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Mathematical modeling of pelvic muscle function in patients with hip joint adduction contracture at single-support standing

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Long existing hip arthritis is accompanied by the development of pain and contractures that cause contractile muscle spasm, reduction in the length of the adductor muscles and flexors of the thigh, relative overstretching of the abductor muscles, which over time leads to changes in their structure. The result is weakness of the pelvic muscles, the clinical manifestation of which is a violation of postural balance — lameness, torso tilts while walking, changes in pelvic position, etc. Objective. To determine the effect of the hip joint adduction contracture on the ability to maintain balance standing position with mathematical model. Methods: mathematical model is worked out that represents the pelvis with the thigh and the vectors of action of the adductor and abductor muscles. The muscular effort required to maintain body balance during one-leg standing was normal and the hip position was set at 5° and 10°. Calculations were performed for patients weighing 70; 100; 120 kg. Results. It is determined that at the adduction contracture in 5° m. gracilis, m. add magnus, m. piriformis are not able to perform the functions of maintaining body balance due to the necessity to develop greater efforts than their maximum possible, even at the minimal patient's weight. If the patient's weight exceeds 120 kg, then almost the entire muscular system of stabilization of the thigh works beyond its capabilities. The adduction contracture of 10° increases the required force of the thigh stabilizer muscles. The absolute values showed an increase in their strength indicators. Conclusions. The adduction contracture of the hip joint causes a change in the biomechanical conditions of the pelvic muscles due to changes in the angles of action of the abductor muscles, reducing the effectiveness of their work to stabilize the pelvis. As the angle of adduction contracture increases, there is a tendency for the pelvic muscles to work effectively. An additional factor that negatively affects this indicator is the patient's overweight. Key words. Postural balance, hip abductors and adductors muscles, mathematic model.

Тривалий перебіг коксартрозу супроводжується розвитком больового синдрому та контрактур, які спричинюють контрактильний спазм м'язів, зменшення довжини привідних м'язів і згиначів стегна, відносне перерозтягнення відвідних м'язів, що з плином часу призводить до змін їхньої структури. Наслідком цього є слабкість м'язів тазового пояса, клінічним проявом якої є порушення постурального балансу — кульгавість, нахили тулуба під час ходьби, зміна становища таза тощо. Мета. На математичній моделі визначити вплив привідної контрактури кульшового суглоба на здатність підтримки рівноваги під час стояння. Методи. Створено математичну модель, яка представляє таз зі стегновою кісткою та вектори дії привідних і відвідних м'язів стегна. Визначали м'язові зусилля, необхідні для підтримки рівноваги тіла під час одноопорного стояння в нормі та за наявності установки стегна в 5° і 10°. Розрахунки виконували для пацієнтів вагою 70; 100; 120 кг. Результати. Визначено, що за привідної контрактури в 5° m. gracilis, m. add magnus, m. piriformis не здатні виконувати функції з підтримки рівноваги тіла через необхідність розвивати зусилля більші, ніж їхні максимально можливі, навіть за мінімальної ваги пацієнта. Якщо вага хворого перевищує 120 кг, то практично вся м'язова система стабілізації стегна працює за межами власних можливостей. Привідна контрактура в 10° призводить до збільшення необхідного зусилля м'язів-стабілізаторів стегна. За абсолютними значеннями встановлено збільшення їхніх силових показників. Висновки. Привідна контрактура кульшового суглоба спричинює зміну біомеханічних умов роботи м'язів тазового пояса через зміну кутів дії сил відвідних м'язів стегна, зниження ефективності їхньої роботи зі стабілізації таза. Зі збільшенням кута привідної контрактури простежується тенденція до погіршення умов ефективної роботи м'язів тазового пояса. Додатковим чинником, який негативно впливає на цей показник, є надмірна вага пацієнта. Ключові слова. Постуральний баланс, відвідні та привідні м'язи стегна, математична модель.

