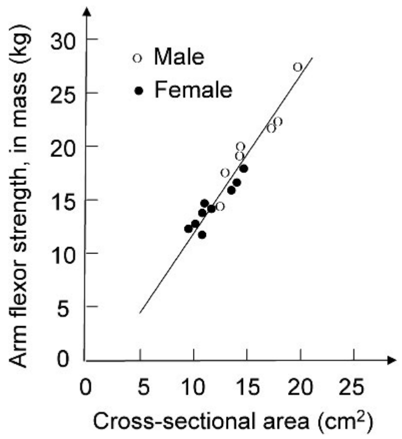
Trabajo Práctico 5 - Biofísica 2016

Músculos

1. Discutir brevemente el efecto que tiene el ejercicio sobre los músculos.

2. La siguiente figura, realizada con datos tomados de Çalculation of Muscle Strength per Unit Cross-Sectional Area of Human Muscle by Means of Ultrasonic Measurement", Ikai & Fukunaga (1968), representa la relación entre la fuerza de los músculos flexores del brazo y el área transversal en hombres y mujeres.



   a) ¿Cómo varía la fuerza de estos músculos con su área de sección transversal?

   b) Explicar el procedimiento utilizado en la publicación para realizar las medidas y el cálculo de la fuerza.

   c) ¿Cuál es la constante de proporcionalidad?

   d) ¿Cómo difiere para hombres y mujeres?

3. *a*) Demostrar que el área de sección transversal de un músculo de fibras paralelas (PCA) es

$$PCA = \frac{m}{Ld} cm^2,$$

   donde m es la masa de las fibras musculares, d es la densidad del músculo ($1,056 gr/cm^3$) y L es la longitud de las fibras musculares.

   b) Demostrar que para músculos plumados,

$$PCA = \frac{m \cos\theta}{Ld} cm^2,$$

   donde θ es el ángulo de plumación (el ángulo entre el eje a lo largo del músculo y el ángulo de la fibra).

   c) Comprobar si las dos relaciones de los incisos anteriores son consistentes con los datos del músculo dados en la siguiente tabla:

muscle	mass (g)	fiber length (cm)	PCA (cm^2)	pinnation angle (°)
sartorius	75	38	1.9	0
biceps femoris (long)	150	9	15.8	0
semitendinosus	75	16	4.4	0
soleus	215	3.0	58	30
gastrocnemius	158	4.8	30	15
tibialis posterior	55	2.4	21	15
tibialis anterior	70	7.3	9.1	5
rectus femoris	90	6.8	12.5	5
vastus lateralis	210	6.7	30	5
vastus medialis	200	7.2	26	5
vastus intermedius	180	6.8	25	5

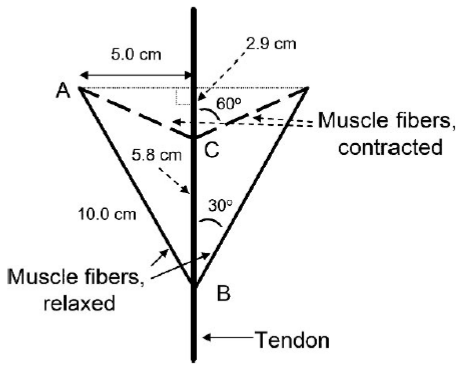
4. A continuación se presentan algunos datos de récords en el levantamiento de potencia en el año 2006:

Peso del levantador/ra (kg)	Peso Levantado Varones (kg)	Peso levantado Mujeres (kg)
48		118
53		127
56	168	--
58	--	139
62	182	--
63	--	141
69	197	157
75	--	159
77	210	--
85	218	--
94	232	--
105	242	--

a) ¿Cómo varía el peso levantado con el peso corporal? (Graficar por separado para hombres y mujeres).

b) ¿Se sigue una ley de potencia?

