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EXPERIMENTAL INVESTIGATION OF ANATOMICAL AND GEOMETRICAL PARAMETERS OF A HUMAN HIP

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Abstract: Data for the forces influencing on the hip under a physiological load are necessary for biomechanical modeling of the processes in the bone. Calculation of the muscle force includes physiological cross-sectional area as a parameter. This work is devoted to measuring anatomical cross-sectional area of 24 muscles of the hip and the pelvis. Two male cadaver specimens and one computed tomogram of an alive patient were investigated. The results were correlated with the anthropometric data for the specimens. The maximum isometric forces of different muscles were calculated.

Key words: physiological cross-sectional area of muscle, maximum isometrical force of muscle, computed tomogram of the lower limb

Introduction

Muscle forces are taken into account by many researchers during the calculation of stress and strain arising in the hip [1-4]. Physiological cross-section area of muscle (S_{ph}) is used as a parameter in different investigation devoted to determination of muscle efforts during walking [5,6]. Solving a problem by the method of static optimization Crowninshield and Brand [7] used S_{ph} when constructing of a purposeful function. Dependence of maximum isometrical muscle force (F_{max}) on S_{ph} allows calculating admissible solution constraint [1, 7, 8]. Different authors note that S_{ph} value depends on the method of measurement, age, sex and anthropometric data of specimens [6,9]. In our work measurement was carried out based on two adult male cadaver specimens with similar habitus and one alive man (according to the computed tomogram of the lower limb). 24 muscles of the right hip and the pelvis were investigated. Measured values were anatomical cross-sectional area (S_{an}), mass, the lengths of the venter and the tendon of each muscle. Using the results of measurement some relative parameters of the lower limb muscle were calculated. The use of the computed tomogram permitted to compare the results obtained on corpses with the data *in vivo*.

Materials and Methods

Two male corpses of the similar habitus and one computed tomogram of an alive man were used for carrying out this experiment. The basic anthropometric data are shown in Table 1.

Table 1. Basic anthropometric data of objects of investigation.

Data	Object		
	1*	2*	3*
Height (cm)	170	165	168
Mass (kg)	70	65	77
Age (years)	54	55	74

1* - cadaver specimen; 2* - cadaver specimen; 3* - alive man.

Measurements on corpses were performed in the period no longer than 3 days after the deaths. Every excised muscle was weighed, the lengths of the whole muscle, the venter as well as the proximal and distal tendons were measured. Measurement of cross-section area was performed in general in five sections: in the center of the distal and proximal tendon and in the central, distal, proximal sections of the venter. The section was colored and imprint of S_{an} was made on the paper. Two imprints of each side of section were made to get more exact results. The results of measurement m.Rectus femoris are shown in Fig. 1.

Average meaning S_{an} for each section was calculated on the basis of four imprints. Standard deviation of measures was no more than 10%. The maximum value of all obtained S_{an} for distal, central, proximal sections of the muscle venter was used for calculation.

The ratio mentioned in the works [1,7,8] was used to calculate maximum isometrical force of muscle:

$$F_{max} = K\, S_{ph} \cos \alpha, \qquad (1)$$

where K is the specific muscle force (~ 40 N/cm^2); α is an angle of the pinnation. Taking into account that for spindle-shaped muscle $S_{ph} = S_{an}$, and $\cos \alpha = 1$, we obtain:

$$F_{max} = K\, S_{an}. \qquad (2)$$

In addition, the length of the tendon to which attached the pinnate muscular fibers (L_T) and an average width of muscle along this portion (h_m) were measured for m.Rectus femoris. The maximum isometrical force of muscle was calculated with use of the formula:

$$F_{max} = K\, S_{an}\ (L_T/h_m) \sin \alpha. \qquad (3)$$

The obtained values for several muscles were compared with the cross-section areas (S_{tom}) of the hip of the alive man measured on the tomogram (Fig. 2).