Key words. Postural balance, hip abductors and adductors muscles, mathematic model

Introduction

Prolonged coxarthrosis is almost always accompanied by the development of pain and abducting-adducting contracture of the hip joint, which adversely affects the outcome of arthroplasty. Prolonged pain and contracture of the hip joint lead to contractile muscle spasm, reduction in the length of the adductor and abductor muscles of the thigh, relative overstretching of the abductor muscles, causing a decrease in their elasticity and contraction, and structural changes and significant loss of strength of the abductor muscles over time. This results in weakness of the pelvic girdle muscles with such clinical manifestation as postural imbalance — lameness, torso tilt while walking, changes in pelvic position, and so on.

One of the characteristic consequences of long-term coxarthrosis is failure of pelvic girdle muscles, which makes it impossible to maintain a horizontal balance of the pelvis. This principle of maintaining the horizontal balance of the pelvis is the basis for building a model of pelvic girdle muscles: the moment of strength of the pelvic floor stabilizers should balance the moment of gravity [1–3].

In recent years, there has been increasing information on the effects of hip contracture on muscle function [4–7]. These data are clinical in nature and need to be generalized and scientifically substantiated.

The aim of the study was to determine the influence of the drive contracture of the hip joint on the mathematical model on the ability to maintain balance while standing.

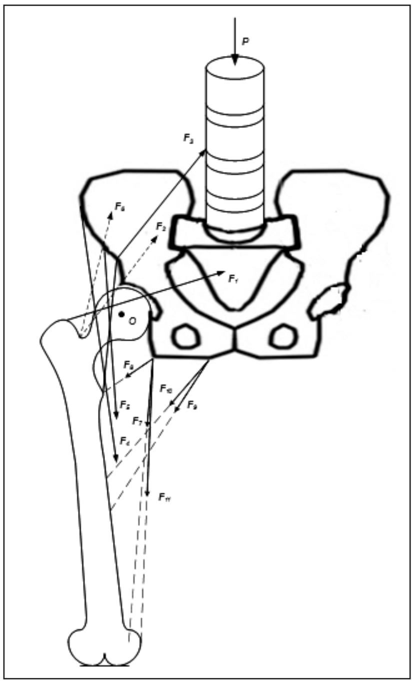

Fig. 1. Scheme of the physical model. Vectors indicate muscle strength: F_1 — *m. piriformis*; F_2 — group of muscles: *m. gluteus medius, m. gluteus minimus, m. tensor fasciae latae*; F_3 — *m. iliacuspsoas major*; F_4 — *m. sartorius*; F_5 — *m. rectus femoris*; F_6 — *m. gluteus maximus*; F_7 — *m. gracilis*; F_8 — *m. pectineus*; F_9 — *m. add longus*; F_{10} — *m. add brevis*; F_{11} — *m. add magnus*; P — body weight

Material and methods

To study the function of maintaining pelvic balance during single-support standing in the conditions of drive contracture of the hip joint, a mathematical model was improved [8], which reflected the pelvis with the femur and vectors of muscles of two groups: abductor and adductor muscles of the thighs in the frontal plane (Fig. 1).

A calculation scheme was constructed on the basis of the proposed model (Fig. 2). It reflects the action of forces on the pelvic girdle of a person in the frontal plane and is presented in the form of a horizontal beam mounted on a movable hinge (as pharmacy scales). The weight of the body along with abductor and adductor muscles act at both ends of the beam with the task of maintaining the beam in balance.

Data on the magnitude of muscle strength involved in the model, as well as the magnitude of the shoulders and angles of their action were selected according to M. R. Carhart [9] and summarized in the table.

In the simulation process, the muscular effort required to maintain body balance while standing in a normal position and with a 5° and 10° adductor position was determined. Calculations were performed for patients weighing 70; 100; 120 kg.

