ORIGINAL ARTICLE

AN ANTHROPOMETRIC COMPARISON OF CURRENT ANTHROPOMETRIC TEST DEVICES (ATDs) WITH MALAYSIAN ADULTS

Mohd Hafzi MD ISA[1,2], Baba MD DEROS[3], Zulhaidi MOHD JAWI[1], Khairil Anwar ABU KASSIM[2]

[1]*Crash Safety Engineering Unit, Vehicle Safety & Biomechanics Research Centre, Malaysian Institute of Road Safety Research (MIROS), Malaysia*
[2]*ASEAN NCAP Operationalization Unit, Director-General Office, Malaysian Institute of Road Safety Research (MIROS), Malaysia*
[3]*Department of Mechanical & Materials Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia (UKM), Malaysia*

ABSTRACT

Anthropometric Test Devices (ATDs) of different nominal percentile values have long been used as human surrogates in automotive crash testing. The Hybrid III family, which is one of the widely used ATDs in frontal crash test, was designed based on the anthropometry dimensions of US adults. Thus, this paper aims to assess the anthropometric differences between Malaysian adults and Hybrid III dummies in terms of 5th percentile (small female), 50th percentile (midsize male) and 95th percentile (large male). A series of anthropometric parameters of Malaysian adults was obtained from a database of 1321 subjects with 708 males and 613 females. The results revealed that the current midsize male population differs from the ATD's statures and body weights by about 35 and 40 percentile points, respectively. This demonstrates that the current ATDs are not truly representative of the current Malaysian adults, which may potentially lead to different injury responses in road traffic crashes. Thus, car manufacturers may as well consider this discrepancy issue in developing their future models especially with regards to safety.

Keywords: *anthropomorphic test device, anthropometry, ATD, Malaysian adults*

INTRODUCTION

Anthropometric Test Devices (ATDs) have been widely used in various configuration of vehicle crash test for evaluation of occupants' injury severity. The most used ATDs for frontal crash test, known as the Hybrid III 50th percentile male (HIII-50M), was first introduced in 1976[1,2]. Since then, the HIII-50M (midsize male) and its adult family members, 5th percentile female (HIII-5F; small female) and 95th percentile male (HIII-95M; large male), as shown in Figure 1, have been well accepted as references for human surrogates in frontal impact crash testing worldwide.

Generally, Vehicle Type Approval (VTA) and New Car Assessment Program (NCAP) have benefited from the frontal impact crash test but at two different levels[3]. The VTA exercise is based on the United Nations (UN) Regulation No. 94 (UN R94 - *Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision*). In that particular test, two units of HIII-50M dummies that are positioned in the front seats of a test vehicle is propelled at a speed of 56 km/hr onto a deformable barrier at 40% offset. The injury data captured from the sensors installed inside the dummies are analysed and compared with the requirements set forth in the UN R94. It serves as the minimum safety requirement for any vehicle to be sold in certain countries.

The NCAP initiative, on the other hand, usually imposes more stringent requirements to suit its objective to ensure the vehicle manufacturers to embed latest advancements in vehicle safety technologies[3]. The main differences between the UN R94 and NCAP (e.g. Euro NCAP) in frontal offset are higher test speed at 64 km/hr, additional test weight and different rating calculation. Nevertheless, both regulation and NCAP tests still utilize HIII-50M as adult dummies at the front seats. Although an advanced frontal dummy i.e. Test Device for Human Occupant Restraint (THOR) has been developed for improved biofidelity response[4], the research work is still ongoing and yet to be used as references in any regulation and NCAP tests.

HIII-5F[5] **HIII-50M[1]** **HIII-95M[6]**

Figure 1 – Adult Hybrid III dummy family

In addition to the offset frontal, there are also several NCAPs that incorporate full width frontal into their existing test regimes. In term of dummy combination, Euro NCAP, US NCAP, China NCAP and Korea NCAP also require HIII-5F as either front or rear occupant in addition to the HIII-50M[7]. Figure 2 illustrates an example of the inclusion of small adult female dummy in China NCAP[8]. The seating location of the HIII-5F as specified in each abovementioned NCAPs was determined primarily based on the findings from the real-world crash investigations. The above fact implies that the injuries sustained by small adult females as vehicle occupants in the road crashes have become a concern in the developed countries.

Furthermore, HIII-95M is not being used as human surrogate in either regulation or NCAP test. It is normally utilized for research purpose and NCAP "modifier" assessment. For example, in Euro NCAP test, the inspector will assess whether or not the test vehicle should be penalised for knee injury based on the judgement on the HIII-50M right after the test[9]. The manufacturers, in the case of potential knee modifier, must submit further information known as the "knee mapping" assessment based on their in-house sled test in order to waive the modifier. As the worst case scenario, the HIII-95M is used and positioned according to the knee impact locations recorded during the NCAP test[10].

