Toward Future ATDs: The Human Body Dimensions and Weight for a Chinese Mid-Size Adult Male

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I. INTRODUCTION

Based on the report by World Health Organization (WHO) in 2018 [1], road traffic injuries are the eighth leading cause of death in the world, and the injury risks are much higher in low and middle income countries than the high income countries. China is the world's largest vehicle consumer market. Statistics from the Ministry of Public Security of the People's Republic of China (2019) show that, in 2018, China's vehicle ownership was 232 million, and the number of registered drivers was 369 million [2]. Reference [3] reported that there were as many as 50 million people injured each year worldwide. In the U.S., more than 2 million people are injured in traffic accidents each year, and it is estimated that the total economic cost by traffic accidents exceed 200 billion dollars per year in the past decade. In 2017, China's traffic accidents caused 63,721 deaths and 209,654 injuries [4]. Compared with the same period in the United States, China's fatality rate per 10,000 vehicles is still more than three times that of the United States [5].

The Anthropomorphic test devices (ATDs) play a vital role in assessing and improving vehicle occupant protection systems. The current adult ATDs, such as the Hybrid-III adult ATDs, were designed to target the 5th percentile female, 50th percentile male, and 95th percentile male. The first development target was the 50th percentile male dummy, the size, weight, biomechanical impact responses, and injury criteria of adult small female and large male ATDs were developed by scaling them from the mid-size male ATD [6]. These three sizes were intended to be representative of the body size and shape of the U.S. adult population. However, the distributions of body dimensions used to design Hybrid-III ATDs were collected in the 1960s and 1970s. In this study, we analysed the specific anthropometric differences between the Chinese and U.S. populations, and compared the differences of size and mass of human body segments between the Chinese mid-size adult male and the American mid-size adult male.

II. METHODS

Anthropometric Statistical Method

The data anthropometric mainly includes height and weight. The body weight is mainly composed of skeleton, muscle, fat, viscera, body fluid and so on, while the muscle and fat have great influence on the body weight difference. The normal distribution curves were fitted onto the height probability density functions, and log-normal distribution curves were fitted onto the weight probability density functions.

The Differences in the Definition of Human Body Segments

The comparison between China and the U.S divide different segments of the human body. The definition of human body segments in the U.S include the head, neck, thorax, abdomen, pelvis, upper arm, forearm, hand, thigh flap, thigh minus flap, shank, foot. The definition of human body segments in China include head and neck, upper torso, lower torso, upper arm, forearm, hand, thigh, shank, foot. There are significant differences between the two methods of defining human body segments. Therefore, this paper assumes that the Chinese and Americans populations have the same mass ratio for the head, neck, thigh flap, thigh minus flap.

III. RESULTS

This paper compares the anthropometric differences between Chinese and Americans populations from two

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aspects. First, it compared the distribution of height and weight between Chinese and Americans populations. Second, it compared the dimensions and weight of each human body segment of the mid-size adult male in China with the standard of the mid-size adult male in the U.S.

Anthropometric Differences between Populations in China and the U.S.

Based on the literature, three human factors can significantly affect human body impact responses and injury tolerances, including geometric characteristics, compositional characteristics and material characteristics. This study only focused on the geometric differences among ATD reference values [7], Chinese populations [8], and U.S. populations [9].

Compared with ATD anthropometry collected five decades ago, significant changes have taken place in human body sizes over the past few decades, especially in body weight. Reference [9] reported the anthropometric reference data measured from 2007 to 2010 in the U.S., which include both male and female adults of all ages, excluding pregnancy. Based on the data reported by [9] the 5th percentile female ATD represents a woman in the 4th percentile height and 4th percentile weight of the current U.S. female population; the 50th percentile male ATD represents a man with the 45th percentile height and 32nd percentile weight; and the 95th percentile male ATD represents a man with the 91st percentile height and 72nd percentile weight of the current U.S. male population (as shown in Figure 1 and 2).

The Chinese populations are generally smaller in size and weight than those in the U.S. In this study, we used data of the Chinese adult anthropometry measurements reported by [8]. The 5th female ATD represents a woman in the 7th percentile height and 22nd percentile weight of the Chinese female population; the 50th male ATD represents a man in the 79th percentile height and 85th percentile weight; and the 95th male ATD represents over 99th percentile height and weight of the Chinese male population.