Results and discussion

According to the laws of mechanics, a system is considered balanced if the sum of all moments of forces acting on it is equal to 0:

$$\sum M = 0 \quad (1)$$

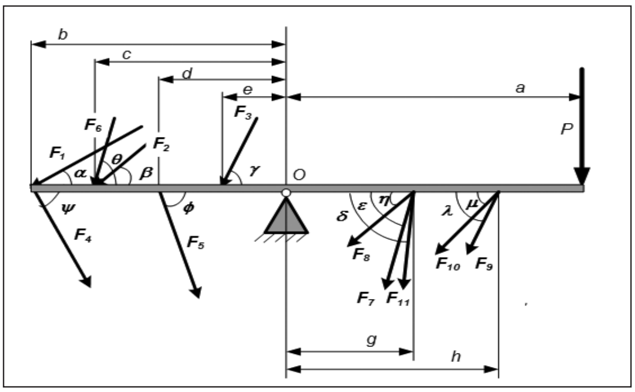

Fig. 2. Calculation scheme

Let us provide the equilibrium equation for our system (Fig. 2). Equilibrium conditions of moments:

$$M(P) - M(F_1) - M(F_2) - M(F_3) - M(F_4) - M(F_5) - M(F_6) - M(F_7) - M(F_8) - M(F_9) - M(F_{10}) - M(F_{11}) = 0 \quad (2)$$

or

$$\alpha P - dF_1 \cos\alpha - cF_2 \cos\beta - dF_3 \cos\gamma - bF_4 \cos\varphi - dF_5 \cos\phi - cF_6 \cos\theta + gF_7 \cos\varepsilon + gF_8 \cos\eta + hF_9 \cos\lambda + hF_{10} \cos\mu + gF_{11} \cos\delta = 0 \quad (3)$$

or

$$\alpha P = bF_1 \cos\alpha + cF_2 \cos\beta + eF_3 \cos\gamma + bF_4 \cos\varphi + dF_5 \cos\phi + cF_6 \cos\theta - gF_7 \cos\varepsilon - gF_8 \cos\eta - hF_9 \cos\lambda - hF_{10} \cos\mu - gF_{11} \cos\delta, \quad (4)$$

where *a, b, c, d, e, g, h* — are the levers of the respective muscles.

Substitute the values of the levers and the angles of action of muscle forces from Table 1 in the equation (4):

$$0{,}07P = 0{,}04F_1 \cos 70° + 0{,}03F_2 \cos 30° + 0{,}01F_3 \cos 20° + 0{,}04F_4 \cos 20° + 0{,}02F_5 \cos 5° + 0{,}03F_6 \cos 10° - 0{,}03F_7 \cos 80° - 0{,}03F_8 \cos 5° - 0{,}05F_9 \cos 55° - 0{,}05F_{10} \cos 50° - 0{,}03F_{11} \cos 85° \quad (5)$$

or

$$0{,}07P = 0{,}038F_1 + 0{,}015F_2 + 0{,}003F_3 + 0{,}014F_4 + 0{,}02F_5 + 0{,}05F_6 - 0{,}03F_7 - 0{,}003F_8 - 0{,}041F_9 - 0{,}038F_{10} - 0{,}03F_{11}. \quad (6)$$

The results of calculations for the adductor contracture of the hip joint of 5°, namely: the magnitude of muscle strength required to maintain balance in its presence are shown in Fig. 3.

As shown in the diagram, the adductor contracture of the hip joint of 5° causes failure of *m. gracilis, m. add magnus, m. piriformis* to carry out the functions of maintaining body balance, as they are forced to develop efforts greater than their maximum possible, even at the minimum weight of the patient. If the patient weighs more than 120 kg, almost the entire muscular system of stabilization of the thigh is forced to work beyond its capabilities.

Increasing the angular contracture angle of the hip joint to 10° results in an even greater increase in all the thigh stabilizer muscles needed to maintain single-support body balance. For a clearer comparison of the magnitude of these efforts, the results of the calculations are presented in the form of a diagram (Fig. 4).

