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Body segment inertial parameters and low back load in individuals with central adiposity

Robert Pryce [a],*, Dean Kriellaars [b]

[a] *Department of Kinesiology and Applied Health, University of Winnipeg, Canada*
[b] *School of Medical Rehabilitation, University of Manitoba, Canada*

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ABSTRACT

There is a paucity of information regarding the impact of central adiposity on the inertial characteristics of body segments. Deriving low back loads during lifting requires accurate estimate of inertial parameters. The purpose was to determine the body segment inertial parameters of people with central adiposity using a photogrammetric technique, and then to evaluate the impact on lumbar spine loading. Five participants with central adiposity (waist:hip ratio > 0.9, waist circumference > 102 cm) were compared to a normal BMI group. A 3D wireframe model of the surface topography was constructed, partitioned into 8 body segments and then body segment inertial parameters were calculated using volumetric integration assuming uniform segment densities for the segments. Central adiposity dependent increases in body segment parameters ranged from 12 to 400%, varying across segments (greatest for trunk) and parameters. The increase in mass distribution to the trunk was accompanied by an anterior and inferior shift of the centre of mass. A proximal shift in centre of mass was detected for the extremities, along with a reduction in mass distribution to the lower extremity. L5/S1 torques (392 vs 263 Nm) and compressive forces (5918 vs 3986 N) were substantially elevated in comparison to the normal BMI group, as well as in comparison to torques and forces predicted using published BSIP equations. Central adiposity resulted in substantial but non-uniform increases in inertial parameters resulting in task specific increases in torque and compressive loads arising from different inertial and physical components.

1. Introduction

The prevalence of low back pain is elevated with obesity (Shiri et al., 2010; Smuck et al., 2014), due primarily to longer-lasting and more severe symptoms (Webb et al., 2003). Although the aetiology of obesity-specific back pain is not well-established, adverse mechanical load arising from an elevated body mass is postulated as contributory (Shiri et al., 2010). For instance, increased loading of disc and surrounding soft tissues may explain the relationship between body mass and MRI-abnormalities in patients with degenerative disc disease (Al-Saeed et al., 2012), as well the association between body mass and Modic changes (Modic et al. 1988) in otherwise healthy adults (Kuisma et al., 2008). Despite evidence of a substantial impact of obesity on lower limb pathology (Lementowski and Zelicof, 2008; Lievense et al., 2002), the influence of excess body mass on low back pathology is of lower magnitude (Shiri et al., 2010) or not consistent across studies (Leboeuf-Yde, 2000).

Recent findings have identified waist circumference as a stronger predictor of back pain versus body mass (Shiri et al., 2013), indicating a potential effect of mass distribution, rather than simply whole body mass. Body mass distribution varies widely between individuals (McConville et al., 1980), and the morphology of obesity can be characterized using android and gynoid somatotypes, reflecting central and peripheral mass distributions, respectively (Bray, 1992). Unlike the lower extremity, the effect of obesity on low back mechanical load would be somatotype-dependent—proportional to upper-body mass distribution, which varies between 45 and 59% of total mass (Clauser et al., 1969; Pearsall et al., 1994), and is greatest for individuals with central adiposity (CA) or android somatotype (waist circumference > 102 cm) (World Health Organization, 2008). Only a small number of studies have quantified the effect of obesity on (or around) the low back, revealing substantial increases in static load secondary to obesity during standing work (Gilleard and Smith, 2007) and in hip joint moments during sit-to-stand tasks (Galli et al., 2000). However, no estimates exist that are specific to somatotype, and particularly for CA where the risk of low back pathology appears greatest (Shiri et al., 2013).

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* Correspondence to: Department of Kinesiology and Applied Health, Faculty of Kinesiology, University of Winnipeg, 515 Portage Avenue, Winnipeg, Mb R3B 2E9, Canada. Tel.: +1 204 786 9341.
E-mail address: r.pryce@uwinnipeg.ca (R. Pryce).

