IDENTIFICATION OF LOADS IN THE LOWER LIMB JOINTS DURING GAIT FOR PATIENTS AFTER TOTAL KNEE OR HIP REPLACEMENT

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The aim of this research was to elaborate the investigation methodology for monitoring the rehabilitation progress of patients with dysfunctional lower limbs. The rehabilitation progress was evaluated on the basis of comparative analysis between kinematic and dynamic parameters measured during individual stages of rehabilitation and standard data. Measurements of ground reaction components and kinematic parameters during gait as well as identification of muscle forces acting on the lower limb were carried out. Muscle forces were identified on the basis of static optimization with the help of our own computer program. Experimental and modelling investigations were performed in GCR Repty with healthy people and with patients after total hip or knee replacement.

KEY WORDS: gait, rehabilitation, modelling.

INTRODUCTION: Present methods of evaluation of treatment and rehabilitation progress are mainly based on the doctor's subjective estimation. Undoubtedly, the lack of possibilities to compare present examinations to previous ones is a great disadvantage. Modern methods of treatment and rehabilitation require the full and objective documentation of the patient's treatment (De Lisa, 1998; Winter, 1979). Experimental investigations enable determination of ground reactions, distribution of kinematic parameters and resultant moments and forces acting on joints (De Lisa, 1998; Ounpuu & Davis & DeLuca, 1996). All these values can be used both to diagnose pathological states and to monitor rehabilitation progress but they do not provide information about loads in the skeletal system and about forces generated by muscles. In order to calculate these quantities it is necessary to formulate a mathematical model (Michnik & Tejszerska & Jurkojc, 2005; Tejszerska et al 2002).

METHODS: The methodology of experimental and modelling research into estimation of rehabilitation progress is presented in this paper. It is assumed that the comparative analysis between kinematic and dynamic parameters, obtained for different stages of rehabilitation, and the standard ones enables monitoring of rehabilitation.

The main part of this research is a mathematical model of the human lower limb motion. It consists of three rigid segments (corresponding to the thigh, lower leg and foot) joint with each other in a kinematic chain which can perform plane movement in the saggital plane. It is assumed, that gravitational forces, inertia forces, ground reactions, reactions in joints and muscle forces act on individual segments of the lower limb. The 9 groups of muscles, acting on the skeletal system, are taken into account. These muscles perform the most important functions operating basic forms of human locomotion in the sagittal plane. All muscles are treated as massless elements acting at defined points of muscle insertions at specified rigid segments. For the force distribution equations of motion were derived. Their matrix form is as follows:

$$\mathbf{M(q)\ddot{q}} = \mathbf{F(q)} - \mathbf{R(q,\dot{q})} + \mathbf{BT}$$

where:	$\mathbf{q} = [\Theta_1, \Theta_2, \Theta_3]^T$	– matrix of general coordinates,
	M(q)	– matrix of inertia,
	$\mathbf{R}(\dot{q}, q)$	– matrix of generalized dynamic forces,
	F(q)	– matrix of generalized external forces,
	B	– control matrix,
	T	– column matrix of moments of muscle forces with respect to joints

In order to determine kinematics quantities the subjects' gaits were examined and measured in the Rehabilitation Center in Repty. Kistler dynamometric platforms and video-recording, with the help of two camcorders (50Hz each), were used. Every patient had markers stuck to characteristic points of the lower limb. Every patient underwent the tests twice: at the beginning of the rehabilitation and at the end.
Then, with the known kinematic quantities, dynamic quantities could be calculated. The first stage of calculations, performed with the use of the inverse dynamic approach, consisted of the determination of resultant moments of muscle forces with the known kinematic quantities and ground reactions. In the second stage muscle forces were identified. Muscle force was modeled on the basis of the Hill model and decomposed into two components: passive and active. The first one was dependent on the length of the muscle and the second one on the cross-section area of the muscle, length of the muscle, muscle activation and velocity of shortening.

$$F^M(t) = a(t)F_A^M + F_B^M \qquad (1)$$

F_A^M – active component of muscle force,
F_B^M – passive component of muscle force,
a(t) – muscle activation
Muscle forces were identified with the help of the static optimization. Objective function was as follows:

$$J = \min \sum_{i=1}^{9} (F^M)^2 \qquad (2)$$

with the following constraints:

$$r_M F^M = T$$

$$0 < F_i^M < F_{max,i}$$

where: rM – matrix of muscle forces arms with respect to joints,
FM – column matrix of muscle forces,
Fmax – maximum muscle force during isometric contraction,

Then the loads in individual joints of the lower limb were calculated.

