

# COMBINED FIELDS

## SEGMENTAL PARAMETERS OF BULGARIAN WOMAN WITHIN MODIFIED KWON HUMAN BODY MODEL\*

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**ABSTRACT.** We present a new geometrical biomechanical model of the Bulgarian women, which represents a modification of the one proposed by Kwon [1]. We performed our own anthropometric measurements of 50 women aged between 30–40 years in order to determine the parameters used in the Kwon’s model. The remaining set of data needed is taken from the representative anthropological investigation of Bulgarian females [2], in which data for 2855 individuals has been collected. We calculate analytically and estimate numerically the mass-inertial characteristics of the segments using the model suggested after deriving the corresponding analytical expressions needed. We present a comparison between the results obtained within this model and our previous results reported in [3], as well as with another data for Caucasian reported in literature. The present investigation provides data for a set of parameters of the Bulgarian women, for which no direct measurements are available. The model proposed is oriented to application in medicine and engineering.

**KEY WORDS:** body segment parameters, anthropometry, 3D human body modelling.

### 1. Introduction

The current article represents a continuation of [4], which is focused of the body segment parameters of the Bulgarian man via extending with a study of the problem of determination of the parameters characterizing the segments of the body of Bulgarian women. As it has been already clarified in Ref. [4], the dynamic analyses of human motion require knowledge of geometric and

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mass-inertial parameters of the body. One shall stress from the very beginning that much less such data is available in the literature for women than for men. Initially, in [5] regression equations for females have been suggested based on the measurements of a sample of 46 adult women using stereophotogrammetry. Then, in [6] the body segments parameters of 15 college-aged females have been evaluated and classified into endo-, meso- and ecto-morphs. In [7] the mass-inertial parameters of 15 female athletes have been investigated using gamma-scanner method. Next, in [8] data for the mass-inertial parameters of the female body has been reported based on a sample of 80 Japanese women and the difference in segment mass proportions with the sample of 215 men has been discussed. Finally, in [9] regression equations for estimating length, mass and moments of inertia of the segments of the human body have been derived on the basis of measurements of 25 young Caucasian females. There are no direct measurements of mass-inertial parameters of the body segments for Bulgarian women as far as the author is aware about. To fill, at least partially, this gap in the current article we suggest a 16-segmental 3D model of the human body of the Bulgarian woman that is used to calculate analytically and estimate numerically the mass-inertial characteristics of the human body segments. Thus, the aim of this study is to modify the Kwon's human body model by performing our own anthropometric measurements of 50 women aged between 30–40 years in order to improve the 16-segmental mathematical model of the human body of the average Bulgarian woman [3] by modelling the upper arm, lower arm, thigh and shank of the females with versions of right elliptical stadium solids instead of using, as in [3], the frustum of a cone. Let us stress that one of the consequences of modelling these segments via right elliptical stadium solids is the lack of the “left-right” symmetry for the inertial moments of these segments. The last symmetry is preserved in [3] and is usually also present in most of the geometrical models of the human body we are aware about.

The measurements needed to be performed have been already described in [4]. Here, we visualize two of the measurements performed – namely those of the subepicondilar diameter of femur and the saggital diameter perpendicular to subepicondilar diameter of femur (see Fig. 1).

## **2. Model and method**

We present a new geometrical biomechanical model of the Bulgarian women following [1] and [4]. We performed our own anthropometric measurements of 50 women aged between 30–40 years in order to determine the

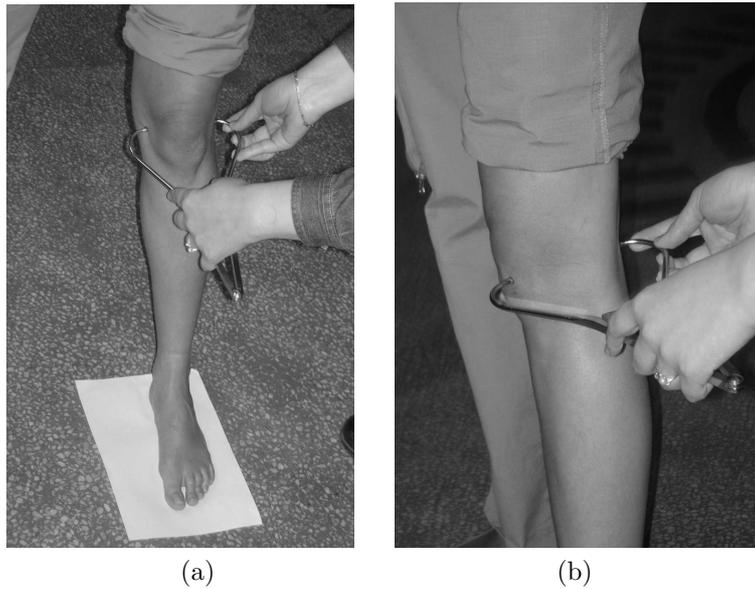


Fig. 1. Anthropometric measurement: (a) – subepicondylar diameter of femur;  
 (b) – saggital diameter perpendicular to subepicondylar diameter of femur