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In order to estimate the mechanical load associated with CA, accurate estimates of body segment inertial parameters (BSIPs) are required. Although individuals with obesity account for a large (and increasing) proportion of the North American population ($>35\%$) (Ogden et al., 2006; Shields et al., 2010) only two investigations of obesity-specific BSIP estimates exist (Chambers et al., 2010; Matrangola et al., 2008). These studies provide important initial BSIP estimates for a limited set of BSIP parameters and for specific subsets of obese individuals, however the influence of obesity-specific somatotypes remain to be considered (i.e. CA).

The most common method of estimating BSIPs, predictive equations, are typically derived from participants that are non-obese, Caucasian males. Despite the obvious validity limitations, BSIP estimates derived from normal BMI populations are often used in biomechanical studies of obesity (Gilleard and Smith, 2007; Sibella et al., 2003). Photogrammetric techniques and medical imaging approaches offer an alternative to predictive equations. While medical imaging approaches (Chambers et al., 2010; Matrangola et al., 2008; Pearsall et al., 1994) can partially account for variation in body shape and density, they are costly and labour-intensive, and most often require assessment in non-vertical postures limiting the external validity. Recent advances in imaging devices and software have facilitated low cost and accurate photogrammetric approaches for obtaining BSIPs of morphologically atypical populations (Davidson et al., 2008).

The purpose was to determine the BSIPs of people with central adiposity using an individual-specific photogrammetric technique, and then to evaluate the impact on lumbar spine loading during various low back loading scenarios. Knowledge of load is important for predicting injury risk and for design of injury prevention programs (McGill, 2009; Pope et al., 2002).

2. Methods

2.1. Participants

A sample of 5 male participants (mean ± SD: 34.4 ± 7.4 years) with an obese BMI and CA was obtained (Table 1). Central adiposity was defined as a waist:hip ratio $>=0.9$ and waist circumference >102 cm (World Health Organization, 2008). A comparative sample of 3 normal BMI male participants was also obtained. The CA participants were 32.4 ± 6.6 kg heavier, with a 12.5 ± 1.1 kg m^2 greater BMI, but with equivalent height ($p>0.11$). Ethical approval was obtained from the Health Research Ethics Board, University of Manitoba.

2.2. Body segment inertial parameters

A 3D model of the surface topography of each participant was constructed using a photogrammetric technique (Davidson et al., 2008). Participants stood on a 122 cm × 122 cm calibration grid (used to determine camera position, orientation and scale), and low and high angle digital images (30 images, 2592 × 3456 pixels) were obtained over a 360° field of view. The participant images were imported into 3D model-generation software (Strata Foto 3D CX, Santa Clara, Utah, USA), where a wireframe model (20,000 polygons) was constructed (Table 1). Supplemental data files are provided for each participant. Visual image data was projected onto each polygon, creating a texture map of actual participant surface features. Models were also constructed for two inert objects (cuboid: 58 cm × 27 cm × 16 cm; sphere: 37 cm diameter) and used to estimate error in dimensions derived from 3D models, which were 1.05 ± 0.72% (0.25 ± 0.13 cm) and 0.52 ± 0.01% (0.20 ± 0.10 cm) for the cuboid and sphere, respectively.

BSIPs are reported for 8 body segments: whole trunk, upper-, middle- and lower-trunk, upper arm, forearm, thigh, and shank. Models were imported into an open source 3D-modelling programme (Blender 2.63a, Blender Foundation, Amsterdam Netherlands) and partitioned or 'virtually dissected' using the Boolean intercept tool (Supplementary Fig. 1). For this procedure a geometric primitive was aligned with the superior and inferior faces (representing segmentation planes) parallel to the proximal and distal ends of the body segment. Extremities were partitioned at proximal and distal joint centres and the trunk was segmented at suprasternal notch, xyphoid and navel (de Leva, 1996). Moments of inertia (kg cm^2) and mass (kg) are reported in absolute units, and CM (% segment length), radii of gyration (% segment length) and mass distribution (% body mass) are reported in normalized units.

