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Estimation of children's 3D body segment inertia parameters from body scans

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1. Introduction

Personalized Body Segment Inertia Parameters (BSIP) are a necessary input to dynamic analyses of human movement such as the estimation of internal loads (net joint torques, musculotendinous forces, ...). BSIPs are not directly accessible using non-invasive techniques. They are therefore usually estimated using statistical regressions, derived from anthropometric tables, and based on subject-specific characteristics easily accessible such as whole-body mass, stature, or segment lengths. However, the literature lacks such regressions for children: only a few studies from the 80s proposed regressions specific to this population for all parts of the body, among which the most used come from Jensen's work (e.g., Jensen, 1989). However, these regressions are based on small samples of children, were obtained from manual processing of pictures, and provide only 3 BSIP per segment instead of 10 (see in section Methods) in coordinate systems that are not formally linked to the anatomical segment coordinate systems (SCS) recommended by the International Society of Biomechanics (ISB). Yet, the growth of children with age and the associated changes in body proportions make children-specific regressions necessary (Otmani et al., 2023).

Recent progress in 3D body shape acquisition allows an automatic estimation of personalized BSIP in the adequate ISB-recommended coordinate systems (e.g., Robert et al. 2017). This technique, applied to a large cohort of children, would make it possible to build a relevant BSIP database. Such a database could then be used to propose a new set of children-specific BSIP regressions that overcomes the current limitations. The goal of this study is to demonstrate the feasibility of this approach.

2. Methods

Data came from a large cohort of children collected at the Instituto de Biomecanica de Valencia (IBV): N = 688 (361 girls) and mean age = 8.29 years ([2.86, 12.67] years).

The raw 3D point clouds of each child were obtained and further processed using the Move4D 3D temporal scanner from IBV. During this step, a 3D homologous template mesh is deformed to match the 3D points cloud. It resulted in personalized watertight homologous meshes with about 50,000 vertices for each child. Interestingly, this step minimally deformed the mesh so that the association between mesh vertices and anatomical landmarks is preserved (Ruescas Nicolau et al. 2022).

Manual work was performed on the template mesh to 1) identify the vertices that correspond to the anatomical landmarks classically used in the 3D analysis of human movement; 2) compute the joint centers and construct the SCS from these anatomical landmarks; 3) segment the template mesh in body parts, following as closely as possible the segmentation described in anthropometric tables used for adult population. The results of this step allowed the segmentation of the personalized homologous 3D mesh of the children and the reconstruction of the ISB-recommended segment coordinate systems. The last step consisted of estimating the BSIP of these segments (mass, 3D location of the CoM, and 6 components of the inertia matrix expressed in SCS) using a volumetric approach and a hypothesis of a homogeneous density. BSIPs were then normalized to body characteristics: Mass is expressed as a % of the whole-body mass (BM), CoM location as a % of the segment length (distance between proximal and distal joint, SL), and elements of the inertia matrix as radii of gyration in % of SL.

This procedure was applied to the head-neck and right thigh segments of the 688 children in the database. In parallel, Jensen's regressions (Jensen, 1989) were used to estimate three BSIP for the head-neck and thigh segments of every child: mass (% BM), position of the CoM along the longitudinal axis (CoMy, in % SL), and radius of gyration along the lateral axis (Rzz in % SL). The normalized BSIPs obtained from volumetric or regressions were then compared for each child using a Bland-Altman approach.

3. Results and discussion

Figure 1 illustrates the mass proportion of the thigh as a function of age estimated for the 688 children using the proposed volumetric approach and the result of Jensen's regressions (Jensen, 1989). It highlights the fact that the mass proportion evolves with age, i.e., that segments' growth is not uniform. Volumetric data follows the tendency proposed by Jensen (1989) and they can similarly be regressed using a 2nd-order polynomial of children's age. Yet, a bias (about 2% of body Mass) can be observed, likely due to differences in segmentation.

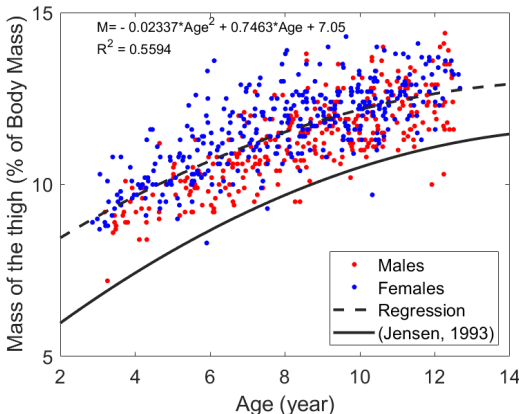


Figure 1. Mass of the thigh (% BM) vs age obtained from the 3D scans database, together with regression from Jensen (1989).

Table 1 shows the Bland-Altman comparison of the BSIP estimated using the volumetric approach or the regression. It confirms that bias and limit of agreement (LoA) remained relatively small. Differences likely come from discrepancies in segmentation and definition of joint centers (for COMy and Rzz) between the two methods, and possibly from the inaccuracies in the manual segmentation and the volume reconstruction (approximation of the section by ellipses) used by Jensen (1989).

Table 1. Comparison of BSIPs obtained by volumetric approach vs regressions from (Jensen, 1989)

		Mass (%BM)	CoMy (%SL)	Rzz (% SL)
Head	Bias	-1.4	2.1	-0.6
	LoA	3.6	3.0	2.1
Thigh	Bias	1.9	-1.6	-0.2
	LoA	1.7	2.5	1.7

The proposed volumetric approach provides BSIP that are consistent with the existing regressions. Yet, these BSIP are readily usable for 3D dynamic analyses. Moreover, this approach is fully automatized. It can thus be applied to large cohorts such as the one used in this study. Therefore, the next logical step is the

extension of this approach to every segment, and, using the children dataset, the proposition of a new set of children-specific BSIP regressions that overcomes the limitations of the existing ones.

4. Conclusions

This study demonstrated the feasibility of an automated volumetric approach to estimate BSIP that are readily usable for 3D dynamic analysis from 3D scans of children. This approach will allow to build a new set of BSIP regressions for children that overcome the current BSIP regression limitations in children.

Conflict of Interest Statement

None.

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