Derived Anatomical Dataset for Malaysian Radiation Adult Phantom

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***Abstract*:** The dependence of radiation effect on individuals led to the actualization and acceptance of the standard man in the 1940s, the standard man later transformed into the reference man in 1963. The definition of the reference man was a Caucasian data, so it conflicts with the physiology, anatomy and the metabolic data of the Asian people; this was challenging for the Asians and races from other adversely affected regions globally. Hence, the Asian man project was instituted but with the exclusion of the Malaysian people. Malaysia, being a tri-racial country therefore lag in reference man data. This is the gap this study intends to fill. In this study, a survey of 450 male and 450 female Malaysians (18-24 years) were used to collect data on the mass, height and the BMI. The total population of the Malaysian male and female within the age range and confidence interval of 95% with margin error of 5% were used as variables to arrive at the population of 450 that was used as a benchmark population for the survey. A mean value for the mass, height and BMI were obtained from this survey sample. An equation was derived from the International Commission for Radiation Protection, ICRP reference data and the Asia Reference Man, ARM data to estimate the needed dataset for the Malaysia phantom. The observed difference between the mass obtained from the equation and the mass obtained from the survey is less than 0.01% of the survey mass. The derived equation was appropriated and used to estimate the mass of the internal organs for the proposed Malaysian phantom. The volume equivalent of the internal organs was estimated using the simple density-mass-volume relation while the voxel number was estimated from the volume estimate. This was achieved using the respective recommended densities of the internal organs and the specified voxel numbers for ICRP male and female voxel phantom. These estimated values of the mass, volume and voxel number of the internal organs for the proposed Malaysian male and female are meant to be used for the modification of an existing radiation phantom or to serve as a background data for the construction of a new phantom.
Keywords: Malaysia phantom, Radiation dosimetry, Internal organs, Analytic estimation.

1.0 Introduction

Lately, calculation of the internal dose is a very sophisticated effort in radiation protection [1], hence, estimating the deposited energy of ionizing radiation and its distribution in the human body has become a challenging task [2]. The dose received by the human body was earlier found to be dependent on the individual exposed, this led to the actualization of the first 'standard man' data in 1949 [3,4]. Further improvements were made on the data in 1950, 1954, 1959 and in 1963, the standard man was revised, and the name changed to the reference man [4]. The improvements so far observed are traced to the efforts in the 1960s where more than 90 human phantoms (models) were developed and used for investigation into radiation dosimetry [3].

The use of reference man models has been of great interest to medical imaging, radiotherapy and radiation protection [2], however, the definition of the reference man indicated that its of Caucasian origin. The reference [4,5] affirmed that the Reference Man was defined as being between 20-30 years of age, weighing 70 kg, is 170 cm in height, and lives in a climate with an average temperature of 10 ℃ to 20 ℃. He is a Caucasian and is a Western European or North American in habitat and custom. This definition was later adopted by International Commission for Radiation Protection, ICRP. The adoption generated reactions from other races which differ anatomically, metabolically and physiological from the Caucasian. With advances in computer, computational phantoms were introduced and a descriptive definition for the computational phantom was provided. A reference male computational phantom is characterized by height of 176 cm, mass of 73 kg, 1.9 million voxels and voxel size of 36.5 mm^3. The reference female is characterized by height of 163 cm, mass of 60 kg, 3.9million voxels and voxel size of 15.2 mm^3 [5].

The knowledge of the human physiology, the physical and the metabolic parameters constitutes very important inputs to the successful determination of the internal dosimetry [6]. To guard against the use of in-appropriate anatomical data, the Task Group on Reference Man [4] authorized various regions with non-Caucasian body parameters to embark on efforts to determine the reference values for their respective population. It is on this premise that Asia Reference Man Project was established [6]. The project probed into the 'scarce' [20] Asian data with samples taken from nine countries [7,8,9], the sampled countries however exclude Malaysia. This made Malaysia to lag in the acquisition of the anatomical data needed for phantom development.

