ANALYSIS OF FORCES CAUSING OR RESTRICTING MOVEMENTS OF THE HUMAN BODY

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The analysis of movements of the human body or biomechanics has significantly evolved lately, thanks to new scientific data and using much more accurate recording techniques. Biomechanics studies the way in which forces are produced, analyzing them in terms of mechanics, how they are related to external forces acting on the body. Starting from these interdependency relations, biomechanics establishes mechanical efficiency and indicates practical methods to increase efficiency depending on the aim. Biomechanics also contributes to a correct understanding of phenomena of life by assimilation of notions such as space, time, motion, those regarding basic properties and forms of matter existence, of notions on interdependency of forces concurring to perform movements. Ground reaction force occupies an important position within the general context of human motion analysis. At the same time, it is an indicator both in terms of geometric shape of the curve and according to the variation of the point of application of the force on the foot plantar, so that experts may quantitatively and qualitatively assess a pathological condition of walking. The purpose of this paper is to analyze forces causing or restricting the movement of the human body.

Keywords: forces, biomechanics, ground reaction.

INTRODUCTION

The great accomplishments of modern technique are based on scientific data provided by physics and chemistry. Mechanics is a part of physics and its basic laws have been formulated by Isaac Newton (1642-1727). Through these laws the connection and interaction between forces and their effects are expressed, highly significant laws for the development biomechanics [1].

Locomotion occurs as an alteration of the body posture or of its parts. It is the result of the interaction between two categories of forces: internal forces and external forces; force meaning the cause altering or tending to alter the rest state or the motion state of a body.

The objectives of researchers in the field of biomechanics are generally bidirectional. First of all, biomechanics aims at understanding the basic aspects of physiological functions, for medical purposes. Secondly, it seeks to elucidate these functions in order to apply the results in non-medical fields.

Corresponding to the first situation, sophisticated techniques of monitoring physiologic functions have been and continue to be elaborated and developed, gathered data are processed and theories are presented explaining these data, the purpose being to diagnose “the human engine”, in order to find the causes of its ineffective functioning, as a result of disease, ageing, wear through fatigue or destruction by accidents.

In static and dynamic activities of man, the harmony between all body components is primary. In our specific case, concerning biped balance, slight perturbations in maintaining it may lead to hindering safety and stability of the body.
FORCES INVOLVED IN BODY MOVEMENTS

There are two types of forces involved in body motions: internal and external. The anatomic-functional basis of a motion is represented by the neuromuscular osteoarticular arch.

Through the activation of the locomotor apparatus under the command of the nervous system, a series of internal forces concurring to produce movements are triggered. Internal forces must defeat a series of external forces opposing to motion, the motion resulting from the interaction of internal forces of the human body with the external forces of the walking environment.

In order to produce mechanical work, internal forces must be superior, in terms of intensity, to resistances opposed by the external forces and must act in the same way, but in the opposite direction of the latter.

Internal Forces

Internal forces are represented by the nervous impulse, muscle contraction, osteoarticular levers and joint mobility.

Organs participating to locomotion belong to the nervous system, the osteoarticular system and the muscular system.

Both locomotion and movement in the form of physical exercise use mechanical energy manifesting as forces.

Thermal, electric, physical-chemical and mechanical energy is a result of metabolic processes in the human body.

The succession of internal locomotion forces interfering in the production of a movement is the following:

- nervous impulse;
- muscular contraction;
- osteoarticular lever;
- joint mobility.

a) Nervous impulse is the phenomenon transmitted on the path of a reflex arc which in its turn has receptors, afferent path, nervous centre, efferent path and motor plate (neuromuscular synapse) through which the motor impulse is transmitted to the muscular cell. The mechanisms underlying movements are of neuromuscular nature, they are reflex actions.

b) Muscular contraction is the second internal force contributing to the production of movement, as a feedback reaction to stimulation, through the nervous impulse. There are several types of contractions.

c) Osteoarticular levers are the third internal forces interfering in the production of movement. Nervous impulses cause muscular contractions, which in their turn draw the shift of bone segments at the level of muscular insertions, thus turning chemical energy into mechanical energy. Bone segments on which muscles act behave, at first sight, like levers in physics.

