УДК 616.748:616.728.2-089.843](045)

DOI: http://dx.doi.org/10.15674/0030-59872024224-32

The study of the work of the muscles responsible for the functionality of the hip joint after total hip arthroplasty using different surgical approaches

S. Ye. Bondarenko, D. I. Sereda, O. D. Karpinska

Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

Muscles that can be damaged during endoprosthesis are indicated. Objective. To study the features of muscle work to ensure walking function after hip arthroplasty depending on the surgical approach. Methods. The basis of the simulation is the basic OpenSim Gate2392 model. Six models were created that predicted the condition of the muscles of the lower limb in normal conditions, during coxarthrosis and after 6 and 12 months. after surgery with lateral and anterior approaches. The results. For lateral access in 6 months. after the operation, the adductor muscles responsible for stabilizing the pelvis in the single-support phase of the step and during the transfer of the foot do not work enough, while the hip flexor muscles (in the model, the rectus femoris muscle) take over the responsibility for the step, but with overvoltage. On the contrary, with the front approach, we observe a weakening of the flexor muscles, which leads to overstrain of the gluteal muscles and hip stabilizer muscles. After 12 months, the muscle strength normalizes for most of them to 90–95 % of the norm, a 2–3 times increase in the torque of the hip flexor muscles and hip stabilizer muscles is observed. Taking a normal step causes muscle strain. During the anterior approach, the foot is transferred during the phase, that is, when most of the muscles are involved. The rectus femoris muscle, which is the strongest of the muscles discussed in the paper, does the main work of moving the foot. In the case of possible damage to the rectus muscle during anterior access, even after a year there is a violation of its work — excessive overexertion and involvement of the reserves of other muscles. Conclusions. Mathematical modeling of the work of muscles that may be damaged during hip arthroplasty surgery, conditional muscle strength for 6 months. after the operation, they are not able to develop the necessary torque to take a normal step. For muscle strength, which in the model corresponded to 12 months, the muscles are able to perform a normal function regardless of surgical access, but their overstrain is observed.

Наведено м'язи, які можуть бути ушкоджені під час ендопротезування. Мета. Вивчити особливості роботи м'язів для забезпечення функції ходьби після ендопротезування кульшового суглоба залежно від хірургічного доступу. Методи. В основі моделювання лежить базова модель OpenSim Gate2392. Створено шість моделей, які передбачали стан м'язів нижньої кінцівки в нормі, за коксартрозу та через 6 і 12 міс. після операції з латеральним та переднім доступами. Результати. За латерального доступу через 6 міс. після операції м'язи-аддуктори, відповідальні за стабілізацію таза в одноопорній фазі кроку та під час перенесення стопи працюють недостатньо, у той час м'язи-згиначі стегна (у моделі прямий м'яз стегна) беруть на себе відповідальність за виконання кроку, але з перенапруженням. Навпаки, за переднього доступу спостерігаємо послаблення м'язів-згиначів, що призводить до перенапруження сідничних м'язів і м'язів-стабілізаторів стегна. Через 12 міс. сила м'язів нормалізується для більшості з них до 90–95 % від норми, спостерігаємно перевищення в 2–3 рази крутного моменту м'язів-згиначів та м'язів-стабілізаторів стегна. Виконання нормального кроку викликає перенапруження м'язів. За переднього доступу зазнає фаза перенесення стопи, тобто коли залучено більшість м'язів. Прямий м'яз стегна, який є найсильнішим серед м'язів, які розглянуті в роботі, бере на себе основну роботу переносу стопи. У разі можливого ушкодження прямого м'яза під час переднього доступу, навіть через рік спостерігається порушення його роботи — надмірне перенапруження і залучення в роботу резервів інших м'язів. Висновки. Математичне моделювання роботи м'язів, які можуть бути ушкодженими під час операції ендопротезування кульшового суглоба, умовні сили м'язів на 6 міс. після операції не здатні розвити необхідний крутний момент для здійснення нормального кроку. За сили м'язів, яка в моделі відповідала 12 міс., м'язи здатні виконати нормальну функцію незалежно від хірургічного доступу, але спостерігається їхнє перенапруження. Ключові слова. Кульшовий суглоб, сила м'язів, модель ходьби, латеральний доступ, передній доступ.

Keywords. Hip joint, muscle strength, walking pattern, lateral approach, anterior approach

Introduction

Walking is the most natural human locomotion, which occurs as a result of complex coordinated activity of the skeletal muscles of the body and limbs.

The main muscles used in walking include the following: quadriceps and hamstrings, gastrocnemius, hip adductors. Gluteal and abdominal muscles also play a significant role in forward movements. The gluteal muscles, hamstrings, calf and soleus muscles are the main factors of support and progression at any walking speed [15].

During walking and running, stabilization of the pelvis, abduction and rotation in the hip joint are provided by the abductor muscles of the thigh [3]. They stabilize the hip in the frontal plane during leg adduction during walking, for example, the right abductor muscle works when the right leg is in the stance phase of the step as the left limb is extended forward. The right hip abductors must provide adequate contraction force to keep the pelvis from dropping to the left. Weakness of these muscles leads to instability of the pelvis during walking or when trying to stand on one leg [16].

Abduction of the hip is the movement of the leg away from the midline of the body. This action is used when a person moves to the side, gets out of bed, gets out of a car, while walking, to support the leg from falling "into space". The main muscles that abduct the thigh include gluteus medius and gluteus minimus, tension of the broad fascia; the secondary hip abductors include the piriformis, tailor's, and upper gluteus maximus fibers [16].

In development of degenerative diseases of the joints, the muscles gradually lose their strength and ability to fully contract, which affects the quality of motor activity. Therefore, first of all, the abductor muscles of the thigh suffer with the development of adductor contracture. It is the insufficiency of these muscles that leads to the formation of lameness, painful pelvic tilt and other pathological conditions.

