COMPONENT INERTIA MODELLING OF FEMALE BODY SEGMENTS

Marianne Gittoes and David Kerwin
Sport and Exercise Science Group, University of Bath, Bath, United Kingdom

A mathematical model is presented which is capable of determining subject-specific inertia parameters for female tissues. The model was evaluated for female sports participants. The model comprises segment-specific soft tissue and bone components. 57 geometric solids (40 soft tissue and 17 bone) are used to represent the tissue components. 95 anthropometric measurements were collected from five female sports participants. The overall accuracy of the model in whole body mass prediction was better than 2% with a maximum error of 5%. The success of the model is considered in relation to the accuracy reported by uniform density models. The appropriateness of the cadaver derived density values used in the model is also discussed.

KEY WORDS: geometric modelling, soft tissue, bone, sports participants.

INTRODUCTION: Female sports participants are particularly susceptible to lower extremity injury resulting from landing movements (Hewett, 2000). An insight into the mechanism with which females sports participants dissipate the loads experienced during landings has been achieved experimentally (McNitt-Gray, Yokoi, & Millward, 1993). A modelling approach has been considered a useful adjunct to experimental studies (Liu & Nigg, 2000).

Rigid body models have typically been used to simulate and investigate lower extremity loading during landing. The assumption that the human can be modelled as a series of rigid bodies was recently shown to be inappropriate for analyses of high-velocity movements. Gruber, Ruder, Denoth, & Schneider (1998) demonstrated that a model comprising soft and rigid tissue properties resulted in more realistic estimates of joint kinetics during a drop-landing simulation. Developments in wobbling mass models, relating specifically to the female are necessary to enhance understanding of lower extremity loading resulting from landings.

Accurate inertia parameters are required to produce realistic simulations of human movement. Subject-specific parameters relating to female tissue components are needed to appropriately represent the size and inertia properties of body segments.

Several approaches have been developed to obtain inertia parameters for human movement analyses. Cadaver-based methods such as Dempster (1955) have been used extensively. The parameters are however, typically based on elderly, male cadavers, unlike the population under investigation. Medical imaging techniques (Mungiole & Martin, 1990) have more frequently been limited to a clinical setting due to the extensive demands on equipment, time and cost. In contrast, mathematical inertia models (Whitsett, 1963; Hanavan, 1964; Jensen, 1976; Hatze, 1980; Yeadon, 1990) have provided a more accessible approach to obtaining a complete profile of subject-specific inertia parameters for human movement investigations.

Mathematical inertia models have been developed with varying complexity. Whitsett (1963) and Hanavan (1975) simplified each segment to a single, homogenous shape, failing to consider the irregular shape of body segments. The varying morphology of body segments was later considered in the models of Hatze (1980) and Yeadon (1990). The models all assumed a uniform density over a given cross-section. The changing nature of human computer simulation models could benefit from the determination of inertia properties for both soft and rigid tissues of body segments. The uniform density assumption therefore limits the extent to which the models can be used to provide subject-specific parameters for analyses using wobbling mass models. The aims of this study were therefore to develop a component inertia model capable of estimating subject-specific parameters for the tissues of female body segments and to determine its accuracy for application to female sports participants.

METHODS: The human body was simplified to a series of geometric solids used to represent the properties of soft tissue and bone.

Model Segmentation: The component inertia model comprises a series of linked segments. Segments are defined at biomechanical joint centres corresponding to the inertia model of Yeadon (1990). Each segment is divided into a series of subsections to accommodate for variations in morphology and tissue distribution. The overall shape of each segment is represented by a series of solids corresponding to the inertia model of Yeadon (1990). A series of additional solids are incorporated to represent the bone components.
Tissue distribution and geometric representation: The component inertia model assumes a segment-specific tissue mass distribution. Each of the limbs and extremities comprise a single bone solid and a surrounding soft tissue shell. The bone components of the limbs and extremities are cylindrical.
The head, neck and trunk are formed from five bone solids. A soft tissue core is located within the bone components and a soft tissue shell surrounds the bone. The head and neck comprise a spherical shell and a cylindrical solid. The bone component of the trunk is formed from a cylindrical shell, half a conical shell and an elliptical cylinder. The component inertia model is shown in figure 1.

