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The estimation of rehabilitation progress in patients with psychomotor diseases of upper limb based on modelling and experimental research

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The methodology of experimental and modelling investigations enabling the monitoring of rehabilitation process in patients with upper limbs diseases is presented. The mathematical model and the set of computer programs were developed in order to identify the forces generated by muscles and to carry out a comparative analysis within a framework of inverse dynamic problem and with the use of optimization techniques. The changes of the selected muscle forces as well as the changes of the ranges of motion in individual joints of upper limb, while performing typical rehabilitation exercises, were assumed as an indicator of the rehabilitation progress.

1. Introduction

Nowadays modern methods of treatment and rehabilitation enable full and objective evaluation, comparison and recording of the effects of therapeutic methods. Direct noninvasive measurement of forces, generated by individual muscles, still seems to be impossible. The development of computer techniques and numerical methods as well as our knowledge of the principles that govern a musculoskeletal system functioning offer the possibility of adequate mathematical modelling and reliable computer simulations of upper limb motion [2], [4], [5].

The aim of this paper was to develop the method, which enables estimation and comparison of loads of musculoskeletal human upper limb system, especially the values of muscle forces, as well as the ranges of motion in the shoulder and in the elbow joint during typical therapeutic exercises. The main purpose of our method was to construct a comparative tool, which enables estimation of rehabilitation progress of patients with psychomotor diseases of upper limb.

2. The methodology of modelling and experimental research

In this article, the typical active therapeutic exercises, consisting in flexion and extension of the upper limb in elbow joint being loaded with the weight that creates determined resistance, were considered. Accepted simplifying assumptions of the model of the upper limb were adequate to achieve the aim of the work.

2.1. Model of the human upper limb

Upper limb was treated as a system of four rigid elements modelling the parts of anatomical structure: trunk, arm, forearm and hand. Connections between bones of limb were modelled as rotary joints, with one degree of freedom, disregarding a complex structure of joints and the possibility of motion in other planes. A motion in the sagittal plane only was considered, and in such a plane the exercises considered were performed. The motion was determined by 5 generalized coordinates, including position of the shoulder joint (x_1, y_1), and 3 angles which define an absolute orientation of movable elements (Θ_1, Θ_2, Θ_3). The values of the coordinates were determined by video-recording, with automatic computer processing of recorded pictures. Anthropometric parameters were measured or estimated on the basis of published statistic characteristics [6]. The following muscles were selected: *pectoralis major pars clavicularis*, *deltoideus pars anterior*, *deltoideus pars posterior*, *musculus coraco-brachialis*, *musculus teres major*, *musculus teres minor*, *triceps brachii caput longum*, *musculus subscapularis*, *biceps brachii caput breve*, *triceps brachii caput laterale*, *triceps brachii caput mediale*, *biceps brachii caput longum*, *musculus brachialis*, *musculus brachioradialis*, *musculus extensor carpii radialis longus*, *musculus extensor carpii radialis brevis*, *musculus flexor carpii radialis*, *musculus flexor carpii ulnaris*, *musculus extensor carpii ulnaris*, because their contribution to the movements of upper limb in saggital plane was fundamental.

Dynamic equilibrium equations were formulated for the hand and for two sets comprising hand and consecutive elements. Based on the set of three equations of moments, with three unknown values of the resultant moments of muscular forces, acting on the first joint of the set, the muscular forces were identified. In the first step, the resultant moments of muscle forces acting in individual joints of upper limb are determined based on the kinematical quantities obtained from video-recording. Having determined – by optimizing techniques – the forces generated by muscles, six dynamic equilibrium equations of forces acting on each part of the limb were used to calculate reactions in individual joints [1]–[3].

2.3. Experimental investigations

Experimental investigations were carried out in the Silesian Center of Rehabilitation in Repty on a special-purpose stand destined for therapeutic exercises (figures 1 and 2).