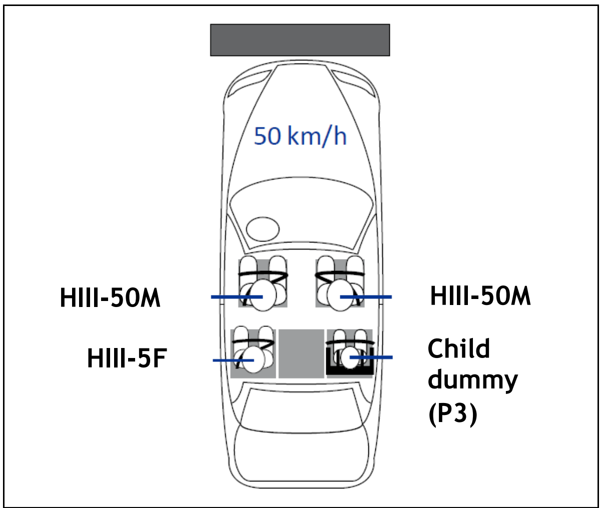

Figure 2 – Combination of dummy positioning that includes small adult female (HIII-5F) in China NCAP's full frontal test

Historically, the size of Hybrid III adult dummy represents the anthropometry parameters of the US adult population. It was established in a four-step process[11]. First, the reference population was defined and specified as the males and females of the US adults. Second, based on the various dimensions measured from the reference population, only the stature and body weight were considered. Third, the target percentiles of 5th, 50th and 95th were chosen based on the pre-determined ATD sizes to represent small, midsize and large adults[12]. Fourth, other detailed anthropometric dimensions for the ATDs were acquired from individuals who have similar size with the reference dimensions.

Since the earliest effort of ATD development in the seventies, there has been a substantial change in the distribution of body weights among US adult population[12]. Based on the 2008 data, both the reference body weights of the 50th and 95th percentile males ATDs are currently at 33rd and 81st percentiles, respectively. This suggests that the current midsize and large US males are relatively overweight, reflecting an increase in the obesity rate among US adults[13]. In terms of stature, the deviation is rather minimal, in which the highest decrement was recorded among the midsize males at 5 percentile points.

For comparison, Cao et al. studied the Chinese population and found that both the statures and body weights were relatively lower than the reference values of ATDs[14]. Nevertheless, based on the recent data collected in 2010, the discrepancies were getting closer to the reference values. The difference is more significant with respect to body weights, which ranges between 10% and 20%. Moreover, the differences were also found to be greater when comparing with the 2008 data of the US adult population[12]. In summary, the abovementioned fact proved that there was a mismatch of anthropometric measures between the ATDs and the adult populations of the two world's most populated nations (i.e. USA and China).

Therefore, this paper aims to assess the anthropometric differences between the Malaysian adult population and the ATDs based on the 5th female, 50th male and 95th male percentiles. This is relevant in Malaysia as the ATDs are widely used to assess new vehicles sold in this country[3,15]. It may also add another dimension in the human anthropometric study as well as to be used as an additional reference by the relevant stakeholders.

METHODS

Data Source

The stature and body weight anthropometric data were retrieved from a database established by the Universiti Kebangsaan Malaysia (UKM). The work was based on the recommendations made by the World Health Organization (WHO), as highlighted by Bridger[16], in which anthropometric studies are required to have a minimum of 200 samples. Furthermore, in order to ensure the anthropometric data represents the Malaysian adult population, the data collection was conducted in all 14 states in Malaysia.

In addition to that, the researchers had also considered the ethnicity proportion since Malaysia is a multiracial country with the Malays, Chinese and Indians representing 65.1%, 26% and 7.7% of the entire population, respectively[17]. The measurement was conducted in 2011 and based on the procedure specified by MS ISO 7250:2003 (*Basic human body measurements for technological design*). The instruments used were human body measuring kit and anthropometer.

In this study, other relevant parameters of sitting anthropometry such as sitting height, which can be compared with the values specified in the ATD's manufacturer user manuals[1,5,6], were not considered. Limited number of samples representing the small females, midsize males and large males deterred the researchers' effort to replicate the fourth step in determining the other ATD's anthropometry dimensions, as highlighted by Schneider et al.[11].

