ELLIPTICAL ZONE BODY SEGMENT MODELING SOFTWARE: DIGITISING, MODELING AND BODY SEGMENT PARAMETER CALCULATION

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The purpose of this paper is to introduce biomechanists to the 'eZone' software program as an efficient and readily accessible means of obtaining body segment parameter (BSP) data by the elliptical zone method. eZone is a MATLAB based program that eliminates the need for digitizing tables and thereby offers the possibility that the elliptical zone method could be used widely to maximize the accuracy of derived kinematics and kinetics. Preliminary results indicate that the product is 'user friendly'. However, the accuracy and reliability of the eZone program in particular and the elliptical zone method in general need to be established relative to other methods.

KEY WORDS: accuracy, body segment parameters, centre of mass, elliptical zone, kinematics, kinetics, moment of inertia, reliability

INTRODUCTION: It is well established and recognized that the accuracy of kinematics and kinetics derived from position-time data using a rigid-link human body model is dependent on the accuracy of estimating the segment masses, segment centre of mass locations relative to the segment endpoints and, in the case of angular momentum and angular kinetics, segment moments of inertia. These are collectively referred to as body segment parameter (BSP) data. The accuracy of segment centre of mass position also affects the accuracy of angular momentum and whole body angular kinetics due to its influence on the remote terms.
BSP data may be obtained from various sources that may be categorized as cadaver studies, immersion studies, direct measurement techniques, and mathematical models (Sprigings et al., 1987). The methods vary in the extent to which they take into account individual characteristics and therefore vary in the accuracy of the BSP data and consequent calculated values of kinematics and kinetics. For example, Miller and Nissinen (1987) found large discrepancies between ground reaction forces derived from whole body centres of mass digitized from cine film and ground reaction forces measured directly from a force platform. BSP data were identified as contributing to those errors.
The Elliptical Zone method developed by Jenson (1978) is a mathematical modeling technique to determine BSP data of each body segment of individual subjects. The method applies the assumption of Weinbach (1938) that cross sections of the body segments can be modeled accurately as ellipses. Dempster (1955) found that this assumption yielded very small errors with the exception of the shoulders. Using BSP data obtained by the elliptical zone method Sanders et al. (1991) found that the low frequency parts of the ground reaction forces of drop jumps derived from digitized high speed video were within 3% of those obtained directly from a force platform. Wicke and Lopers (2003) found that the volumes of several body segments and the whole body can be measured accurately using the elliptical zone method.
Although the elliptical zone method appears to offer the advantage of providing accurate BSP data for any individual its use has not become common. Proponents of the method typically project photographic slides of the front and side views of the subject onto a large digitizing table such as a PCD Model ZAE 3B (Jensen, 1978) and Calcomp 9100 (Sanders et al., 1991). A cursor is moved along the edges of body segments to obtain the diameters of the ellipses required for input to the ZONE program that then calculates the BSP data. Therefore, application of the method is limited by the availability of digitizing tables and data collection programs compatible with the digitizing device.
Recently the authors have developed a PC based digitizing software program that combines the functions of digitizing digital photographs to obtain the diameters of the ellipses with calculation of the BSP data using the mathematical model detailed by Jensen (1978).
The purpose of this paper is to introduce biomechanists to the eZone software program as

an efficient and readily accessible means of obtaining BSP data by the elliptical zone method.

METHODS: eZone is written in MATLAB code. The present version requires a computer running MATLAB with the Image Processing Toolbox installed. An optical mouse is highly recommended so that the outlines of segments can be traced easily without the friction problems sometimes encountered with mice using roller balls.

The eZone program uses the same procedures and methods as those established by Jensen (1978). Briefly, the body is divided into 16 segments: head, neck, thorax, abdomen, and right and left upper arms, forearms, hands, thighs, shanks, and feet. Each body segment is modeled as a series of elliptical cylinders. An ellipse has two radii digitized respectively from the front and side views. For each elliptical cylinder the volume, mass, centre of mass, and moments of inertia are calculated by the standard formulas presented by Jensen (1978). Segment masses are determined by summing the masses of the elliptical cylinders of the segment. Segment COM positions are calculated by summing moments of the elliptical cylinders using the positions of the centroid of the cylinders with respect to the proximal endpoint as the moment arm. Moments of inertia of the segments about the segment centre of mass are determined for the anteroposterior, medio-lateral, and proximal-distal axes of the segment by summing the local and remote moment of inertia terms in accordance with the parallel axis theorem.