Fig. 1. The stand for therapeutic exercises

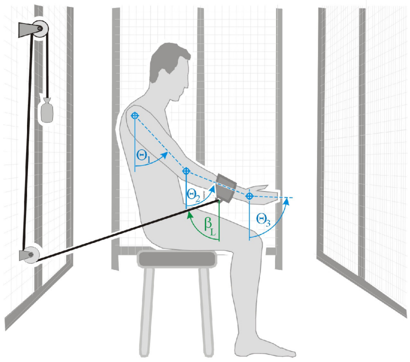

Fig. 2. The angles describing the upper limb motion obtained with the use of video-recording

2.2. Computer program "RehHand"

The software package "RehHand" enabling calculations, comparison and graphic presentation of the forces and loads measured was elaborated based on the methodology of experimental and model investigations of musculoskeletal system of upper limb. The package is composed of:

- the input data block, with personal information about patients and their anthropometric parameters,
- the block processing the results of video-recording, calculation values of kinematical parameters,
- the basic block identifying the values of muscular forces and the loads of joints during therapeutic exercises,
- the data base gathering information about patients and the results of measurements and calculations enabling statistic analysis and comparative presentation of the results obtained.

3. Results and summary of experimental and modelling research

The data concerning the sex and diseases of six patients, who took part in the research, are presented in the table.

Table. Data of patients

Patient	Sex	Loads [kg]		Diagnosis
		The first measurement	The second measurement	
Patient 1	Female	0.1	0.5	Degenerative changes of the cervical spine, compound fracture of upper limb in the shoulder joint
Patient 2	Male	1.5	3	Left-sided cervical-shoulder syndrome, discopathy on the level of C3–C4, degeneration of the shoulder and the elbow joint
Patient 3	Female	0.5	1	Discopathy of C5–C6 and C6–C7, degenerative changes of the cervical spine
Patient 4	Male	1.5	2.5	Fracture of the humeral
Patient 5	Male	2.5	3.5	Stabilization on the level of Th 12–L2, vertebral arthrodesis of C6–C7–Th1, stabilization on the level of C6–Th1
Patient 6	Male	0.5	1	Anterior stabilization of C1–C2 with the use of screw

Comparison of the time-dependent moments of muscle forces in the shoulder joint and in the elbow joints during rehabilitation and the time-dependent muscle force of *biceps brachii caput longum* are presented in figures 3 and 4.