One of the important indicators of walking quality is muscle strength. Degenerative changes in the joints gradually lead to its decrease. In coxarthrosis, the decrease in the strength of the muscles of the lower limb can reach from 10 % for the muscles of the lower leg and foot to 60 % of the gluteal muscles. Restoration of their strength to 90 % of the norm can last from a year or more [1, 11, 23]. Therefore, regardless of the methods of surgical access in case of hip joint endoprosthetics, full recovery of the muscles does not occur after a year, moreover, the integrity of the muscles is injured during the operation. It can be both the muscle itself and its partial place of attachment to the bone. And although modern methods of organ-sparing interventions are designed to minimize injury to the muscular apparatus in the area of endoprosthesis, partial violation of muscle integrity still might be observed.

Lateral and anterior approaches are low-traumatic organ-sparing operations, during which the mass of muscles is practically not damaged. During access to the hip joint, the muscles are stretched, which has a minimal effect on their integrity. Although according to literary sources [1, 7, 11, 23], full recovery is still delayed.

Full-fledged walking requires a creation of the appropriate moment by the muscles, which depends on the strength of the muscle and its length; that is, the ability to contract the muscle affects the occurrence of the necessary moment in the corresponding phase of the step. In patients with coxarthrosis, the reduction in muscle strength leads to a decrease in the moment during hip elevation. So, after endoprosthetic repair, first, it is necessary to restore muscle strength.

In our study, we consider the moments created by the muscles of the pelvic girdle during hip flexion, as its main movement during walking. We study the muscles that can be damaged during endoprosthetic repair.

Purpose: to study the features of muscle work to ensure walking function after hip arthroplasty using lateral and anterior approaches.

Material and methods

To analyze the work of muscles during walking in mathematical models, the Hill's diagram of the muscle-tendon element (MTE) is used [26].

Conditions for creating models

The muscles of the hip joint, which are considered in the study, can be grouped according to their functions in relation to the movements of the hip during walking. Flexors: *m. rectus femoris, m. psoas major, m. iliacus (iliopsoas).* Hip abduction muscles: *m. gluteus medius, m. tensor fascia latae*. Muscles of internal rotation: *m. tensor fascia latae, m. gluteus minimus*. Muscles of external rotation: *m. gluteus maximus, m. quadratus femoris*.

M. rectus femoris (straight thigh muscle) together with *m. iliopsoas* (iliac-lumbar muscle) bends the hip during walking in the "toe-off" phase, i. e. when the toes come off the support and the foot is moved forward [19]. In the case of a decrease in the strength of the hip flexors, accordingly, the patient is unable to fully move the foot. With a significant loss of muscle strength, a negative step can be observed, that is, the foot does not go beyond the foot of the opposite limb [30, 32]. This feature of gait is often observed in elderly people, when the decrease in muscle strength in the case of degenerative joint diseases is complicated by age-related changes in the muscles themselves.

During endoprosthetic repair, depending on the access, the integrity of the flexors may be partially violated [6]. During the front approach, the tendons of the rectus femoris muscle are damaged, and during both approaches, *m. iliopsoas* (iliac-lumbar muscle), a tendon that is attached to the small trochanter of the femur [6, 17, 27].

Considering the fact that during endoprosthetic repair with the indicated approaches, the muscles of the back surface of the thigh (extensors) are not injured, a significant imbalance in the work of the flexors and extensors can be observed.

M. gluteus medius (medial gluteal muscle) is a large fan-shaped muscle located in the back of the thigh, stretching from the ilium to the proximal part of the femur. Its fibers converge into a tendon, which is attached to the lateral surface of the greater trochanter. The very location of the tendon on the acetabulum makes this muscle vulnerable during arthroplasty, especially its anterior branch. *M. gluteus medius* is the main abduction motor in the hip joint, its anterior part abducts, helps to flex and medially rotate the hip [18, 24, 28]. The muscle plays a critical role in maintaining pelvic stability in the frontal plane. It interacts with the ipsilateral tensor fascia latus (TFL) and the contralateral quadratus lumboris muscle. This muscle complex prevents the pelvis from dropping toward the limb during the abduction phase. When the limb is detached from its support, the pelvis on that side will tend to descend due to the loss of support from below. The *gluteus medius*, along with the TFL, work to support the side of the pelvis that is being lowered, thus allowing the other limb to swing forward for the next step [21, 22]. The risk of TFL damage in the case of a lateral approach is higher [29].

Due to its location, the front part of *m. gluteus medius* is more damaged during the anterior approach than during the lateral one. This statement is indeed controversial, especially when analyzing clinical sources. But according to the literature, which examines muscle damage in dead people after prosthetics, or during prosthetics on cadaveric material, there is information about trauma to the anterior parts of the gluteal muscles in the case of anterior access, but no longer during the access itself, but under conditions of femoral head separation. The possibility of such damage is reported by B. T. Higgins et al. [6], and B. A. Lanting [14] writes about the high probability of injury to the anterior gluteal muscles.

M. gluteus minimus (small buttock muscle) [4] is the muscle responsible for internal rotation of the thigh and *m. quadratus femoris* (square thigh muscle) [12, 19], responsible for external rotation. They both keep the hip in balance both during standing and when transferring the foot over the support, that is, they prevent the hip from deviating from the line of progression. An imbalance in their work leads to a violation of balance due to a pathological effort of the hip to deviate outward or, conversely, in the middle, which causes a decrease in balance. Lateral access is associated with damage to the *m. gluteus minimus*, and the anterior one to *m. quadratus femoris* [6].

Therefore, a disturbance in the work of any of these muscles will lead to their imbalance and a change in gait. Although endoprosthetic surgery contributes to the stabilization of walking and the gradual restoration of muscle strength, it is accompanied by a violation of the integrity of muscles or their tendons. Depending on the access, different muscles are damaged; accordingly, recovery after the operation will proceed depending on the damaged part of the joint (Fig. 1).

