NEW METHODS TO DETERMINE 3-D ROTATIONAL INERTIA

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Due to the different stature of the various nationalities and the limitation of the sample or the divergent research methods, the results on human-body inertia parameters of occidentals are not suitable to be applied to oriental adults. In this study, the 3-D principal inertia of each segment and of the entire body of Chinese adults was determined and the mathematical models for calculating their parameters were constructed. The results from this study can aid in the development of the prosthetic limbs for invalids, and analysis of the movements of astronauts, etc. In addition, the regression equations for calculating 3-D principal inertia of human standard postures and for each segment were derived. Their reliability are tested and verified by three-string pendulum method.

KEY WORDS: human-body segments**,** CT**,** rotational inertia, inertia parameters, three-string pendulum

INTRODUCTION: Research on human-body principle moments of inertia is a fundamental component in the fields of ergonomics, sports biomechanics, and aeronautics, etc. In the study of human body rotation, these parameters must be accessible. Some developed countries, such as U.S.A., Russia, and Germany, have done the research on three-dimensional principal inertia of each segment and the entire body. Their results are different due to the different physical characteristics of the various nationalities and the limitation of the sample or the divergent research methods. It is of significant importance to find out the appropriate methods of measuring the specific inertia parameters of the human body for the Chinese and Asian..

The purpose of this research was to determine 3-D principal inertia of each segment and the entire body of Chinese adults, and to construct the mathematical models for calculating their parameters, including regression equations for calculating 3-D principal inertia of human standard postures and each segment. Two kinds of regression equations were provided: one based on two independent variables of the weight and height, the other being multivariate regression equations based on independent variables of human body surface measurements. By means of these equations, the 3-D principal inertia of each segment and the entire body of an individual could be calculated. The data can be applied in design of safety protection and to analysis of performance of athletes in sports. Moreover, it is helpful in the analysis of injury mechanism and prescription of the precautions concerned. Additionally, research of this nature, can aid in the development of prosthetic limbs for invalids and analysis of the movements of astronauts, etc

METHOD: Subjects. The test sample consists of 40 males and 48 females by CT method, whose average weight and height conform to the standard statistics for Chinese adults.

The test sample includes 2 males and 2 females that are selected by weight from the sample of Chinese adults by three-string pendulum method.

Standardization. GB/T 5703-1999 Basic human body measurements for technological design (China, 1999)[1] were followed strictly in the division of Chinese adult segments and measurement of the human-body surface dimensions [2]. Methods of anthropometry are also

used in some special items in order to ensure the generality of the data.

Computerized topography. Computerized medical topography (CT) and digital image processing system were employed to scan living human-body slides, and the 3-D principal inertia of human-body segments were measured one by one. Steps read as follows:

1.The slides of each object are scanned by means of CT every 3 centimeters, and the photographs of each section are taken with positive films.

2.The images are processed by digital image processing system. Firstly, Automatic Recognition by Classified Valuation, proposed by Professor Xiuyua Zheng[3] of Tsinghua University is used to calculate the area of each tissue segment of every section and the volume of each slide. Secondly, according to the densities of 19 kinds of tissues or organs of Chinese human body provided by Professor Zhiliang Zheng etc. of Norman Bethune University of Medical Science, the mass, the mass center and 3-D principal rotational inertia of the section are calculated. Finally, the 3-D principal rotational inertia of each segment and the whole body are determined. Construction of mathematical models was accomplished according to the 3-D principal of rotational inertia for each segment. This was done by means of CT and the surface human-body dimensions and regression equations for calculating 3-D principal rotational inertia of each segment. In this way, the model of the whole body by weight and height or by surface human-body dimensions is constructed.

Three-string pendulum method. In order to test and verify the reliability of two kinds of regression equations by CT, the principal rotational inertia of the whole body and some segments were calculated. The data obtained from 2 Chinese males and 2 females were measured by three-string, pendulum method. Each person completed 12 postures in order to check the equations, which were made by CT method. According to the periodic formula of three-string pendulum:

$$T = 2\pi \sqrt{\frac{HJ}{mgR^2}}$$

(T—rotation period; H—string length; R—radius of the disc on which the object sits or stands or lies; m: the total mass of the disc and the object). By measuring the correlated parameters, the principal rotational inertia (Jx, Jy, Jz): $J = \frac{T^2 mgR^2}{4\pi^2 H}$ of their sum or difference are determined.

RESULTS: In order to introduce the research results simply and clearly, an example of research on the thigh is presented here. However, the other segments are omitted.