The eZone program differs from Jensen's methods in that the elliptical sections are perpendicular to the long axis of the body segment rather than being in a vertical plane (when the subject is prone) or a horizontal plane (when the subject is standing). This allows the subject to assume positions whereby body segments are not necessarily aligned parallel to the body's long axis thereby making it considerably easier to ensure that as much of the segment outline is visible for each segment and that the landmarks for segment endpoints are not obscured.

Photography and Calibration: Maximizing accuracy of BSP data requires attention to the following during calibration and photographing the subjects:

1. Two digital cameras shuttered simultaneously – one for the side view and one for the front view.
2. The pictures should be 2 megapixels or greater.
3. Ensure that the camera axes are perpendicular to each other.
4. Position the cameras at a good distance from the subject, preferably more than 6 metres.
5. Put the cameras on tripods with the axes perpendicular to the subject's frontal and sagittal planes respectively.
6. Ensure that the cameras are oriented so that the frame is aligned with the subject's reference frame. That ensures that both the camera and subject reference frames are aligned by aligning them with e.g. the axes of the walls.
7. Mark segment endpoints and landmarks with markers that contrast with the subject and background.
8. Adjust lighting and establish contrast with the background so that the edges of the segments are distinct.
9. The subject should wear minimal clothing and the clothing worn should be tight fitting. A swim cap is very helpful to help define the edges of the head, particular when subjects have long hair.
10. The subject's head should be oriented so that the jaw is parallel to the transverse plane.
11. The subject's ankles should be plantar flexed. If the subject is standing, an inclined board should be used.
12. The arms of the subject should be positioned so that the long axis is in the frontal plane.
13. The palms should be in the frontal plane, that is, facing the front view camera.
14. Adjust the focal length of the camera so that the image size of the subject is maximised.
15. Avoid the use of uni-directional lighting such as a camera flash.
16. Without changing camera position or focal length, take photographs of a calibration scale positioned along the axes corresponding to the subjects principal axes.
17. Ensure that the locations of segment endpoints selected to define the body model when

collecting data correspond to those used for determining the BSP data (Table1).

Table 1 Anatomical Landmarks and Marker Locations for the eZone Method.

Anatomical Landmark	Side View Marker Location	Front View Marker Location
vertex	highest point of head in line with auditory meatus	midline of head at highest point
C2	mandible angle	centre of chin
C7	at level of C7 but in the centre of the neck segment	Adam's apple
AC joint	AC joint	same marker as side view
head of humerus	head of humerus	on the midline of the arm at same level as side marker
elbow	elbow	elbow
wrist	wrist	wrist
finger	tip of longest finger	same marker as side view
xiphoid	on the midline of the trunk at the level of the front marker	base of the sternum
pubic bone	not required	applied by the subject
greater trochanter	greater trochanter of femur	on the midline of the thigh at same level as side marker
knee axis	knee axis	on the midline of the knee at same level as side marker
ankle axis	ankle axis	on the midline of the ankle at same level as side marker
metatarsal phalangeal joint	metatarsal phalangeal joint	same marker as side view
toe	tip of the longest toe	same marker as side view

Features to facilitate ease of use and accurate calculation of BSP data:

1. Images of the calibration rods and body segments can be zoomed prior to digitising or tracing.
2. Ability to 'undo' mistakes and continue from the last correct entry.
3. Ability to outline the segment (examples are displayed in Figure 1). If the outline is not as desired it can be redone.
4. The elliptical cylinders are generated and displayed automatically.

