Chinese finite element human body model development based on THUMS occupant v402

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I. INTRODUCTION

Traffic accidents are a major societal problem, causing large numbers of fatalities and injuries. Each year 1.35 million people die in road accidents worldwide, which is completely unacceptable [1]. In vehicle safety research, as computation power continues to increase, Human Body Models (HBMs) are being used as a supplemental tool in vehicle safety design. However, most state-of-the-art HBMs represent the build of the populations in the western countries of the world, America and Europe, with only a few standard body sizes, e.g. 50th and 95th percentile males, 5th percentile female. It is essential to develop HBMs that represent Chinese populations, especially given the fact that vehicle ownership and traffic injuries have both increased dramatically in China over the past two decades.

The differences in anthropometric dimensions between Western populations and Chinese populations lead to different injury outcomes in traffic accidents and therefore require different restraint system configurations [2]. There have been some preliminary works carried out on Chinese HBM development. Focusing on liver modelling, a simplified Chinese finite element (FE) HBM was generated from a CT scan of a single person [3]. For the anthropometric dimensions needed in HBM development, data from the China National Institute of Standardization (CNIS) can better represent the physical build of the Chinese population statistically. Using the data from the CNIS database, a Chinese FE dummy model was developed [4]. Previously, in our lab, two Chinese HBMs were scaled manually from the corresponding small female and average male models of THUMS [5], using pre-processor to match Chinese dimensions [6-7].

In order to enrich the FE HBM library and to improve the scaling method, we used a generic process that can automatically and accurately scale finite element human body models. This process can avoid inconsistent operations possibly occurring in the manual process. A Chinese 5th percentile female HBM and a Chinese 50th percentile male HBM were developed, based on the THUMS occupant models (version 402), AF05 and AM50. The two developed models were named “THUMS-T-CNIS” (“T” stands for Tsinghua University).

II. METHODS

Anthropometric Database

The CNIS 2009 database contains 3,000 anthropometric data records of Chinese adults, roughly 50% males and 50% females. The percentile values of Chinese male and female heights were calculated. There are differences in the anthropometric dimensions between the Eastern and Western populations. Statistically, Chinese males and females have shorter statures compared to their western counterparts. The data show that the 5th percentile Chinese female is 56 mm shorter than THUMS AF05 (1484 mm vs. 1540 mm), and the 50th percentile Chinese male is 37 mm shorter than THUMS AM50 (1693 mm vs. 1730 mm). The lower extremity length (buttock-knee length + knee height sitting) of western male is 11% longer than that of Chinese male (1169 mm vs. 1056 mm) and that same length for western female is 4% longer than that of Chinese female (980 mm vs. 946 mm).

In ergonomics there are two accepted approaches for the calculation and presentation of somatotypes (for example the fifth percentile). The first one is to make up a person with the fifth percentile in all body part segments, which does not exist in actual reality. The second one is to calculate all body part segment dimensions (such as leg length, arm length, seating depth) using the specified percentile (in our case the fifth percentile) of the body height.

As shown in Fig. 1, 16 key dimensions on the main body parts of the 5th percentile female and the 50th percentile male were selected for HBM scaling. They were: head width, upper arm circumference, waist

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circumference, forearm circumference, pelvis width, hip width, calf circumference, foot width, head depth, chest depth, upper arm length, forearm length with hand, thigh depth, buttock-knee length, knee height sitting, and foot length.

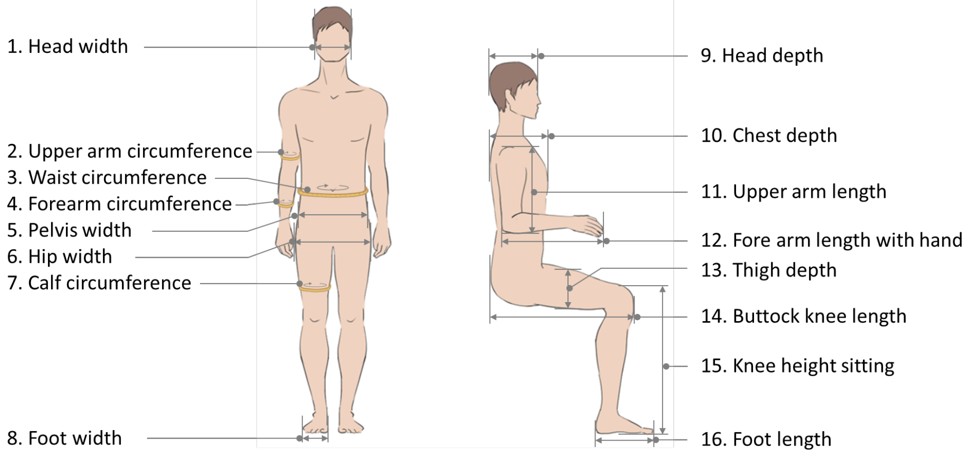


Fig. 1. The 16 anthropometric dimensions used in the development of THUMS-T-CNIS.