For comparison with the reference ATDs' statures and body weights for each nominal percentile, the values were adopted from Mertz et al.[18]. The latest data available from the previous studies with regards to US[12] and Chinese[14] adult populations were utilized for further discussion on comparison with Malaysian adult population.

Data Analysis

Prior to further analysis, the data was checked for any discrepancy. Outliers that were deemed unreasonable which resulted from errors during measurement were carefully identified and eliminated. The descriptive statistics of mean, standard deviation (SD) and weighted percentiles were calculated for both males and females.

An independent t-test was used to compare the mean values of males and females in terms of anthropometric parameters. The p-value of less than 0.05 indicates the significant mean difference. All of the analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21.0.

The differences between the data of Malaysian adults with the reference values of each ATD size were determined according to the following equation:

$$\text{Diff.} = \frac{\text{Data}_M - \text{Data}_{ATD}}{\text{Data}_{ATD}} \times 100$$

where,

Diff. is the percentage difference between Malaysian adults and ATD;
Data_M is the Malaysian adults' data; and
Data_{ATD} is the ATD's data.

RESULTS

The anthropometric data was collected from 1321 Malaysian adults comprised of 708 males and 613 females, with age ranging from 15 to 80 years old. In term of ethnicity, majority of the subjects were Malays (77.7%), followed by Chinese (12%), Indians (10.1%) and others (0.2%).

Comparison between males and females shows that the differences of mean statures and body weights are statistically significant (p-value less than 0.05). Further observation in Table 1 revealed that the average males were roughly 121mm taller and 11kg heavier than females.

In addition, both statures and body weights of Malaysian adults are lower than the reference values of ATDs, as shown in Table 2. Significant difference can be observed on the body weights rather than statures, with the highest difference recorded for midsize male at 19.4%. For statures, the values are slightly lower than the ATDs ranging from 2.2% to 4.5%.

Deviation from the ATDs' design targets can also be presented as percentiles by matching the anthropometric values of the ATDs with the values obtained from the current data. As illustrated in Table 3, the current percentiles of Malaysian adults are relatively higher than the reference ATD percentiles. For example, the reference values of statures and body weights for the midsize male dummy, nominally at 50^{th} percentile, are currently at 85^{th} and 89^{th} percentiles for Malaysian adults, respectively.

Table 1 – Anthropometric data for males and females of Malaysian adults

Anthropometry	Gender	Number of sample	Mean	SD	p-value
Stature (mm)	Male	706	1687.9	59.0	.000
	Female	613	1567.1	58.3	
Body weight (kg)	Male	708	65.1	11.0	.000
	Female	612	54.4	11.1	

Table 2 – Anthropometric differences between Malaysian adults and ATDs

Variables	Small female			Midsize male			Large male		
	ATD	Malaysian	Diff. (%)	ATD	Malaysian	Diff. (%)	ATD	Malaysian	Diff. (%)
Stature (mm)	1513.0	1480.0	-2.2	1751.0	1690.0	-3.5	1864.0	1780.0	-4.5
Body weight (kg)	46.7	41.0	-12.2	78.2	63.0	-19.4	102.5	85.0	-17.1

Table 3 – The current Malaysian adults' percentiles based on the reference ATDs' statures and body weights

ATD	Stature			Body weight		
	ATD		Malaysian	ATD		Malaysian
	Reference value (mm)	Nominal percentile	Current percentile	Reference value (kg)	Nominal percentile	Current percentile
Small female	1513.0	5	16	46.7	5	25
Midsize male	1751.0	50	85	78.2	50	89
Large male	1864.0	95	99	102.5	95	99

DISCUSSION

The main purpose of this study is to compare the anthropometric characteristics of Malaysian adults with the reference ATDs' design targets. The current analysis demonstrates that the widely used ATDs for crashworthiness evaluation of new vehicles in Malaysia are not truly representative of the Malaysian adult population, with respect to statures and body weights.

This finding supported the previous study on the Chinese adults[14] with regards to the Asian population. Although the latest available data utilized in the study for small female and large male was dated back in the year 1988, it can still be used as a useful reference. As illustrated in Figure 3, the statures of both Chinese and Malaysian populations are slightly shorter than the ATDs, with almost similar values.

Nevertheless, there is a substantial difference in body weights for both the Malaysian and Chinese adults. For Chinese, a significant deviation from the reference ATD values can be seen for the large males. The Chinese' body weights (75kg) were significantly different from the HIII-95M (102.5kg) and even lower than the HIII-50M (78.2kg). Similar trend can also be observed for Malaysian population but the highest difference is recorded for midsize male, as shown in Figure 4.

