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New and old theories in hip biomechanics

Teorii noi și vechi în biomecanica șoldului

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Abstract

Knowledge of kinematics, the physiological load bearing during statics and dynamics, and all forces that act on the hip joint have been and still are a major challenge even today, and this subject was also the purpose of the authors' study. The authors suggest that through this work the qualitative analysis of the movement, patterns and motion geometry, forces and anatomy of the movement should be encouraged. The aim of this paper was to draw an up-to-date picture of the normal anatomical and biomechanical knowledge of the hip. Only by observing the anatomical elements of the hip can the architecture and stability of the hip be understood. By corroborating the anamnesis and physical examination data the source of the pathology can be identified and evaluated. This paper should serve as a foundation for understanding, evaluating and treating the musculoskeletal deficiencies that concern not only the hip, but also the knee and the pelvic ring.

Key words: hip, anatomy, biomechanics.

Rezumat

Cunoașterea cinematicii, a încărcăturii fiziologice din timpul static și dinamic și a forțelor mecanice ce acționează asupra articulației șoldului au fost și au rămas o provocare, fiind și subiectul lucrării propuse de autori. Această prezentare servește drept fundament în analiza calitativă a patternului și geometriei mișcării, prezentarea forțelor și complexului anatomic ce conduc la realizarea mișcării. Lucrarea de față își propune să ofere o imagine de ansamblu, actualizată, a cunoștintelor anatomice și biomecanice la șoldul normal. Observarea componentelor anatomice ale șoldului, înțelegerea arhitecturii și stabilității lui, în combinație cu anamneza și examinarea fizică, constituie un element important pentru a identifica și evalua sursa durerilor. Cu acest referat ne-am propus o ințelegere completă a forțelor ce traversează articulația șoldului și detaliile anatomiei acesteia, creând și dezvoltând astfel soluții în recuperarea patologiilor aferente acestei articulații.

Cuvinte cheie: șold, anatomie, biomecanică.

Introduction

We have envisioned a wide comprehension of the forces that act on the hip joint and the anatomical details of the latter, creating and developing solutions for the rehabilitation process in the diverse pathology of this joint.

Biomechanics is essential for understanding the mechanisms of the pathological process, also bringing a valuable perspective on the diagnosis and treatment of the disease. The domains that reap the fruits of this science are both surgical (with the development of reconstructive surgery and hip arthroplasty) and medical, such as rehabilitation medicine with the implementation of new adapted and complex therapeutic programs (Jumaa et al., 2014).

The coxofemoral joint or the hip joint is one of the most robust joints of the human body, combining stability and mobility due to the combination of a highly resistant joint capsule and 3 thick ligaments. By making a short description, we can say that this is the most important joint in the human body, sensitive to load bearing, especially if there are any axial anomalies. We can separate the hip into the hip bone, hip ligament and hip muscle.

Anatomy

The coxofemoral joint is a synovial, typical spheroidal joint (enarthrosis) with 3 degrees of freedom, in which the following movements can be produced: flexion-extension, abduction-adduction, internal rotation-external rotation

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and circumduction; so it can be said that the hip allows movement in all directions.

In order to understand the pathology of the hip joint, an accurate knowledge of its internal structure and anatomy as well as biomechanics is required; therefore the authors have decided to study the hip joint in the following order:

1. The hip bone

The acetabulum: a round cavity formed by 3 bones: ilium (roughly 40% of the acetabulum), ischium (40%) and pubis (20%). The immature skeleton has these 3 bones separated by the ypsiloformis cartilage - the fusion of these bones starts around the age of 14-16 years and is final at about 23 years of age (Moore et al., 2014).

Attached to the acetabulum is the acetabular labrum, with a role in holding the femoral head in the reception cavity. This is a fibrocartilage in the shape of a ring that is composed of collagen fibers with a circumferential arrangement, and covers almost the entire acetabulum, continuing with the transverse ligament (Byrne et al., 2010).

The physiological functions of the labrum are not yet fully known, but this seems to have multiple purposes, including the limitation of external mobility and joint stability through deepening of the acetabular dome. It also has the role of ensuring a high hydrostatic pressure of the intra-articular fluid, thus contributing to the proper lubrication of the synovium and giving resistance to forced traction movements (Crawford et al., 2007). Modern surgical techniques focus on maintaining and repairing the acetabular frame in order to keep the intra-articular environment and, also, to minimize the degenerative potential (Bowman et al., 2010).

The femoral head is a round articular surface which represents 2/3 of a sphere.