The lever is usually a bar which can rotate around a point called fulcrum (S). The main purpose of using a lever is to be able to lift a greater weight, applying a smaller force. Thus, two forces act on the lever:

- the force which must be defeated, called resistance force – R.
- the force by means of which the resistance force is defeated, called active force – F.
Depending on the relations between these three points, levers are divided into:

- class I levers, with the fulcrum in the middle – RSF.
- class II levers, with resistance in the middle – SRF.
- class III levers, with force in the middle – SFR.

d) Joint mobility – the shift of bone segments engages the mandatory participation of joints in the chain of motor mechanisms.

Joints are the places where resistance structures, represented by the bones, ensure the movement of one of its components in relation to the other. The anatomical structure of joints allows transmission of tractions, stability of the kinematical chain and friction reduction.

Joint mobility must be considered an active factor participating in movement production. The shape of joints and their degrees of freedom are important factors leading the path and direction of movements and which, at the same time, limit the amplitude of motion [3].

**External Forces Involved in Movement Production**

a) Force of gravity – is the manifestation of a universally valid law in nature. According to the universal law of attraction, the earth attracts bodies and at the same time it is attracted to them. The force of gravity always acts vertically, from top to bottom. Against it, the cumulative internal forces act in the opposite direction, from bottom to top.

b) Body weight always acts vertically, from top to bottom on the body’s or the segments’ center of gravity. The value of this force is related to the volume, length, density of the moving segment or to the number of segments involved in motion.

c) Atmospheric pressure is an indirect form of action of the gravitational force. It presses on the body with a variable intensity depending on the moving speed. The action of atmospheric pressure on the body is compensated by the internal pressure of large cavities, and has identical values to those of atmospheric pressure.

d) Environmental resistance is that of the external environment in which physical exercises take place, which can be practiced outdoors and in water. That is why segments of the human body or the body as a whole will have to defeat their resistance. It depends on the size of the frontal surface that the body opposes to the environment.

e) Inertia is the force which tends to prolong and sustain a given situation. Thus, a body at rest tends to stay at rest, and a body in motion tends to continue to move.

f) The reaction force of the support surface (support) is static when the body is immobile and it equals the static weight of the body, and it is dynamic when the body is in motion and it equals the static weight of the body plus inertia.

g) The friction force is proportional to the body weight (G) which slides on a support surface and to the coefficient of friction (K):

\[ F = G \cdot K \]  (1)

Internal and external forces are inseparable and in continuous interaction. The entire activity of man is developing by means of these forces, in which the decisive role is that of muscular contraction directed by the neural cortex.

h) Various external resistances are all the objects with which the human body interferes and they act on the body from various directions [3].
GROUND REACTION FORCE

Ground reaction force occupies an important position within the general context of human motion analysis. At the same time, it is an indicator both in terms of geometric shape of the curve and according to the variation of the point of application of the force on the foot plantar, so that experts may quantitatively and qualitatively assess a pathological condition of walking.

Ground reaction force derives from the principle of action and reaction, representing the force of pushing horizontal support surfaces of the body from bottom to top. It is the resultant of three vector components which have three directions: vertical, anterior-posterior and mediolateral (transversal), all of them being transmitted to the foot during the support phase when walking or running.

The size of the reaction force is equal to the producer of the action which is dependent on the size of the body mass and on the acceleration value of its center of gravity.

When a body is still, only the body mass acts on the ground, namely its gravitational force which increases together with the body mass. When the body is set in motion, an acceleration appears which is perceived by the ground as a force that must be countered by increasing the ground reaction force

As the body weight shifts on the support foot, vertical, horizontal and rotational forces are generated at ground level which can be measured with appropriate instruments. These ground reaction forces are equal in intensity and in the opposite direction to those borne by the limb on which the body weight falls. From this information, the strain on the joints and necessary muscle control can be identified.