In addition, although the ATDs were developed based on the US adults' anthropometry, the current data in 2010 shows marked changes since 1974[12]. In contrast with the Chinese and Malaysian, the current statures and body weights of the US adults are larger than the reference ATDs that was developed more than three decades ago. This suggests that the adult ATDs may not be "sufficiently representative" of the current US population[12], as well as for the Chinese and Malaysian populations.

The main concern regarding the anthropometric differences between the ATDs and domestic populations is the different injury outcome in road traffic crashes. In an evaluation of the scaled down HIII-50M based on the Chinese population using MADYMO software, the results indicate higher head and neck injuries for the smaller dummy model in comparison with the HIII-50M[19].

This can be explained by the seating position of the dummy model. Due to smaller physique, its location is closer to the steering wheel. As a result, the optimal effect of airbag's energy absorption may not be achieved as the performance of driver's head and neck protection is highly related to the trigger time and contact with the airbag[20]. The higher neck injury could also be explained by the close contact of shoulder belt to the dummy model neck due to smaller stature[14].

Mass of ATDs also plays an important role in the outcome of a crash test. It is directly related to the absorption performance of restraint systems such as seatbelt, airbag, knee bolster and other related components[12]. Due to the substantial differences in body weights as shown by the result of current study and previous studies in the US and China, the intended benefits of the abovementioned systems in terms of injury mitigation may not be optimally achieved and applied to the overall population. Therefore, it is timely to conduct further research on improving the existing ATDs by incorporating current anthropometric parameters.

It is also to be noted that the number of sample used in the current study is low as compared to the studies by Reed and Rupp[12], and Cao et al.[14] which utilized larger samples from national databases. For improved analysis, a standardized anthropometry database for the Malaysian population shall be established in the future despite many challenges in terms of sample representativeness, funding, cooperation among researchers and measurement standardization[21].

This effort is important as Malaysia is the leading country in the region towards elevating the vehicle safety level through crash testing. The UN R94 has become a requirement for manufacturers to sell their vehicles in the country. The New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP), a consumer-based initiative, was also initiated by Malaysia through the Malaysian Institute of Road Safety Research (MIROS).

On another note, the ATDs being discussed in this paper only applies for frontal crash test. For side impact test, a different ATD type is used which is called the Euro Side Impact Dummy version 2 (SID-2). This particular dummy has different anthropometric characteristics as well as injury criteria than the HIII-50M. The same goes for child dummies.

In the current ASEAN NCAP test regime, apart from the HIII-50M, there are also other child dummies used in the test at the rear seats which represent 3-year old (P3) and 18-month old (P1.5)[15]. Nevertheless, these P dummies will no longer be used and replaced by improved biofidelic dummies (i.e. Q type) starting from 2017[22].