As shown in the diagram, as the value of the adductor contracture of the hip joint increases to 10°, the nature of the changes in muscular effort required

Table

The magnitude of traction force of the muscles involved in pelvis stabilization, and the magnitude of the force application levers

Group	Force	Muscles	Max. strength, N		Lever of force, m	Angle of force, degree
Abductor	F_1	piriformis	296		0.04	70
	F_2	gluteus medius	1365	2105	0.03	30
		gluteus minimus	585			
		tensorfasciae latae	155			
	F_3	iliacuspsoas major	800		0.01	20
	F_4	sartorius	104		0.04	20
	F_5	rectus femoris	779		0.02	5
	F_6	gluteus maximus	1296		0.03	10
Adductor	F_7	Gracilis	110		0.03	80
	F_8	Pectineus	175		0.03	5
	F_9	Add Longus	420		0.05	55
	F_{10}	Add Brevis	285		0.05	50
	F_{11}	Add Magnus	1100		0.03	85

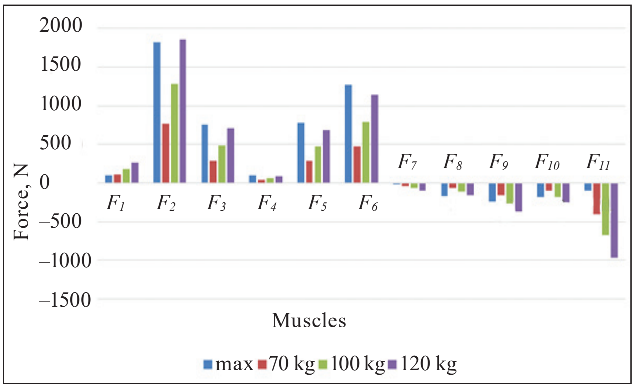

Fig. 3. Diagram of the magnitude of muscle force required to maintain pelvic balance in the presence of adductor contracture of the hip joint of 5°

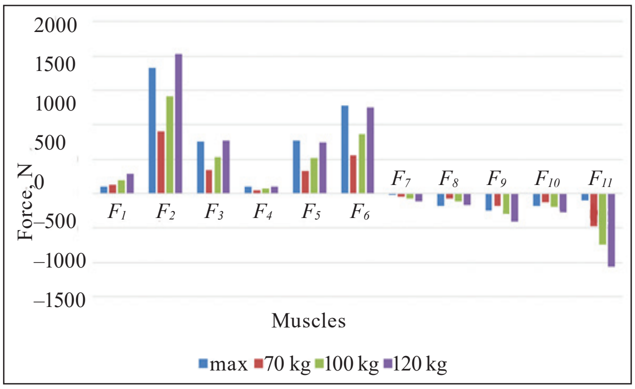

Fig. 4. Diagram of the magnitude of muscle force required to maintain pelvic balance in the presence of a adductor contracture of the hip joint of 10°

to maintain body balance remains the same as at 5° adduction. But the absolute values determine the increase in strength for all thigh stabilizers.

Taking into account a certain conditionality of the developed model, it should be noted that the results indicate a clear tendency to deteriorate the conditions of efficient muscle function with increasing adduction contracture of the hip joint. At the same time, the efficiency of the abduction mechanism of the hip joint decreases, which has clinical manifestations in the form of lameness, torso tilts while walking, pelvic tilts and the like. The pelvic girdle model used has a number of limitations, namely that it is static and does not take into account the combined work of the antagonist muscles — abductors and adductors. But it works and allows to identify certain trends. In particular, different muscles react differently to changes in their working conditions, which can lead to a certain clinical picture.

A very important factor that negatively affects the maintenance of the efficiency of the abduction mechanism of the hip joint is the decrease in functional activity and absolute strength of the abductor muscles. We did not take this factor into account in the presented model, but our previous work shows this [10]. This factor (reduction of absolute muscle strength in the case of long-term coxarthrosis) should not only be taken into account when performing hip arthroplasty, but, if possible, eliminate it before surgery.

Conclusions

Adduction contracture of the hip joint changes the biomechanical conditions of the pelvic girdle muscles due to changes in the angles of action of the abductor muscles of the thigh, which reduces the effectiveness of their work to stabilize the pelvis. As the angle of adduction contracture increases, there is a tendency for the conditions of efficient muscle function to deteriorate. An additional factor that negatively affects the effective functioning of the pelvic girdle muscles is the overweight of the patient.

Conflict of interest. The authors declare no conflict of interest.

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MATHEMATICAL MODELING OF PELVIC MUSCLE FUNCTION IN PATIENTS WITH HIP JOINT ADDUCTION CONTRACTURE AT SINGLE-SUPPORT STANDING

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