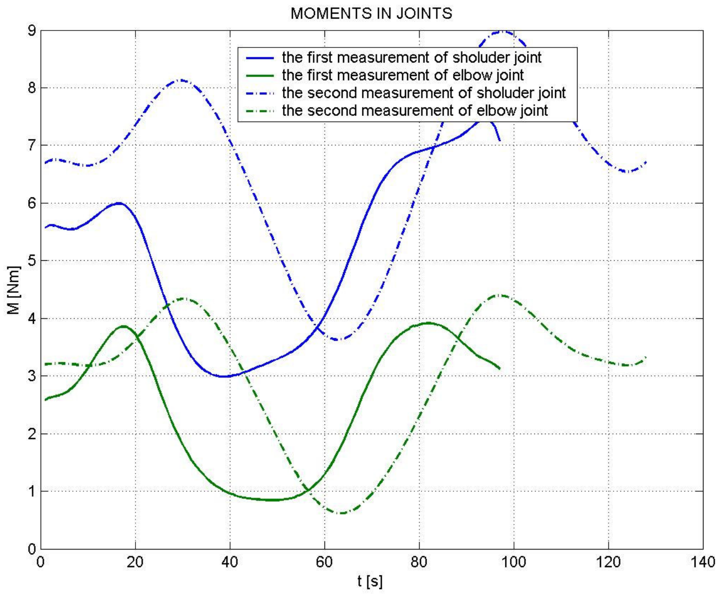

Fig. 3. Time versus the moments of muscle forces in joints

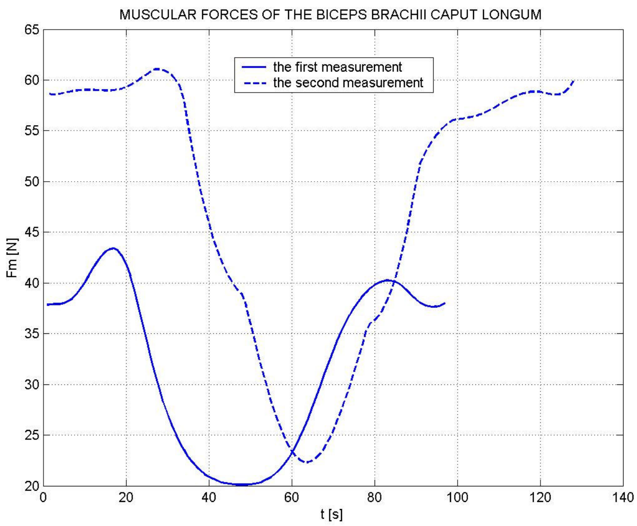

Fig. 4. Time versus the muscle force of *biceps brachii caput longum*

Besides the qualitative analysis of the curves obtained, the time of performing exercises, the range of motion in the shoulder and in the elbow joint, the maximal moment in the shoulder joint, the maximal moment in the elbow joint, the maximal force generated by selected muscles (*biceps brachii caput longum*, *deltoideus pars anterior*, *coracobrachialis*) were used to estimate the rehabilitation progress in the upper limb.

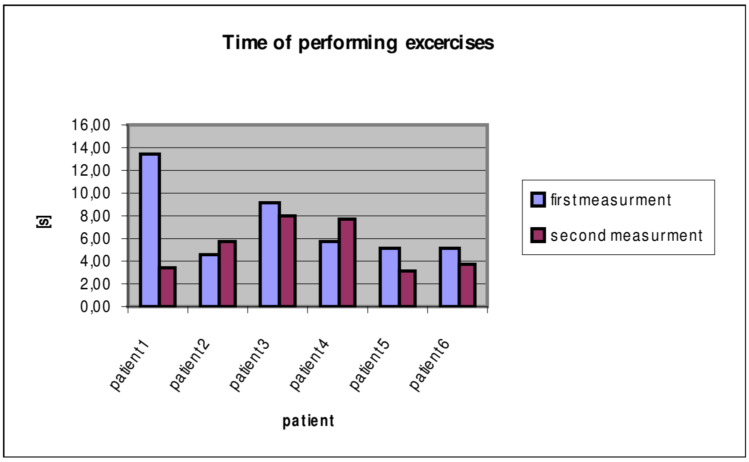

Fig. 5. The time of performing exercises

An average time of flexion and extension motions in the second measurement was about 5 s (figure 5). The shortening of the time of performing therapeutic exercises after the end of rehabilitation process in relation to the first measurements can be observed for the 1st, 3rd, 5th and 6th patients. Such a time, i.e. 1.16 s and 2.0 s, was not considerably longer for the 2nd and the 4th patients, respectively.