Figures 1 and 2 show the probability density functions of height and weight for male and female of both Chinese and U.S. populations. In general, the weight distribution differences between the two countries are more evident than the height differences. In particular, the height distributions of the female populations are rather small between China and the U.S., while the difference is substantial in male height distributions. In terms of weight distributions, the results show highly significant differences between China and the U.S. populations for both males and females. The Chinese populations have significantly lower means and standard deviations of body weight than those in the U.S. populations, for both male and female. In fact, the 50th percentile weight of the Chinese male is lower than the 50th percentile weight of the U.S. female, which highlights the significant body weight differences between these two countries.

Figures 1 and 2 also plot the ATD heights and body weights relative to the height and weight distributions of Chinese and U.S. populations. Despite the differences between China and the U.S., the heights of the three sizes of the current adult ATDs can reasonably cover the whole distributions for both the U.S. and Chinese populations. However, one can argue that the majority of the female populations in both China and the U.S., and the male population in China are not covered as well as the U.S. male population. In terms of weight, the current three sizes of adult ATDs missed a substantial portion of the U.S. population and a substantial portion of the Chinese female population.

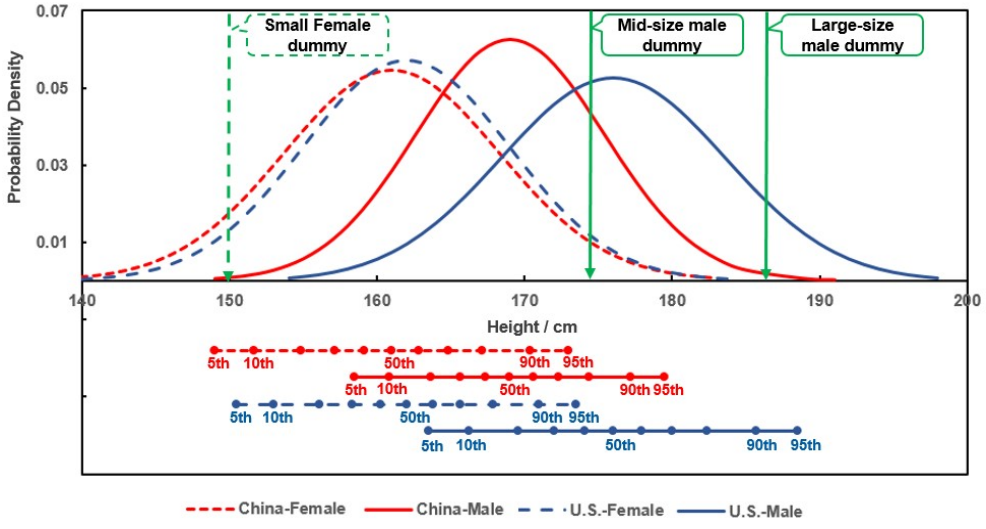

Fig. 1. Comparison of probability density functions of height between Chinese and U.S. populations.

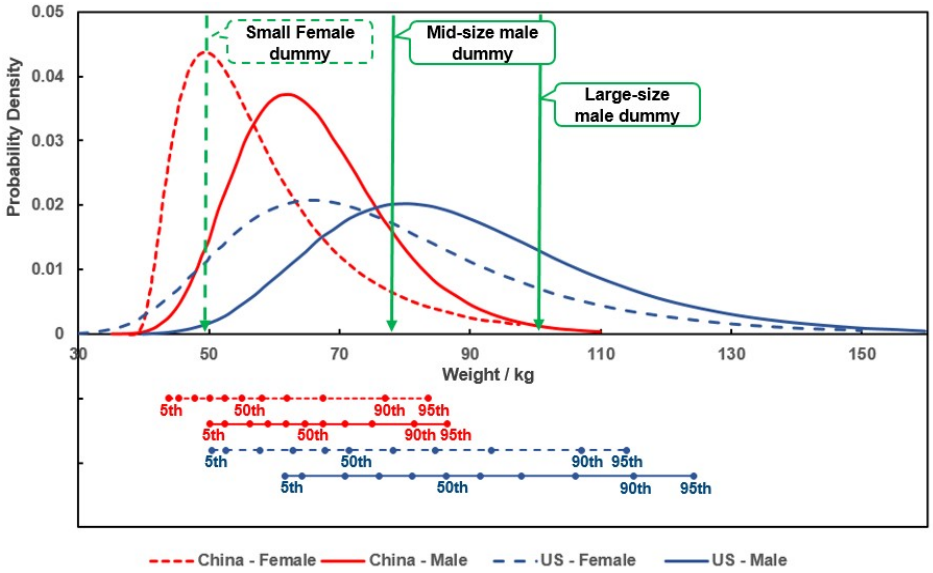

Fig. 2. Comparison of probability density functions of weight between Chinese and U.S. populations.