1.1 Statement of the Problem

In Malaysia, phantom development based on the anatomy of the Malaysia people is lacking due to the exclusion of Malaysia in the Asia reference man studies [8,9]. Sampled countries for the project have developed their peculiar phantoms: Japan [10], Korea [7], China [11], and recently, Taiwan [12]. Phantoms are useful in the safe estimations of the absorbed dose and the specific absorption fraction [1,13]. Developing Malaysia phantom will provide a means for improved radiotherapy planning. The focus of this study is to estimate the scarce [6] anatomical data, that is, mass, volume and the voxel numbers of the human internal organs applicable to Malaysian people

and suitable for Malaysia phantom development. This anatomical data is the background information needed for radiation phantom development.

1.2 Malaysia

Malaysia is in southeastern Asia with coordinate 2 30 N, 112 30 E and total dimensions of 329,847 square km (the land occupied 328,657 square km while water occupied 1,190 square km). Malaysia is a federation of 2 territories, 13 states and practicing a parliamentary democracy [14]. The health care system is well developed, accessible clean water and proper sanitary system is accompanied by strong social/economic programs [15].

The population is 31,809,660 (July 2018 estimate) and the tribal distribution is 61.7% Bumiputera (Malays, Orang Asli, Dayak, Anak Negeri), 20.8% Chinese, 6.2% Indian, 0.9% accounted for other citizens while 10.4% represent the percentage population of non-citizens in 2017 [14]. There are 802 public primary health care facilities and over 2000 small community clinics distributed over the country [15]. The percentage population of 0-14 years is 27.48% (male 4,498,796 /female 4,243,418); 15-24 years represents 16.74% of the population (male 2,704,318 /female 2,621,444); 25-54 years account for 40.97%, (male 6,587,529 /female 6,444,430); 55-64 years represent 8.46% (male 1,364,858 /female 1,325,595) while population with age ≥ 65 years is equivalent to 6.35% (male 957,841 /female 1,061,431) of the total population according to 2018 estimate [14] The birth rate is 1.88%, death rate is 0.52% and the population growth rate is given as 1.34% [14]. The life expectancy at birth is 73 years [15]. However, the Department of Statistics, Malaysia [16] assert that the population of the age range 15 – 24 years for male is 2665700 while the female figure is given as 2553200. Reference [16] further stated the racial population as Bumiputera (male 1926900, female 1850900), Chinese (male 533700, female 504700) and Indians (male 165300, female 170200).

1.3 The Phantom

The physical device that is useful in mimicking a human body for the purpose of radiation dose measurement is referred to as phantom [2]. There are three types of phantom: The Stylized phantoms are physical phantoms, commonly referred to as mathematical phantom [2,17] and made from solid materials that are equivalent to human tissues radiologically [2]. They are flexible but anatomically unrealistic [17,18]. The second type is the voxel phantom. These are 3D voxel phantoms [18] that provide better anatomical realistic data [17,18]. Each 3D voxel array contains elemental composition, peculiar identity and density [19]. The assembly of voxel phantom is through pixel tagging of image slices in MRI or CT. The third type is the NURBS or polygon mesh or hybrid phantom. It combines the flexibility of the stylized phantom and the realistic anatomy of the voxel phantom. The construction of hybrid phantom is achieved using the soft copy of the CT or MRI scan of the subject, that is the DICOM file, as it represents the voxel geometry of the image [5,18,19].

2.0 Material and Method

A reference height and mass were estimated for the Malaysian population using the combination of a published survey data [20] of 150 male and 150 female sample Malaysian population, and an actual survey result of 300 Malaysian Male and 300 Malaysian females obtainable from the Universiti Technologi Malaysia, UTM clinic. The Clinic was used because of accessibility, and the sample size when combined with that of the reference [20] gave a total of 450 for male and 450 for female. The ratio of the ICRP and ARM reference values to the estimated Malaysian reference were evaluated for the male and female. This approach is in accordance to the method by [6] among other methods used for the Asian reference. The equation used for the Malaysia values, M is:

$$\frac{ICRP+ARM}{2} = M_M \therefore ICRP + ARM = \frac{ICRP_M}{M_M} + \frac{AR_M}{M_M} = 2 \quad \text{Hence,} \quad \frac{\left(\frac{ICRP_M}{M_M}+\frac{AR_M}{M_M}\right)}{2} = 1 \tag{1}$$

where the ICRP, ARM and M represent the corresponding values of the masses respectively. The corresponding internal organs were estimated as in equation 1.