parameters used in the Kwon's model. The remaining set of data needed is taken from the representative anthropological investigation of Bulgarian females [2], in which data for 2855 individuals has been collected. The women body in the so-constructed model, as in [3], [4] and [10] is divided in 16 segments: head + neck, upper part of torso, middle part of torso, lower part of torso, thigh, shank, foot, upper arm, lower arm and hand that are considered to be represented by geometrical bodies like frustum of cone, ellipsoid, elliptical solid, stadium solid, etc. – see Table 1 in [4]. The height and weight of the average woman are 1.58 m and 65.3 kg [2]. The relevant, appropriate for our case choice of the anthropometric points, explanation of one of the possible ways one determines the numerical values of the geometrical parameters, the way the segments are modelled, etc., is described in [3], to which we refer the interested reader for details. Specific problem for modelling women body is the question about the division of the torso – both the question about the proper choice of anthropometric points used to divide it in parts, as well as the related to it problem of mass distribution and inertial moments of these parts. The separation of the thigh from the torso poses an additional special problem [10]. In the current study, in contrast with [3], we will use the geometrical modelling of the thigh, shank, foot, upper arm and lower arm of the average Bulgarian females as described in [4], and will verify that the new model proposed de-

scribes the inertial parameters of these segments better than the model used in [3]. Two of the anthropometric measurements needed for our model are visualized in Fig. 1. Let us remind that, as in [4], in the model used in this study the upper arm, lower arm, thigh and shank are represented by an right elliptical stadium solids (see Fig. 1 in [4]). All the steps of the way we modified Kwon's human body model, detailed description of our own anthropometric measurements (the same are performed for 50 men too), their notations and symbols have been shown in [4].

Table 1. The average values of the directly measured independent parameters (cm) for females. In brackets the standard deviation (SD) is given. Here  $D_l$  and  $D_t$  shall be understood as  $D_{l,0}$  and  $D_{t,0}$  for elbow and knee and as  $D_{l,1}$  and  $D_{t,1}$  for wrist and ankle

Parameter	$D_l$	$D_t$	$L_{cir}$
Axillary arm circumference	—	—	25.5 (3.8)
Elbow	6.6 (0.2)	5.1 (0.2)	22.8 (1.6)
Wrist	4.6 (0.3)	3.0 (0.2)	14.9 (0.7)
Knee	9.1 (0.7)	10.0 (0.8)	36.0 (2.7)
Ankle	5.6 (0.5)	7.4 (0.7)	21.7 (1.6)

Again, data on the basis of the anthropometric measurements performed for  $D_l$ ,  $D_t$  and  $L_{cir}$  (see [4] for the definition of the notations used) has been collected and reported in Table 1.

### 3. Results and discussion

One can determine the values of  $a$ ,  $r_l$  and  $r_t$  of the corresponding segments using the data reported in Table 1 for the segments of interest and keeping in mind the analytical properties of the stadium solid, see Eqs (1)–(4) from Appendix in [4] – see Table 2. In addition, the lengths  $L$  (in cm) of the segments according to [2], and the densities  $\rho$  (in  $\text{kg/m}^3$ ) of the segments according to [11] are given in this Table. We determine analytically and estimate numerically the masses, the positions of the centers of the masses and the inertial characteristics of the average Bulgarian woman on the basis of the model suggested, the original experimental data measured and the analytical properties of the solid bodies involved in modelling the segments of the human body, after deriving the corresponding analytical expressions needed, see the

Appendix in [4]. Table 3 contains the so-obtained results for the principal moments of inertia for the upper arm, lower arm, thigh, as well as for all remaining segments of the human body for the “average” Bulgarian woman. A set of regression parameters, which depend on gender, race, body height and body mass are found using body-profile method, introduced in [9] for approximation of anthropometrical values for segment lengths, masses and moments of inertia using the 16-segment model [7]. The participants in this study (100 subjects) are categorized into four groups (German males and females, Chinese males and females) with 25 subjects each. We use for comparison that data for German females because the authors used the same segmentation of the body as in [7], segmentation also used in our model. Furthermore, [9] contains the most “representative” study of another group of Caucasian than the Bulgarian one [2] – namely of 25 German females.