5. En músculos paralelos (o fusiformes) todas las fuerzas contráctiles musculares son orientadas a lo largo del eje del tendón y existe una relación entre los cambios en los músculos y la longitud del tendón que depende de las condiciones (contracción isométrica, etc). En músculos plumados y biplumados estas relaciones son cualitativamente diferentes. La siguiente figura representa un músculo biplumado en una configuración inicial relativamente más relajada y una configuración final relativamente más contraída.



a) En la configuración inicial, el largo del tendón (al punto donde el músculo es insertado en el tendón, punto B) es de 8,7cm (2,9 + 5,8cm en la figura). Cada fibra muscular tiene 10cm de longitud y está unida al tendón en un ángulo de 30°. Digamos que hay un total de N fibras unidas al tendón cerca de ese punto (con igual número de fibras a ambos lados) y que cada fibra ejerce una fuerza F_{fiber}. Encontrar la fuerza total transmitida al tendón, F_{tendon}.

b) El músculo se contrae de manera que la longitud del tendón (al punto C) es 2,9cm y el ángulo músculo/tendón es ahora 60°. Encontrar la longitud del músculo (ver líneas punteadas). Durante esta contracción, ¿qué se ha acortado más, las fibras musculares o el tendón? ¿Esto es bueno o malo para la acción muscular?

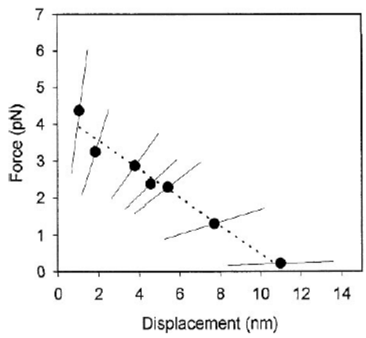
c) Encontrar la expresión de la fuerza transmitida al tendón luego de la contracción del apartado (b), F_{tendon}, asumiendo que la fuerza contráctil de cada fibra muscular es todavía F_{fiber}. ¿Cómo ha cambiado la fuerza transmitida al tendón?

d) Considerar ahora un caso más general, en el que conocemos que la fuerza ejercida por la fibra muscular cambia con la longitud. Suponer que F_{fiber} tiene un pico a una longitud $L = 8cm$, con $F_{fiber}(L) = F_{max}(1 - \frac{1}{8}(L-8)^2)$. Graficar F_{tendon} a medida que L se contrae de 10 a 6cm. ¿Presenta F_{tendon} un pico en la zona exacta donde $F_{fiber}(L)$ tiene el pico?

6. Determinará los valores de T y v que maximizan la potencia de un músculo descriptas por la ecuación de Hill fuerza-velocidad y encontrar P_{max} del músculo. Tomar $a/T_{max} = 0{,}25$, recordar que $P = Tv$ (Sugerencia: derivar la expresión de la potencia con respecto a v e igualar a cero).

7. Cuando se levanta un peso, la longitud del músculo varía de 25 % más corto que su longitud en reposo a 25 % más largo. Si la longitud en reposo del sarcómero es 2,5μm, ¿cuántos saltos (crossbridge power strokes) de 11nm ocurren en cada sarcómero durante la elevación?

8. La siguiente figura muestra la curva de fuerza en función del desplazamiento de una sola molécula de miosina interactuando con una molécula de actina durante la entrega instantánea de potencia.



   a) Estimar el trabajo realizado por una molécula de miosina durante una entrega instantánea de potencia. Expresar esto en J y eV ($1eV = 1{,}6 \times 10^{-19}J$) por crossbridge y en $kcal/mol$ (para un mol de crossbridge).
   b) Si la energía disponible de la hidrólisis de ATP en una célula muscular es de $10^{-19}J$, calcular la eficiencia de un 'powerstroke' de miosina en el uso de la energía proveniente de la hidrólisis de ATP.

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Calculation of Muscle Strength per Unit Cross-Sectional Area of Human Muscle by Means of Ultrasonic Measurement

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Summary. By means of the ultrasonic photography of the cross-section of the acting muscle bundle, together with the measurement of the muscle strength developed by the subject with maximum effort, the strength per unit area of the muscle was calculated in 245 healthy human subjects, including 119 male and 126 female.