$$\frac{\%ICRP_{IO}+\%AR_{IO}}{2} = \%M_{\mathrm{IO}} \tag{2}$$

According to [4], the equation for the reference man estimation is:

$$W(g) = (0.26L)^{3.108} + 4.6 \tag{3}$$

The equation 3 of the refence man [4] was found to be approximately equal to the theoretical estimation from ICRP and the ARM of equation 1.

$$W(g) = (0.26L)^{3.108} + 4.6 \cong ICRP_R + ARM = 2M_R \qquad \text{L=Height} \tag{4}$$

Equation 1 represents the normalized Malaysian mass equivalent of the ICRP and ARM reference. Equation 2 is the percentage representation of the internal organs, IO of a Malaysian with respect to the total mass derived from equation 1. Equation 3 is the ICRP

benchmark equation for the reference man. And equation 4 is used to confirm the benchmarking of equation 1 with an established equation from reference [4] used for ICRP reference man.

When L is substituted with the height of Malaysian male obtained in this study, and the total mass of ICRP and ARM are substituted in equation 3, equation 1 (the right side of equation 4 is approximately equal to the reference man equation [4], the left side of the equation 4. The conversion of mass to volume approximate is achieved using the equality of density to mass per unit volume. The volume is transformed into voxel number component by dividing the estimated volume with the voxel size recommendation of the ICRP (male = 36.5 mm^3 and female = 15.2 mm^3). In this study, the mass is obtained as shown in the procedure Figure 1, 2 and 3. The mass for each organ is divided by the density of each organ to give the volume of the organ. The volume is divided by a specified voxel size to give the number of voxels in the organ. The figure 1 shows the procedure for the model estimation of the mass of the internal organs, figure 2 is the comparison of the approach of this study with the Taiwanese reference, and the figure 3a to figure 3g shows the expanded steps taken to establish the estimation for the mass of the internal organs.

The procedure adopted in generating the values for the Malaysian phantom development in this study is exactly the reversal of the procedure used in generating Taiwanese values for Taiwanese reference man and Taiwanese reference woman [12], Figure 2.

