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ANALYSIS OF CHANGES IN THE BIOMECHANICS OF THE FOOT

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Abstract

Currently, problems related to posture play an important role within the concerns of specialists to detect as early as possible the causes which contribute to their appearance, but also in terms of therapeutic and prophylactic measures able to limit them as both incidence and against possible complications. It is obvious that the foot is the one that stabilises the vertical position of the human body, the one that plays an important role in propelling and shifting, adjusting movement on different surfaces and coordinating posture in these situations. The ideal posture is similar to the architecture of a building. The rules of the different anatomic elements in the three planes of the space must be respected. This ensures perfect resistance of the body to the action of unbalanced gravity force. The purpose of this paper is to conduct a thorough analysis of the literature specialised in the biomechanics of the foot and ankle, the combined effects of the muscle, tendon, ligament and bone functions, as well as the coordinated and unified effect of these structures at the level of the foot and ankle results in the attenuation of forces, a process carried out with great efficiency. We believe that this analysis represents an important first step in addressing the problems that may occur in the case of the foot posture changes, with impact on the function of the musculoskeletal system.

Keywords: Foot posture, supination, pronation, foot biomechanics.

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1. Introduction

The structural complexity of the foot is due to its varied and precise characteristics. Such a small structure is able to adapt to different situations completing the movement by walking on rough terrains, for instance mountain areas, or running on flat ground, and manages to keep the body in balance on very narrow/small surfaces.

The prenatal and postnatal development of the foot is important from the point of view of how this organ of locomotion will work. With regard to the foot, four main criteria are described relating to the normality of the foot (Donatelli, 1996):

- absence of pain;
- normal muscle balance;
- centrally positioned heel;
- rectilinear and mobile toes.

The adequate distribution of forces into the foot that supports the weight during rest and walking also represents an important criterion of normality.

The feet are made up of small bones united by joints. The shape of these small bones, as well as the biomechanical relationship between them, participate in the balance of each foot and the formation of plantar arches. Any disturbance in the foot joints will produce changes in plantar support and hence changes in posture. In the presence of an abnormality in support, the study of movement and position is necessary. Any joint blockage between the various bones of the foot will be susceptible to change support and therefore the general posture of the body.

The lower extremity must distribute and dissipate the compressive, traction, shear and rotation forces during walking. The improper distribution of these forces may lead to abnormal movements that, in turn, produce excessive stress, which will lead to degradation of the connective tissue and muscles (Donatelli, 1996).

2. Problem Statement

The basic elements of body posture are the feet, therefore all irregularities relating to the normal architecture of the foot will pass over the entire body posture the same way the faulty global or segmentation postures above the foot will pass on to the support points of the skeleton on the ground. A detailed analysis through the examination of foot biomechanics in orthostatism significantly contributes to the effective treatment of patients with problems of the foot and ankle. Stress problems mainly related to distortions can be alleviated by the suitable correction of foot biomechanics by using orthoses and, in some cases, by changing the shoes.

At present, it is assumed that static distortions in the foreground produce predictable changes in the dynamic phase of foot biomechanics. Orthoses are made based on a static assessment; it is believed that they can correct faulty biomechanics of the orthostatic and walking phases. The effectiveness of orthoses in relieving a variety of phenomena that produce stress to the foot and ankle or even the lower limb supports the idea that the desired changes will occur in the biomechanics of the dynamic phase (Donatelli, 1996). The use of orthoses, associated with a physical therapy program based on a careful assessment, leads to the decrease and disappearance of problems related to the biomechanics of the foot and ankle.

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3. Research Questions

Normal biomechanics of the foot and ankle is related to the combined effects of muscle, tendon, ligament and bone functions. The coordinated and unified effect of these structures at the level of the foot and ankle results in the attenuation of forces, a process carried out with great efficiency.

Where changes occur at any level, this system will try to compensate somehow, as much as possible, and because of these adjustments, some problems may appear: incorrect plantar support, the asymmetry of shoulders, changes in the pelvis position, changes in the alignment of the spine. Under these conditions, people complain about pain in the feet, lower feet, knees, cervical or lumbar spine etc. Can all these be considered as the consequence of changes in muscle tension that ultimately produces pain?