The basis of the simulation is the basic model OpenSim [2] Gate2392 [10].

Six models were created: the norm, without changing the muscle parameters set in the software [19], the condition due to coxarthrosis with a decrease in muscle strength [1, 11, 32, 7, 23], the condition of the muscles during lateral and anterior approaches to 6 and 12 months after surgery, muscle strength to which changes were made in accordance with the literature [3, 4, 6, 7, 11–25, 28, 29] (Table). We did not find direct comparisons of the degree of muscle damage with different approaches, and conducting a network meta-analysis was not part of the task of this work. Therefore, indicators regarding the degree of injury are taken conditionally, during force calculations, the strength is changed by 10–15 % from the level of recovery, provided they are not injured. The values of changes in muscle strength had a significant spread, so averaged indicators were chosen for calculations.

The moment of the muscles for performing a step with the right limb was determined. For the phases of the step with the right limb [15], a corresponding diagram of the bending angles is constructed in the OpenSim software (Fig. 2).

Results

M. rectus femoris (rectus femoris) is the main muscle responsible for hip flexion. It works almost throughout the entire step but is maximally involved in the phase of bringing the supporting limb forward and keeping the foot above the surface before the heel touches the support. So, in the norm (Fig. 3, a, norm) we observe the maximum torque that the muscle develops in this step phase (from 0.6 to 0.75 s) and in the limb support phase (0.85). Next, the work of the muscle is observed only as an additional support, and the main work in the single-support phase of the step is performed by other muscles (we do not consider it in this publication).

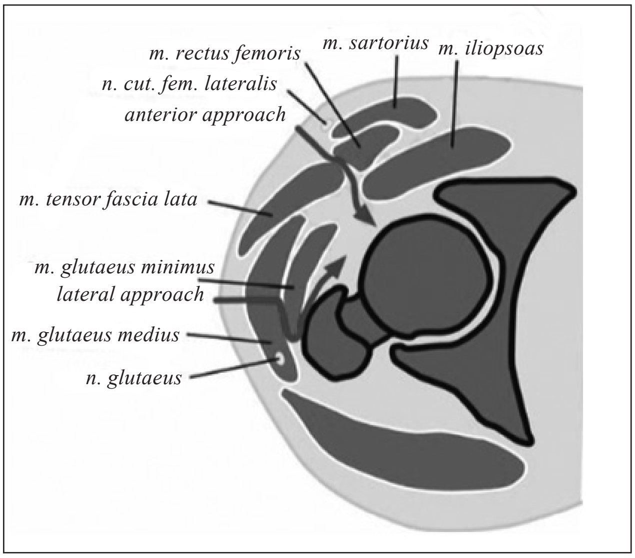

Fig. 1. Trajectory of approaches [9]: a) lateral approach (in Fig. *Lateral approach*); b) anterior approach (in Fig. *Anterior approach*)

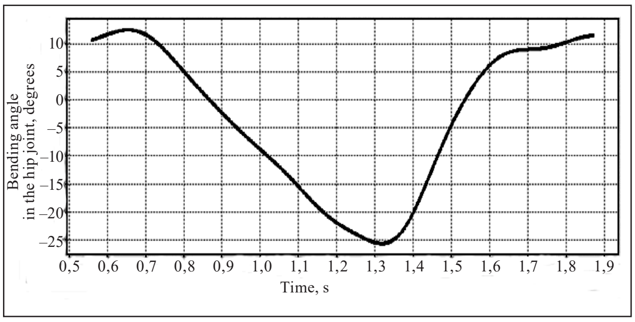

Fig. 2. Diagram of hip flexion angles during walking

In case of loss of muscle strength (from 15 to 30 %) because of coxarthrosis, according to the simulation data, it is possible to note the absence of its activation in the phase before supporting the heel, i. e. with the loss of a third of the strength, the muscle is unable to move the foot forward. Its activity during foot support increases compared to the norm.

As we mentioned, the rectus femoris muscle works in synergy with the iliopsoas muscle. Their simultaneous work provides for maintenance of the vertical position of the body while walking.

The iliolumbar muscle, which consists of two parts, namely *m. psoas major* and *m. iliacus*, also loses strength in case of coxarthrosis. *M. psoas major* can lose from 15 to 30 %, *m. iliacus* from 20 to 40 % of its strength. According to T. Roth et al. [25], a loss of muscle strength of more than 40 % leads to the impossibility of full walking. The only way to get the force necessary to perform a step is to reduce the length of the muscle, the lever of force action.

For rectus femoris and iliopsoas, this is possible if the body is tilted forward. This is observed in patients with coxarthrosis.

During hip arthroplasty, the rectus femoris can be damaged during an anterior approach, so recovery is

Table

Calculation of the theoretical recovery of muscle strength in 6 and 12 months in different accesses for hip joint replacement

Muscles	Gait2392	Lateral approach				Anterior approach			
		6 months		12 months		6 months		12 months	
		%	calculated	%	calculated	%	calculated	%	calculated
m. rectus femoris	1 169					70	818.3	90	1052.1
m. iliacus	1 073	70	751.1	80	858.4	70	751.1	85	912.05
m. psoas major	1 113	60	667.8	70	779.1	60	667.8	80	890.4
m. gluteus medium	819	60	491.4	75	614.25	70	573.3	80	655.2
m. gluteus minimus	270	50	135.0	70	189.0	—	—	—	—
m. gluteus minimus	285	50	142.5	70	199.5	—	—	—	—
m. gluteus minimus	323	50	161.5	70	226.1	—	—	—	—
m. quadratus femoris	381	—	—	—	—	65	247.7	80	304.8
m. tensor fascia latae	233	50	116.5	70	163.1	55	128.2	75	174.75

slower than with a lateral approach. The torque that develops *m. rectus femoris* after surgery with lateral access (Fig. 3, b) has a significantly greater moment than normal (Fig. 3, a), but the peak of activation falls on the second half of the foot roll phase (0.9–1.0 s), unlike in the norm, when the maximum of activation occurs in the middle of the single-support phase of the step (0.8–0.9 s). Six months after surgery with anterior access, the activity of the rectus muscle practically approached the norm, but the period of activation is significantly extended in time, and the appearance of a moment of muscle excitation during hip extension in the phase of separation of the toes from the support is observed (1.2–1, 4 c). The general excitation curve of the muscle after the anterior approach is higher than normal during the entire stride period.