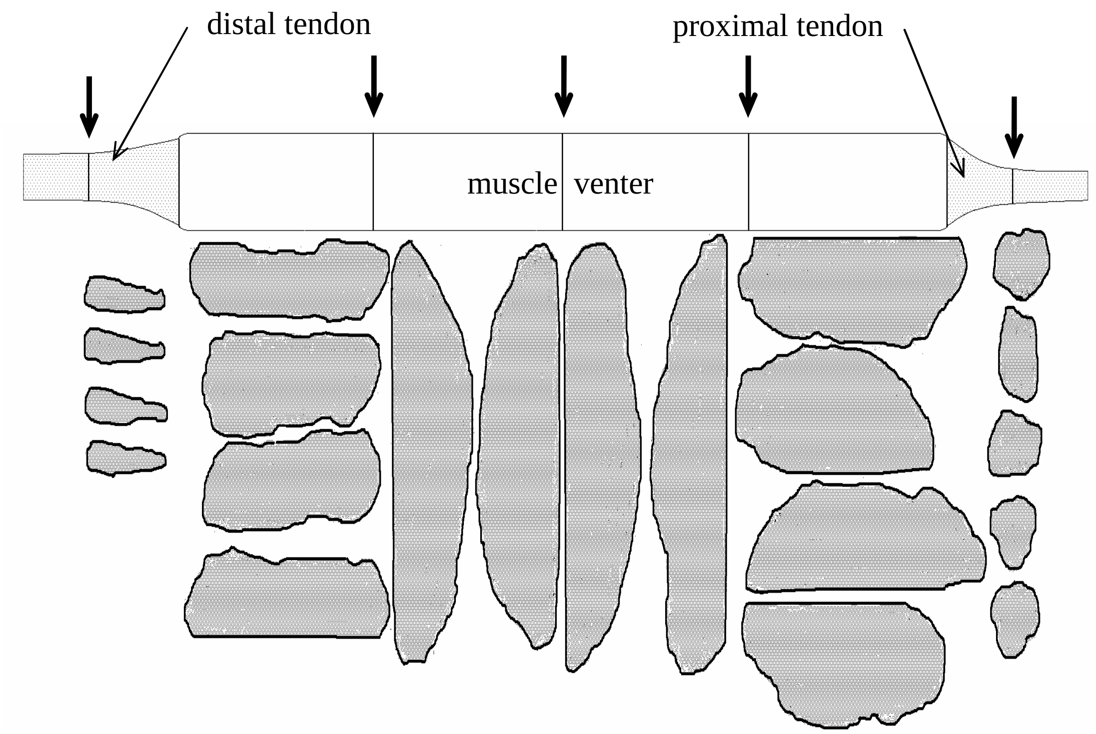

Fig. 1. Imprints of cross-sections of the venter and tendon of m.Rectus femoris. Arrows show the points of cross-cuts.

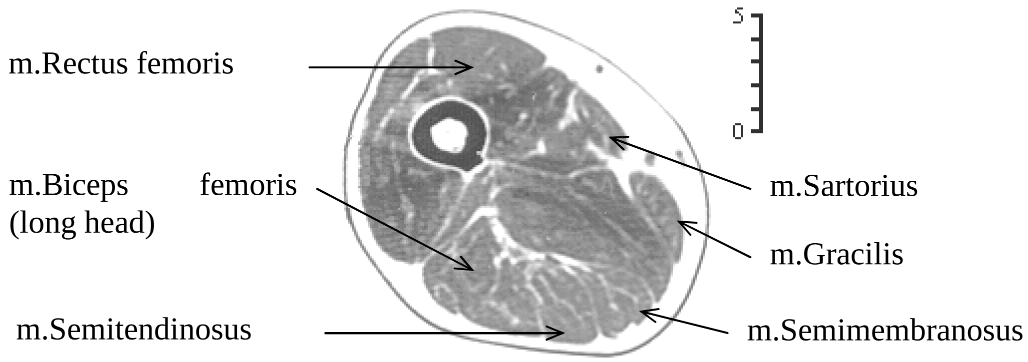

Fig. 2. Tomogram of the femur diaphysis. Arrows show some muscle of the hip. Scale 5 cm.