The result was summarized as the following:

1. The ultrasonic method used in this work was possibly admitted as the best way to calculate the cross-sectional area of the muscle.

2. The arm strength was fairly proportional to the cross-sectional area of the flexor of the upper arm regardless of age and sex.

3. The strength per unit cross-sectional area of flexor of the upper arm was 6.3 kg/cm^2 in the average, standard deviation of 0.81 kg/cm^2. When cross-sectional area of muscle was measured at extensive position of the forearm the strength per unit area was calculated to be 4.7 kg/cm^2 at flexed position of the forearm.

4. As to the individual variation, the strength per unit area was distributed in a range from 4 kg/cm^2 to 8 kg/cm^2.

5. The strength per unit cross-sectional area was almost the same in male and female regardless of age. In addition to that, there was not found any significant difference in ordinary and trained adult.

The muscle strength per unit cross-sectional area has been calculated by many authors. It has been understood that the strength must be proportional to the physiological cross-sectional area of the muscle (HETTINGER, 1961). There are found, however, some differences among the results of researches as the followings: 6—10 kg/cm^2 (FICK, 1910), 6.24 kg/cm^2 (HERMANN, 1898), 9.2 kg/cm^2 (MORRIS, 1948), 4 kg/cm^2 (HETTINGER, 1964).

The present authors have conducted a study to determine the strength per unit cross-sectional area by means of ultrasonic method in living human subject. They also intend to make clear whether some differences exist among ages and sexes as well as trained and untrained.

Methods and Procedures

1. Subjects

As the subject 245 healthy persons of 119 male and 126 female participated to the experiment.

2. Measurement of Maximum Strength

The muscle strength was measured at the arm flexor at the right angle of the elbow joint in sitting position isometrically. The subject contracted the muscle against the cloth belt attached over the wrist with maximum effort. The belt, 45 mm wide, was connected with a straingauge tensiometer. The legs were extended on a chair. To get the maximum strength, any special procedure, was not used. After three trials for measurement, the highest value was adopted as the maximum strength of each individual.

3. Measurement of the Cross-Sectional Area of the Muscle

The subject was asked to keep the lying position, while his arm was fixed to extend to the bottom of the water tank (Fig. 1). The ultrasonic scanner circulates around the upper arm to be tested for 30 sec. The pulsed echo reflects on the cathode ray screen in brightness modulation.

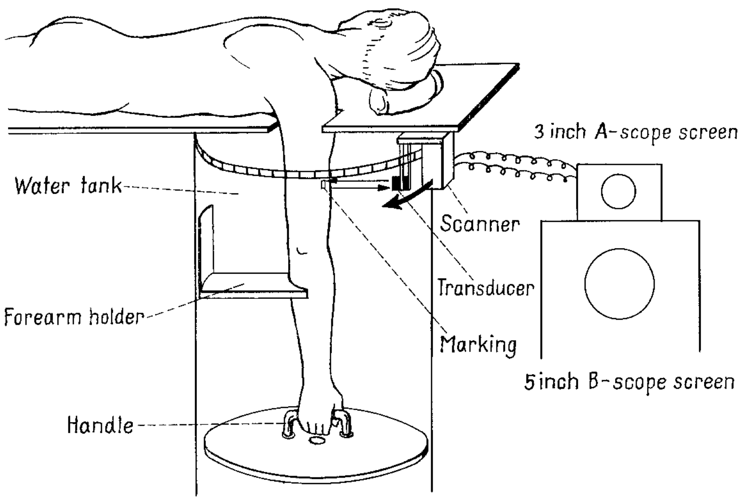

Fig. 1. Scheme of ultrasonic equipment

The frequency of ultrasonic wave was chosen to be 2.25—5 megacycle (MC) per second to get clear view of bone, muscle as well as subcutaneous fat. Fig. 2 shows the cross-sectional picture of the upper arm.

In this picture, the boundaries among subcutaneous fat, muscle, fascia and bone were observed clearly. Under consideration of the structure of subcutaneous fat and fascia, muscle of the upper arm was devided into flexor and extensor.