Geometry scaling method

The first scaling step was performed on an open source software (OSS) PIPER, which was designed by a European project of the same name (http://piper-project.org/start) [8]. This platform provided an approach for positioning and personalizing/scaling of HBMs. Since the THUMS models are commonly used in the injury biomechanics community, they were selected as the baseline models in this study. THUMS v402 AM50 and AF05 were imported to PIPER using specified PIPER metadata. The metadata files describe the information to be interpreted by PIPER modules (e.g. anatomy, relationships, mesh). The metadata files for AM50 were provided by JSOL, as an outcome of the PIPER project. In addition, in this study the metadata files for AF05 were generated by modifying those for AM50. Both metadata files were then used to develop Chinese HBMs. (We are willing to share the metadata files we produced with the PIPER organization as well as with other researchers.) The 16 anthropometric dimensions were defined in PIPER by measuring the distance between feature points on skin or the circumference of skin section (e.g. pelvis width refers to the distance between left and right iliocristale). A kriging module, which was an interpolation method commonly used to deform geometrical models, was used to perform scaling along with Radial Basis Function (RBF) and Moving Least Square (MLS) [9].

As pointed out in the PIPER manual, the model output from PIPER exhibited bad element quality that would lead to numerical issues in simulation. In order to solve this problem, we used function mapping (RBF) to fix the local mesh disorders and improve the overall mesh quality of the output model. The whole process is shown in Fig. 2 and comprises four steps: HBM division, landmark selection, RBF, and HBM assembly. This process was done automatically with in-house MATLAB codes.

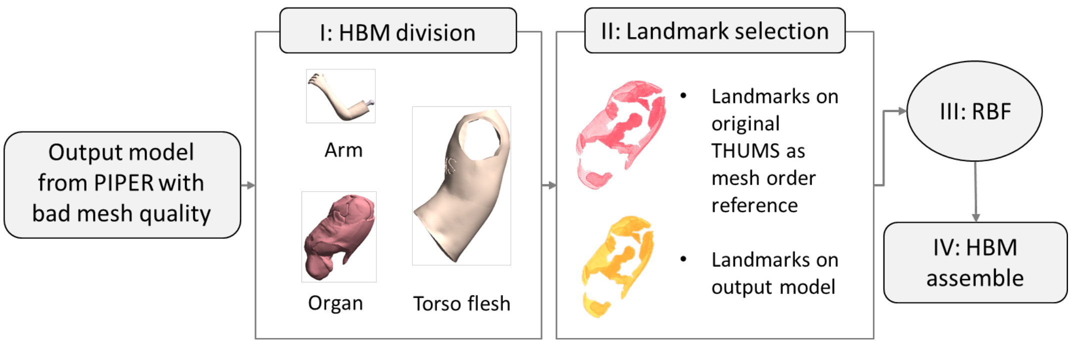
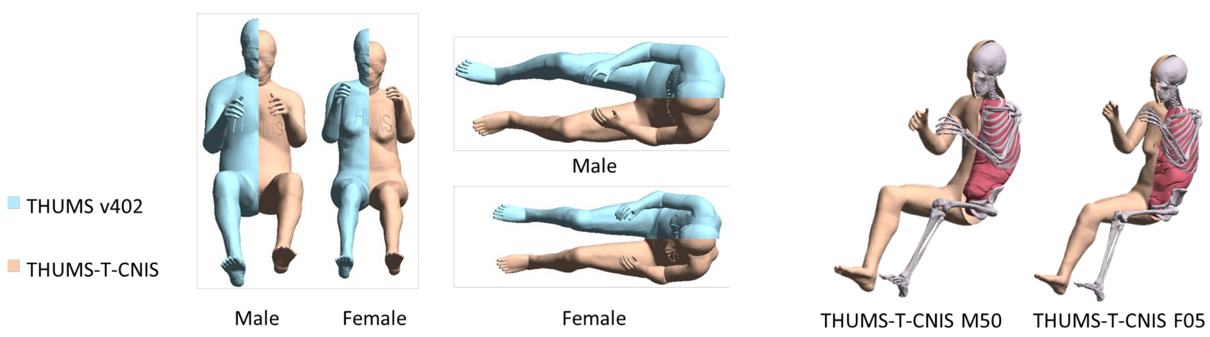


Fig. 2. Workflow to improve the mesh order of the output model from PIPER.