From the results of the 3-D principal rotational inertia of each segment based on CT, the regression equations of the 3-D principal rotational inertia have been derived, calculated by the weight and height. The coefficients of the two-parameter regression equations of the 3-D rotational inertia are listed in Table1.

The comparison between the correlated coefficient of the multivariate regression equations of the thigh based on CT and the counterpart from Western or Occidental research results are provided in Table 3.

The segment parameters are chosen by successive regression in order to calculate the 3-D rotational inertia of the segment, such as the thigh. The coefficients of the multi-varied regression equations are listed in Table 2.

Table 1 The Coefficients of Regression Equations of the 3-D Rotational Inertia of Chinese Male and Female Thigh from the Weight and Height

Sex	Rotational inertia of thigh	B_0	B_1	B_2	Multiple correlative R	δ
Male	Jx	-3705.377	4.284	28.621	0.834	145.889
	Jy	3664.889	5.549	28.078	0.831	147.947
	Jz	65.270	7.165	-1.461	0.674	30.031

	Jx	-1926.934	25.374	10.331	0.926	70.318
Female	Jy	1622.265	29.200	7.321	0.908	83.536
	Jz	197.363	9.548	-3.177	0.626	50.272

$J=B_0+B_1\times$weight $+B_2\times$height J: rotational inertia of thigh (unit: kg×mm^2)

Table 2 The Coefficients of Successive Multi-Variate Regression Equations of the 3-D Rotational Inertia of Chinese Male and Female Thigh

sex	Rotational Inertia of thigh	B_0	B_1	B_2	B_3	B_4	Multiple correlative R
	Jx	-82196.75	-53.52	0	263.38	279.56	0.7288
Male	Jy	-89531.00	-48.58	0	278.65	277.38	0.7340
	Jz	-42696.50	25.46	7.43	89.33	0	0.9194
	Jx	-304530.90	90.89	106.88	257.18	288.15	0.8949
Female	Jy	-319702.68	105.39	123.57	280.85	248.97	0.9097
	Jz	-66850.90	35.42	41.10	73.40	-19.35	0.9513

$J=B_0+B_1\times$waist circumference$+B_2\times$hip circumference$+B_3\times$thigh circumference+B4×thigh length J: rotational inertia of thigh (unit: kg×mm^2)

Table 3 The Comparison of the Relatives of the Multi-variety Regression Equations of the Thigh Based on CT with the Research Data on Occidentals

Rotational inertia of thigh	Chandler*		B.M.Zatsiorsky**		This study	
	R	δ	R	δ	R	Δ
Jx	0.939	14	0.893	206	0.8949	123
Jy	0.865	19	0.896	205	0.9097	122
Jz	0.876	8	0.878	52	0.5130	11

***,** Liangbiao Li etc, Sports biomechanics (text book), pp70-75,1991.
******B.M.Zatsiorsky Russia,Biomechanics of the human body sport organs,1987,p120-141.

The comparison of the whole body's measurements by the three-string pendulum method with that of CT and the foreign research results are listed in Table 4.

Table 4 The Comparison of the Whole Body Measurement Results by the Three-string Pendulum Method with that of CT and Western Research Results

Rotational inertia	This study (three-string pendulum)	Xiuyuan Zheng et al. CT method		Chandler		B.M.Zatsiorsky	
	Measured values	Calculated value	Difference (%)	Calculated value	Difference (%)	Calculated value	Difference (%)
Jx	110491	107103	3.066	83066	24.821	104202	5.692
Jy	110357	111552	1.082	98019	11.180	109219	1.031
Jz	9157	6751	26.271	7463	18.499	6606	27.858

DISCUSSION: The 3-D rotational inertia of the human-body segment, which is calculated by the regression equations on the basis of CT, considerably conforms to the reality of Chinese human body. The multiple correlated coefficients, obtained by multivariate successive regression of human body surface dimensions of Chinese adults according to the rotational inertia by CT, are relatively high. From the test and verification of the three-string pendulum, it is clear that the CT method is the best one to calculate the inertia parameters of Chinese adults. If the equations provided by the western researchers are used to calculate the 3-D principal rotational inertia of the segments of the Chinese adults, discrepancies will occur because of the different statures of oriental and occidental people.

CONCLUSION: CT is a new method to determine the 3-D principal rotational inertia. Three-sting pendulum method, which used in China for the first time, can test and verify the results of CT. The presented methodology can also help to obtain and develop mathematical model of human body's principle moments of inertia.
The parameters introduced in this study have important value of reference to research on oriental people. The methods provided in this study are also valuable for the research on people who are occidental in origin.

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