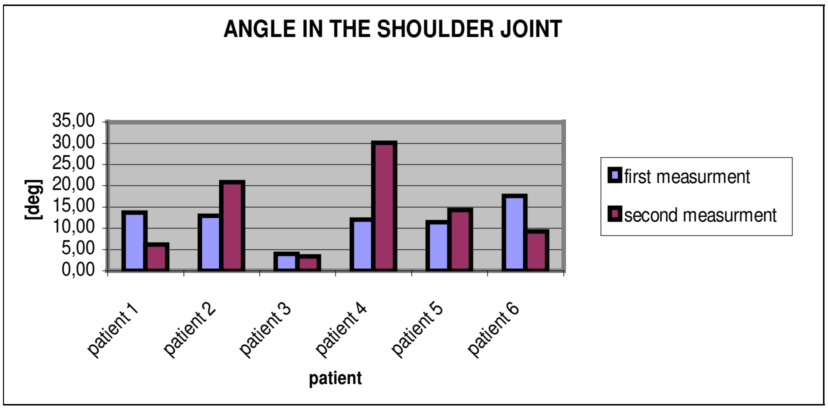

Fig. 6. The angle in the shoulder joint

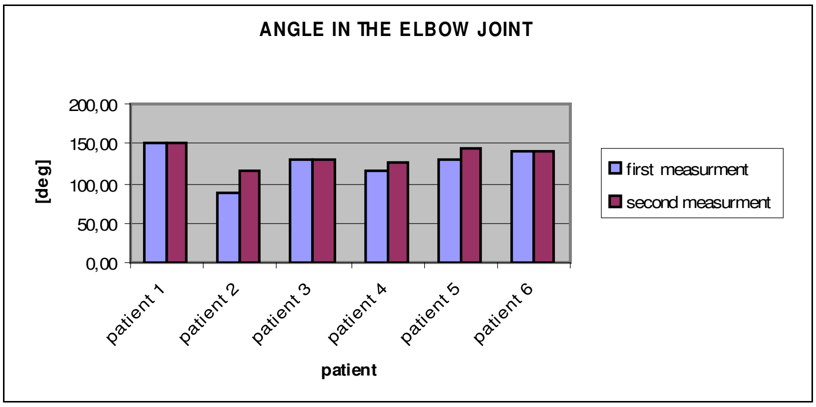

Fig. 7. The angle in the elbow joint

Analysing the range of an angle in the elbow joint, it can be noticed that rehabilitation process contributed to the increase in the range of motion in this joint (figures 6 and 7). The greatest progress can be observed for the 2nd and 5th patients, in whom this angle increased by about 27.5^{o} and 14^{o}, respectively.

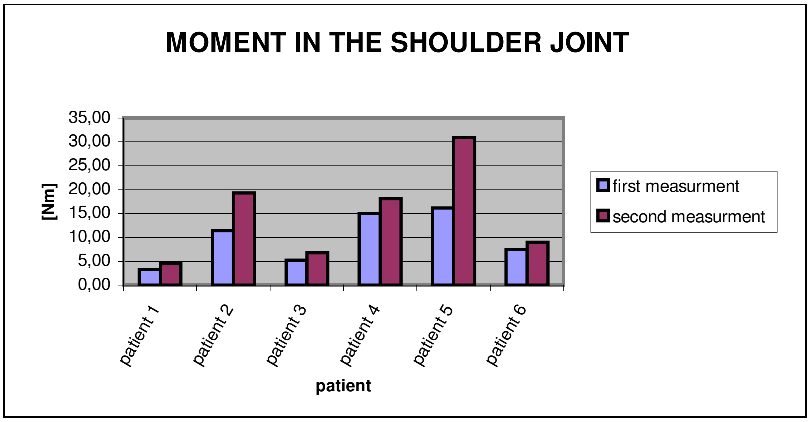

Fig. 8. Moment in the shoulder joint

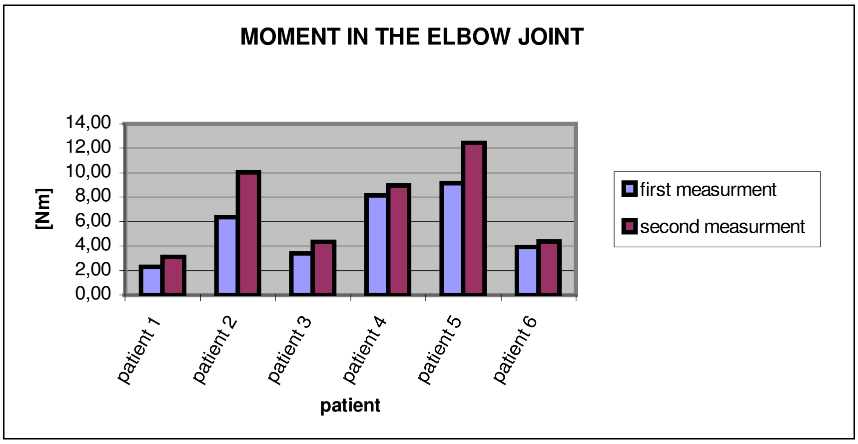

Fig. 9. Moment in the elbow joint

An increase in the maximal moments in the shoulder and in the elbow joints occurred in all patients (figures 8 and 9). One of the crucial factors affecting this increase is rising loads during the exercises performed. The increase in the resultant moments of the muscle forces in joints is connected with a growing possibility of generating larger forces by muscles. This mainly concerns the force of *biceps brachii caput longum*, which is of a fundamental importance in the exercise performed (figure 10). An increase in the muscle forces of the shoulder joint (*deltoideus pars anterior*, *coracobrachialis*) enables a better stabilization of the shoulder joint (figures 11 and 12).