Taiwanese: Voxel Number → Volume → Mass

This Study: Mass → Volume → Voxel Number

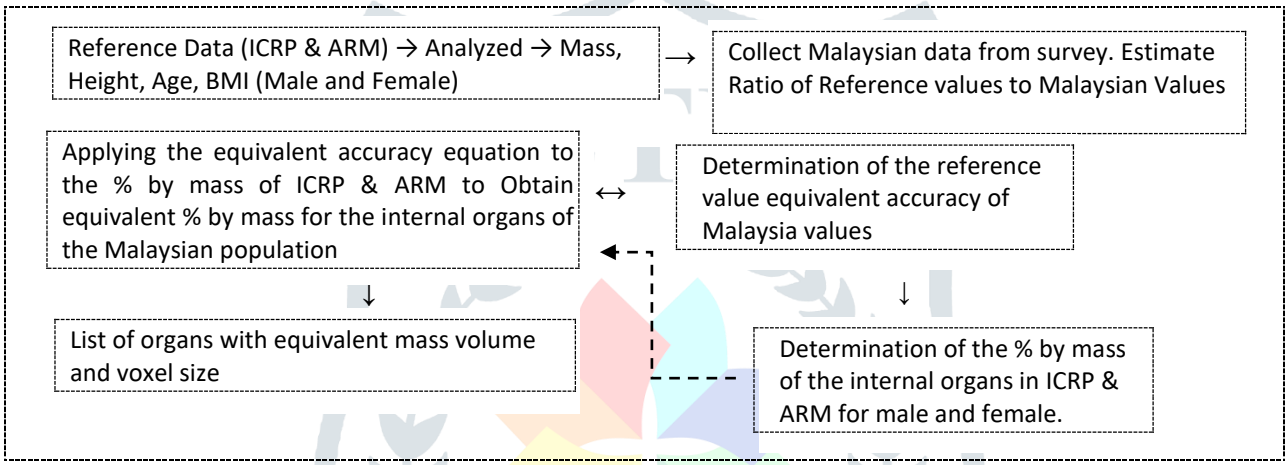


Figure 1: The Model

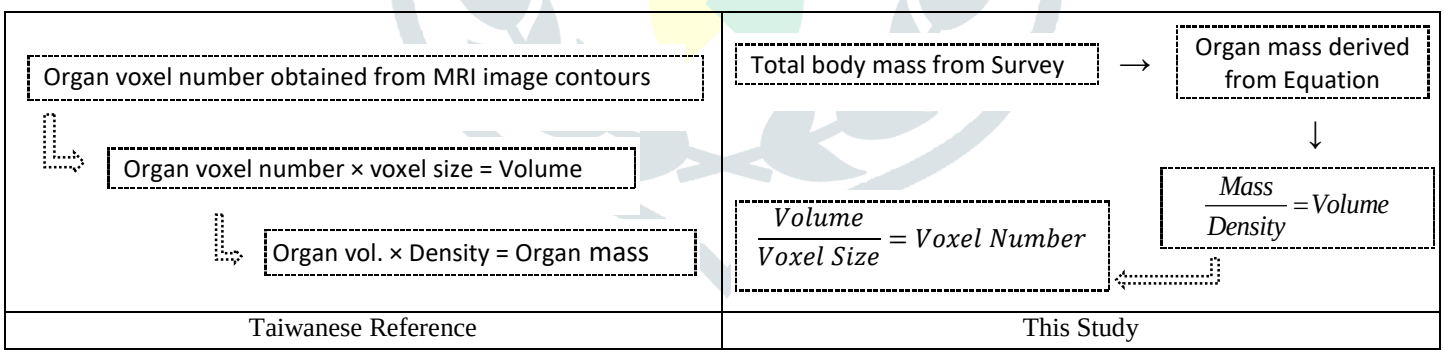
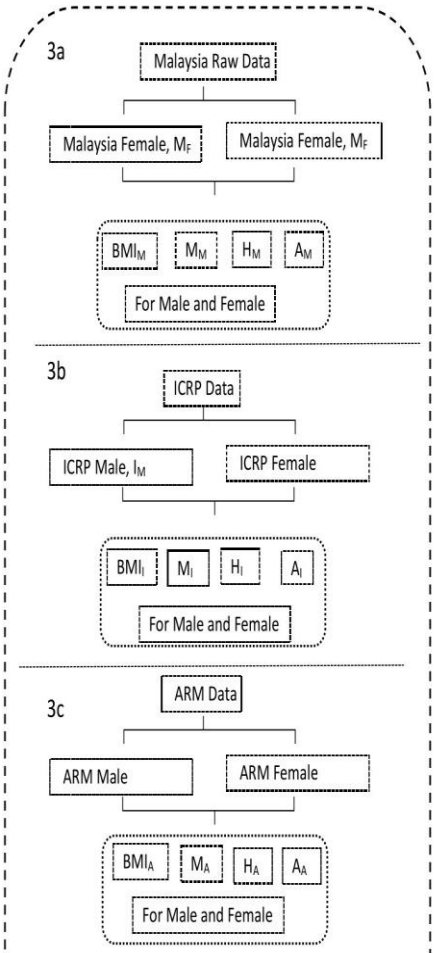


Figure 2: Model for voxel-mass-volume conversion: Taiwanese reference [12] and this study



-Figure 3a: Estimation of Mean Mass, Height, Age and BMI from Malaysia Survey Data
-Figure 3b: Reference Mass, Height, Age and BMI for ICRP data
-Figure 3c: Reference Mass, Height, Age and BMI for ARM data