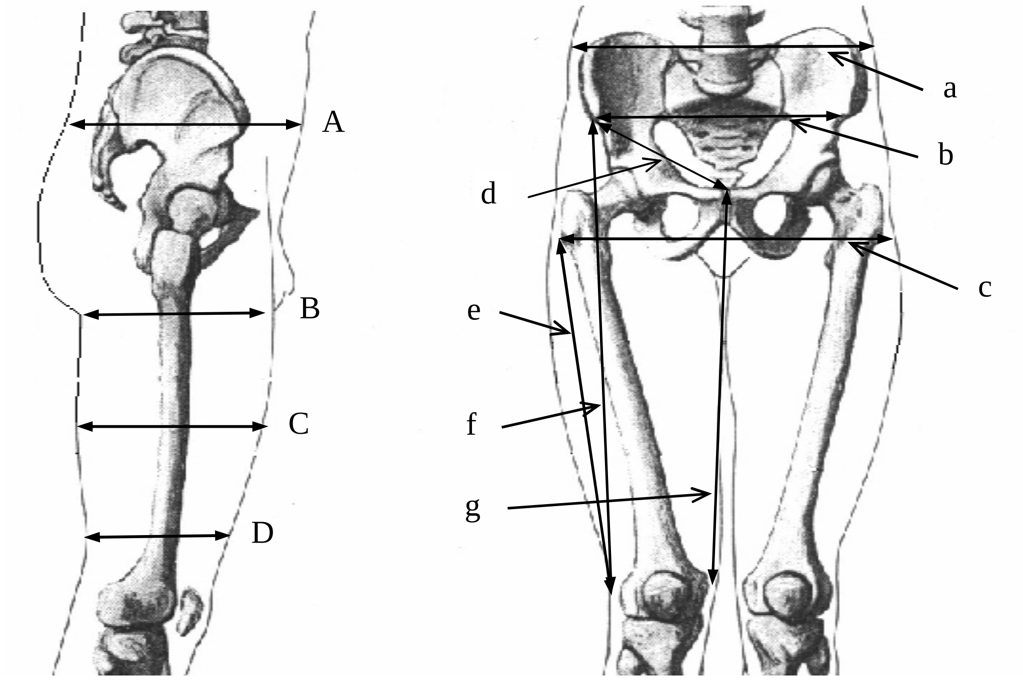

Fig. 3. Points of additional anthropometric measurements. Capital letters (A, B, C, D) - points of measurement perimeters, small letters (a-g) - points of measurement distance between marks.

The plane of tomogram does not coincide with the section of the muscle, therefore it is necessary to take into consideration the direction of the muscle in the space during a calculation of S_{an} if S_{tom} is known. The angle of the incline of muscular fibers to plane of tomogram was calculated on the basis of the data of the work [10] which analyses the points of attachment of the muscles to the bones (the hip and the pelvis) and the muscle is regarded as the straight line. The values of S_{tom} are given for m.Iliopsoas and m.Rectus femoris because the direction of the muscular fibers in m.Iliopsoas changes and the straight line model is not suited, as for m.Rectus femoris it is impossible to measure the angle of the pinnation.

Some external sizes of the hip and the pelvis were measured to receive relative values of the parameters investigated (Fig. 3). Additional anthropometric data of investigated objects are shown in Table 2.

Table 2. Additional anthropometric data of investigated object.

Data (mm)	Object		
	1*	2*	3*
*P(A)***	820	810	1020
P(B)	490	400	540
P(C)	460	400	520
P(D)	420	370	490
l(a) (distantia cristarum)	300	272	320
l(b) (distantia spinarium)	250	247	286
l(c) (distantia trochanterica)	320	288	360
l(d)	160	159	170
l(e)	390	350	360
l(f)	470	450	450
l(g)	390	360	325

1* - cadaver specimen; 2* - cadaver specimen; 3* - alive man.
**Capital letters (*P(A)- P(D)*) - measured perimeters of the hip and the pelvis, small letters (*l(a)* - *l(g)*) - measured distance (see Fig. 3).