2. The hip ligament - joining methods/intra-articular components

The joint capsule is very strong, with a wide insertion surface on the coxal bone (the acetabular upper edge and the external face of the labrum) and a small area on the femur (the anatomical neck) (Kishner et al., 2015).

Pericapsular joint ligaments are soft tissues that have the role of connecting the bone surfaces. The iliofemoral ligament can be observed anteriorly in the shape of an inverted "Y". It has the property of being the strongest ligament of the body, supporting a load of 350-500 kg, helping maintain the bipedal position with minimal help from the muscles (Martin et al., 2008). It also limits the extension, internal rotation and abduction of the hip. Inferior and posterior of the iliofemoral ligament and mixing with this on the medial side is the pubofemoral ligament, which only has a small role in reinforcing the anterior-inferior side of the joint capsule and limits the external rotation and abduction of the hip (Fig. 1).

The femoral head is covered by articular cartilage in a proportion of 60-70% of a sphere, where the central part, which is uncovered, forms the fovea capitis, the femoral insertion of the round ligament of the femoral head. It contains blood vessels but it has little contribution to the joint stability. The cartilage is composed of collagen type II fibers rich in glycosaminoglycan, which are hydrophilic and have the role of retaining water inside the cartilage, thereby protecting the joint surface from inherent stress, absorbing shocks, and disseminate the forces that are generated around the joint. These three ligaments are the main stability force of the hip (Popescu et al., 2007). Posteriorly, the ischiofemoral ligament completes the ligament anatomy. It connects the ischiatic acetabular wall with the femoral neck, thus limiting the internal rotation and adduction of the hip.

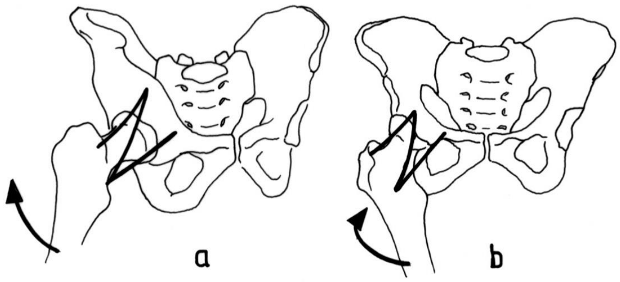

Fig. 1 – The concomitant tensioning of the three ligaments, which form the letter N shape, from an anterior view: a) in extension, b) in external rotation.

3. The hip muscle – extra-articular structures, motion

The 21 muscles that traverse the hip joint provide a wide range of motion as well as stability between the hip bone and the femur. Muscle analysis should consider spatial distribution in respect to the rotation axis of the hip, as well as the co-activating muscles of the trunk (Neumann, 2010).

The strongest flexor of the hip is the iliopsoas muscle (psoas major, minor and iliacus muscles), helped by the sartorius, rectus femoris and tensor fasciae latae muscle. The strongest extensor of the hip is the gluteus maximus muscle with an important role in anteroposterior stability. The main abductors are gluteus medius and gluteus minimus muscles. Adduction is done by the adductor muscles (long, short and magnus), gracilis, external obturator and pectineus muscles.

In normal kinematics, the flexion-extension motion, as well as abduction-adduction is associated with rotation movements due to the length of the femoral neck and the inclination angle. The small muscles (piriform, external and internal obturator, quadratus femoris muscles), with the insertion around the greater trochanter, help augment the rotations. Besides ensuring movement and stability of the hip joint, the muscle bed prevents peaking tensions on the femur and potential harming by moving the weight center (Byrne et al., 2010).

Biomechanics

The coxofemoral joint is a grade 1 lever with unequal arms. The support point is the femoral head, the force is represented by abductor muscles, and resistance is the weight of the body (Erceg, 2009).

Regardless of unipodal or bipodal support, the force that acts on the hip joint is conditioned by:

- the area and the integrity of the articular surface;
- the cartilaginous surface integrity.

When one of the parameters in modified, the balance is disturbed and biomechanical overloads of the joint segments occur with clinical-functional echoes.

The factors that can influence the magnitude and direction of action for the compression force on the femoral head are:

- the position of the body's weight center;
- the length of the lever arm;
- the value of resistance.

