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Comparison of static and dynamic model tests of loads of the musculoskeletal system during isometric rotation of the lower limb

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SUMMARY: This paper presents the use of mathematical modeling methods of the human musculoskeletal system in assessment of the muscular system functioning and to determination of the loads occurring in the lower limbs during external isometric rotation. In order to conduct the research, it was necessary to design the proprietary Rotenso measurement platform, allowing for the simultaneous measurement of the ground reaction and the value of the rotating moments in the lower limbs. After designing and verifying the operation of the device, research was carried out on a group of 33 people. The tests consisted of performing isometric rotation of the lower limbs. Based on the obtained results of the kinematics tests, the value of the ground reaction and the values of the rotating moments of the lower limb, static and dynamic model tests were carried out. Based on these studies, the value of the activation of the lower limb muscles responsible for the rotation of the hip joint and stabilization of the knee joint in the frontal plane was determined. The last stage was to compare the results obtained in dynamic and static simulations.

KEYWORDS: modeling, lower limb, isometric rotation

1. Introduction

Based on the literature review, it can be noted that the problem of rotation should not be underestimated due to the limb injuries related to the reduced ability to generate the rotating moment of the lower limb in the hip joint [1-2]. In connection with the above information, a very important aspect during the course of rehabilitation and diagnostics of the skeletal and muscular system of the lower limb is to pay attention to the isometric rotation of the lower limb. The literature review also showed that there are no measuring devices that would allow for the examination of the isometric rotation of the lower limb in a standing position. Therefore, it was necessary to develop the proprietary Rotenso device (Fig. 1) and the research methodology that allowed to obtain the results necessary for model tests.

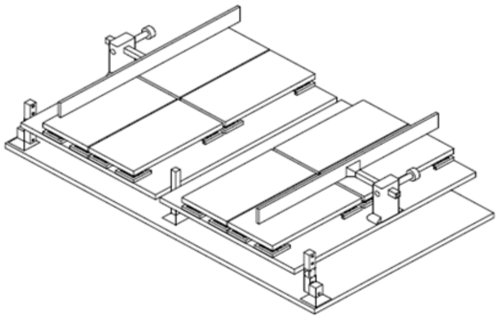

Fig. 1. Schematic drawing of the proprietary Rotenso platform

The operation of the platform's measurement system was verified with the use of a reference device: AXIS FA500. The verification was carried out by comparing the measurement data with the reference data in the functional range of the device, and then the linear regression coefficient was calculated, obtaining the regression accuracy R^2 equal to 0.995.

2. Method

33 people aged 22.8 years (SD=2.4), weighing 71.2 kg (SD=18.5) and body height 166.2 cm (SD=18.5) participated in the experimental studies. The study was conducted using the Rotenso platform and YostLabs 9DoF IMU sensors.

Before starting the measurement, the patient's foot was placed on the Rotenso platform each time in a way that would allow the pressure forces to be measured from appropriate anatomical points and so that the limb rotation axis was always coaxial with the platform rotation axis.

During the study, 1 trial for each person was recorded. It was maximum isometric rotation of the right limb for 10 seconds.

The static simulation was performed using the FreePostureStatic model. Dynamic simulations in the AnyBody environment were performed using the FreePostureMove model. The values of the ground reaction forces, pelvic rotation and rotating moment (Tab. 1.) have been implemented in the model in accordance with Fig. 2. For the dynamic model, the time courses of the above parameters have been implemented, while for the static model values at the time when the highest value of the limb rotating moment occurred. The values of muscle activity expressed in the form of the ratio of the maximum muscle strength to the muscle strength generated during the exercise were analyzed.