Results

The results of the investigation are shown in Tables 3-5. In Table 3 the following symbols are used: $S_{an.}^{max}$ - maximum value of the anatomic cross-section of muscle; F_{max} - the maximum isometric force of muscle; m - the mass of muscle.

In Table 3 the following symbols are used: $\% L_{ven}$ - length of the venter relative to the length of the whole muscle; $\% L_{ten}$ - length of the tendon relative to the length of the whole muscle; L_{muscle} - length of the muscle; L^{rel} - length of the muscle relative to l; l - external parameter of the hip (see Table 2).

In Table 5 the following symbols are used: S_{an}^{rel} - the relative value of S_{an} calculated with the use of $S_{an}^{rel}= S_{an}/S_{m.S}$; F_{max}^{rel} - the relative value of F_{max} calculated with the use of $F_{max}^{rel} = F_{max}/(9.8M_o)$; m^{rel} - the relative value mass of muscle calculated with the use of $m^{rel}=m/m_{m.S}$; where $S_{m.S}$ - value of S_{an} measured for m.Sartorius; m -the mass of muscle; $m_{m.S}$ - the mass of m.Sartorius; M_B -the mass of the body.

Discussion

The results of anatomical cross-sectional area (S_{an}) measurements obtained in this investigation correlate well with the values of physiological cross-sectional area (S_{ph}) in female cadaver specimen shown in the work [6]. In our investigation we used objects with similar anthropometric data. It allowed us to avoid the scatter in values received in [6] (in our work it was no higher than 2.5 times). The data for the muscle and tendon length obtained in our work correlate well with the results received by other investigators [9,10]. Comparison of the values of maximum isometric force of muscle (F_{max}) with the data of other authors revealed that efforts of muscles during walking calculated in the works [1,5,6] in some cases exceeded our values of F_{max}, therefore it is necessary to take into account physiological limit during the research.

Table 6 presents m.Sartorius sizes relative to external anthropometric data with the aim of using relative values during calculation of muscle parameters based on the measured external sizes in patients with different anthropometric results.

Table 3. Absolute values of measured muscle parameters.

Name of muscle	$S_{an.}^{max}$ (cm^2)			F_{max} (N)			m (gm)	
	1*	2*	3*	1*	2*	3*	1*	2*
Psoas major	11.29	4.61	15.55	451.6	184.4	622.0	185	-
Iliacus	12.43	11.50	11.31	497.2	460.0	452.4	175	140
Gemellus superior	0.96	-	-	38.4	-	-	7	-
Gemellus inferior	2.23	-	-	89.1	-	-	10	-
Obturator externus	7.84	5.99	-	313.8	239.6	-	40	40
Obturator internus	10.75	-	-	430.0	-	-	59	-
Piriformis	4.99	2.22	4.01	199.5	88.8	160.4	11	20
Quadratus femoris	-	8.09	-	-	323.6	-	-	70
Pectineus	6.81	3.60	6.54	272.5	144.0	261.5	58	75
Adductor minimus	3.80	-	-	152.0	-	-	30	-
Adductoe brevis	6.46	9.61	9.45	258.4	384.4	378.1	70	110
Adductor longus	12.29	9.40	11.23	491.8	376.0	449.1	176	180
Adductor magnus	26.09	11.26	32.61	1043.6	450.4	1304.2	490	260
Adductor magnus (ant)	10.40	-	-	415.9	-	-	180	-
Adductor magnus (med)	6.14	11.26	-	245.8	450.4	-	130	260
Adductor magnus (post)	9.55	-	-	382.0	-	-	180	-
Gluteus minimus	18.43	14.51	9.58	737.2	580.4	383.2	98	120
Gluteus minimus (ant)	5.85	5.77	-	234.1	230.8	-	28	45
Gluteus minimus (med)	8.21	5.35	-	328.4	214.0	-	50	45
Gluteus minimus (post)	4.37	3.39	-	174.9	135.6	-	20	30
Gluteus medius	30.31	21.01	29.44	1212.4	840.4	177.4	265	160
Gluteus medius (ant)	5.61	6.93	-	224.5	277.2	-	30	50
Gluteus medius (med)	10.81	7.74	-	432.5	309.6	-	78	50
Gluteus medius (post)	13.89	6.34	-	555.5	253.6	-	157	60
Gluteus maximus	43.64	30.36	34.83	1745.6	1214.4	393.1	760	700
Gluteus maximus (inf)	19.85	8.67	-	794.1	346.8	-	420	380
Gluteus maximus (sup)	23.79	21.49	-	951.5	859.6	-	340	320
Tensor fascia latae	8.74	4.07	9.04	349.7	162.8	361.7	110	50
Semimembranosus	11.58	7.68	6.43	463.3	307.2	257.3	228	190
Semitendinosus	8.88	4.62	8.55	355.3	184.8	342.2	202	105
Gracilis	3.21	3.86	5.57	128.4	154.4	222.6	100	85
Sartorius	3.13	2.68	3.36	125.2	107.2	134.5	141	125
Rectus femoris	12.69	6.77	10.73	428.0**	383.6**	429.4	258	165
Biceps femoris (long)	10.50	7.86	14.89	420.0	314.4	595.5	166	-
Biceps femoris (brev)	8.87	4.82	4.68	354.6	192.8	187.2	128	95

