# Is Strength Scaling Sufficient for the Development of Personalized Multi Body Models?

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**Introduction**
In orthopedics a solid understanding of the impact of muscle forces on skeletal loading is of importance. Recent advances in modeling software have facilitated the application of multi-body models to understand the contribution of individual muscles to human movement. One of the major challenges is to determine the muscle strength parameters. Strength scaling laws are thought to be useful to match a model to a specific individual. However, existing scaling methods lack validation [1]. Properly validated models are an essential requirement for the application of personalized models [2].
The purpose of this study is to validate two different scaling laws for a leg press task.

**Materials and Methods**
20 young and healthy subjects participated in this validation study. Anthropometrical data (e.g. age, gender, leg volume and mass) was obtained (table 1) and imported into the Anybody modeling system to scale subjects individually.
A leg-press setup was used to obtain maximal isometric leg press data. Ankle, knee and hip angles were obtained with a 2D motion system. A Pressure plate was vertically attached at the foot rest of the leg-press
In Anybody a model with two legs and a trunk with 3 element Hill muscles was used. Anybody was used to simulate the same leg-press as the practical set-up. Joint angles of the ankle, knee and hip from the motion system were calculated and inserted in the modeling software, together with the center of pressure and maximal force from the pressure plate.
Two scaling methods were examined ; 1) a scaling method based on 3 variables: Length, Mass and Fat ($SSF_3$) [1], this factor is calculated for each segment individual; 2) a scaling method using 7 empirically variables ($SSF_7$) including, segment specific masses and lengths, fat percentage, age and gender [2], this factor is similar for all segments. All results were compared to a standard model for which the strength scaling factor was defined as 1 (SSF=1).
Muscle activations during leg press were calculated by running the inverse dynamics routine in Anybody. The primary outcome measure was maximal muscle activity (MMA), where 100% indicated that the muscle was activated to its full potential. The closer the MMA values approached 100% the better the scaled model matched the subject's maximal effort.

Table 1. Subject characteristics and results. Displayed as mean (±sd)

| | Total | Male | Female |
|---|---|---|---|
| N | 20 | 11 | 9 |
| Age (y) | 22.4 (±2.5) | 22.2 (±2.4) | 22.6 (±2.8) |
| Height (m) | 1.79 (±0.10) | 1.84 (±0.09) | 1.72 (±0.07) |
| Mass (kg) | 71.8 (±12.0) | 77.9 (±12.3) | 64.4 (±6.4) |
| BMI (kg/m2) | 22.4 (±2.5) | 23.0 (±3.0) | 21.7 (±1.5) |
| Fat (%)* | 20.6 (±7.2) | 15.2 (±4.8) | 27.1 (±2.9) |
| Shank mass (kg) | 3.7 (±0.6) | 3.9 (±0.6) | 3.5 (±0.5) |
| Thigh mass (kg) | 5.5 (±1.0) | 5.8 (±1.0) | 5.2 (±0.8) |
| Shank length (m) | 0.43 (±0.04) | 0.45 (±0.03) | 0.40 (±0.04) |
| Thigh length (m) | 0.46 (±0.04) | 0.47 (±0.04) | 0.45 (±0.03) |
| MVC (N) | 1923 (±557) | 2180 (±592) | 1608 (±310) |
| $SSF_3$ | 0.74 (±0.18) | 0.88 (±0.08) | 0.57 (±0.11) |
| $SSF_7$ | 0.91 (±0.17) | 1.03 (±0.11) | 0.77 (±0.11) |
| MMA $SSF_3$ (%) | 90 (±20) | 84 (±19) | 97 (±19) |
| MMA $SSF_7$ (%) | 105 (±25) | 102 (±21) | 109 (±30) |
| MMA SSF=1 (%) | 94 (±20) | 104 (±17) | 82 (±16) |

* Calculated by method of Gallagher et al (2000) [3]

**Results**
Overall results (table 1), female and male subjects combined, show better prediction of MMA in scaling laws with more variables ($SSF_3$=90%, $SSF_7$=105). The results indicate that female subjects were better scaled with the $SSF_3$ method (MMA=97%) while male subjects were better scaled by the $SSF_7$ method (MMA=102%).
Overestimations or underestimations of individual subjects are shown in figure 1. Standard deviations of mean MMA are 20% in $SSF_3$ and 25% in $SSF_7$ (table 1).

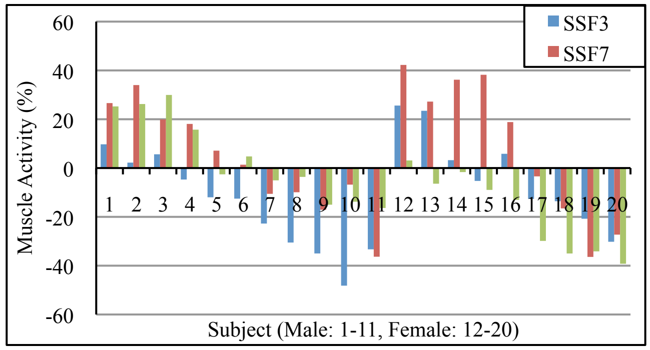


Figure 1: Individual results of the muscle activity (overestimation > 0% or underestimation < 0% of the muscle force).

**Discussion and Conclusion**
The results of this validation study show that on average the MMA approached 100%, however there was a relatively large standard deviation of MMA. This indicates that for generic purposes scaling might be a useful tool, but that it is less effective for personalized modeling. Therefore, personalized scaling requires different methods. Possibly, using individual muscle parameters obtained from imaging techniques might improve results for personalized body models.

*Ongoing research:* MRI research shows that T1-imaging has potential for detecting accurate individual muscle volumes. In combination with Diffusion Tensor Imaging (DTI) [4] it can detect muscle fiber lengths in a measured volume, in order to calculate the physiological cross sectional area. First steps are taken to load one subject's lower extremity data obtained from MRI into the Anybody modeling system. The generated models with imaged musculoskeletal parameters will be again validated by experimental setups, e.g. maximal strength tests and gait analysis. A comparison with EMG and muscle activities in the model will give us information about the accuracy generated by the model.

*Future research:* We will examine patients with knee osteoarthritis (OA), who suffer from muscle weakness and altered walking patterns. These walking patterns will be evaluated with gait-analysis. Also maximal strength will be tested and patients will receive a MRI scan. Individualized models of these patients with inserted muscle parameters will be compared with performance tests and gait analysis. This gives valuable information about the possibility of introducing these models in specific patient groups. Therefore, it could be a tool for calculating joint loading or altered activation patterns during walking, which is an important factor in the development in OA [5].

**References**
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