After 12 months the rectus femoris muscle is restored to 95 % of normal, provided it is preserved, which is observed during lateral access simulation (Fig. 3, c). After an anterior approach, muscle recovery is less — up to 85–90 %, which affects the level of torque. In both approaches, the torque in the phase of support on the foot is normalized (0.7–0.8 s). Sharply, especially after lateral access, the torque increases during vertical single-support standing. The activity of the muscle is restored when the foot is moved forward, but its "tremor" is observed due to insufficient muscle strength of the muscles responsible for walking.

Results of modeling the work of the iliopsoas muscle (Fig. 4, a), show that in the coxarthrosis model, the torque is reduced, compared to the norm, by approximately 10 % at the maximum. The peak of the moment in the coxarthrosis model falls on the toe-off phase (1.25 s), and normally on the step phase, when the general center of mass coincides with the body's center of gravity (1.3 s), which may indicate a violation of the vertical posture of the body.

The degree of damage to the iliopsoas muscle during lateral and anterior approaches does not differ, which causes the same decrease in torque 6 months after surgery. But a smaller torque of *m. iliapsoas* in anterior access is affected by a decrease in the strength of *m. rectus femoris* by 10 % at the peak of excitement (1.1–1.3 s).

Twelve months after endoprosthetic surgery *m. iliapsoas* develops a maximum torque of up to 55 Nm, which is less than the norm, but more than for a period of 6 months. The activity of the muscle during the movement of the foot forward, which was absent for a period of 6 months, is restored. A noticeable tremor of the muscle is observed, which indicates its tension.

M. gluteus medius (medial gluteal muscle, front part). In the case of coxarthrosis, it loses from 15 to 25 % of its strength. Given that this is a fairly strong muscle, and even after losing a portion of its strength, it remains the most powerful among all adductor muscles (Table), therefore it performs the main work

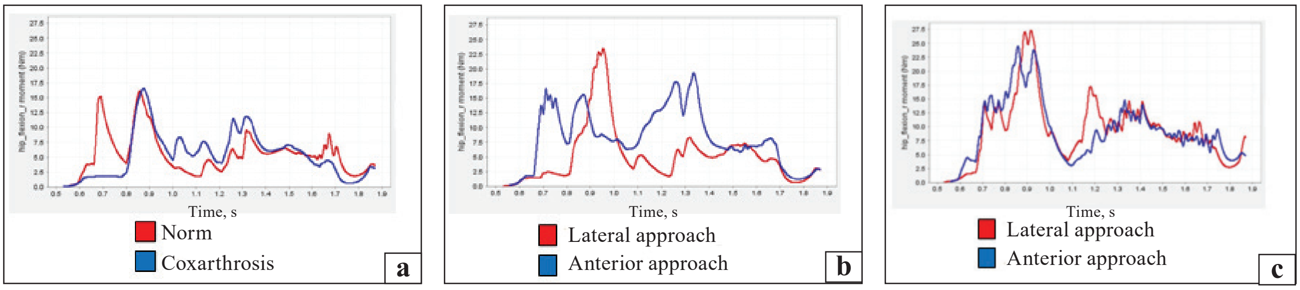

Fig. 3. Torque diagram of *m. rectus femoris*: a) normally and in coxarthrosis; b) for the calculated muscle strength 6 months after endoprosthetic repair; c) for the calculated muscle strength 12 months after endoprosthetic repair

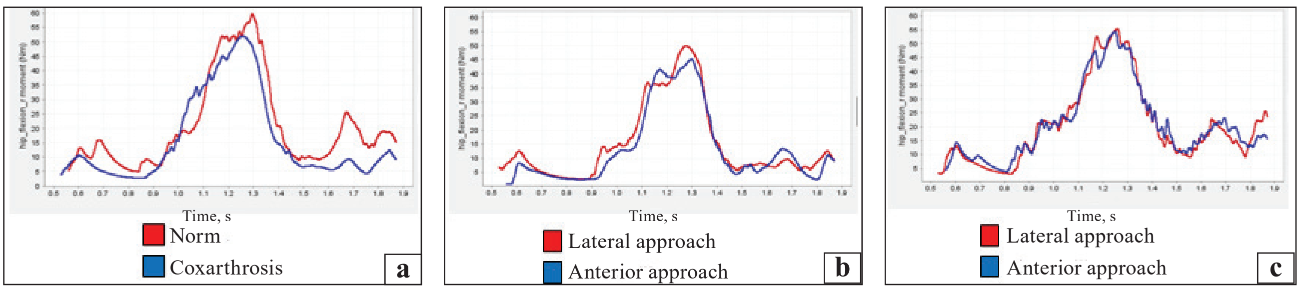

Fig. 4. Torque diagram of *m. iliapsoas*: a) normally and in coxarthrosis; b) for the calculated muscle strength 6 months after endoprosthetic repair; c) for the calculated muscle strength 12 months after endoprosthetic repair

of stabilizing the pelvis during walking. The torque decreases (Fig. 5, a) to 30 % in the foot transfer phase (1.25–1.4 s) and reaches its maximum in the single-support step phase (0.95–1.1 s). However, there is almost no muscle activity in the phase of taking the foot forward (starting from 1.7 s). The inability of the muscle to develop the moment necessary to transfer the foot (1.1–1.45 s) increases the time of this step phase.