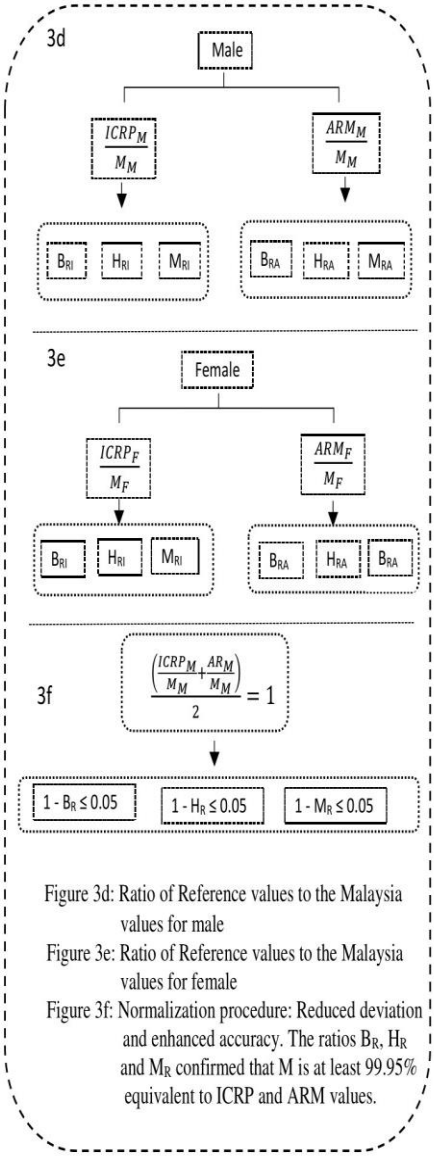


Figure 3d: Ratio of Reference values to the Malaysia values for male
Figure 3e: Ratio of Reference values to the Malaysia values for female
Figure 3f: Normalization procedure: Reduced deviation and enhanced accuracy. The ratios B_R, H_R and M_R confirmed that M is at least 99.95% equivalent to ICRP and ARM values.

3g

$$\frac{\%ICRP_{io}+\%ARM_{io}}{2} = \%M_{io}$$

$\%ICRP_{io} = \%\ of\ ICRP\ organ\ mass$

$\%ARM_{io} = \%\ of\ ARM\ organ\ mass$

$\%M_{io} = \%\ of\ phantom\ organ\ mass$

NB: The % is wrt the total mass. The Equation 3g is applicable to the male Phantom. The %ICRP values was used For the female phantom.

Figure 3g: Equation for estimating the Mass of the internal organs of the Malaysian phantom

ARM = Asia Reference Man Data
ICRP = Int. Comm. For Rad. Prot. Data
M = Malaysia Data; B = BMI; H = Height
io = Internal Organ

Table 1: Survey Population

Male	Female	Total (Male & Female)
Age Range: 15 - 24 years Male Population: 2665700 [16] Ideal sample Size: 385 Sample size used (This Study): 450	Age Range: 15 - 24 years Female Population: 2553200 [16] Ideal sample Size: 385 Sample size used (This Study): 450	Age Range: 15 - 24 years Population:5218900 [16] Ideal sample Size: 385 Sample size (This Study): 900

Table 2: Harmonized Malaysian Dataset (Male)

	Minimum	Maximum	**Mean**
Age (year)	18.00	23.75	**19.6**
Height (mm)	1603.3	1845.0	**1712.6**
Mass (g)	41.00	118.58	**67288.0**
BMI	12.92	50.72	**22.9**

Table 3: Harmonized Malaysian Dataset (Female)

	Minimum	Maximum	**Mean**
Age (year)	18.00	24.00	**19.7**
Height (mm)	1425.3	1709.0	**1559.3**
Mass (g)	37.55	98.73	**56280.0**
BMI	13.61	43.86	**23.2**

Table 4: Ratio of ICRP and ARM Reference to Malaysia Data (Male and Female)

	Mass		Height		BMI	
	Male	Female	Male	Female	Male	Female
$\frac{ICRP}{M}$	1.084884	1.0661	1.0276622	1.0453576	1.02767	0.9746864
$\frac{ARM}{M}$	0.891685	0.90619	0.9926283	1.0261179	0.90515	0.8598651
$\underbrace{\frac{\frac{ICRP}{M}+\frac{ARM}{M}}{2}}$ Equation used for Malaysian Male (Mass)	**0.988284**		**1.0101452**		**0.9664142**	

Table 5: Modified Table of Standard References [3,4,7,10,11].

