Skin to Bone: Predicting Tibia and Fibula geometry from shank surface skin in paediatrics

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Summary

Musculoskeletal models of bones and joints are increasingly used in medical and scientific fields to support personalised care and analysis. A critical step in creating such models is extracting patient-specific bone geometry. This study demonstrates the potential of a statistical shape model predicting tibia/fibula geometry from skin shape with a 1.55 ± 0.55 mm root mean square (RMS) error, outperforming landmark-based methods. These findings suggest 3D scanning as a viable approach for bone geometry prediction.

Introduction

Low-cost 3D scanners, including LiDAR and photogrammetry, offer potential to measure body segment parameters for scientific or clinical use. Shape modelling can predict bone morphology in paediatric populations using sparse landmarks and demographic data [1]. Coupling surface skin to the underlying bone would enable direct prediction of bone morphology from a 3D body scan. The SKEL model fits a skeleton to a 3D body mesh in adults, scaling it for the best fit but without accounting for morphological changes [2]. To this end, we evaluated a statistical shape model to predict tibia and fibula bone geometry using shank skin surface data as input in a typically developed paediatric population.

Methods

Post-mortem full body CT scans from 294 children (127F; 12 ± 4 [4-18] years; 49 ± 20 [15-124] kg; 150 ± 23 [96-192] cm) were segmented to create meshes of the left shank skin and left tibia/fibula bones. These were non-rigidly registered and fitted to a template mesh separately, using radial basis functions to achieve nodal correspondence, then rigidly aligned after being merged [3]. A Principal Component (PC) Analysis was performed to capture the coupled morphological variation between the skin and bones. The accuracy of the shape model was assessed using fitting error, compactness, specificity, and generality using a leave-one-out (LOO) analysis. The LOO analysis was conducted 24 times for each individual to determine the optimal number of PC needed (increments from 1 to 280). However, we could not find a consensus and decided to create an optimisation to determine the optimal number of PC for each shank. The optimisation criterion minimises the root mean square (RMS) distance error between predicted and 3D shank surfaces from the CT scan across PC conditions, predicting the corresponding tibia/fibula.

Results and Discussion

The largest errors for the shank prediction were found at the extremities, likely due to artifacts from skin segmentation and body positioning within the CT scan. For the bone, the greatest errors occurred at the tibia's extremities, where growth-related variations are most pronounced (Figure 1).

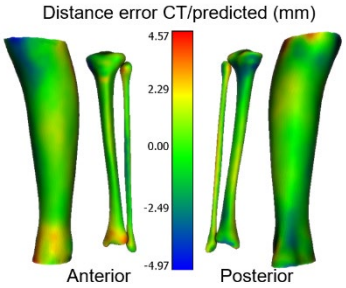

Figure 1: Heatmap comparison of segmented vs. predicted skin and bones for a participant with near-average RMS error.

The PC-optimised LOO analysis outperformed by 8.23% the bone geometry prediction using 30PCs, which had the lowest RMS error (Table 1). RMS distance error of the PC-optimised condition error ranged from 0.74 to 5.78 mm. This markerless technique outperformed the leading paediatric shape model of the tibia/fibula (1.72 ± 0.51 mm) [4].

Conclusions

This study highlights the potential of predicting bone morphology from surface skin. Future work will include the femur and pelvis with articulation constraints for full lower limb fitting. Incorporating all lower limb bones could simplify 3D gait analysis and improve accuracy by predicting patient-specific geometry directly from a 3D body scan, rather than scaling adult models for paediatric analysis.

Acknowledgments

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References

[1] Carman L et al. (2022). *Sci. Rep.,* **12**, 3251
[2] Keller M et al. (2023). *ACM Trans. Graph.* **42**(6), 1-12
[3] Zhang J et al. (2016). *Med. Eng. Phys*., **38**: 450–457.
[4] Carman L et al. (2024). *J. Biomech.*, **172**, 11221

Table 1: RMS distance error for 6 different number of PCs used for the LOO PC fitting and the optimisation

	4 PCs	10 PCs	30 PCs	50 PCs	100 PCs	240 PCs	Optimisation
RMSE Bones (mm)	2.00 ± 0.92	1.97 ± 0.91	1.70 ± 0.94	1.75 ± 1.14	2.28 ± 2.02	2.79 ± 2.72	1.55 ± 0.55