Before the foot transfer phase, the muscle activation is the same and reduced compared to the norm by 10– 12 % for both approaches. In the phase of foot transfer, after anterior access, a zone of prolonged excitation (1.25–1.40 s) is observed. For 6 months after endoprosthetic surgery for both accesses, the damaged muscle *m. gluteus medium* is not able to develop the force to fully hold the limb during the forward movement of the foot, i. e., muscle excitation during the phase (1.6–1.7 s) does not occur.

Twelve months after surgery, the gluteus medius muscle develops a torque that is twice the normal value in both approaches to perform the step. The maximum excitement occurs during the phase of foot transfer (1.2–1.6 s). A visible tremor of a muscle indicates its overstrain.

M. tensor fascia latae (TFL) is also responsible for supporting the pelvis during foot abduction and support on one limb. This shows that the decrease in strength cannot be compensated by the anthological posture, the torque in the coxarthrosis model is significantly reduced (Fig. 6, a) and does not exceed 0.5 Nm throughout the entire step, except for the single-support phase, where it increases to 1.8 Nm while normally in this step phase the moment is 4.5 Nm.

M. tensor fasciale latae has a greater risk of injury with a lateral approach. Six months after endoprosthetic surgery with lateral access, during the simulation of muscle work, there is no excitation period in the phase of support on the foot (0.5–0.8 s) (Fig. 6, b), and the development of a slight, up to 2.5 Nm of torque in the phase of support for it. After surgery with anterior access, a period of excitation up to 1.5 Nm is recorded in the first half of the phase of support on the foot. For both approaches, the TFL torque is reduced by half compared to the norm and remains at the level of the state before the operation (Fig. 6, a).

TFL restores its work to 90% of the norm in 12 months. The muscle recovers better with an anterior approach. During this period, there is an increase in the excitation time in the phase of support on the foot — from 0.7 s to 1.0 s. The muscle works with overstrain.

Hip rotator muscles *m. gluteus minimus* and *m. quadratus femoris* work as antagonist muscles, that is, they are activated in different phases of the step. Internal rotator *m. gluteus minimus* reduces activity in the phase of foot transfer, while *m. quadratus femoris*, on the contrary, is activated precisely in this phase of the step.

M. gluteus minimus due to coxarthrosis can lose up to 60 % of its strength, which will reduce its torque during walking (Fig. 7, a), while the quadratus femoris muscle reduces its strength to only 30 %, and given that it has a small length, the moment it can develop will be significantly greater than that of its antagonists (Fig. 6, a). Perhaps it is this imbalance of muscle strength that causes the development of adductor contracture in patients with coxarthrosis.

M. gluteus minimus is damaged only during lateral access. During the simulation, it was determined that after 6 months the muscle is able to develop a torque 10 % greater than the norm, but not in the phase of taking the foot forward (1.6–1.8 s) (Fig. 7, a, norm), but under conditions of support on it (Fig. 7, b). Work of *m. gluteus minimus* is also disturbed during the front access, the torque value increases by 15 % (Fig. 7, b) from the level before the operation (Fig. 7, a), but the excitation continues during the entire phase of support on the foot and is absent during the movement of the foot forward, as in lateral access. This may indicate muscle overload.

Recovery of small gluteal muscles 12 months after endoprosthetic surgery (Fig. 5, c) leads to an increase in the torque twice as compared to the norm (Fig. 7, a), and both for lateral and anterior access. The maximum torque occurs during the phase of separation of the toes from the support (1.45 s) (Fig. 7, c). The presence of high-frequency peaks on the entire step diagram indicates muscle overstrain.

M. quadratus femoris is damaged during anterior access, but considering its small size, after 6 months it is practically restored, which is shown in Fig. 8, b. Twelve months after the operation (Fig. 8, c), the torque of the muscle reaches a normal level, but its excitation lasts for a longer period of time — from 1.3 to 1.55 s, in contrast to the norm - from 1.3 to 1.45 s in the phase of foot transfer. The muscle is overstrained.

Discussion

According to this simulation, it can be determined that with lateral access 6 months after surgery, the adductor muscles responsible for stabilizing the pelvis in the single-support phase of the step and during the transfer of the foot do not work enough, while the hip flexor muscles (recti femoris in the model) take over the responsibility during execution step, at the same time begin to work with overvoltage. On the contrary, with the front approach, we observe a weakening of the flexor muscles, which leads to overstrain of the gluteal muscles and hip stabilizer muscles.

After 12 months, when the muscle strength normalizes for most of them to 90–95 % of the norm, we observe an excess of 2–3 times the torque of the hip flexor muscles and stabilizer muscles. But an attempt to perform a normal step results in overstraining of the muscles, which is shown in the diagrams by a series of peak stress drops.