To measure the size of the tissues, a calibration curve was made by means of bakelite models of several diameters.

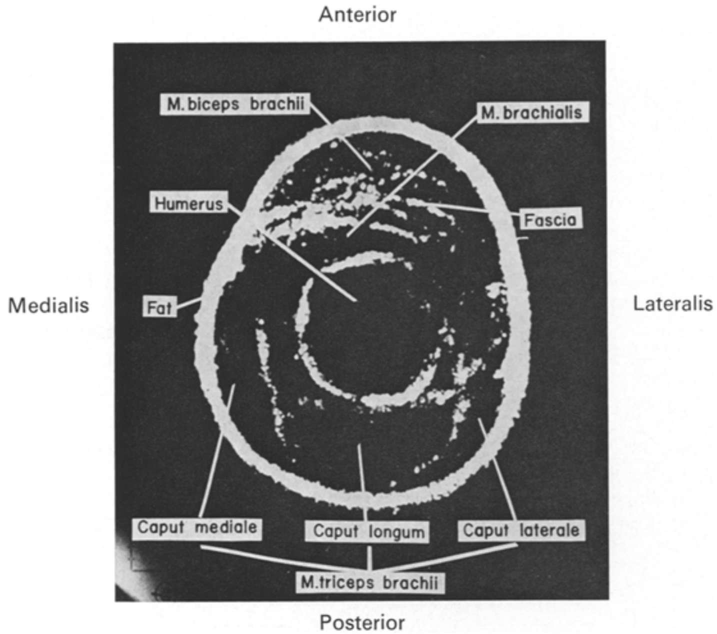

Fig. 2. Cross-sectional view of human upper arm by ultrasonic method

4. Calculation of Absolute Strength

To calculate the absolute strength of flexor muscle, biceps brachii, the following procedure was applied. The arm of the subject flexed at the elbow joint at right angle as the same position as in the measurement of strength, X-ray photograph

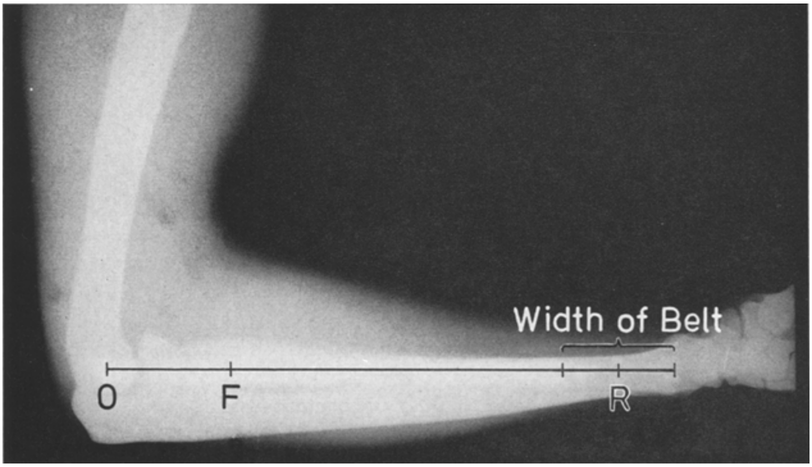

Fig. 3. Determination of fulcrum (*O*), force point (*F*) and resistance point (*R*) by means of X-ray photograph

was taken as was shown in Fig. 3. The distance between the arm and X-ray tube was held to be 2 m.

From the picture, the lever arms were measured for further calculation: The *O* means the center of axis of rotation of the elbow joint at the condylus humeri which acts as fulcrum. The *F* means the point at which biceps brachii muscle attaches tuberositas radii. It acts as the force point. The *R* means the point on which the belt is applied connected with tensiometer which acts as the resistance point.

