Analysis of Boundary Conditions in Locally Focused Passive Validation Experiments for Human Body Models

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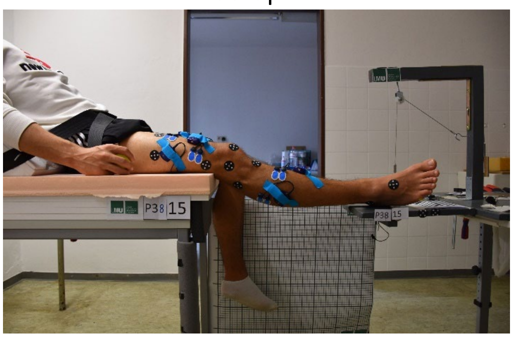
I. INTRODUCTION

High quality experimental data is vital for isolated validation of passive and active Human Body Model (HBM) parts. Based on a series of gravity-induced knee flexions the passive behaviour was approximated with relaxed volunteers, with relaxation level determined by superficial muscle activity measurement [1]. So far, there is no other proof for lower leg motion being carried out completely passive. Therefore, further experimental verification of passive kinematics was deemed necessary to create a reliable validation baseline characterising fully relaxed behaviour, in turn facilitating validation of muscle controllers. For this, we plan to support volunteer results presented in [1] by carrying out corresponding experiments with awake and general anaesthetised patients undergoing planned surgery, e.g. [2]. Prior to testing on anaesthetised patients, gravity-induced knee flexions will be evaluated in an experimental sensitivity study with awake (i.e. not anaesthetised) subjects. In the present short communication, stepwise differences between the future clinical and existing laboratory environment that may affect direct transfer to the simulation environment will be investigated.

II. METHODS

So far, one 50th percentile male volunteer (24 years old, height: 178 cm, weight: 66 kg) has been tested. All test procedures were approved by the Ethical Committee of the Medical Faculty of Ludwig-Maximilians University (LMU), Munich, Germany. Setup L represents the baseline lab setup, with the trunk elevated at 40°, left knee flexed with one shank suspended freely [1][3]. Setup C corresponds to clinical boundary conditions replicated in the laboratory. Here, the subject is supine with the left leg straightened out on the operating table. In both setups, the right leg is supported only at the thigh by a padded foam. The heel rests on a hatch, which is actuated by an electromagnet (Figure 1). To understand every positioning detail's level of influence adding up to possible global kinematic differences between setup C and L, stepwise alterations were evaluated. First, the upper body was changed to supine (as in setup L (intermediate setup I1)). Second, the left leg was repositioned to match the posture in setup L (intermediate setup I2). For all trials, the right knee angle was adjusted to initially load the thigh minimising soft tissue influence. Baseline setup L, intermediate steps I1 and I2 and setup C were tested three times, respectively.

Setup L



Setup C

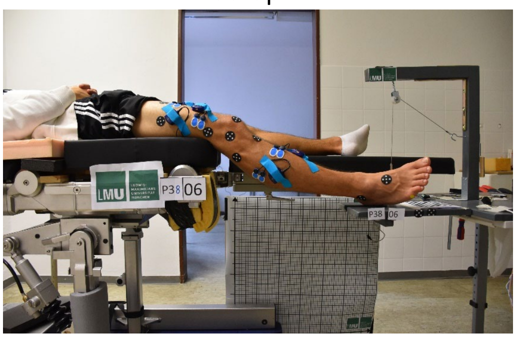


Fig. 1. Sagittal view of test setups: setup L with subject in reclined seating position (left); setup C with subject in supine position on operating table (right)

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In this sensitivity study, the volunteer was given a verbal countdown prior to testing to foster a relaxed response [1]. Among others, activity of the vastus lateralis (VL), biceps femoris (BF) and rectus femoris (RF) muscle was measured at 2000 Hz using wireless surface electromyography (EMG). 2D motion was captured at 2000 Hz using a high-speed camera. As a first metric for comparison, gravity induced lower leg drop pendulum time at 65° knee flexion was calculated from 2D skin markers (described in detail in [3]) whenever EMG data suggested passive or very low muscle activity relative to individual maximum voluntary contraction level.

III. INITIAL FINDINGS

Preliminary results of one are presented. Pendulum times in setup C, I1, I2 and L, respectively, at 65° knee angle are presented in Table 1. Median pendulum time was shorter for setup L than setup C by 61.7 ms. Main increases in median pendulum time were observed between setups I2 and C with 45.1 ms and I1 and I2 with 15.4 ms, respectively. A minor difference occurred between L and I1 with 1.2 ms. Ten out of twelve trials were classified as passive. Minor muscle activity in two trials was observed in either BF or RF but no relevant change in fall times was detected. The repeatability exceeds the marker tracking accuracy of ± 1 ms.

TABLE I

LOWER LEG DROP PENDULUM TIMES (N=3) FOR ONE SUBJECT IN SETUP L AND SETUP C AND INTERMEDIATE SETUPS I1 AND I2 (MS)

Trial/Setup	**L**	**I1**	**I2**	**C**
01/03	373.6	375.7	392.7	448.9
02/03	376.9	375.2	388.9	435.7
03/03	374.0	372.4	390.6	434.0

The flexion angle of the hip joint represents the most prominent difference of the positioning of the two test setups (Figure 1). In addition, a variation in external rotation of the hip joint was noted between Setup C and L, which was evident from the increased lateral tilt of the foot in the supine C setup. The thigh cushioning allowed various degrees of motion for the right lower leg and thus the knee joint around the sagittal axis. This motion was noticed in the initial phase of the pendulum movement of the right lower leg.

IV. DISCUSSION

In the supine position on the operating table, passive flexion of the knee joint appeared to be slower than in the upright position. The observed pendulum times for setup L align adequately with the mean pendulum times shown in [2], which indicates a good reproducibility of the data in the tested setup. Based on preliminary results it must be assumed that the test conditions in C cannot be standardised as accurate as in corresponding laboratory tests. This requires the most accurate analysis of possible external influencing factors. In this study, the differences concerning the pendulum times between the two setups can be ascribed to corresponding variations. Especially, the different seated position with regard to the tension in the hip flexor muscles during different hip flexion angles should be considered a potential influential factor. Beyond that, the different cushioning possibly leads to small movement variations of the right thigh initially; its potential influence on the passive flexion of the knee joint is not entirely negligible. The preliminary findings are based on a single subject and therefore will need to be reviewed in light of more subjects' results.

Despite the subject's ability to relax sufficiently, we cannot rule out muscle activity completely. However, for the optimisation of muscle parameters in Finite Element Human Body Models validated passive behaviour is obligatory. In order to achieve complete muscle inhibition, a subsequent trial of passive knee pendulum tests with patients medicated with muscle relaxants during anaesthesia is required [2]. In that respect the demonstrated results indicate that pendulum times cannot be transferred directly from already gathered findings from previous studies to prospective trials under anaesthesia. Influential factors such as positioning should be considered and will be further investigated on a larger number of volunteers.

V. REFERENCES

[1] Muehlbauer, J., et al., IRC-21-77, 2021.

[2] McKay W.P., et al., Eur J Appl Physiol, 2010.

[3] Muehlbauer, J., et al., IRC-20-26, 2020.