**Figure 1. Ground reaction force components**

GRF is a force vector made up of three components: a vertical component \( F_z \) and two shear components, anterior sagittal (in the moving direction) \( F_y \) and horizontal-transversal \( F_x \) (perpendicular on the moving direction), components which act parallel to the plate surface (Figure 1).

The size of the components results from deconstruction of the main force, which in its turn cannot be equivalent to the body weight as in the case of foot static, but acquires values which can exceed it, depending on the various positions (of which impact, total contact and propulsion are important) of the supported foot.

Vertical component has two maxima (Figure 2a) which exceed the body weight in value (due to the overlapping of dynamic components), maxima which correspond to lift off of the oscillatory foot and to the propulsion moment. The minimum of the vertical component occurs when placing the foot on the support surface and its value is below the body weight because at the beginning of contact (impact), a part of the body...
weight is still supported by the other foot (it is another minimum occurring in swinging the oscillatory foot).

The horizontal sagittal component (Figure 2b) has two opposed direction (and sign) maxima, namely: one in the walking direction, occurred when placing the heel on the support surface and the second one in the opposite direction, occurred as recoil in the metatarsal area when the support foot makes the propulsion.

In order to maintain balance, oscillations of the body in the transversal plane generate two maxima of opposite direction (and sign) (Figure 2c) of the transversal component, the first one determined by the body leaning towards the foot beginning to support the weight and the second one in the opposite direction, occurring in the propulsion instant, when the body begins the second balance, opposed to the first one.

By additional processing of these data, vertical load, horizontal shear, vector patterns, joint torques and centers of pressure can be determined.

**Vertical Load**

Vertical forces are generated by the moving speed, with two maxima ($F_1$, $F_3$), separated by a minimum ($F_2$), (Figure 2a). The maxima value reaches 110% of body weight, while the force in the minimum is approximately 80% of body weight.

The vertical force pattern in patients with unilateral pathology of the hip (degenerative disease) generally shows a reduction in the vertical load of the injured member compared to the healthy one. Vertical load is not a safe clinic measure when the disability is severe.

**Horizontal Shear**

Shear forces are generated parallel to the walking surface. Horizontal forces in the anterior-posterior plane (AP) occur when the vector of the ground reaction force deviates from the vertical one. Similarly, the change of body weight from one leg to the other creates horizontal mediolateral shear forces (ML). Without appropriate friction at the foot/floor interface, these shear patterns would cause slips and possible threats to stability. However, the magnitude of the horizontal forces compared to the vertical load is small (Figure 2b, 2c).

**Vectors**

Ground reaction forces can be represented by a single vector which combines simultaneous vertical, sagittal and coronal forces. It is the only line of force which comprises the three-dimensional experience.
Joint Torques

Body muscles stabilize joints, as the body weight acts on the support member. The alignment of each member segment and their mass influence the joint stability. When the mass center of a body segment is not vertically aligned over the joint, its weight generates a rotational force causing the joint to move. This is called torque.

CONCLUSIONS

The paper presents the analysis of forces significantly contributing to understanding the mechanics of walking. In order to maintain the static balance, the balance of each part is required, balancing the action of gravity forces by means of the passive and active forces of the locomotor apparatus. To maintain the position of the whole body, the balance of all external forces acting on the body is necessary.

Some biomechanical assessments involve a research of the motion itself. Typically, the curves of ground reaction forces are examined, obtained by means of a force plate. This mechanical equipment produces an electric signal proportional to the body weight acting on it. A trained observer can detect modifications resulting from a pathologic gait and can draw conclusions on the progress or involution of the patient but will not be able to estimate the cause of these modifications.

Joints capable to develop sufficient movement and the muscles generating a corresponding force contribute to a normal gait cycle. If joints are less flexible, most often due to muscular contractions, limiting the amplitude of motion, or muscles are weak, the body finds ways to compensate this problem, finally leading to biomechanical dysfunctions.

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