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CONSIDERATIONS ON DYNAMIC SOLICITATIONS ON HUMAN LOW LIMB DURING LOCOMOTION

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ABSTRACT

During human locomotion, in every moment of a walk cycle, the loading on support leg or on the two legs is variable and produces different solicitations on the low limb. These progressive forces produce mechanical reactions in concerned articulations.

On one hand the forces are dependent on subject’s weight and on its anthropometrical dimensions and on the other hand, the dynamic characteristics are variable on performed movement locally and globally by the low limb and by the whole human body. The knowledge of these solicitations intensity of has a great importance in designing the prosthesis and orthesis that are personalized devices.

The present paper presents some results obtained by an authors’ method as to obtain series of numerical values in different moments of the locomotion and for different subjects in established sections on the length of limb. These results are further used to model the concerned prosthesis and to design it.

Keywords: human gait, solicitation, dynamics

1. LOCOMOTION SYSTEM MOVEMENT FUNCTION

Last years an increasing interest on human locomotion dynamics is evident. Human gait is a moving process in which the body is cyclically and alternately supported by each leg (with a transition period when both legs are in contact with the soil). Using prosthesis and orthesis devices, during locomotion is necessary to consider two basic conditions: continuous soil reaction and periodic movement of every leg from a support position in the next one in displacement sense. Every displacement cycle is a complex mechanism that needs to consider different factors as: soil reaction, total dispensed energy for locomotion and physic action of muscles and it can be decomposed in two principal phases: *support phase (62 %)* when the leg is in contact with soil and *balance phase (38 %)* when it is no more in contact and it is balancing to prepare the next support phase. Each of them is divided in more sub-phases and that drives, finally, to eight periods contents in a gait cycle, each of them defining the events connected to leg’s movement in respective period.

2. DYNAMICAL AND KINEMATICAL STUDY OF INFERIOR LIMBS

Human and animal systems formed from bones and muscles always were in scientists’ attention; they had tried to explain organic functions by mechanical theories. Most outstanding ideas belonged to Da Vinci, Galileo and Borelli and they are even today used to determine the forces in muscles. Much later (1892), appeared Wolf’s law saying that mechanical solicitations determine bones’ modeling. In 1965, the influence of muscles on long bones’ solicitations was demonstrated (Pauwels). All this knowledge is important for orthopedics devices conception but due to practical and ethical reasons is very difficult to determine in vivo the forces developed by the muscles. This imposed the use of mathematical models for human segments considered as rigid solids with inertial properties. One of most frequently used models for the reaction forces in leg and ankle articulation, for example, is Bresler and Frenkel model (1950) that is simple and easy to define (figure 1).

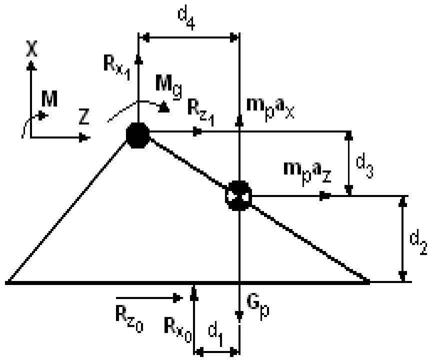


Figure 1. Triangular rigid model of leg.

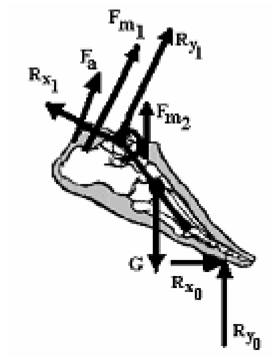


Figure 2. Biomechanical model of leg-ankle system

The movement equations can be written by two methods:
- *Dynamic direct method* where the kinematical parameters are obtained by integrating movement equations in which articulations moments and forces are supposed to be known or equal to zero;
- *Dynamic inverse method* where the kinematical parameters are considered as known and the forces and moments in articulations are determined. The bones are considered to be articulated rigid bodies and forces a re divided in two categories: internal and external – gravitational and reactions of the soil (the only measurable forces). Gravitational forces are calculated in same manner as segments' inertial moments using approximating techniques and anthropometrical dimensions.