Tab. 1. Maximum average rotating moment during right lower limb rotation

	Left limb rotating moment [Nm]	Right limb rotating moment [Nm]
mean	8.34	11.28
std	4.63	6.28

The results of the research on the Rotenso platform were compared with the research of Uritani D. et. all [3] that were carried out on Biodex System 3. In this publication, the mean value for the lying position was 36.5 ± 8.5 [Nm], for the reclining position it was 42.0 ± 14.5 [Nm], for the sitting position the mean value of the moment of forces rotating the lower limb was 43.4 ± 13.8 [Nm]. Differences in the results may have occurred due to the position taken during the study.

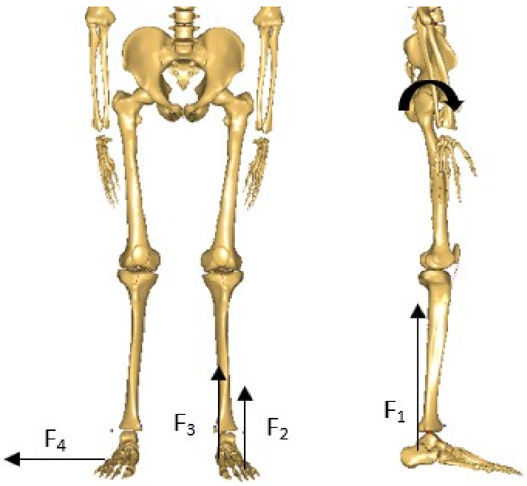

Fig. 2. Presentation of the input data implemented in the FreePosture model

3. Test results – comparison of static and dynamic simulation

The static and dynamic model was calculated by a high-performance consumer computer (i7 9700k processor, 32 GB RAM, 2350 MB/s write disk). Dynamic simulations were carried out for 8 seconds of movement with a frequency of 20 Hz. The calculation time for the static simulation was 75 seconds, and for the dynamic simulation it was 1100 seconds. In addition, the angles of the joints in the FreePostureStatic model are entered before simulation and are controlled by the file "mannequin.any". In the FreePostureMove model, the angles in the joints during the simulation are controlled by the file "MannequinInterpolation.any". Another difference for the given models is the complexity of calculations for the dynamic model, which affects the errors that occur during the calculations.

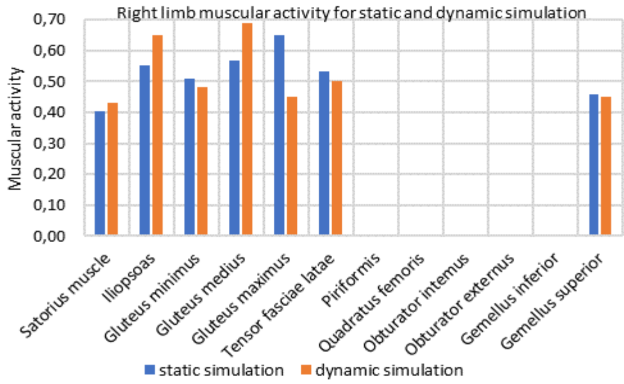

Fig. 3. Comparison of static and dynamic simulation results for right limb rotation

The results were presented for one test person. For the rotation of the right limb only, the highest mean difference in average activity was found for the *gluteus maximus* 0.16 ± 0.10. There was no difference for the muscles that were not activated. (Fig. 3).

4. Summary

The presented experimental and model studies allowed for the analysis of the influence of isometric rotation of the lower limb on muscle activity and the comparison of the value of muscle activity determined with the use of a static and dynamic model.

Conclusions:

1) In order to conduct the model tests, it was necessary to construct the proprietary Rotenso device, which enabled the collection of input data for numerical simulations, ensuring the appropriate reliability of the results.
2) The use of the static model allowed for a significant reduction in the computation time, but the results for some muscle groups differed from each other.
3) The implementation of the input data for the static model is much simpler due to the necessity to enter data only for one time moment.
4) The muscle that increased its average activity the most during the static simulations was the *gluteus maximus* muscle.
5) The muscle that increased its average activity the most during the dynamic simulations was the *gluteus medius* muscle.

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