Thereby, if the weight center overlaps the centers of the femoral heads, minimal muscular forces will be required to maintain equilibrium. If the trunk is slightly bent posteriorly, the weight center is in the posterior area of the femoral heads, and the anterior capsule of the hip will become tense and the Y-shaped ligament of Bigelow will ensure stability. Thus, with unipodal support, the weight center will move distally and away, the lifted member being considered as body weight that acts on the bearing hip. Because the bearing pillar is outside the action of the weight center, this will have to be compensated through the abductor forces of the muscles with insertion on the lateral femur (upper fibers of gluteus maximus, gluteus minimus and medius, tensor fasciae latae, piriform, internal obturator muscles). The shortening of the lever arm through coxa valga or excessive femoral anteversion will result in increased action of abductor muscles and, hereby, an increase in the load of the joint. If the shortening of the lever arm is increased, the muscles become overloaded and there is a lateral shift of the weight center, over the bearing hip, or an inclination of the pelvis which leads to the Trendelenburg sign (1).

The hip bears the whole weight of the body that it transmits to the ground. During walking or standing, the human bipedal posture is a vertical balance in respect to the gravitational force. In certain conditions, the mobility of the hip can be sacrificed, but not its stability. The concept of hip instability and capsular laxity has recently emerged, as an identifiable and potentially correctable cause of hip pain and disability (Tibor & Sekiya, 2008). The origin of instability can be split between traumatic and atraumatic causes; the hypothesis of atraumatic instability may be the result of injury to the ligament capsule during activities that force and tend to overload the hip, a main cause for coxa saltans (Bowman et al., 2010).

Hip biomechanics has attracted a lot of attention from researchers and clinicians. Julius Wolff became interested in the relationship between bone architecture and the functional load bearing as early as the 19th century (Morlok et al., 2011), when he tried to understand the joint load trough a mechanical approach (Erceg, 2009). He tried to understand the pathological influence of the anatomical valgus and varus positions of the femoral neck, proving that, for a joint, the valgus position suggests a smaller lever and abductor muscles have to develop a greater force. This increases the role of the resultant force in the hip joint and changes the action point on the pelvis into a more lateral position. His discoveries have influenced the treatment of femoral neck fractures and femoral osteotomies in a decisive way.

From all animal species, only humans and birds use bipedal walking and standing in a regular way. Even big primates use quadrupedal walking. When the body weight is supported on both feet, the weight center is centered between the two hips and weight is equally distributed to both joints. This is around 2/3 of the total body weight, which means 1/3 of the body mass distributed per hip in a vertical manner (Fig. 2).

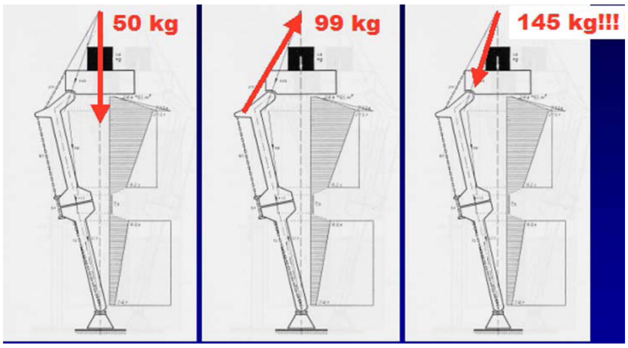

Fig. 2 – Pressure zones imposed by the body weight on the hip

This changes when the force is concentrated on a single hip, for example in the stance phase of gait. The pelvis tends to fall on the unloaded side, the abductor muscles opposing this motion and, also, having a role in maintaining the pelvis in a horizontal position. Pauwels compared this with a horizontal lever in equilibrium K1 and K2, whose position is influenced by body mass G and muscle force F (Pauwels et al., 1935).

In present days, Pauwels' theory has been recently criticized by some authors. The fundamental elements of the classical approach have been revised, analyzed and completed, through some modern solutions. Kummer did not contradict Pauwels, he just added 2 conditions:

- The weight bearing limb should be positioned on the line of action of the gravitational force;
- The abductor forces of the hip are composed of gluteus medius and minimus muscles (70%) and the muscles that control the iliotibial tract (30%) (Kummer, 1993).

During posterolateral hip dislocation, the femoral head moves proximally and laterally. The Pauwels method explains the effects of lateral motion, without considering or mentioning cranial movement. This approach was debated by Erceg et al. (2014), and it could be useful in understanding the influence of cranializing the hip during hip arthroplasty when the acetabulum is implanted more to the side or cranial than its natural position.

In conclusion, numerous researchers support Pauwels' theory, but they believe that in addition to the gluteus medius and minimus muscles which counterbalance the forces that act on the hip and the iliotibial tract, the gluteus medius-vastus lateralis complex also plays a role (Martin et al., 2015).

