THE STUDY OF A MATHEMATICAL MODEL AND OF THE REGRESSION EQUATION FOR CALCULATING INERTIAL PARAMETERS OF BODY SEGMENTS IN YOUNG CHINESE WOMEN

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Preliminary communication
UDC 577.3.001(=95)-055.2

Abstract:

Objective: In this study a mathematical model was set up for calculating the inertial parameters of body segments in young Chinese female students. *Methods*: On the sample of 50 young Chinese women the inertial parameters, mass and mass center of body segments, were determined by using the Computed Tomography – Digital Image Processing (CT-DIP) method. *Results*: A 16-segment mathematical model of young Chinese women was set up and a binary regression equation for inertial parameters of body segments calculation was established, in which body weight and stature were treated as independent variables. *Conclusion*: The study provided a method for a simple calculation of mass, mass centre and moment of inertia both of the segments and of the total body in the population of young Chinese women.

Key words: *Chinese female students, body, mathematical model, regression equation*

DIE ANALYSE EINES MATHEMATISCHEN MODELLS UND DER REGRESSIONSGLEICHUNG FÜR DIE BERECHNUNG INERZIÄLLER PARAMETER VON KÖRPERTEILEN IN JUNGEN CHINESINNEN

Zusammenfassung:

Ziel: In dieser Studie wurde ein mathematisches Modell für die Berechunng inerziäller Parameter von Körperteilen in jungen Chinesinnen gestaltet. *Methoden*: Inerziälle Parameter, die Masse und das Massenzentrum von Körperteilen wurden bei 50 jungen Chinesinnen mittels der Digitalen Bildbearbeitungsmethode (Digital Image Processing – DIP) bestimmt. *Ergebnisse*: 16-teiliges mathematisches Modell von jungen Chinesinnen wurde gestaltet zusammen mit der binären Regressionsgleichung für die Berechnung von inerziällen Parametern des Körpergewichts und der Körperteile. Körpergewicht und Statur wurden als unabhängige Variablen betrachtet. *Schlussfolgerung*: Das Resultat dieser Analyse war die Gestaltung einer Methode für die einfache Berechnung von Masse, Massenzentrum und Inerzmoment einzelner Körperteile und des ganzen Körpers bei jungen Chinesinnen.

Schlüsselwörter: *junge Chinesinnen, Körper, mathematisches Modell, Regressionsgleichung*

Introduction

The inertial parameters of the body are the essential data and an important foundation in researching sports medicine and biomechanics of motion, the analysis of the characteristic quantities in anthropology and of the morphology of the body (Miller & Nelson, 1973; Zatsiorsky & Seluyanov, 1983).

Ever since man was interested in studying human movement, the concept of physical body modelling was immanent to this study. Already Braune and Fischer in 1895 (citation according to Medved, 2001) considered human body as being rigid in the form of a series of dynamic links, which enabled them to realise for the first time an inverse dynamic approach in the study of movement. Hanavan (1964), however, is considered to have provided a good compromise between simplicity and relative precision in physical body modelling. The development of models is marked, further, by the Hatze's comprehensive approach (Hatze, 1980). Today, we witness the proliferation of very complex and sophisticated models such as the one by Delp et al. (1990), which rely on genuine anatomical representation (43 muscles for leg!) combined with CT and MRI scanning method (the bone geometry measurement) and high computer graphic power.

The aim of this study was to determine and analyse inertial data of the body in young Chinese women using the Computed Tomography – Digital Image Processing (CT-DIP) method (Shi et al., 1991; 1994), to provide a mathematical model of body segments, and to set up a regression equation that could in a simple way calculate the inertial parameters of body segments.

Methods

Materials

The sample consisted of 50 Chinese female students, aged 18 to 23. Anthropometric measures of body height and weight were obtained. According to Zatsiorsky (Zatsiorsky & Seluyanov, 1983), 16 body segments were analysed using the Computed Tomography – Digital Image Processing (CT-DIP) method (G.E. 8800 Type). On the basis of the grey level and the density of every structure and tissue in these segmental images (Shi Xinkun et al, 1990), the inertial parameters of the segmental surface, segmental lump, and every segment were calculated by the finite unit method. Finally, mass, mass centre and inertia of the segments were estimated (Shi Xinkun et al, 1998).