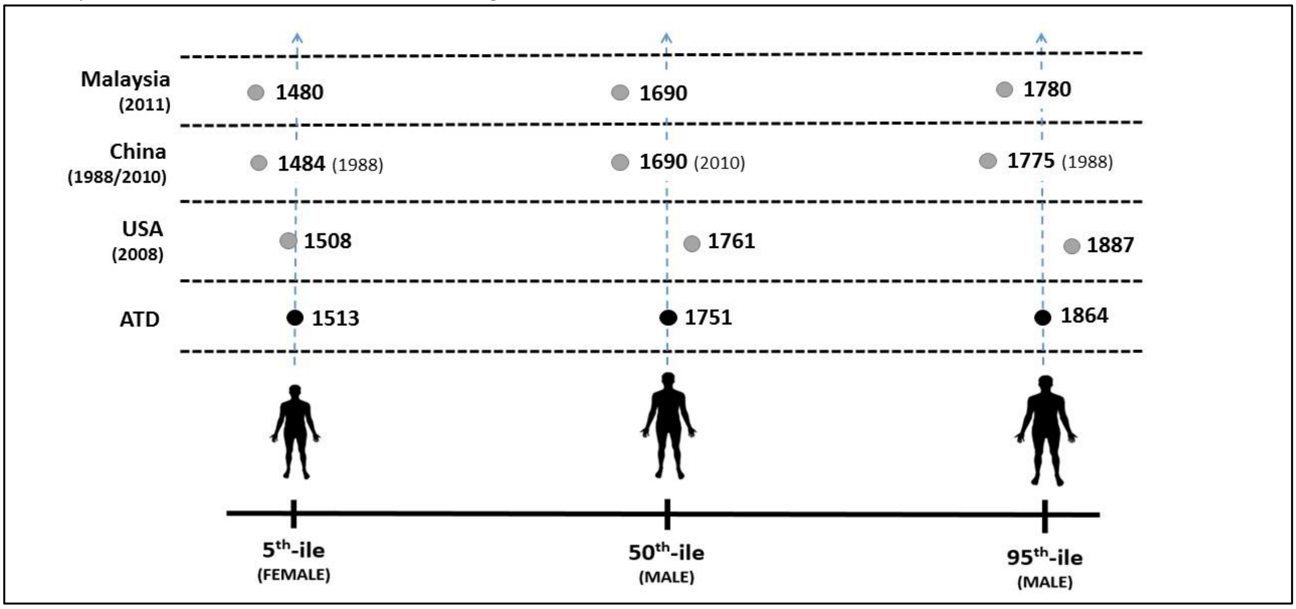

Figure 3 – Stature (mm) comparison between adult populations of Malaysian, Chinese and the US, and the reference ATDs (diagram not according to scale)

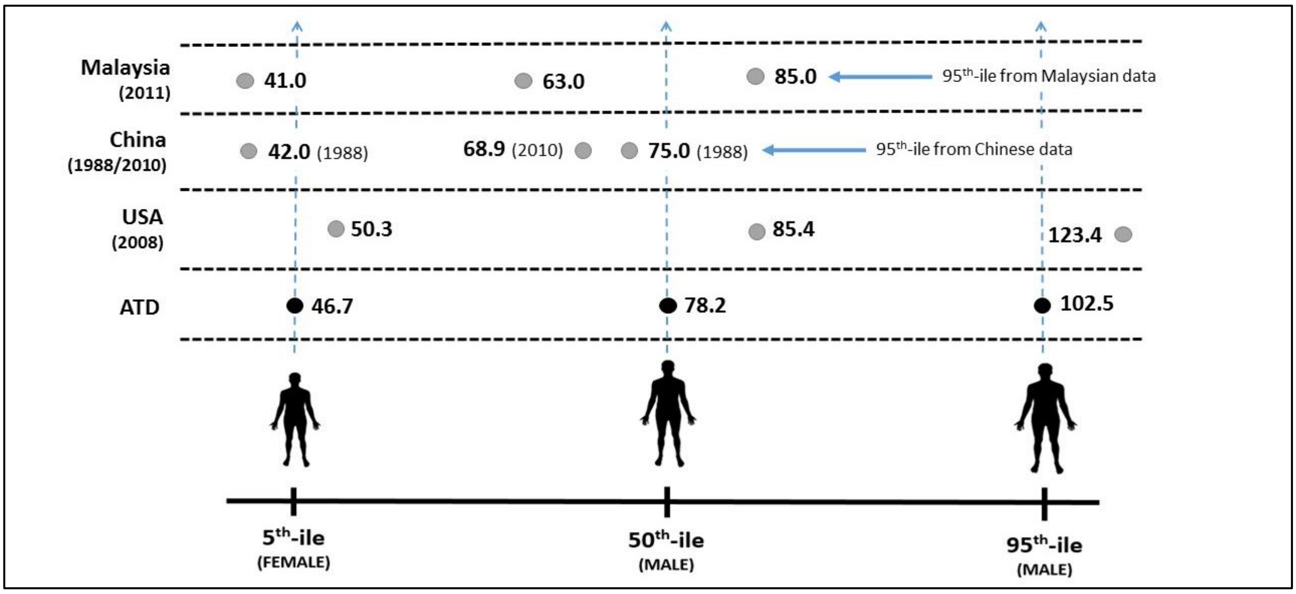

Figure 4 - Body weight (kg) comparison between adult populations of Malaysian, Chinese and the US, and the reference ATDs (diagram not according to scale)

CONCLUSION

In summary, the anthropometry of Malaysian adults does not truly represent the widely used ATDs for crash testing. This may affect the injury outcome as well as on the consideration of restraint system design for Malaysian population. With regards to the Asian population, this study complements the finding from previous study among the Chinese adults which has almost similar results. Even for the current US size, their statures and body weights have grown over the years. Therefore, there is a need for collaborative research around the world in improving the existing ATDs, not only from the anthropometry aspect, but also on the biofidelity performance i.e. representing human actual response to impact. Also, car manufacturers have to take the discrepancy matter into consideration as well when developing new models in the future.

ABBREVIATIONS

Anthropometric Test Devices – ATDs, Hybrid III 50th percentile male – HIII-50M, Hybrid III 95th percentile male – HIII-95M, Hybrid III 5th percentile female – HIII-5F, New Car Assessment Program (NCAP)

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COMPETING INTERESTS

There is no conflict of interest.

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