In order to know whether the ratio of "resistance arm" and "force arm" may change in advance of age, measurement was done in two groups of young boys and

Table 1. *Ratio of lever arm for calculation of the absolute muscle strength*

Age	Number of subjects	Ratio of lever arm $= \frac{\text{resistance arm (OR)}}{\text{force arm (OF)}}$
Boys 13	5	5.08 ± 0.10 (mean ± S. D.)
Adult men 20—30	10	4.81 ± 0.32 (mean ± S. D.)

adult men (Table 1). From these results, any significant difference between the averages of the ratio was not found in both groups ($P > 0.1$). Therefore the ratio could be estimated to be 4.90 in the average with the standard deviation of 0.29.

From the measured strength *(M)*, the absolute strength *(A)* was calculated as follows:

$$A = M \cdot 4.90.$$

Result and Discussion

The measured strength of the arm flexor was plotted against the cross-sectional area of the flexor muscle as shown in Fig. 4.

This presents a close relationship between the strength of the arm flexor and cross-sectional area of the flexor observed in all the subjects including male and female, young and adult of trained and untrained.

The strength per unit cross-sectional area of the muscle (kg/cm^2) was calculated from the arm strength and the cross-sectional area of the flexor of the upper arm. Table 2 presents the average of the strength per unit area respected to age and sex.

It was found in Table 2 that the strength per unit area was almost the same in male and female, regardless of age. In addition to that, there was not found significant difference in ordinary and trained adult as shown in Table 3.

As to the individual variation, the strength per unit area is distributed in a range from 4 kg to 8 kg as shown in Fig. 5.

Morris (1948) reported that the strength per unit area of the flexor of the upper arm was 9.2 kg/cm^2 in male, and 7.1 kg/cm^2 in female