1* - cadaver specimen; 2* - cadaver specimen; 3* - tomogram data.

** Value F_{max} for this muscle was calculated with the use of the formula (3).

Table 4. Absolute and relative length of muscle.

Name of muscle	% L_{ven}		% L_{ten}		L_{muscle}(mm)			L^{rel}		l
	1*	2*	1*	2*	1*	2*	D*	1*	2*	
Psoas major	0.58	0.47	0.42	0.53	190	170	91**	0.40	0.38	*l(f)*
Iliacus	0.81	0.91	0.19	0.09	270	110	91**	0.57	0.24	*l(f)*
Gemellus superior	0.67	-	0.33	-	75	-	90	0.23	-	*l(c)*
Gemellus inferior	0.67	-	0.33	-	75	-	71	0.23	-	*l(c)*
Obturator externus	0.94	0.94	0.06	0.06	85	85	104	0.27	0.30	*l(c)*
Obturator internus	0.57	0.63	0.43	0.38	140	80	80**	0.44	0.28	*l(c)*
Piriformis	0.64	0.65	0.36	0.35	110	108	140	0.34	0.38	*l(c)*
Quadratus femoris	-	1.00	-	0.00	-	52	63	-	0.18	*l(c)*
Pectineus	1.00	1.00	0.00	0.00	116	110	141	0.36	-	*l(c)*
Adductor minimus	1.00	-	0.00	-	110	-	126	0.34	-	*l(c)*
Adductor brevis	1.00	1.00	0.00	0.00	170	163	138	0.53	0.57	*l(c)*
Adductor longus	0.96	0.97	0.04	0.03	260	330	199	0.67	0.92	*l(g)*
Adductor magnus (ant)	1.00	-	0.00	-	280	-	-	0.72	-	*l(g)*
Adductor magnus (med)	1.00	1.00	0.00	0.00	320	315	185	0.82	0.88	*l(g)*
Adductor magnus (post)	1.00	-	0.00	-	300	-	348	0.77	-	*l(g)*
Gluteus minimus (ant)	0.86	0.75	0.14	0.25	70	110	107	0.18	0.31	*l(g)*
Gluteus minimus (med)	0.80	0.68	0.20	0.32	100	125	125	0.26	0.35	*l(g)*
Gluteus minimus (post)	0.86	0.50	0.14	0.50	70	130	124	0.18	0.36	*l(g)*
Gluteus medius (ant)	1.00	0.91	0.00	0.09	75	117	136	0.19	0.33	*l(g)*
Gluteus medius (med)	1.00	0.92	0.00	0.08	100	120	168	0.26	0.33	*l(g)*
Gluteus medius (post)	1.00	0.90	0.00	0.10	150	104	154	0.38	0.29	*l(g)*
Gluteus maximus (inf)	1.00	1.00	0.00	0.00	220	210	209	0.69	0.73	*l(c)*
Gluteus maximus (sup)	1.00	1.00	0.00	0.00	173	210	-	0.54	0.73	*l(c)*
Tensor fascia latae	0.23	0.24	0.77	0.76	480	470	515	1.02	1.04	*l(f)*
Semimembranosus	0.68	0.72	0.32	0.28	390	355	398	0.83	0.79	*l(f)*
Semitendinosus	0.57	0.49	0.43	0.51	495	478	399	1.05	1.06	*l(f)*
Gracilis	0.67	0.66	0.33	0.34	450	420	387	0.96	0.93	*l(f)*
Sartorius	0.85	0.77	0.15	0.23	620	646	515	1.32	1.44	*l(f)*
Rectus femoris	0.53	0.61	0.47	0.39	562	560	453	1.20	1.24	*l(f)*
Biceps femoris (long)	0.70	0.72	0.30	0.28	379	374	409	0.81	0.83	*l(f)*
Biceps femoris (brev)	0.84	0.82	0.16	0.18	160	310	-	0.34	0.69	*l(f)*