RESULTS: Figure 2 illustrates how the eZone software identifies and displays the elliptical cylinders for the segments. Preliminary values obtained for BSP data of numerous subjects are within the ranges expected based on the literature. Whole body mass agrees with actual body mass to within 5%. Sources of error include using density values that do not match the actual values of individual subjects and the assumption of uniform density throughout the segment; errors in tracing the outline of the body; actual cross sections of the body not conforming to the shape of an ellipse; and small duplications or missed sections of mass or mass assigned inappropriately to a particular segment.

Although there is a 'learning process', reliability of the method indicated by repeat digitisations is encouraging. However, before definite conclusions can be drawn with respect to the accuracy and reliability of the method several studies must be conducted. The following are in progress or planned:

1. Establish the reliability of calculating BSP data for each body segment from repeated digitisations. Investigate within and between operator variability.
2. Validate the procedures, mathematical model, and coding of the software by comparing results obtained for identical subjects using the new software and existing methods that use digitizing tables.
3. Compare derived kinematics and kinetics obtained when using BSP data from e-Zone with those obtained using BSP data from other commonly used sources.

CONCLUSION: The development of the eZone software increases the availability and ease of use of the elliptical zone method of BSP parameter calculation. This may lead to improved accuracy of derived kinematics and kinetics of individual subjects. However, that expectation has yet to be verified by studies of the accuracy and reliability of the method compared to other methods of estimating BSP data.

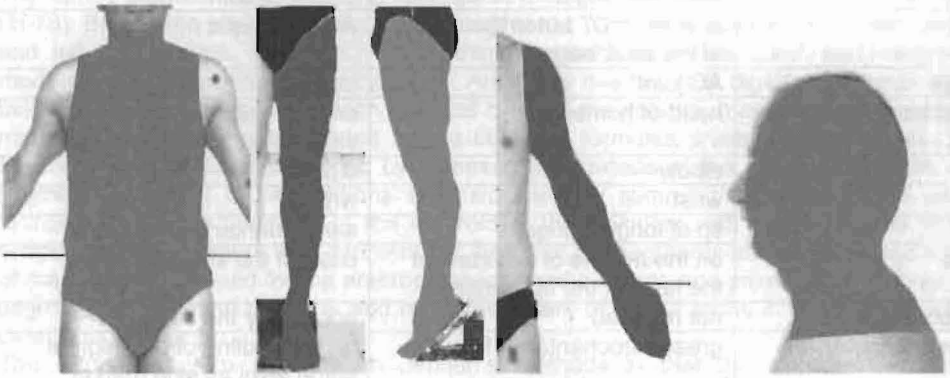

Figure 1 Examples of the outlines of body segments obtained by tracing the image with the mouse.

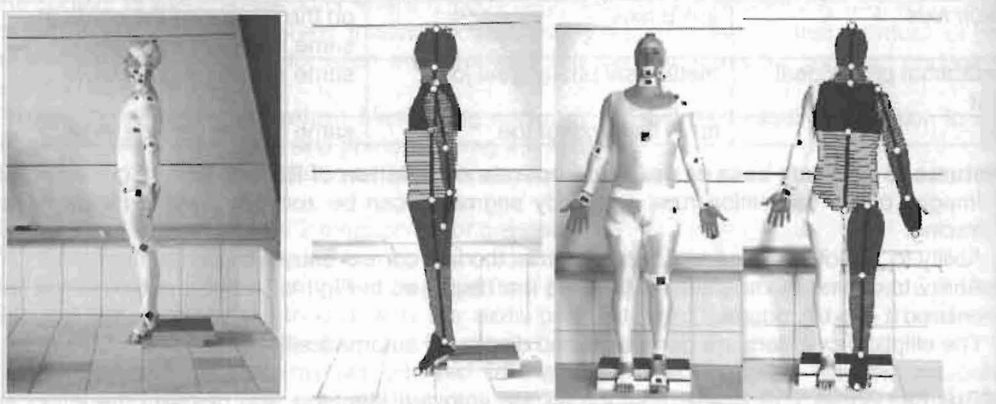

Figure 2 Example of a marked subject and the computer generated eZone model.

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