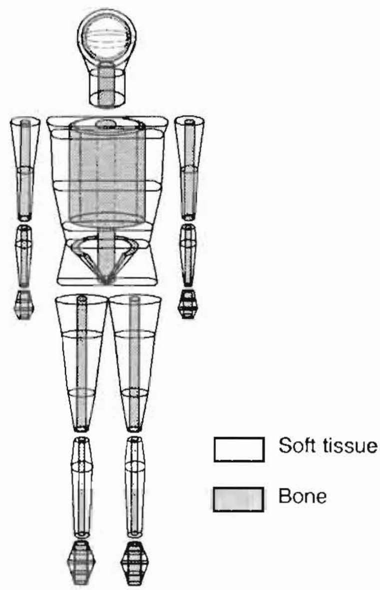

Figure 1: Segmentation and tissue distribution in the component inertia model.

Bone and whole segment measurements: Direct measurements from a life-like female skeleton (SOMSO-QS 10/8) were taken at positions located along the bone. All dimensions were scaled to the artificial skeleton's segmental length. Segment lengths were taken between positions corresponding to biomechanical joint centres. 95 subject-specific perimeter, width and depth measurements were required to produce personalised dimensions. Bone dimensions were scaled to the subject's segmental length to produce personalised bone dimensions.
Density assumptions: Segmental soft tissue and bone densities were taken from cadaver studies. Limb and extremity densities were taken directly from (Clarys & Marfell-Jones, 1986b). Trunk, head and neck densities were predicted from (Dempster, 1955; Clarys, Martin, & Drinkwater, 1984; Clarys & Marfell-Jones, 1986b; Clarys & Marfell-Jones, 1986a).
Parameter determination: Personalised dimensions were used to determine whole segment volumes. Subject-specific bone dimensions were used to calculate segmental bone volumes. Soft tissue volumes were obtained through the removal of the bone volume from the whole segment volume. Density values were combined with volumes to produce component masses. Component mass centre locations were obtained about the distal joint of the segment. Component principal moments of inertia were calculated using the parallel axis theorem.

Formulae for the stadium solids of the trunk and extremities were taken from Yeadon (1990). Standard formulae were used for the remaining solids.

Model application: The local research ethics committee gave approval for the study. Anthropometric measurements were obtained from five young, athletically trained females (mean age, 22 years, body mass, 58.4 ± 7.6kg). All subjects signed a written consent form. Subject specific whole segment measurements were taken as described by Yeadon (1990). A direct measurement of the subject's whole body mass was made using a laboratory weighing scales (Weylux). The model was applied to all subjects.

RESULTS: Estimations for subject-specific component volume, mass, mass centre locations and principal moments of inertia are achievable with the presented model. However, the scope of this study focuses on the estimation of mass. The overall accuracy of the model for application to female sports participants was assessed.

Model accuracy for each subject was determined as the percentage difference between predicted and measured whole body mass. Table 1 provides results for the five subjects investigated. The overall accuracy of the model was determined as the mean percentage difference over the five subjects.

Table 1 Comparison of predicted and measured whole body mass.

Subject	Age (years)	Predicted body mass (kg)	Measured body mass (kg)	Difference (%)
A	22	64.81	61.75	4.96
B	24	55.08	55.75	-1.20
C	18	49.12	49.30	-0.36
D	22	69.96	69.45	0.74
E	23	58.23	55.65	4.64

The model was capable of determining whole body mass with an overall accuracy of 1.75%. The maximum error found for the model was less than 5%. Magnitude of body mass was not related to the percentage difference found for the five subjects.

DISCUSSION: The component inertia model represents a method to determine tissue parameters for female body segments. The accuracy of the model was assessed for a small group of female sports participants.