1* - cadaver specimen; 2* - cadaver specimen; D - length of muscles calculated with the use of data from research [7].

** For the muscles changing their directions the length of the straight line of the muscle is used.

Table 5. Relative values of measured muscle parameters.

Name of muscle	S_{an}^{rel}			F_{max}^{rel}			m^{rel}	
	1*	2*	3*	1*	2*	3*	1*	2*
Psoas major	3.61	1.72	4.63	0.66	0.29	0.82	1.31	0.00
Iliacus	3.97	4.29	3.37	0.72	0.72	0.60	1.24	1.12
Gemellus superior	0.31	0.00	0.00	0.06	-	-	0.05	0.00
Gemellus inferior	0.71	0.00	0.00	0.13	-	-	0.07	0.00
Obturator externus	2.50	2.24	0.00	0.46	0.38	-	0.28	0.32
Obturator internus	3.43	0.00	0.00	0.63	-	-	0.42	0.00
Piriformis	1.59	0.83	1.19	0.29	0.14	0.21	0.08	0.16
Quadratus femoris	0.00	3.02	0.00	-	0.51	-	0.00	0.56
Pectineus	2.18	1.34	1.95	0.40	0.23	0.35	0.41	0.60
Adductor minimus	1.21	0.00	0.00	0.22	-	-	0.21	0.00
Adductor brevis	2.06	3.59	2.81	0.38	0.60	0.50	0.50	0.88
Adductor longus	3.93	3.51	3.34	0.72	0.59	0.60	1.25	1.44
Adductor magnus	8.34	4.20	9.71	1.52	0.71	1.73	3.48	2.08
Adductor magnus (ant)	3.32	0.00	0.00	0.61	-	-	1.28	0.00
Adductor magnus (med)	1.96	4.20	0.00	0.36	0.71	-	0.92	2.08
Adductor magnus (post)	3.05	0.00	0.00	0.56	-	-	1.28	0.00
Gluteus minimus	5.89	5.41	2.85	1.07	0.91	0.51	0.70	0.96
Gluteus minimus (ant)	1.87	2.15	0.00	0.34	0.36	-	0.20	0.36
Gluteus minimus (med)	2.62	2.00	0.00	0.48	0.34	-	0.35	0.36
Gluteus minimus (post)	1.40	1.26	0.00	0.25	0.21	-	0.14	0.24
Gluteus medius	9.68	7.84	8.76	1.77	1.32	1.56	1.88	1.28
Gluteus medius (ant)	1.79	2.59	0.00	0.33	0.44	-	0.21	0.40
Gluteus medius (med)	3.45	2.89	0.00	0.63	0.49	-	0.55	0.40
Gluteus medius (post)	4.44	2.37	0.00	0.81	0.40	-	1.11	0.48
Gluteus maximus	13.94	11.33	10.37	2.54	1.91	1.85	5.39	5.60
Gluteus maximus (inf)	6.34	3.24	0.00	1.16	0.54	-	2.98	3.04
Gluteus maximus (sup)	7.60	8.02	0.00	1.39	1.35	-	2.41	2.56
Tensor fascia latae	2.79	1.52	2.69	0.51	0.26	0.48	0.78	0.40
Semimembranosus	3.70	2.87	1.91	0.68	0.48	0.34	1.62	1.52
Semitendinosus	2.84	1.72	2.54	0.52	0.29	0.45	1.43	0.84
Gracilis	1.03	1.44	1.66	0.19	0.24	0.29	0.71	0.68
Sartorius	1.00	1.00	1.00	0.18	0.17	0.18	1.00	1.00
Rectus femoris	4.05	2.53	3.19	0.62	0.61	0.57	1.83	1.32
Biceps femoris (long)	3.35	2.93	4.43	0.61	0.49	0.79	1.18	0.00
Biceps femoris (brev)	2.83	1.80	1.39	0.52	0.30	0.25	0.91	0.76