Designing the mathematical model

The mathematical model is more accurately described as an n-link mechanical system with multiple degrees of freedom at the junctures of segments. It is a system composed of a series of assumed homogeneous rigid bodies of simple geometrical shape hinged at the joints. Each rigid body corresponds to a segment of the body. The specific geometrical property of rigid bodies depends on the calculated inertial data. It regards the radii of gyration and the carriaging parameters of body segments as the main parameters, so as to be able to interrelate and analyse them in this research. On these grounds, a 16-segment mathematical model was devised according to Hanavan's mathematical model of human body (Hanavan, 1964).

Establishing a regression equation

The ultimate aim of the study of inertial parameters of the body is to achieve directly the dependable inertial data of the human body. In order to obtain the inertial data and the carriaging parameters of the sample and to design the mathematical model of the body, different variable quantities and the compound interrelated coefficients were calculated to go through the interrelated regression analysis. Finally, the binary regression equations that could immediately calculate the mass, mass centre and inertia of the body segments of the young Chinese women were inferred and set up. Body weight and stature were used as independent variable quantities in this study.

Results

The average data regarding mass, mass center and inertia of the segments and the whole body of the 50 young Chinese women, obtained using the CT-DIP method, are given in Table 1.

Table 1. The basic parameters (mass, mass centre and inertial parameters) of body segments and the whole body of 50 young Chinese women

Item / Segments	Mass kg M±SD	Mass centre cm M±SD	Inertia $kg \cdot cm^2$		
			Ix M±SD	Iy M±SD	Iz M±SD
Head&Neck	4.52±0.30	11.32±0.87	226.55±25.04	223.51±29.42	103.42±16.07
Upper trunk	8.93±0.83	11.91±0.76	382.32±84.70	601.74±114.05	486.85±100.50
Mid—trunk	6.78±1.15	8.53±0.89	269.39±64.62	391.67±88.53	316.14±73.50
Lower trunk	6.46±0.92	8.26±0.81	226.22±63.09	321.81±87.04	273.40±77.90
Upper arm	1.42±0.20	15.11±1.11	83.66±20.01	79.13±19.17	11.48±3.78
Forearm	0.62±0.09	11.54±1.67	19.7±4.13	19.11±3.95	4.54±1.30
Hand	0.26±0.05	11.10±1.65	—	—	—
Thigh	7.54±0.98	24.79±1.01	866.67±179.61	883.67±192.15	142.39±34.99
Leg	2.11±0.30	19.89±1.39	175.36±40.83	179.13±41.81	19.70±6.23
Foot	0.73±0.14	3.70±0.33	—	—	—
Whole body	52.80±5.32	71.19±2.65	—	—	—

M - arithmetic mean; SD – stand. deviation
Ix – moment of inertia of rotation around the horizontal axis; Iy – moment of inertia of rotation around the sagittal axis; Iz – moment of inertia of rotation around the vertical axis.

According to the average data of inertial parameters of the body segments based on the data of the radii of gyration of body segments, a 16-body-segment mathematical model was devised. The head was depicted as an ellipsoid of revolution, the upper, the middle and the lower torso as right elliptical cylinders, the hands as solid spheres and all other segments as frusta of right circular cones in this mathematical model .

On the basis of specific geometrical properties of the designed mathematical model of the body, the inertial data and the carriaging parameters of the sample, the corresponding reason variables, the compound interrelated coefficient and the standard deviation were calculated. Finally, binary regression equations for calculating the mass, mass centre and the moment of inertia of body segments were inferred and set up, in which height and weight acted as independent variable quantities (Table 2 and 3) .

Table 2. The binary regression equations and its calculated coefficients, mass and mass centre of body segments of young Chinese women in which height and weight act as independent variable quantities

Segments	Norm	B_0	B_1	B_2	R	σ
Head&Neck	**G** **G •C**	1.965 6.430	0.024 0.032	0.009 0.021	0.459 0.391	0.269 0.528
Upper trunk	**G** **G •C**	-9.172 0.389	0.113 0.036	0.077 0.061	0.559 0.540	1.201 0.642
Mid—trunk	**G** **G •C**	-6.379 -5.647	0.061 -0.083	0.063 0.116	0.543 0.453	0.884 0.807
Lower trunk	**G** **G •C**	-3.201 0.247	0.154 0.050	0.013 0.034	0.845 0.310	0.549 0.728
Upper arm	**G** **G •C**	1.121 2.671	0.039 0.046	-0.011 0.064	0.744 0.418	0.137 1.010
Forearm	**G** **G •C**	-0.138 5.678	0.014 0.062	0.001 0.019	0.720 0.498	0.062 0.611
Hand	**G** **G •C**	-0.003 8.406	0.002 0.030	0.001 0.009	0.249 0.303	0.046 0.537
Thigh	**G** **G •C**	-3.173 6.370	0.145 0.004	0.022 0.114	0.755 0.390	0.645 1.245
Leg	**G** **G •C**	-2.502 -4.357	0.042 0.035	0.018 0.141	0.737 0.776	0.234 0.622
Foot	**G** **G •C**	-0.684 -0.059	0.010 0.015	0.006 0.019	0.484 0.448	0.122 0.284