Biomechanics becomes even more complicated in hip arthroplasty, because all articular parameters are influenced by the surgical procedures: the articular center, the neck angle, levers, muscles, the range of motion (ROM), until articular impingement. ROM and joint stability become decisive in younger patients, with great quality of life expectations after hip arthroplasty. The valgus or varus position and the articular center are determined by the implant positioning in the pelvis and femur, influencing the local load bearing situation on the components. For example, a slightly cranial, posterior or medial articular center after the implant is associated with a greater articular force (Erceg et al., 2014).

In vivo studies have shown that patients performing daily activities with relative joint load during the immediate postoperative period may generate forces up to 8 times the weight of the whole body on the prosthetic hip during unexpected events or instability periods during unipodal load bearing (Mirza et al., 2010). The most physiological position of the adult hip in which intra-articular pressure is the lowest is in slight extension, abduction and internal rotation, a position in which the jointing of articular surfaces is the best and the pressure is the lowest (Erceg, 2009). This physiological position becomes opposite to the antalgic position, the most common vicious position of the hip joint: flexion, adduction, external rotation.

Knowing the degree of motion of a joint or the value of the contraction force necessary for a muscle to perform a certain movement is absolutely necessary in establishing a functional diagnosis, as well as in evaluating the efficiency of treatment. Hip movements performed with a flexed knee are 20-30 degrees wider than with the knee extended. Also, the difference between active and passive motion is greater in the hip than in any other joint of the body. Due to this reason, the values recorded by hip joint testing will be accompanied by these specifications. For a functional hip we have to start from the exact knowledge of movement physiology. The range of motion (ROM) during regular activities is considerable: flexion/extension up to 124^0, abduction/adduction up to 28^0 and internal/external rotation up to 33^0 (Charbonnier et al., 2015).

Lower back, hip, knee and ankle problems can be affected by inefficient pelvic and/or hip stabilization, because the muscles are weak or tight. The most followed principles in the rehabilitation program are to focus on centring or maintaining the body in a neutral position. In all types of exercises that are used to restore mobility, increase muscle strength, obtain stability, it is important to apply the entering concept when performing and keeping the movement in controlled, small ranges (2).

Kinetic program

We present a series of exercises as examples to follow in global rehabilitation of the hip that we use in our department. This program starts with analytical elements and ends with global exercises.

Hip extensor stabilizing exercises:

- prone position, hip extension;
- supine position, hip extension, starting from flexed knee position, load bearing using pulleys;

Anterior hip stabilization exercises:

- quadricipital isometry, maintain knee extension for 5 minutes. It can use: towel, ball, pillow, sand sacks;
- knee extension from sitting position;
- hip flexion using elastic bands;
- triple flexion of the lower limb from standing position, maintained for 3 seconds, without exceeding the hip protection limit;

Hip stabilization exercises that tonify the real hip stabilizer, the gluteus medius, coupled with tensor fasciae latae exercises:

- hip abduction, from heterolateral position, with a pillow or rug between the knees for hip stabilization;
- from supine position, hip abduction with load bearing using pulleys;
- using elastic bands, starting from standing position, lower limb abduction;
- hip abduction, from standing position keeping the alignment of the hip, knee and ankle, followed by a slow return and hip extension which is maintained for 3 seconds, all while maintaining a straight position of the trunk.

Conclusions

1. Human bone structures are sufficiently light to allow movements with reduced energy consumption, rigid enough to build strong levers for the muscles and strong enough to withstand usual load bearing without breaking.
2. A thorough clinical-functional evaluation of the hip joint and muscle biomechanics is required when establishing the patient's functional state and for selecting the most efficient techniques and methods to re-educate the patient. Strict individualization of kinetic treatment in accordance with the functional deficit leads to shortening of the recovery time.
3. During this study, we reviewed a series of basics of hip anatomy and biomechanics, important for patients as well as for medics and therapists. Once the forces that affect the hip and its anatomy are understood, we can learn from past mistakes and focus on current and future solutions.
4. Rehabilitating the hip, as well as inguinal lesions represents a clinical challenge. While the mass of clinical knowledge is growing, there are still missing pieces in the diagnosis and treatment of these lesions. Differential diagnosis is complex and many entities may co-exist. During our continuous exploration of hip and inguinal disorders, physiotherapists analyze and identify corresponding group and individual rehabilitation strategies.

Conflicts of interest
There are no conflicts of interest.

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