4. Purpose of the Study

The study of musculoskeletal system biomechanics represents the analysis of forces and their effects on anatomical structures (bones, muscles, tendons and ligaments). The study of forces acting on musculoskeletal structures can be divided into an examination of the body at rest (static) and in motion (dynamic) (Smidt, 1984).

The three-dimensional movements of the foot and ankle are represented by supination and pronation movements (Root, Orien, & Weed, 1977). As we understand better the function of the foot, the assessment of foot biomechanics will have added significance.

Pronation takes place immediately after adopting the position on the heel for shock absorption, adjustment in relation to the specific nature of the ground and torsion force conversion.

Supination occurs during the walking phase. Supination of the subtalar joint allows the foot to act as a rigid lever for propulsion. This rigid lever, during the propulsion phase, allows muscles to stabilise the movement. The movement determined by the tarsal bones changes the action direction of muscles, thereby increasing the efficiency of muscle function.

5. Research Methods

It is imperative for the therapist treating a disorder of the lower limbs to have an understanding of the biomechanics of the foot and ankle. Furthermore, the therapist must understand the interdependence of the foot and ankle and the normal function of the kinetic chain of the lower limb (Donatelli, 1996).

Normal biomechanics of the foot and ankle can be divided into static and dynamic components. Static components include bones, joint surface congruence, ligaments and fibrous tissue. Dynamic components include tarsal bones kinetics and muscle function.

The combined effects of static and dynamic structures of the foot and ankle are responsible for attenuating the forces within the foot and lower limb. The winch-type effect of the plantar aponeurosis, the tensile strength of plantar ligaments, the balancing arm effect of metatarsal bones and the common congruence of tarsal and metatarsal bones include static mechanisms for the attenuation of forces.

The three-dimensional movements of the foot and ankle, as well as the interaction of muscle function, are the dynamic components of force attenuation. Pronation is initiated at the high heel attack and is controlled by an eccentric action of the muscles and the fixation characteristics of the connective tissue. Pronation allows the foot to absorb compressive forces, adapt to uneven ground and maintain balance.

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Supination establishes a rigid lever for propulsion and creates pulley-type systems for multiple extrinsic muscles. Pronation takes place immediately after adopting the position for high-heel attack and reaches a maximum in the support position. Supination occurs during early adoption of the support position, allowing the foot to pass through a neutral position during the support position. Supination at the end of the flat position continues until position with raised toes is adopted.

Abnormal pronation and supination in the foot and ankle joints are nothing more than the result of hypermobility or hypomobility.

In general, the term "abnormal pronation" is used to describe distortions of flat foot, and the terms are interchangeable. The literature divides the causes of abnormal pronation into three basic categories: congenital, acquired and secondary to neuromuscular diseases (Jaffe & Laitman, 1982).

Abnormal congenital or acquired pronation changes the alignment of the talus, calcaneus, cuboid and navicular bones. Changing the alignment produces low joint congruence and modifies kinematics of the ankle joints, subtalar and medial tarsal joints. Excessive joint movements produce excessive forces in the foot and ankle and the kinetic chain of the lower limb. The tibia, talus and calcaneus move simultaneously, depending on the pronation of the foot. The talus and tibia are rotated medially, and the calcaneus rotates laterally in eversion (Donatelli, 1996).

In normal pronation, the calcaneus has been described as partially dislocating under the talus. Such joint kinematics is abnormal as it presents excessive and persistent characteristics throughout the duration of the support phase. The normal compensation of pronation is a temporary condition of the subtalar joint, which might occur in response to a change in the surface of the ground.

Changes in the mechanics of the posterior and central part of the foot produce certain typical anatomical modifications, in the case of a foot flat. They can be seen in the context of supporting the weight or (in serious cases) in positions that cannot support weight. These changes include the eversion position of the calcaneus, median deviation of navicular tuberosity, abduction of the anterior part of the foot to the posterior part of the foot and a reduction in the height of the medial arch. The result of excessive pronation is that the structures of soft tissues are traumatised for a long period of time, leading to deterioration and pathology (Donatelli, 1996).

