A 3D Muscle Scaling Method Based on Skin and Fat Deformation

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Summary

The geometry of 3D muscles, particularly volume and physiological cross-sectional area (PCSA), is crucial for muscle modeling. Traditional methods, such as linear scaling, struggle to account for body weight and sex differences, limiting their accuracy. This study presents a novel 3D muscle scaling method based on the SMPL model, incorporating subcutaneous fat layers and bone from a statistical model. Validation on four subjects demonstrates that the proposed approach predicts muscle geometry more accurately compared to traditional linear scaling.

Introduction

The geometric properties of 3D muscles, particularly volume and PCSA, are crucial for accurate muscle modeling. Existing methods primarily use MRI or CT scans to construct subject-specific muscle models, ensuring high accuracy but exposing subjects to radiation. In contrast, anthropometric-based linear scaling offers a faster, no radiation exposure alternative. However, this approach neglects key factors such as body weight and sex, where fat coverage and muscle distribution significantly influence muscle geometry. Although various muscle scaling methods exist, none provide zero radiation exposure while considering individual factors like body weight and sex. To address these, this study proposes a novel leg muscle scaling method based on SMPL model. The SMPL model is a statistical human skin model that captures individual body shape and sex characteristics[1]. Additionally, the HIT model, a statistical data-driven model, is used to incorporate subcutaneous fat layers and bones, predicting internal tissue distribution based on population-wide MRI-based data[2]. A quantitative comparison with linear scaling is conducted to evaluate the accuracy of the proposed method in approximating MRI-derived muscle geometry.

Methods

This study proposes a muscle scaling method based on the SMPL model which is shown in Figure 1. First, we align a standard muscle mesh from BodyParts3D with the SMPL skin model. The muscle mesh is converted into vertices to extract the muscle surface *M*. SMPL represents body shape variations by applying a deformation *Bs(β)* to a template model, influenced by shape parameters *β*. We use *Bs(β)* as the deformation vector of *M*. *M*'s deformation is primarily based on the skin deformation *Bs(β)* provided by SMPL, influenced by shape parameters *β*. To account for the effect of the fat layer, *Bs(β)* is multiplied by a weight factor *W*, which is mainly influenced by fat thickness before being applied to *M*. *W* is calculated by using physical quantities extracted from the HIT results *HIT(β)*, which provide adipose tissues (fat) mesh and long bones (legs and pelvis) mesh. *W* consists of three components, each considering different physical quantities: (1) the distance from M to the bone (2) the ratio of the distance from *M* to the fat layer to the distance from *M* to the skin; and (3) the ratio of fat layer deformation to skin deformation. By applying *Bs(β)*, weighted by *W*, to *M*, the scaled muscle *Ms(β)* can be obtained.

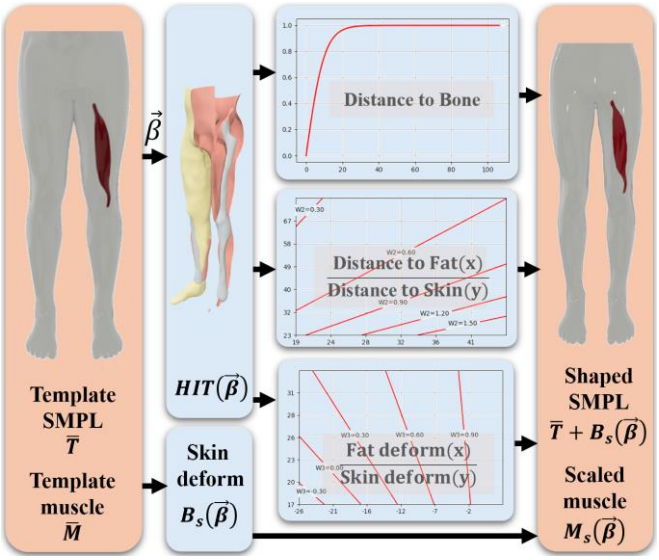

Figure 1: Workflow of the proposed method

Results and Discussion

We evaluated our method based on four subjects whose MRI-derived 3D muscle models are regarded as ground truth[3]. For three muscles (Semimembranosus, Adductor Longus, and Semitendinosus), we compared the deviations of both linear scaling and our method from the ground truth geometry in terms of muscle volume and PCSA. The results show that our approach exhibits smaller deviations than linear scaling, demonstrating improved accuracy.

Conclusions

This study proposes an SMPL-based muscle scaling method incorporating subcutaneous fat layers, which captures individual anatomical variations compared to linear scaling. Further evaluation shows that the proposed method more accurately estimates muscle geometry, with smaller deviations from MRI-derived geometry, demonstrating its potential as a novel alternative for muscle modeling.

References

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