Human Body Segments Differences between Mid-Size Male in China and the U.S.

The anthropometry data of the China mid-size adult male are from the data completed by [10]. The anthropometry data of the U.S mid-size adult male are from the data of [11]. This data was used to develop the Hybrid-Ⅲ mid-size adult male dummy. As shown in Table Ⅰ and table Ⅱ, there are significant differences in the dimensions and mass of various segments of the human body due to different races. The height and weight of the Chinese mid-size adult male is 1,685mm and 68.8kg, while that of the American mid-size adult male is 1,751mm and 78.2kg. Compared with the American mid-size adult male, the head circumference of the Chinese mid-size adult male is the same, but the Chinese head width is bigger and the head depth is less than the American mid-size adult male. The seated height of the Chinese mid-size adult male is 14 mm higher than that of American mid-size adult male. The extremities of American mid-size adult men are longer than those of Chinese mid-size adult men. The dimensions of shoulder to elbow length, elbow to tip of finger, rump to knee and knee to sole of the American mid-size adult male are more than 15.1%, 12.9%, 3.7% and 9.9%, respectively, compared with Chinese mid-size adult male. The head mass of Chinese mid-size adult male is larger than that of American mid-size adult male, and the neck mass is smaller than that of American mid-size adult male. The upper torso of the Chinese mid-size adult male is 55.9% lighter than that of American mid-size adult male, and the lower torso is 14.9% heavier. The mass of shoulder to elbow length, elbow to tip of finger, rump to knee and knee to sole of the American mid-size adult male are more than 5.3%, 56.7%, 15.5% and 46.2%, respectively. It can be seen that the seated height of the Chinese mid-size adult male is slightly higher than that of the American mid-size adult male, but the extremity dimensions and mass of the Chinese mid-size adult male are smaller than that of the American mid-size adult male.

TABLE Ⅰ

COMPARISON OF HEIGHT BETWEEN CHINESE AND THE U.S. MID-SIZE MALE

Anthropometry Dimensions	U.S. mid-size male (1968)/mm	China mid-size male (2018)/mm	Difference
Standing Height	1751	1685	3.9%
Erect Seated Height	907	921	-1.5%
Head Circumference	574	573	0.2%
Head Width	154	158	-2.5%
Head Depth	197	187	5.3%
Neck Circumference	383	381	0.5%
Shoulder to Elbow	366	318	15.1%
Elbow to Tip of Finger	465	412	12.9%
Rump to Knee	589	568	3.7%
Knee to Sole	544	495	9.9%

TABLE ||

COMPARISON OF WEIGHT BETWEEN CHINESE AND THE U.S. MID-SIZE MALE

Human body segment			U.S. mid-size male (1968)/kg	China mid-size male (2018)/kg	Difference
Head			4.54	4.69	-3.2%
Neck			1.54	1.17	31.6%
Torso	*Upper Torso*		17.2	11.03	55.9%
	Lower Torso		23.03	27.05	-14.9%
Extremities	*Upper Extremities*	*Arms*	4.00	3.80	5.3%
		Forearms & Hands	4.53	2.89	56.7%
	Lower Extremities	*Thighs*	12.00	10.39	15.5%
		Legs & Feet	11.36	7.77	46.2%
Total Body Mass			78.2	68.8	13.7%

IV. DISCUSSION

In this paper, the anthropometric and weight differences between Chinese and Americans populations were analysed by using the normal and log-normal distribution. It highlights that the height and weight of the mid-size male dummy (1968) represent 45th and 32nd American adult males (2011), and 79th and 85th Chinese adult males (2009), respectively.

Further, comparing the size and weight of each segment of the body between the Chinese mid-size adult male and American mid-size adult male, highlight that the seated height of the Chinese mid-size adult male (2018) is slightly higher than that of the American mid-size adult male, but the size and weight of extremities are much smaller than that of the American mid-size adult male.

This paper only compared the anthropometric data of Chinese and American mid-size adult males, while other anthropometric data of human body, gender and data of vulnerable populations need analysis in the future work.

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