	Male		Female	
	ICRP, '95	ARM	ICRP	ARM
Age	35	35	35	35
Height	1.76	1.7	1.63	1.6
Mass	73	60	60	51
BMI	23.57	20.76	22.58	19.92
Race	*	**	*	**
Race: *Caucasian; **Mongaloid/South Caucasoid				

3.0 Result and Discussion

The values used in this study are obtained using confidence level of 95% and margin error of 5% on a sample size calculator obtained from https://www.qualtrics.com/blog/calculating-sample-size/. The 450-population sample comprises of 300 samples from UTM clinic while 150 samples from a previous survey [20]. The Table 1 provide information on the survey population.

The mean mass, height and BMI obtained from the survey of 450 samples each for male and female Malaysian are 67.29 kg, 1.713 m and 22.9 for male while 56.28 kg, 1.56 m and 23.2 for female respectively, see Table 2 and 3. The justification for the 450-population sample is given above. The Table 5 compares the reference ICRP and ARM values.

The equation 1 given by $\frac{ICRP_R+ARM}{2}$ is equal to M_M + 0.7 kg where M_M is the Mass for Malaysian Male obtained from the survey. The ratio of the 0.7 kg (the differential) to M_M, ICRP and ARM equal an approximate value of 0.01. The 0.01 represent the tolerance of the value of M_M, see Table 4. The Table 5 compares the ICRP and the ARM dataset. The Table 6 presented the detail result of this study, that is, the mass, volume and the voxel number of the internal organs obtained for the construction of the Malaysian phantom in this study.

Table 6: Estimated mass, volume and voxel number of the internal organs for male and female Malaysian phantom

Organ	Density	Modified Adult Male Phantom			Modified Adult Female Phantom		
		Mass	Vol. (ml)	Voxel #	Mass	Vol. (ml)	Voxel #
Total Mass		**67288.00**			**56280.00**		
Brain	1.04	**1470.25**	**1413.70**	**38731.51**	**1179.10**	**1133.75**	**74588.82**
Stomach Wall	1.04	**147.70**	**142.02**	**3890.96**	**110.68**	**106.42**	**7001.32**
Stomach Contents	1.04	**249.98**	**240.37**	**6585.48**	**176.34**	**169.56**	**11155.26**
Small Intestine	1.04	**625.78**	**601.70**	**16485.21**	**457.74**	**440.10**	**28956.58**
Heart Wall	1.04	**147.70**	**142.02**	**3890.96**	**110.68**	**106.42**	**7001.32**
Heart Contents	1.04	**454.73**	**437.24**	**11979.18**	**351.75**	**338.22**	**22251.32**
Kidney	1.04	**322.98**	**310.56**	**8508.49**	**254.20**	**244.42**	**16080.26**
Liver	1.04	**1729.31**	**1662.80**	**45556.16**	**539.35**	**518.61**	**34119.08**
Lung	0.25	**1110.26**	**44410.40**	**1216723.29**	**711.00**	**28440.00**	**1871052.62**
Skeleton	1.4	**9780.36**	**69859.70**	**1913.96**	**7146.62**	**51047.29**	**3358.37**
Thyroid	1.04	**19.85**	**19.09**	**523.01**	**16.88**	**16.23**	**1067.76**
Pancreas	1.04	**119.10**	**114.52**	**3137.53**	**79.73**	**76.66**	**5043.42**
Spleen	1.04	**161.49**	**155.28**	**4254.23**	**144.45**	**138.89**	**9137.50**
Testes	1.04	**37.00**	**35.58**	**974.79**	**-**	**-**	**-**
Ovaries	1.04	**-**	**-**	**-**	**10.32**	**9.92**	**652.63**
Gall Bladder	1.04	**9.08**	**8.73**	**239.18**	**7.50**	**7.21**	**474.34**

4.0 Recommendation

The values of the mass, volume and voxel number estimated and presented in Table 6 of this study are physical parameters representing the internal organs of the surveyed population in Malaysia. The values are very useful in modifying an existing radiation phantom or to construct a phantom. Such phantoms that could be modified include the VIP man, AMALE and AFEMALE phantom of the ORNL

5.0 Summary and Conclusion

The physical parameters estimated in this study for the Malaysian phantom are mass (67.29 kg for male and 56.28 kg for female), height (1.71 m for male and 1.56 m for female), BMI (22.94) for male and 23.17 for female), and age (18-24years) as adult reference age range. These values presented alongside the values for the internal organs are hereby proposed for consideration in constructing the Malaysian phantom.

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