Binary regression equation: $Y = B_0 + B_1X_1 + B_2X_2$
Note: X_1…weight (kg), X_2…height (cm), B_0, B_1,B_2 … different criterion variable quantity: R … correlation coefficient: σ… standard deviation: G… mass (kg): G·C… mass centre (cm).

Table 3. The binary regression equations and its coefficients calculated of the moments of inertia of the body segments of the Chinese young females in which the height and weight act as independent variable quantities

Segments	Norm	B_0	B_1	B_2	R	σ
Head&Neck	I_x	-66.312	0.921	1.759	0.465	22.977
	I_y	-14.953	1.458	1.243	0.411	27.799
	I_z	164.749	2.148	-0.973	0.506	14.358
Upper trunk	I_x	-641.459	9.649	3.734	0.738	59.235
	I_y	-875.465	13.121	5.688	0.765	76.063
	I_z	-215.125	15.335	0.000	0.777	64.364
Mid—trunk	I_x	-390.617	2.681	3.544	0.421	60.818
	I_y	55.612	7.770	0.000	0.448	80.620
	I_z	181.678	11.446	-2.506	0.688	55.332
Lower trunk	I_x	-399.252	15.237	0.000	0.892	40.120
	I_y	-110.492	14.494	-1.932	0.867	40.211
	I_z	-6.363	0.000	0.096	0.617	0.544
Upper arm	I_x	-147.689	2.470	0.752	0.748	14.191
	I_y	-155.563	2.187	0.858	0.751	13.138
	I_z	-12.541	0.511	0.000	0.695	2.772
Forearm	I_x	-72.429	0.148	0.552	0.729	2.934
	I_y	-63.088	0.137	0.492	0.686	2.974
	I_z	-12.867	0.000	0.113	0.380	1.223
Thigh	I_x	-1926.934	25.374	10.331	0.926	70.318
	I_y	-1622.265	29.200	7.321	0.908	83.536
	I_z	197.363	9.548	-3.177	0.626	50.272
Leg	I_x	-621.885	3.578	4.044	0.825	23.923
	I_y	-588.609	3.859	3.773	0.811	25.326
	I_z	-15.166	0.749	0.000	0.612	5.019

Binary regression equation: $Y = B_0 + B_1X_1 + B_2X_2$

Note: X_1...weight (kg), X_2...height (cm): B_0, B_1, B_2 ... different criterion variable quantity: I_x...moment of inertia of rotation around the horizontal axis, I_y...moment of inertia of rotation around the sagittal axis, I_z...moment of inertia of rotation around the vertical axis: R ... correlation coefficient: σ... standard deviation.

Discussion

Using both the balance plate and the CT-DIP method, the body-related inertial data were determined and compared. The average relative variation of the initial data of the whole body fall within a range of ±1.10%. The largest absolute variation of the mass of the whole body was 1.76 kg, the largest absolute variation of mass centres of the whole body was 1.06cm. The results indicate a high calculating accuracy of the CT-DIP method.

The specific geometrical property of the segmental mathematical model was defined in accordance with the length and the radii of gyration of body segments of the samples in this paper. In the average inertial data of the body segments of the 50 young Chinese women, the moment of inertia and the radii of gyration of body segments around the coronal and sagittal axis were calculated so that the original points of coordinates are without the notable discrepancy between the upper, middle and lower trunk segments. For this reason, these models were plotted differently into the solid spheres, the frusta of right circular cones, the ellipsoid of revolution and the upper, middle and lower torso were depicted as right elliptical cylinders according to the specific characteristics of their parameters. These models reflect different characteristic of the different races of people.

When evaluating the binary regression equation, the coefficient magnitude indicates the closely related linear relation between the independent variate and the causal variate of the regression equation. It can be seen that the inertial parameters of large segments are in linear relation with the causal variate of its regression equation, i.e. $R>[R]_{0.05}>[R]_{0.01}$, besides the coefficient of regression equation calculating the mass centre of the hand and foot $R<[R]_{005}<[R]_{0.01}$. In the total body of inertial parameters, the biggest discrepancies appeared in the results for the hands and feet. These discrepancies, however, did not have a serious effect calculations since their moments were extremely small when compared with those of other segments. Therefore, the local terms of the hands and feet are negligible for the whole analysis.