Table 2. Calculated parameters (cm), lengths and densities for females

Segment	Parameters							
	$a_0$	$r_{l,0}$	$r_{t,0}$	$a_1$	$r_{l,1}$	$r_{t,1}$	$L$	$\rho$
Upper arm	3.1	0.2	2.6	3.5	0.2	2.9	28.6	1053
Lower arm	3.1	0.2	2.6	2.2	0.1	1.5	21.9	1100
Thigh	3.9	0.7	5.0	6.4	1.1	8.2	47.9	1062
Shank	3.9	0.7	5.0	0.9	1.9	3.7	34.6	1088

The inspection of Table 3 shows that the new model for most of the quantities of interest produces results closer to ones reported in [9] than those derived from the model described in [3].

It is well known that anthropometric data depends strongly on age, therefore, one should keep in mind that the method described above could be applied by using the data provided only to females aged 30–40 years. The proposed more realistic modelling of the segments for this age group can predict data for the inertial parameters of a given female *individual* provided the corresponding easily measurable geometrical data for this individual is known.

Finally, we end this Discussion by presenting in Table 4 a comparison of two of the very basic characteristics of the human body for Bulgarian females with the values for two other groups of Caucasians. In this Table the values of the body height and body mass of the average Bulgarian female are contrasted to the corresponding average data for Russian and German females.

Table 3. Moments of inertia of the body segments through the centre of mass (kg.cm<sup>2</sup>) for females

Segment	Shan and Bohn <sup>a</sup> (see Ref. [9])			Nikolova and Toshev (see Ref. [3])			Our data		
	I <sub>XX</sub>	I <sub>YY</sub>	I <sub>ZZ</sub>	I <sub>XX</sub>	I <sub>YY</sub>	I <sub>ZZ</sub>	I <sub>XX</sub>	I <sub>YY</sub>	I <sub>ZZ</sub>
Head + Neck	251.3	212.9	119.5	198.7	198.7	117.5	195.0	195.0	79.7
Upper torso	1331.6	2223.4	1766.8	1386.2	1594.8	1749.9	541.5	841.1	957.7
Middle torso	269.6	489.4	533.1	445.5	509.6	537.2	356.9	518.6	518.9
Lower torso	464.5	660.7	692.5	498.2	553.6	688.9	144.2	248.8	309.2
Upper arm	88.6	87.0	19.6	123.5	123.5	15.8	85.9	83.5	13.6
Lower arm	29.9	31.8	4.2	34.6	34.6	4.0	23.7	22.7	4.3
Hand	3.1	2.5	1.2	1.5	1.5	1.5	1.7	1.7	1.7
Thigh	1111.1	1118.2	299.8	1714.7	1714.7	290.5	1578.9	1678.0	373.1
Shank	256.2	298.8	69.0	119.4	119.4	24.8	224.0	239.8	34.5
Foot	12.1	12.3	2.2	35.8	35.8	3.7	31.5	31.5	3.7

<sup>a</sup> The data is obtained by using the regression equations derived in [9] applied for the average Bulgarian female person.

The data indicates that average Bulgarian female is shorter in height than both the Russians – with 15 cm, and the Germans – with 11 cm. The average Bulgarian female height is closer to Germans. It should be noticed here that all the Russian females are national athletes. One can see with respect to the mass that the mass of the average Bulgarian female is closer to the

Table 4. Average values and range of age, body height and body mass of Russian, German and Bulgarian female

	Zatsiorsky (see Ref. [10]) Russian ( <i>n</i> = 15)	Shan and Bohn (see Ref. [9]) German ( <i>n</i> = 25)	Yordanov et al. (see Ref. [2]) Bulgarian ( <i>n</i> = 2435)
Age (year)	19.0	27.0	30–40
Body height (m)	1.73	1.69	1.58
Body mass (kg)	61.9	63.6	65.3

Germans – she is about 2 kg heavier than German and 4 kg than the average Russian.

In the current article, following [1], a new modified geometrical model of the Bulgarian woman is presented. This study has as one of its goals to improve the existing 3D biomechanical model of the female body, presented in [3]. We have found the geometrical parameters of the body segments on the basis of the existing anthropometric data and our own anthropometric measurements, which have been approximated by elliptical solids, which are closer to the real shape of some of the segments of the human body. We have derived analytically and estimated numerically the three principal moments of inertia for all the segments of the body using the model thus designed. Wherever possible, we have presented a comparison between the results obtained within this model and our previous results reported in [3], as well as with another data for Caucasian reported in literature [9]. We have observed an overall good agreement among all of them.

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