Abnormal supination is a hypomobility of the joints of the foot and ankle, which may result from muscle imbalances and contractures/retractions of the soft tissues. It is usually associated with a rigid structure that cannot operate as an effective shock absorber or cannot adapt to the change of the support surface. Abnormal supination does not usually demonstrate a progressive deterioration of the tissue, such as the flexible foot with pronation. It is rather a foot without flexibility, causing inflammation of the tissues and possible destruction of the joints.

Terminology in the specialised literature describing a foot with high arching creates confusion. A pure pes cavus deformity is represented by the extension of the anterior part of the foot on the posterior part of the foot. Pes cavus deformity is usually associated with other deformities of the anterior part and the posterior part of the foot.

The foot represents a major link in the kinetic chain of the lower limb. Abnormal pronation (flat foot) and abnormal supination (foot with high arching) can produce changes in foot and ankle kinematics.

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6. Findings

Numerous studies have addressed the issue of changes in the foot posture and the effects of these changes on the lower-limb muscle activity, the results of the research conducted by Murley, Landorf, Menz and Bird (2009) being relevant in this regard. Thus, these authors aimed to identify the studies concerning the effect of foot postures, orthoses and footwear on the lower-limb muscle activity. Studies have revealed that the pronation posture of the foot is associated with higher EMG amplitude for muscles performing the foot inversion movement (the posterior tibial, anterior tibial and long flexor of the hallux) compared to the normal posture of the foot or the foot in supination. The foot posture in pronation is associated with lower EMG amplitude for muscles performing the foot eversion movement (the long peroneal bone) compared to the normal posture of the foot in supination.

As mentioned before, the causes of abnormal pronation are congenital, acquired or secondary to neuromuscular diseases.

The most common congenital deformity of the flat foot is talipes calcaneovalgus, which occurs in about 1 in 1,000 births. There is a high correlation between the presence of calcaneovalgus in the newborn and the subsequent development of the flatfoot in the larger child. Thus, the cause of talipes calcaneovalgus is a malposition of the foetus in the uterus. As the foetus develops, the position is determined by the development of the neuromuscular function (Tachdjian, 1985).

Several studies demonstrated gross morphological changes in the muscular tissue of the crooked congenital idiopathic foot. The studied muscles included triceps surae, peroneal muscles and hallucid abductor muscles. Type I muscle fibres showed an increase of joint deformation in all muscle groups. Furthermore, degeneration of fat cells with fibrosis was observed and postulated to be a consequence of immobilisation. Some authors believe that neuromuscular atrophy is a primary cause of a crooked congenital foot (Donatelli, 1996).

The exact cause of the crooked foot deformity is unknown, although several genetic factors have been taken into account: the sexual, autosomal recessive, multiple genetic and autosomal dominant ones. Some authors consider that the cause of leg deformity has been suggested to be the wear of shoes in early childhood. Thus, the flatfoot was frequently encountered in children who wore closed shoes and was less common in children who wore sandals or slippers or did not wear shoes at all (Phillips, Christeck, & Phillips, 1985).

7. Conclusion

The understanding of the biomechanics of the foot and ankle has deep implications for clinical applications, as the impossibility of the foot to convert cross rotation at the level of the subtalar joint can have harmful effects on other joints of the kinetic chain of the lower limb, such as the knee, medial tarsal joint and anterior part of the foot.

The three-dimensional movements of the foot and ankle, as well as the interaction of muscle function are the dynamic components of force attenuation. Pronation is initiated at the heel position and is controlled by an eccentric muscular action and the connective tissue fastening characteristics. This allows the foot to absorb compressive forces, adapt to uneven ground and maintain balance. Supination establishes a rigid lever for propulsion and creates pulley-type systems for multiple extrinsic muscles.

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The normal foot passes from a supple position in the early phase of the support phase to a rigid position in the second part. The abnormal foot presents an anomaly in posture, biomechanics or function compared to the normal foot in general; two types of abnormal foot are described: pes planus and pes cavus.

It is assumed that static distortions in the foreground produce predictable changes in the dynamic phase of foot biomechanics, its detailed analysis through an examination of the foot and ankle during rest significantly contributing to an effective therapeutic approach.

The study has revealed that, regardless of the cause of the abnormal biomechanics of the foot and ankle resulting from abnormal strain or supination, deformations can cause greater forces to support the weight in the lower kinetic chain.

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