It is simple and convenient to test the adaptation of this binary regression equation by comparing the tally level with the calculated data of the binary regression equation and the determined data with a balance plate. The whole masses and mass centres of the 50 randomly sampled female students were calculated by this binary regression equation. These data were compared to the data obtained by the balance plate. The results show that the largest absolute variation of mass of the whole bodies is 3.01kg, the largest relative variation 3.88%, the largest absolute variation of mass centers of the whole body 3.78cm, and the biggest relative variation 3.75%. It gives indication of a very reasonable adaptation that the binary regression equations could immediately calculate the inertial parameters of body segments in which height and weight act as an independent variate in the young Chinese women (18-23 year-old).

Conclusion

The present study has shown that mathematical modelling approach is well suited to the population of young women in China. The binary regression equation has proven to be a simple yet valuable tool in the realisation of this procedure. Further research is needed to increase the reliability of conclusions.

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Received: February 1, 2003
Accepted: June 13, 2003

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STUDIJA MATEMATIČKOG MODELA I REGRESIJSKE JEDNADŽBE ZA IZRAČUNAVANJE INERCIJSKIH PARAMETARA TJELESNIH SEGMENATA MLADIH KINESKIH ŽENA

Sažetak

Uvod

Od samih početaka proučavanja čovječjeg kretanja, koncept fizikalnog modeliranja tijela bio je imanentan tim istraživanjima. Braune i Fischer, Hanavan, Hatze, Delp – autori su koji su obilježili razvoj modeliranja ljudskog tijela s primjenama u kineziologiji. Ovaj rad temelji se na pristupu Millerove i Nelsona, odnosno Zatsiorskyog i Seluyanova.

Cilj je bio odrediti i analizirati inercijske podatke tijela mladih kineskih žena.

Metode

Uzorak je obuhvatio 50 žena, studentica, u dobi od 18 do 23 godine. Uporabljena je metoda Computed Tomography – Digital Image Processing (CT-DIP) za analizu 16 segmenata tijela. Na temelju razine sive boje i gustoće svake strukture i tkiva u slikama tih segmenata, inercijski parametri segmenata izračunati su metodom konačnih jedinica. Na kraju su procijenjeni masa, središte mase i moment inercije segmenta.

Matematički model je opisan kao n-segmentni sustav s više stupnjeva slobode na spojevima segmenata. To je sustav sastavljen od niza pretpostavljeno homogenih krutih tijela jednostavnih geometrijskih oblika koji su spojeni u zglobovima, a na temelju Hanavanova koncepta 16-segmentnog sustava.

Utvrđena je binarna regresijska jednadžba kojom se može izračunati masa, središte mase i moment inercije tjelesnih segmenata. Tjelesna masa i visina korištene su kao nezavisne varijable.

Rezultati

Prikazani su prosječni podaci za masu, središte mase i moment inercije segmenta i cijelog tijela izračunati metodom CT-DIP.

Prikazani su kompletni rezultati dizajna 16-segmentnog modela tijela i inercijalni parametri izračunati binarnom regresijskom jednadžbom.

Rasprava

Uporabom balansne ploče i metode CT-DIP određeni su i uspoređeni inercijski podaci tijela. Pored standardnih nalaza, autori konstatiraju da ovakav pristup odražava različite karakteristike različitih ljudskih rasa.

U okviru evaluacije binarne regresijske jednadžbe najveće diskrepancije u rezultatima pojavile su se u rezultatima za šake i stopala. Međutim, te diskrepancije nisu ozbiljnije utjecale na izračune jer su njihovi momenti bili izuzetno maleni u usporedbi s onima ostalih segmenata.

U usporedbi izračunatih vrijednosti i onih dobivenih na balansnoj platformi najveća apsolutna varijanca mase cijeloga tijela iznosila je 3.01 kg, najveća relativna varijacija 3.88%, najveća apsolutna varijanca središta mase cijelog tijela 3.78 cm i najveća relativna varijacija 3.75%.

Zaključak

Provedena studija pokazala je da je pristup matematičkim modeliranjem dobro prilagođen populaciji mladih kineskih žena. Binarna regresijska jednadžba pokazala se jednostavnim, a vrijednim sredstvom u primjeni tog postupka. Potrebna su daljnja istraživanja da bi se povećala pouzdanost zaključaka.