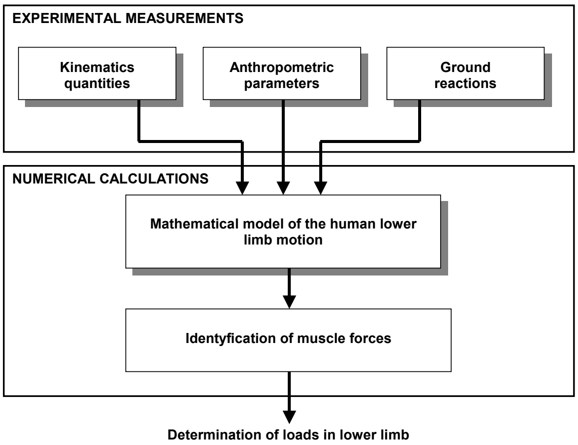

Figure 1: Block of numerical calculations

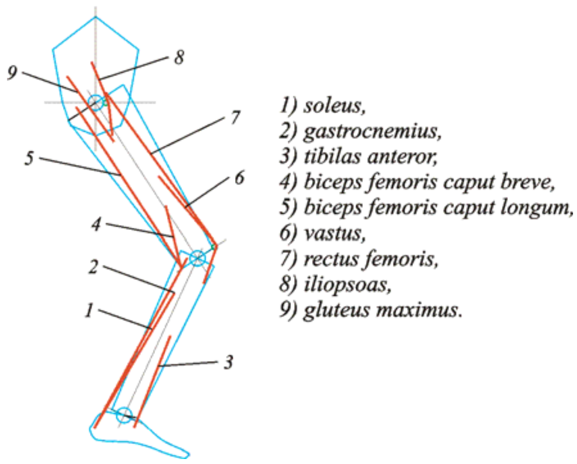

Figure 2: Scheme of physical model of human lower limb

On the basis of the obtained results, with the use of the APAS program and our own computer program, prepared in the Department of Applied Mechanics, comparative analyses of kinematic and dynamic quantities were performed.

RESULTS: Figures 3-5 present exemplary results obtained from patients after total knee replacement. What is important, kinematic quantities do not show the entirety of the progress of rehabilitation. Although there are noticeable differences between the distributions of kinematic quantities obtained before and after rehabilitation, they are not very significant. These differences are bigger and more visible in results obtained from calculations (moment of muscle forces and joint reactions) carried out with the help of the mathematical model.