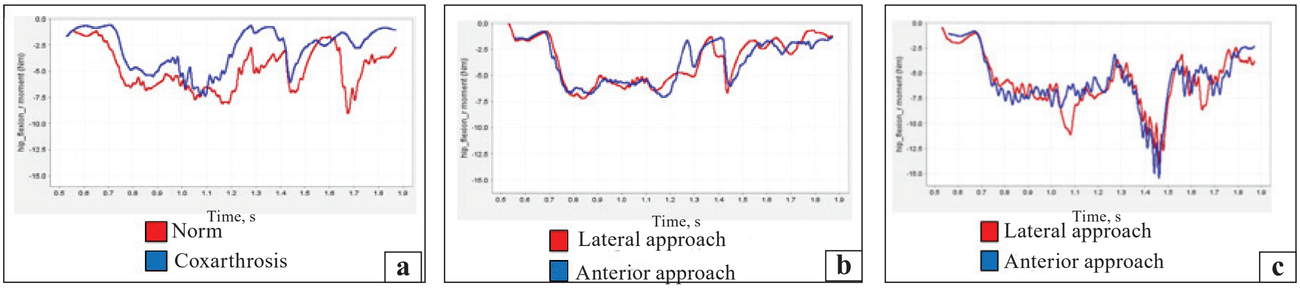

Fig. 5. Torque diagram of *m. gluteus medium*: a) normally and in coxarthrosis; b) for the calculated muscle strength 6 months after endoprosthetic repair; c) for the calculated muscle strength 12 months after endoprosthetic repair. * The muscle force vector is directed backwards, so the data have a negative value on the diagram. The magnitude of the torque should be estimated by its modulus

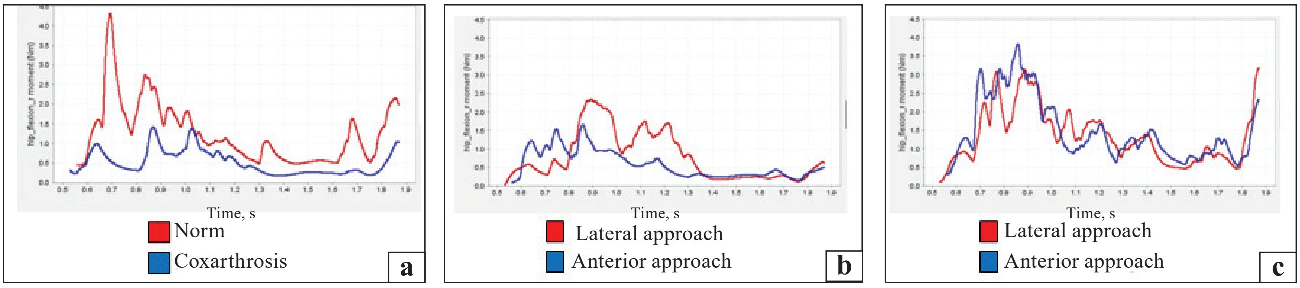

Fig. 6. Torque diagram of the TFL: a) normally and in coxarthrosis; b) for the calculated muscle strength 6 months after endoprosthetic repair; c) for the calculated muscle strength 12 months after endoprosthetic repair

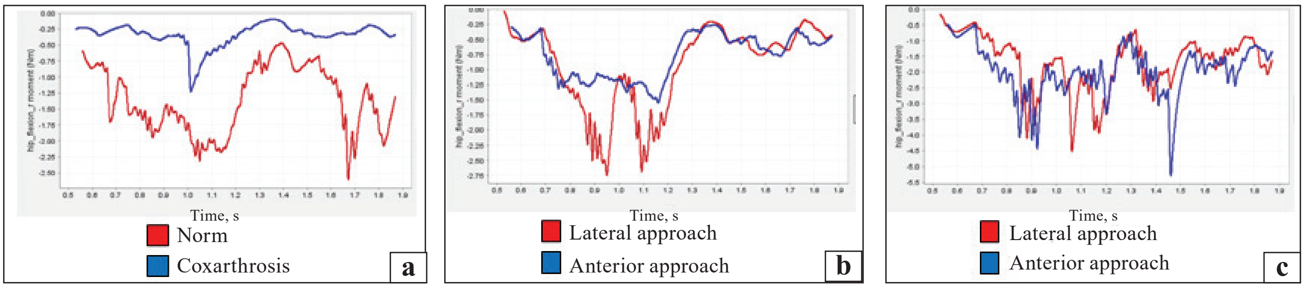

Fig. 7. Torque diagram of *m. gluteus minimus* (sum): a) normally and in coxarthrosis; b) for the calculated muscle strength 6 months after endoprosthetic repair; c) for the calculated muscle strength 12 months after endoprosthetic repair

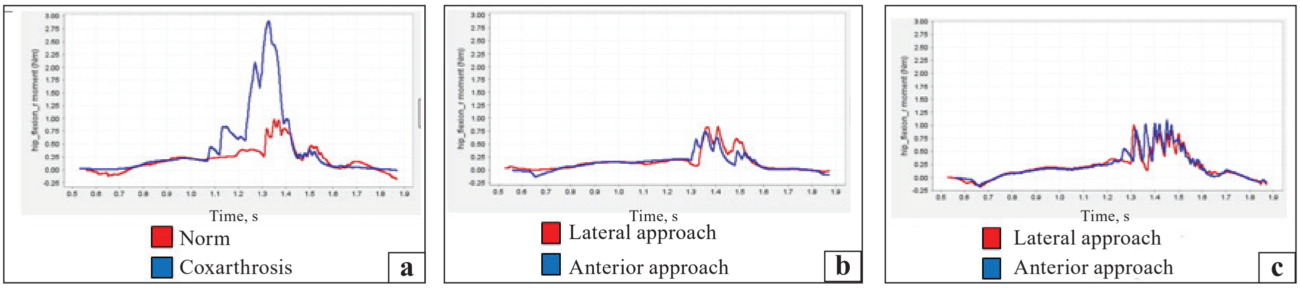

Fig. 8. Torque diagram of *m. quadratus femoris*: a) normally and in coxarthrosis; b) for the calculated muscle strength 6 months after endoprosthetic repair; c) for the calculated muscle strength 12 months after endoprosthetic repair

With the anterior approach, the main problems arise in the phase of foot transfer, that is, when most of the muscles are involved. The rectus femoris muscle, which is the strongest of the muscles discussed in the study, does the main work of moving the foot. In the case of its possible damage during anterior access, even after a year there is a violation of its functioning, such as excessive overstrain and the involvement of reserves of other muscles. O. A. Tyazhelov et al. [31] showed that if the patient's weight is more than 100 kg, the muscles are not able to maintain balance, that is, to ensure a full step. Therefore, endoprosthetic surgery with an anterior approach in overweight patients should be approached carefully not only because of hygienic difficulties, because of this technique, but also taking into account the possibility of restoring the hip flexor muscles.