Good agreement was found between predicted and measured whole body mass (1.75%). The accuracy was comparable to that reported by previous uniform density models. Hatze (1980) and Yeadon (1990) reported mean percentage differences of no greater than 3%.

The error reported by the model can partially be attributed to the density values used. The assumption that cadaver derived density values are firstly, appropriate to living tissue properties and secondly, appropriate for the target group under investigation, continually limits the overall accuracy of inertia models. The density values used in the model were obtained from a sample group comprising mainly elderly cadavers (mean age 66.8 years), uncharacteristic of the young sample group measured in this investigation. Although female cadavers were investigated, the previously reported inertia properties comprise combined male and females profiles. The density values used were therefore considered appropriate until component values for young, healthy females are determined.

The model reported a maximum error in whole body mass of less than 5%, which was comparable to the 5% and 2.3% error reported by the models of Hatze (1980) and Yeadon (1990), respectively. No relationship was found between measured body mass and model accuracy. Establishing the location of errors in the model was difficult since segmental mass predictions could not be evaluated directly. However, the inertia parameters obtained can be used as input into computer simulation models. The agreement between simulated and actual performances of landing movements can therefore be used to provide an indication of the accuracy of segmental mass predictions. Future research should aim to investigate tissue mass proportions predicted by the model. An evaluation of the full profile of inertia parameters estimated by the model is also required.

CONCLUSION: A component inertia model has been presented which provides a method for estimating tissue parameters for female body segments. The model demonstrated a comparable accuracy to previously developed uniform density models. The inertia model was found to be capable of appropriately estimating parameters for female sports participants. The parameters can be used as input into wobbling mass models to enhance understanding of the loads experienced during potentially injurious landing movements. An evaluation of the ability of the model to predict segmental masses and tissue proportions is however, required to provide a more appropriate assessment of the accuracy of the model.

REFERENCES:

Clarys, J.P., & Marfell-Jones, M.J. (1986a). Anatomical segmentation in humans and the prediction of segmental masses from intra-segmental anthropometry. Human Biology, 58(5), 771-782.

Clarys, J.P., & Marfell-Jones, M.J. (1986b). Anthropometric prediction of component tissue masses in the minor limb segments of the human-body. Human Biology, 58(5), 761-769.

Clarys, J.P., Martin, A.D., & Drinkwater, D.T. (1984). Gross tissue weights in the human-body by cadaver dissection. Human Biology, 56(3), 459-473.

Dempster, W.T. (1955). Space requirements of the seated operator. WADC TR 55-159, AD-087-892. Wright-Patterson Air Force Base, Ohio.

Hanavan, E.P. (1964). A mathematical model of the human body. AMRL-TR-64-102, AD-608-463. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

Hatze, H. (1980). A mathematical model for the computational determination of parameter values of anthropometric segments. Journal of Biomechanics, 13, 833-843.

Hewett, T.E. (2000). Neuromuscular and hormonal factors associated with knee injuries in female athletes. Sports Medicine, 29(5), 313-327.

Jensen, R.K. (1976). Model for body segment parameters. In P.V. Komi (Ed.), Biomechanics v-b. Baltimore: University Park Press.

Liu, W., & Nigg, B.M. (2000). A mechanical model to determine the influence of masses and mass distribution on the impact force during running. Journal of Biomechanics, 33(2), 219-224.

McNitt-Gray, J.L., Yokoi, T., & Millward, C. (1993). Landing strategy adjustments made by female gymnasts in response to drop height and mat composition. Journal of Applied Biomechanics, 9(3), 173-190.

Mungiole, M., & Martin, P.E. (1990). Estimating segment inertial properties: Comparison of magnetic resonance imaging with existing methods. Journal of Biomechanics, 23(10), 1039-1046.

Whitsett, C.E. (1963). Some dynamic response characteristics of weightless man. AMRL-TDR-63-18, . Aerospace Medical Research, Wright-Patterson Air Force Base, Ohio.

Yeadon, M.R. (1990). The simulation of aerial movement .2. A mathematical inertia model of the human-body. Journal of Biomechanics, 23(1), 67-74.