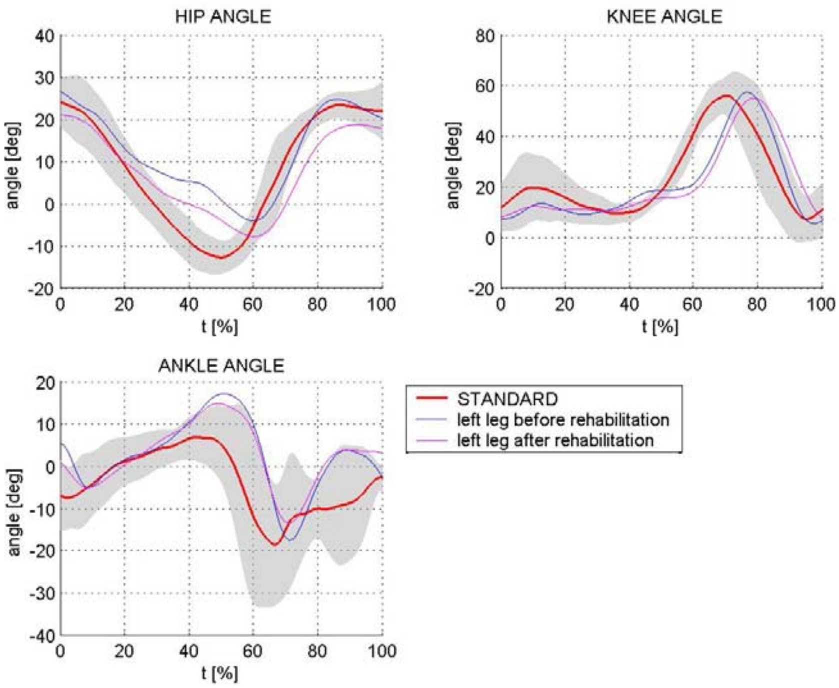

Figure 3: Time courses of joint angles during gait cycle

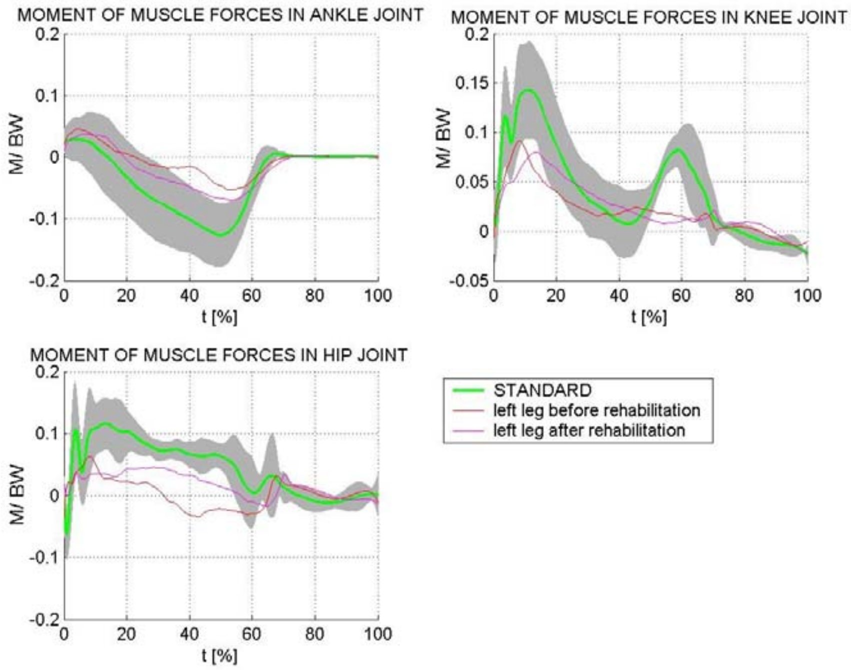

Figure 4: Time courses of moments of muscle forces during gait cycle

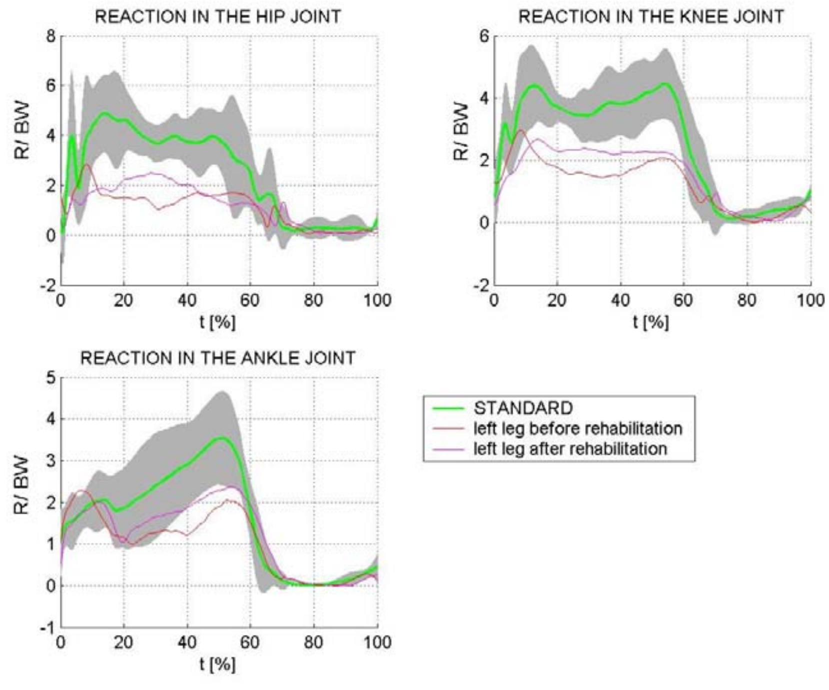

Figure 5: Time courses of reactions in joints during gait cycle

CONCLUSION: All determined values enable doctors to get to know a lot about the state of the human organ of motion. The great advantage of these kinds of research is that they can be carried out on every stage of treatment and rehabilitation process and one is able, on the basis of kinematic parameters, to conduct qualitative and quantitative analyses. Currently obtained results are complementing the computer data base, which also includes data of patients, their affections, treatment process etc. On the basis of these data methods of treatment and rehabilitation can be more easily assessed and modified.

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