With a lateral approach, there is a risk of damage to the hip adductors, which stabilize the pelvis during walking. However, with the normal functioning of the flexor muscles, their work stabilizes to normal after a year, except for the small gluteal muscles, which are responsible for the internal rotation of the hip. Recovery of gluteal muscles occurs more slowly than other muscles of the lower limb. Therefore, this feature of theirs should be taken into account during rehabilitation measures after hip arthroplasty and recommendations for walking rules until full muscle recovery.

In our study, we tried to reproduce the damage of all possible muscles, but their condition does not lead to instability of the model. Therefore, this is only a trend, which in no way reflects the real state, which cannot be reproduced during simulation without taking into account the characteristics of the patient.

Conclusions

Mathematical modeling of the work of muscles that may be damaged during hip arthroplasty surgery showed that conventional muscle forces 6 months after surgery are not able to develop the necessary torque to perform a normal step. During the lateral approach, the lateral muscles undergo the greatest changes in the phase of separation of the foot from the support and its transfer, and during the anterior one the muscles responsible for bending the hip, that is, in the phase of the step, when the hip is bent and the foot is extended forward.

Under the conditions of muscle strength, which in the model corresponded to 12 months, they are able to perform normal function regardless of surgical access, but their overstrain is observed.

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

References

1. Bertocci, G. E., Munin, M. C., Frost, K. L., Burdett, R., Wassinger, C. A., & Fitzgerald, S. G. (2004). Isokinetic performance after total hip replacement. *American Journal of Physical Medicine & Rehabilitation, 83*(1), 1-9.
2. Delp, S. L., Anderson, F. C., Arnold, A. S., Loan, P., Habib, A., John, C. T., Guendelman, E., & Thelen, D. G. (2007). OpenSim: Open-source software to create and analyze dynamic simulations of movement. *IEEE Transactions on Biomedical Engineering, 54*(11), 1940-1950.
3. Ganderton, C., Pizzari, T., Harle, T., Cook, J., & Semciw, A. (2017). Gluteus medius, gluteus minimus and tensor fascia latae are overactive during gait in post-menopausal women with greater trochanteric pain syndrome. *Journal of Science and Medicine in Sport, 20*, e72. Available: https://www.researchgate.net/publication/ 51823221_A_review_of_the_anatomy_of_the_hip_abductor_muscles_gluteus_medius_gluteus_minimus_and_tensor_fascia_lata
4. Greco, A. J., & Vilella, R. C. (2020). Anatomy, Bony Pelvis and Lower Limb, Gluteus Minimus Muscle. In StatPearls. StatPearls Publishing.
5. Hamm, K. (n. d.). Biomechanics of Human Movement [E-book]. https://pressbooks.bccampus.ca/humanbiomechanics/
6. Higgins, B. T., Barlow, D. R., Heagerty, N. E., & Lin, T. J. (2015). Anterior vs. posterior approach for total hip arthroplasty, a systematic review and meta-analysis. *The Journal of Arthroplasty, 30*(3), 419-434. doi:10.1016/j.arth.2014.10.020
7. Holm, B., Thorborg, K., Husted, H., Kehlet, H., & Bandholm, T. (2013). Surgery-induced changes and early recovery of hip-muscle strength, leg-press power, and functional performance after fast-track total hip arthroplasty: A prospective cohort study. *PLoS ONE, 8*(4), e62109. doi:10.1371/journal.pone.0062109
8. (2015). I Downloaded OpenSim: Now What? Introductory OpenSim Tutorial. GCMAS: Annual Meeting, Portland
9. Ilchmann, T., Gersbach, S., Zwicky, L., & Clauss, M. (2013). Standard Transgluteal versus Minimal Invasive Anterior Approach in hip Arthroplasty: A Prospective, Consecutive Cohort Study. *Orthopedic reviews, 5*(4), e31. https://doi.org/10.4081/or.2013.e31
10. John, C. T., Anderson, F. C., Higginson, J. S., & Delp, S. L. (2012). Stabilisation of walking by intrinsic muscle properties revealed in a three-dimensional muscle-driven simulation. Computer Methods in Biomechanics and Biomedical Engineering. https://doi.org/10.1080/10255842.2011.627560
11. Judd, D. L., Dennis, D. A., Thomas, A. C., Wolfe, P., Dayton, M. R., & Stevens-Lapsley, J. E. (2014). Muscle strength and functional recovery during the first year after THA. *Clinical Orthopaedics and Related Research, 472*(2), 654-664.
12. Kassarjian, A., Tomas, X., Cerezal, L., Canga, A., & Llopis, E. (2011). MRI of the quadratus femoris muscle: anatomic considerations and pathologic lesions. AJR. *American journal of roentgenology, 197*(1), 170–174. https://doi.org/10.2214/AJR.10.5898
13. Kendall, F. P., McCreary, E. K., & Provance, P. G. (2006). Muscles: Testing and Function With Posture and Pain (5th ed.). Baltimore: Lippincott Williams & Wilkins.
14. Lanting, B. A., Hartley, K. C., Raffoul, A. J., Burkhart, T. A., Sommerville, L., Martin, G. R., Howard, J. L., & Johnson, M. (2017). Bikini versus traditional incision direct anterior approach: is there any difference in soft tissue damage? *Hip international : the journal of clinical and experimental research on hip pathology and therapy, 27*(4), 397–400. https://doi.org/10.5301/hipint.5000478.
15. Liu, M. Q., Anderson, F. C., Schwartz, M. H., & Delp, S. L.