III. INITIAL FINDINGS

The developed Chinese HBMs are shown in Fig. 3. They are the 50th percentile Chinese male (“THUMS-T-CNIS M50”) and the 5th percentile Chinese female (“THUMS-T-CNIS F05”). The anthropometric dimensions on the developed model are in good agreement with the data in the CNIS database, with relative errors controlled to less than 1% (Table I). The mesh quality indicators (Aspect Ratio, Skew, Warpage, Jacobian) of the developed THUMS-T-CNIS models are close to those of THUMS v402.



(a) Comparison between THUMS v402 and THUMS-T-CNIS. (b) THUMS-T-CNIS.

Fig. 3. Overview of the developed Chinese HBMs, THUMS-T-CNIS.

TABLE I
ANTHROPOMETRIC DIMENSIONS OF THE DEVELOPED MODEL THUMS-T-CNIS AND THUMS V402 (UNIT: MM)

Anthropometric dimensions	50th percentile male				5th percentile female			
	CNIS	THUMS v402	THUMS-T-CNIS	Relative Error	CNIS	THUMS v402	THUMS-T-CNIS	Relative Error
Head width	163	164	163	0.00%	155	140	155	-0.01%
Upper arm circumference	264	299	265	0.41%	251	248	252	0.41%
Waist circumference	824	979	823	-0.08%	797	763	796	-0.10%
Forearm circumference	251	264	251	-0.03%	230	215	229	-0.47%
Pelvis width	296	357	296	0.12%	291	284	291	0.02%
Hip width	341	347	341	-0.10%	339	332	339	-0.01%
Calf circumference	353	373	353	0.06%	335	299	334	-0.31%
Foot width	91	92	91	0.01%	83	75	83	0.00%
Head depth	196	210	196	0.00%	186	180	186	0.00%
Chest depth	230	250	230	0.02%	212	199	212	0.03%
Upper arm length	312	409	312	0.00%	269	324	269	0.00%
Forearm length with hand	445	472	445	0.00%	390	407	390	0.00%
Thigh depth	136	169	136	0.02%	122	146	122	0.03%
Buttock-knee length	561	595	561	0.00%	510	518	510	0.00%
Knee height sitting	495	573	495	-0.01%	436	462	436	0.00%
Foot length	249	274	249	0.00%	221	220	221	0.00%

* Relative error is the error between THUMS-T-CNIS HBM and CNIS database.

To assess the THUMS-T-CNIS models, during the model development crash simulations were performed using THUMS v402 AM50 and THUMS-T-CNIS M50, respectively. In the simulations, the 56.36 km/h crash pulse was from test No. 9065 of the NHTSA vehicle crash test database. Due to the differences in dimension, mass and moment of inertia of the body, the THUMS AM50 and THUMS-T-CNIS M50 had different kinematic responses as well as different contact times and contact locations with the airbag. This preliminary result suggests that optimization of occupant restraint systems is necessary to ensure better crash protection of the Chinese population.

In another assessment, we jointly used the active Chinese female HBM ("A-THUMS-D F05 CNIS") [10] and the THUMS-T-CNIS F05 to simulate both the pre-collision phase and collision phase. The two HBMs have the same anthropometric dimensions. Using the method described in [11], the pre-crash results of A-THUMS-D F05 CNIS transferred well to THUMS-T-CNIS F05 for the subsequent in-crash simulation. These assessments have demonstrated that the THUMS-T-CNIS models developed in this project can be used in crash simulations for injury biomechanics studies with reasonable satisfaction.

IV. DISCUSSION

By scaling the commonly used THUMS models, we developed two Chinese HBMs (50th percentile male and 5th percentile female) with Chinese anthropometric data (CNIS). OSS PIPER and in-house MATLAB RBF code were jointly used in the scaling process. Moreover, this process can be used in scaling different sitting postures for future studies. The developed models retain the fine mesh of the body parts in THUMS version 402.

These two THUMS-T-CNIS models can be used in designing and optimizing occupant restraint systems using a computer simulation tool to account for population diversity. The importance of accounting for occupant diversity has been emphasized in [12]. The difference in anthropometric dimensions and mass distribution between the Eastern and Western populations is one crucial reason for this. In addition, the different responses between Eastern and Western occupants under vehicle crash loading must also be studied in-depth.

Limitations of this study include the following. First, the developed THUMS-T-CNIS models only represent the geometric contour of Chinese people by dimension based scaling. There is no 3D surface scan data to use for more detailed geometric description. The internal organs were simply scaled from the THUMS models. Second, the material properties were adopted directly from the THUMS models. Third, the sitting postures were measured in different ways in CNIS and in THUMS development. The former sits straighter. Consequently, we had to make a rough curve in THUMS v402, from hip to head top, as the measure of its sitting height. This approximation led to larger errors than scaling.

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