2.1. Dynamic reaction forces in ankle's articulation

Dynamic inverse method is used taking into account the two known categories of forces: internal forces – reaction of the articulation $R_{x,y1}$, Achilles' tendon force F_a , force in triceps muscle of shank F_{m1}, force in tibia anterior muscle F_{m2}, the weight G, and the external forces – the reaction forces of the soil on leg $R_{x,y0}$) (figure 2).

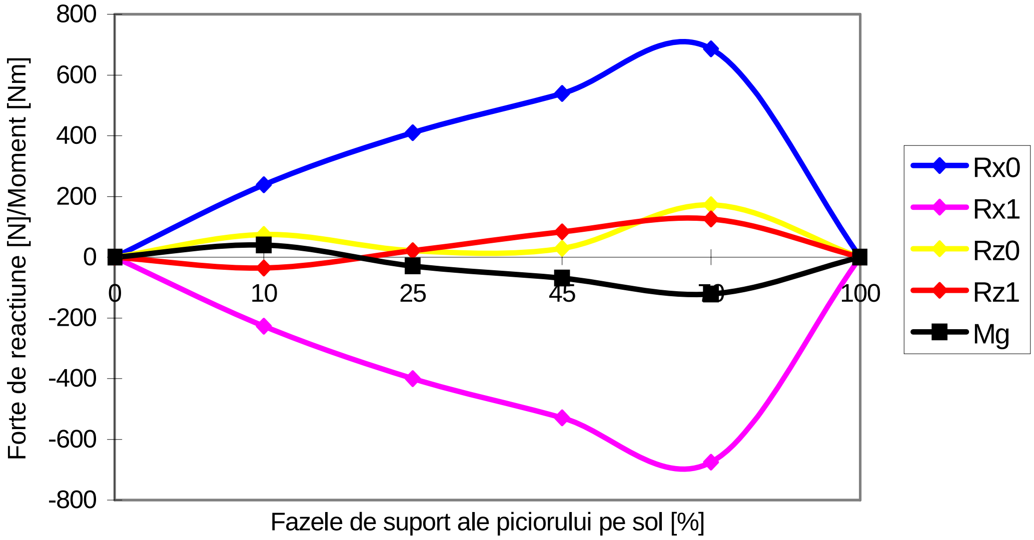


Figure 3. Reaction forces (of soil on the leg) – support phase evolution diagram for a subject of 70 kg weight, where $R_{x,z\,o}$. are the soil reaction along respective directions on the articulation, $R_{x,z\,1}$. are the reaction forces in articulation and M_q is the total developed moment.

Using the knowledge on support phase periods, reaction forces and the moment of forces in muscles were estimated. The used anthropometrics were those corresponding to adult persons (70-100kg).
Writing the dynamic equilibrium equations and reducing the unknown parameters by doing simplifying hypothesis, we obtain an equations system giving us the possibility to calculate the reactions and the moment in leg – ankle articulation system during all periods of movement and to recover the correct biomechanical model.
Based on kinematical parameters obtained values, the variation of internal and external forces during the support phase evolution could be graphically represented (figure 3).
The developed moment determine what group of muscles is acting in every moment of the movement and the necessary value for a normal locomotion.
Mechanical power shows us the contracting muscles in a specified moment of locomotion. If there is no movement (contraction of certain muscles), the angular acceleration and mechanical power will be zero. If the articulation is rotating in the muscles' contracting sense, mechanical power will be positive and correspondent to concentric contraction. In contra sense, the negative mechanical power will correspond to eccentric contraction of muscles. These types of contractions promote a better understanding of muscles' action; if they are working to produce an external mechanical work or to absorb energy, to accelerate or to break the articulation.

2.2. Dynamic reaction forces in knee articulation

Following the same algorithm as above, we can determine the articulation reaction and total moment in knee. As previous, the tibia segment was considered as a rigid body and the friction forces with the air and internal friction in articulation were considered as equal to zero.
Based on kinematical parameters obtained values, the variation of internal and external forces in knee, during the support phase evolution could be graphically represented (figure 4).