1* - cadaver specimen; 2* - cadaver specimen; 3* - tomogram data.

Table 6. m.Sartorius sizes relative to external anthropometric data.

Size	Object		
	1*	2*	3*
$S_{an}/ P^2(C)$	$1.48\ 10^{-5}$	$1.68\ 10^{-5}$	$1.24\ 10^{-5}$
m/M_B	$2.01\ 10^{-3}$	$1.92\ 10^{-3}$	-

1* - cadaver specimen; 2* - cadaver specimen; 3* - alive man.

In Table 6 the following symbols are used: S_{an} - anatomic cross-sectional area of the muscle; $P(C)$ - the perimeter of the hip (see Fig. 3.); m - the mass of the muscle; M_B - the mass of the body.

The alive patient's tomogram data allow calculating exact individual values of S_{an} and F_{max}.

To receive more exact results it is necessary in the future to perform a greater number of experiments. The scatter in absolute and relative values in our work may be connected with the fact that measurements of S_{an} of the second object was performed at the third day after the death.

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ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ АНАТОМИЧЕСКИХ И ГЕОМЕТРИЧЕСКИХ ПАРАМЕТРОВ БЕДРА ЧЕЛОВЕКА

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Данные о силах, действующих на бедро, необходимы при биомеханическом моделировании процессов происходящих в костной ткани. В некоторых задачах, например, при прогнозировании развития асептического некроза головки бедренной кости нужно учитывать не только контактную силу в суставе, но и силы мышц,

огибающих головку. При расчетах оптимальной конструкции эндопротеза используют значения сил, возникающих в мышцах при ходьбе. Различные алгоритмы определения мышечных сил включают в качестве параметра площадь физиологического поперечного сечения мышц. К примеру, некоторые авторы при поиске решения в качестве ограничений используют максимальную изометрическую силу, развиваемую мышцей, которая линейно зависит от площади физиологического поперечника, у других исследователей целевая функция включает в себя площадь физиологического поперечного сечения.

В нашей работе измерялись некоторые анатомические и геометрические характеристики мышц таза и бедра правой ноги. Исследования проводились на двух мужских трупах схожего телосложения и одном живом человеке (по компьютерной томограмме нижней конечности). Исследовались 24 мышцы нижней конечности. Измеряемыми величинами являлись: площадь анатомического поперечного сечения, масса, длина брюшка и сухожилия каждой мышцы. По результатом измерений были вычислены некоторые относительные параметры мышц нижней конечности, а также максимальная изометрическая мышечная сила. Для сравнения полученных результатов использовались томографические снимки бедра и таза живого человека. Выявлено хорошее соответствие между измеряемыми параметрами для объектов с одинаковыми антропометрическими данными. Приведены данные для вычисления площади анатомического поперечного сечения и длины мышцы через внешние геометрические размеры бедра и таза. Описана методика использования томографических данных при исследовании параметров мышц in vivo. Библ. 10.

Ключевые слова: площадь физиологического поперечного сечения мышцы, максимальная изометрическая сила мышцы, компьютерная томограмма нижней конечности

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