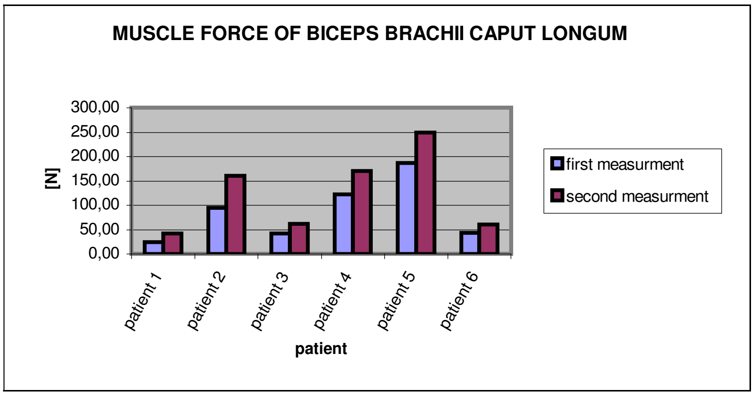

Fig. 10. Muscle force of *biceps brachii caput longum*

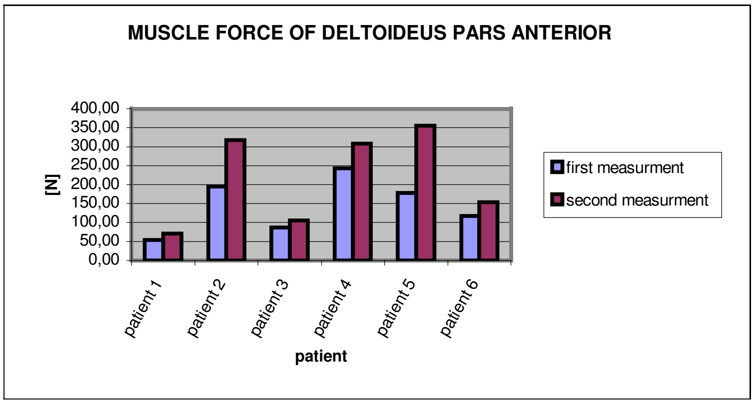

Fig. 11. Muscle forces of *deltoideus pars anterior*

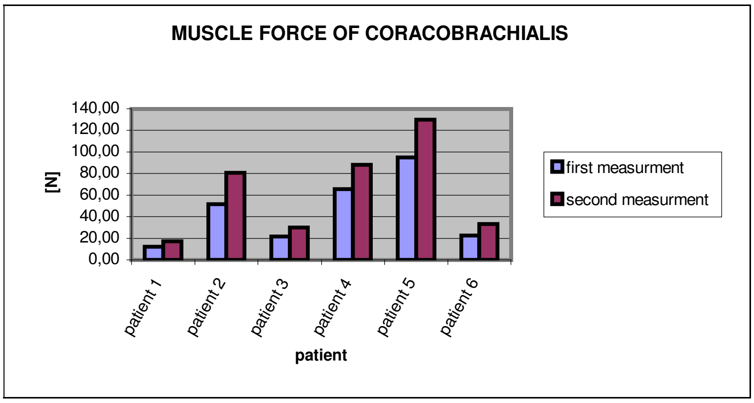

Fig. 12. Muscle force of *coracobrachialis*

On the basis of the analysis performed it can objectively be noticed that improvement occurred in all patients, which testifies to a successful rehabilitation process. An increase in the range of motion in the elbow joint as well as an increase of selected muscle forces were observed in all patients. A large improvement was noticed in the 2nd, 4th and 5th patients, in whom an increase of muscle force of *biceps brachii caput longum* approaching respectively 65%, 48% and 63% was noticed.

4. Conclusion

The mathematical model of upper limb motion and an adequate software package “RehHand” were the main elements of the methodology developed. The method presented is based on the measurement of kinematic and dynamic parameters during typical active therapeutic exercises. Our methodology was used in preliminary examination of a selected group of patients. The results obtained confirmed the efficiency of the method, showing the muscular forces and loads of joints during exercises and their effect on the progress in the rehabilitation process.

It is expected that a future development of our method will include its full implementation in routine patient examinations taken in the cooperation with the Silesian Center of Rehabilitation in Repty and in extensive comparative analysis of the influence of different exercises on rehabilitation progress in selected diseases.

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