(2008). Muscle contributions to support and progression over a range of walking speeds. *Journal of Biomechanics, 41*(15), 3243-3252

16. Mansfield, P. J., & Neumann, D. A. (2018). Essentials of kinesiology for the physical therapist assistant e-book. Elsevier Health Sciences. Available: https://www.sciencedirect.com/book/9780323544986/essentials-of-kinesiology-for-the-physical-therapist-assistant
17. Matta, J. M., Shahrdar, C., & Ferguson, T. (2005). Single-incision anterior approach for total hip arthroplasty on an orthopaedic table. *Clinical orthopaedics and related research, 441*, 115–124. https://doi.org/10.1097/01.blo.0000194309.70518.cb
18. Mjaaland, K. E., Kivle, K., Svenningsen, S., & Nordsletten, L. (2019). Do Postoperative Results Differ in a Randomized Trial Between a Direct Anterior and a Direct Lateral Approach in THA? *Clinical orthopaedics and related research, 477*(1), 145–155. https://doi.org/10.1097/CORR.0000000000000439
19. Moore, K. L., Dalley, A. F., & Agur, A. M. (2014). Clinically oriented anatomy (7th ed.). Baltimore, MD: Lippincott Williams & Wilkins.
20. Opensimconfluence.atlassian.net/wiki/pages/viewpageattachments.action?pageId=53086215&preview=%2F53086215%2F53092279%2FMuscleIsometricForces%202.pdf
21. Palastanga, N., & Soames, R. (2012). Anatomy and Human Movement: Structure and Function (6th ed.). London, United Kingdom: Churchill Livingstone.
22. Presswood, L., Cronin, J., Keogh, J. W., & Whatman, C. (2008). Gluteus medius: Applied anatomy, dysfunction, assessment, and progressive strengthening. *Strength & Conditioning Journal, 30*(5), 41-53. DOI: 10.1519/SSC.0b013e318187f19a
23. Rasch, A., Bystrom, A. H., Dalen, N., Martinez-Carranza, N., & Berg, H. E. (2009). Persisting muscle atrophy two years after replacement of the hip. *The Journal of bone and joint surgery. British volume, 91*(5), 583–588. https://doi.org/10.1302/0301-620X.91B5.21477.
24. Reiman, M. P., Bolgla, L. A., & Loudon, J. K. (2012). A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. *Physiotherapy theory and practice, 28*(4), 257–268. https://doi.org/10.3109/09593985.2011.604981
25. Roth, T., Rahm, S., Jungwirth-Weinberger, A., Süess, J., Sutter, R., Schellenberg, F., Taylor, W. R., Snedeker, J. G., Widmer, J., & Zingg, P. (2021). Restoring range of motion in reduced acetabular version by increasing femoral antetorsion — What about joint load? *Clinical Biomechanics (Bristol, Avon), 87*, 105409. https://doi.org/10.1016/j.clinbiomech.2021.105409
26. Shao, Q., Bassett, D. N., Manal, K., & Buchanan, T. S. (2009). An EMG-driven model to estimate muscle forces and joint moments in stroke patients. *Computer Methods and Programs in Biomedicine, 39*(12), 1083-1088. https://doi.org/10.1016/j.compbiomed.2009.09.002
27. Siccardi, M. A., Tariq, M. A., & Valle, C. (2023). Anatomy, Bony Pelvis and Lower Limb: Psoas Major. In StatPearls. StatPearls Publishing.
28. Supra, R., Supra, R., & Agrawal, D. K. (2023). Surgical Approaches in Total Hip Arthroplasty. *Journal of orthopaedics and sports medicine, 5*(2), 232–240. https://doi.org/10.26502/josm.511500106
29. Zhao, G., Zhu, R., Jiang, S., Xu, N., Bao, H., & Wang, Y. (2020). Using the anterior capsule of the hip joint to protect the tensor fascia lata muscle during direct anterior total hip arthroplasty: a randomized prospective trial. *BMC musculoskeletal disorders, 21*(1), 21. https://doi.org/10.1186/s12891-019-3035-9]
30. Strafun, S. S., Fishchenko, O. V., Moskovko, G. S., & Karpinska, O. D. (2018). Clinical studies of walking parameters of patients with coxarthrosis according to the GAITRite system. *Trauma, 19*(6), 56-61. https://doi.org/10.22141/1608-1706.6.19.2018.152221
31. Tyazhelov, A. A., Karpinsky, M. Yu., Yurchenko, D. A., Karpinska, O. D., & Goncharova, L. E. (2022). Mathematical modeling as a tool to study the function of pelvic girdle muscles in dysplastic coxarthrosis. *Trauma, (1)*, 4-11. https://doi.org/10.22141/1608-1706.1.23.2022.876
32. Tyazhelov, O. A., Karpinsky, M. Yu., Karpinsky, O. D., Branitsky, O. Yu., & Obeydat, Kh. (2020). Pathological postural patterns under conditions of long-term course of osteoarthritis of the joints of the lower extremities. *Orthopedics, traumatology and prosthetics, (1)*, 26-32. https://doi.org/10.15674/0030-59872020126-32

The article has been sent to the editors 21.05.2024

THE STUDY OF THE WORK OF THE MUSCLES RESPONSIBLE FOR THE FUNCTIONALITY OF THE HIP JOINT AFTER TOTAL HIP ARTHROPLASTY USING DIFFERENT SURGICAL APPROACHES

S. Ye. Bondarenko, D. I. Sereda, O. D. Karpinska

Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

✉ Stanislav Bondarenko, MD, DSci in Orthopaedics and Traumatology: bondarenke@gmail.com

✉ Dmytro Sereda, MD: ortsurgeon@gmail.com

✉ Olena Karpinska: helenkarpinska@gmail.com