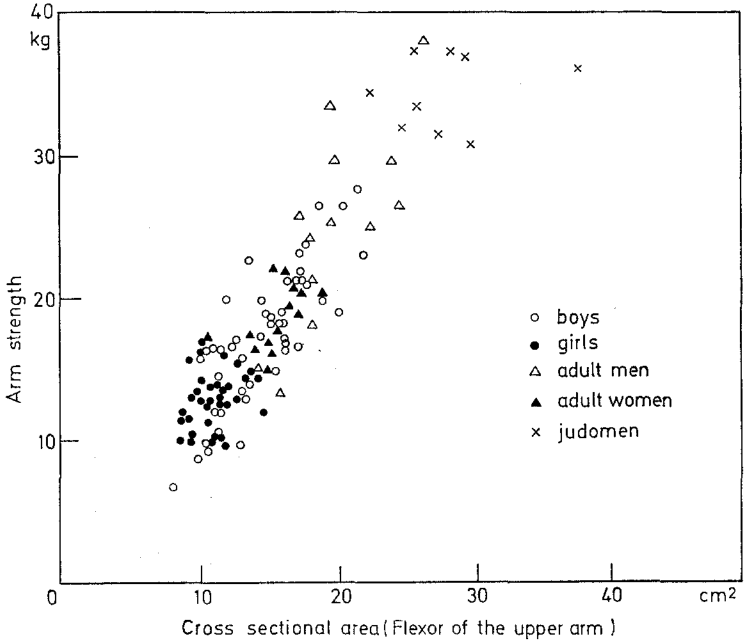

Fig. 4. Relationship between arm strength and cross-sectional area of flexor

Table 2. *The strength per unit cross-sectional area*

Age (yrs)		Arm strength (kg)	Flexor of upper arm (cm^2)	Strength per unit cross-sectional area (kg/cm^2) of muscle
12	M[a] (12)	14.7 ± 2.9[b]	12.1 ± 2.3	6.0 ± 1.1
	F (10)	13.1 ± 2.0	10.1 ± 1.7	6.4 ± 0.9
13	M (21)	17.6 ± 2.2	13.0 ± 0.6	6.7 ± 0.9
	F (19)	13.1 ± 2.0	10.6 ± 1.0	6.1 ± 1.1
14	M (15)	19.5 ± 2.7	14.4 ± 1.5	6.7 ± 0.8
	F (11)	11.9 ± 1.1	11.0 ± 1.3	5.3 ± 0.8
15	M (23)	19.1 ± 3.4	14.3 ± 2.1	6.6 ± 0.9
	F (13)	14.1 ± 1.0	11.2 ± 1.6	6.3 ± 0.9
16	M (12)	21.7 ± 3.2	16.6 ± 2.7	6.5 ± 1.0
	F (18)	14.4 ± 1.7	11.5 ± 1.3	6.1 ± 0.6
17	M (18)	21.8 ± 2.9	16.9 ± 2.7	6.4 ± 0.9
	F (8)	15.0 ± 2.2	11.4 ± 1.7	6.3 ± 0.5
18	F (14)	16.0 ± 2.0	13.5 ± 1.6	5.8 ± 0.8
19	F (19)	16.6 ± 1.9	13.6 ± 2.3	6.1 ± 1.0
20s	M (12)	27.4 ± 5.2	20.1 ± 2.9	6.7 ± 1.1
	F (14)	18.2 ± 2.6	14.5 ± 1.8	6.2 ± 1.8
Obese boys (7)		25.8 ± 5.0	23.3 ± 4.0	5.5 ± 1.0
Univ. Judomen (9)		34.5 ± 3.0	27.3 ± 1.3	6.4 ± 0.9

[a] Bracket () shows the number of subject, M = male, F = female. — [b] Mean ± S. D.

Table 3. *Strength of ordinary male and trained Judo athletes*

Subject	N	Arm strength	Strength per unit area
Ordinary 20 yrs	12	27.4 ± 5.2 kg	6.7 ± 1.1 kg/cm²
Judomen	9	34.5 ± 3.0 kg	6.4 ± 0.9 kg/cm²
(Mean ± S. D.)			

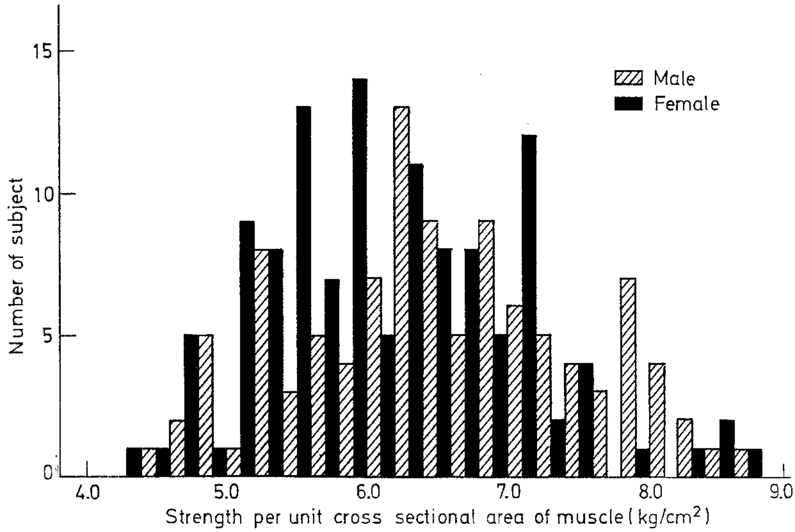

Fig. 5. The individual variation of the strength per unit cross-sectional area of the flexor muscle

subject, based on the measurement of the passive strength. MORRIS mentioned a possibility that the subject could exert the highest strength of 10 kg/cm² as suggested by FICK, if the subject would be trained for highest concentration.

FRANKE (1920) reported the highest value of 11.1 kg/cm² in the flexor of the upper arm.

As to the measurement of the cross-sectional area of the flexor, other authors, including MORRIS, FRANKE, HERMANN, used the anatomical data measured in cadaver and data observed in X-ray film in living subject. Compared with these classical methods, the ultrasonic method could be available to differentiate more accurately the tissue components of the living subject.

The flexor of upper arm, including biceps brachii and brachialis, was chosen for this experiment, because the muscle fibers run parallel to the longitudinal axis of the muscle bundle.

On the other hand, the cross-sectional area of the flexor was calculated, in an flexed position to an angle of 90 degrees, in a maximum contraction. The cross-sectional area was larger by 34% in flexed position than in extended one. According to these procedures, the strength per unit area of the flexor was calculated to be approximately 4.7 kg/cm² in the average.

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