69	L (nd)	R (d)
	9/10	13.7	16.5	2.80	20.44	11.01	12.53	1.52	13.81	6.10	6.45	0.35	5.74	L (nd)	L (nd)
	20/19	12.5	12.0	0.50	4.17	10.14	10.43	0.29	2.86	5.98	5.64	0.34	6.03	L (nd)	L (d)
	42/41	25.6	29.9	4.30	16.80	21.48	18.34	3.14	17.12	5.84	7.99	2.15	36.82	R (d)	L (nd)
	50/49	22.2	21.9	0.30	1.37	16.58	15.32	1.26	8.22	6.56	7.00	0.44	6.71	L (nd)	R (d)
	X				10.13				10.97				12.00		
	SD				8.19				5.54				13.89		
	SE				4.09				2.77				6.95		

is concerned and that this constancy of interindividual variability must have a genetic origin. Findings on bone dimensions obtained in a number of previous studies by anthropometric techniques are in agreement with this view (Vandenberg 1962).

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Dr. Vassilis Klissouras, Physiology Department, McGill University, P. O. Box 6070, Station « A », Montreal, Quebec, Canada H3C 3G1.

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