BSIPs were calculated using a volumetric integration algorithm (Mirtich, 1996) for the CA and normal BMI participants, which computed an exact volume for each segment based upon the polygon surface. Segment densities were assumed uniform (Davidson et al., 2008) and were estimated from previously reported values for the extremities (Dempster, 1955) and trunk (Pearsall et al., 1994). Densities were scale-adjusted such that the sum of segment masses was equivalent to whole body mass. The origin of a local coordinate system was positioned at the superior joint centre for each segment, with the z-axis extending longitudinally to the distal joint centre, and x- (medial–lateral) and y-axes (anterior–posterior) orthogonal. Centre of mass (CM) locations were calculated relative to the local coordinate system for the longitudinal (CMz) and anterior (CMy) directions. CA BSIPs were also estimated using existing predictive equations (de Leva, 1996), providing a comparison of individual-specific, photogrammetric to predictive BSIP estimates in CA.

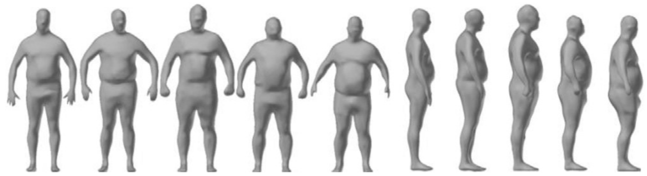
2.3. Lumbar spine loading

The resultant joint moment (RJM) and compressive force acting about L5/S1 during standing, carrying and lifting motions were estimated using a linked segment, inverse dynamics model. The model consisted of 5 segments: head/neck, torso, upper arm (2), forearm/hand (2), and box. Assumptions included rigid body segments, frictionless joints, negligible muscle co-contraction/intra-abdominal pressure, and a fixed lumbar extensor moment arm of 7.0 cm (about L5/S1).

Postures for the standing and carrying conditions were obtained from video analysis of 24 participants ($n=12$ normal, $n=12$ obese) during a 1-hour lifting task involving a medium-sized object (box: 37.5 cm × 36 cm × 25 cm) (unpublished data). The average mass lifted (self-selected) was 18.5 kg and did not differ between obese and normal BMI participants, which was similar to previous investigations (16.5 kg) (Singh et al., 2009). The carrying condition was selected to represent the effect of CA on load carriage and where flexion moments from trunk segments are generally minimal (due to negligible trunk flexion). Static and dynamic loading estimates for a lifting task were derived using identical postures and load carriage as the carrying condition, with the exception of the trunk segment, which was flexed 45°. The lifting condition was chosen as a prototypical lifting posture and one where flexion moments from trunk segments are elevated (relative to carrying). Estimates of peak angular acceleration were based upon previous investigations (Xu et al., 2008).

Table 1
Participant three-dimensional models and physical characteristics.

(a) 3D models of front and side views of participants with central adiposity (CA)



(b) Physical characteristics of CA and normal BMI groups

	Height (m)	Mass (kg)*	BMI (kg m^2)*	Waist circ (cm)*	Waist:hip ratio*	Waist:ht ratio*	Density (g/cm^3)*	Fat mass (%)*
Central adiposity, M (SD)	1.76 (0.06)	108.34 (13.39)	34.82 (3.99)	115.1 (10.2)	1.00 (0.06)	0.65 (0.07)	1.018 (0.012)	35.79 (5.83)
normal BMI, M (SD)	1.84 (0.06)	75.9 (5.16)	22.3 (0.5)	79.2 (2.1)	0.77 (0.04)	0.42 (0.01)	1.071 (0.011)	16.20 (0.79)

* $p<0.01$ between groups; height was not significantly different ($p>0.11$)