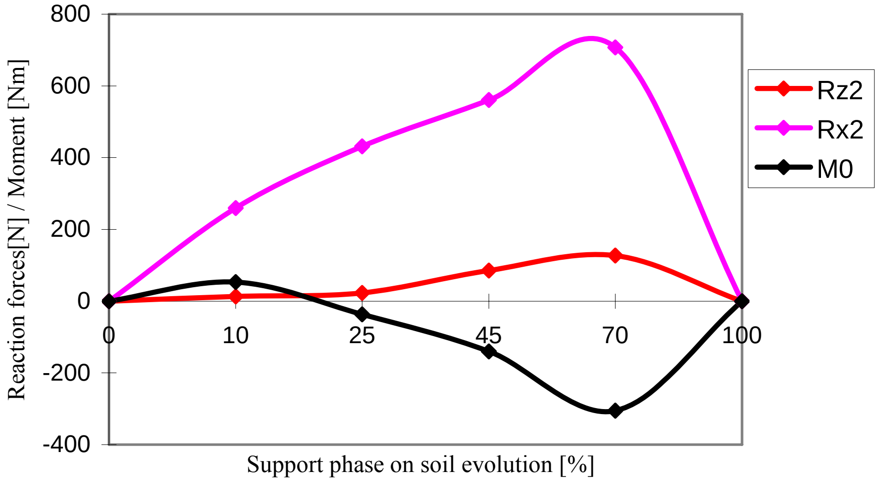
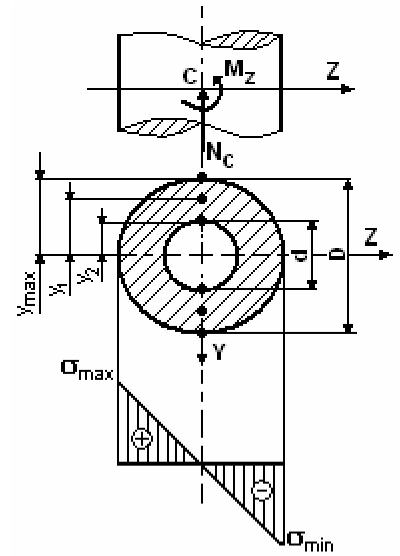


Figure 4. Reaction forces and respectively the moment in knee articulation variation - support phase evolution diagram for a subject of 70 kg weight, where $R_{x,z\,2}$. are the reaction forces in knee articulation and M_g is the total developed moment.

2.3. Stress determination in the fracture section of fibula

Long bones diaphyses of lower limb are normally under a composed solicitation of compression and torsion. In case of bone fracture the stress values are bigger because of muscles' contraction.
For the study, fibula is considered as a beam fixed in top and under a compressive load. In case of fracture, the solicitation will also be of torsion and bending. In order to determine the stress in the fracture section of fibula, it was considered with a constant annular section all along the studied zone. The geometric model was determined by Mimics software having as base the tomographic images of a person having about 70 kg weight. The maximal values were adopted considering the above studied solicitations that are represented in figure 5.



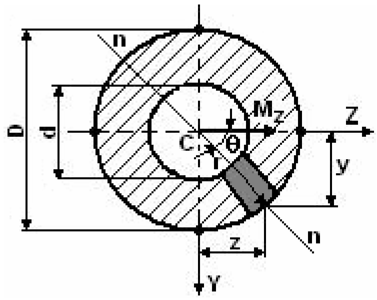


Figure 5. a) Solicitations in fracture section; b) the angle $\theta \in (0,2\pi)$.

The stresses were calculated on contour of fibula and so $\theta \in (0, 2\pi)$ and it has an obvious periodic sinusoidal variation is.

3. CONCLUSIONS

Determining the kinematical and dynamic solicitations acting on the lower human limb has a major importance for the designing and for the construction of orthopedic devices – prosthesis and orthesis that are supposed to resist during their exploitation to the same conditions as the real bones.

Due to ethical reasons a lot of in vivo measurements are not possible and the necessary values are obtained by modeling.

Solicitations' values are dependant of the phase of gait and they are specific to anthropological values for the human subject whose bone is studied.

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