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The effect of age and body composition on body mass estimation of males using the stature/bi-iliac method

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ABSTRACT

The stature/bi-iliac breadth method provides reasonably precise, skeletal frame size (SFS) based body mass (BM) estimations across adults as a whole. In this study, we examine the potential effects of age changes in anthropometric dimensions on the estimation accuracy of SFS-based body mass estimation. We use anthropometric data from the literature and our own skeletal data from two osteological collections to study effects of age on stature, bi-iliac breadth, body mass, and body composition, as they are major components behind body size and body size estimations. We focus on males, as relevant longitudinal data are based on male study samples. As a general rule, lean body mass (LBM) increases through adolescence and early adulthood until people are aged in their 30s or 40s, and starts to decline in the late 40s or early 50s. Fat mass (FM) tends to increase until the mid-50s and declines thereafter, but in more mobile traditional societies it may decline throughout adult life. Because BM is the sum of LBM and FM, it exhibits a curvilinear age-related pattern in all societies. Skeletal frame size is based on stature and bi-iliac breadth, and both of those dimensions are affected by age. Skeletal frame size based body mass estimation tends to increase throughout adult life in both skeletal and anthropometric samples because an age-related increase in bi-iliac breadth more than compensates for an age-related stature decline commencing in the 30s or 40s. Combined with the above-mentioned curvilinear BM change, this results in curvilinear estimation bias. However, for simulations involving low to moderate percent body fat, the stature/bi-iliac method works well in predicting body mass in younger and middle-aged adults. Such conditions are likely to have applied to most human paleontological and archaeological samples.

1. Introduction

1.1. Body mass and its estimation

Body mass is considered to be one of the most important parameters affecting animal behavior, ecological adaptation, and locomotion (Calder, 1984). Known or at least estimated body mass is also needed for assessing relative brain size, tooth size, and skeletal robusticity (e.g., Grabowski et al., 2015; Squyres and Ruff, 2015 and references therein). The development of techniques for estimating body mass has a much shorter history than those for estimating stature in humans. Both stature and body mass estimation methods can be divided into two categories: 1) anatomical or morphometric, and 2) mathematical/mechanical methods (Lundy, 1985; Auerbach and Ruff, 2004). Both types of approach have been applied to human fossil and archaeological material (e.g., Arsuaga et al., 1999; Ruff et al., 2005; Rosenberg et al., 2006).

In mechanical body mass estimation, body mass is estimated from skeletal dimensions (e.g., joint surface size) that mechanically support body mass. Femoral head breadth is often used because it is frequently preserved and demonstrably correlates positively with body mass (Ruff et al., 2012 and references therein). Four different studies have provided regression equations to estimate body mass

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of recent human samples from femoral head breadth (Ruff et al., 1991, 2012; McHenry, 1992; Grine et al., 1995).

In morphometric body mass estimation, body mass estimation is based on the cylindrical model of the human body. Stature (either known or estimated) represents height of this cylinder and bi-iliac (maximum pelvic) breadth represents its breadth (Ruff, 1994, 2000; Ruff et al., 1997, 2005). The morphometric method is to some extent analogous to anatomical stature estimation (Fully, 1956; Raxter et al., 2006) and is considered to provide more reliable body mass estimations than the mechanical method, because it does not rely on any assumptions regarding the relationship between joint size and body size (Auerbach and Ruff, 2004).

Elliott et al. (2016) found that the morphometric equations of Ruff et al. (2005) do not necessarily provide more reliable body mass estimates than the mechanical femoral head equations in their large sample of known-mass individuals, and argue that it is not appropriate to choose the morphometric equations in preference to the mechanical equations. However, the composition of the known-mass sample possibly affected Elliott et al.'s (2016) findings. The body mass range in their sample is so large (31.8–146.0 kg) that it includes both morbidly obese, as well as considerably underweight individuals. The age range of the sample (18–90 years) is also considerable. If study samples are restricted to individuals within a range of healthy body fat percentage (as was done in Schaffer, 2016), the morphometric method provides relatively accurate body mass estimates. However, there are still a number of potential factors that could influence the accuracy of the morphometric method and its applicability to recent and earlier humans, including systematic differences in soft tissue mass and distribution relative to skeletal frame size. In this study, we focus on the role of body composition and age on morphometric body size estimation to further improve the accuracy of this method.

1.2. Effects of age on stature and bi-iliac breadth

Maximum adult stature is generally reached in the late teens or early 20s, depending on the population, sex, and other individual/developmental factors. This maximum adult stature is maintained until stature loss with age commences. According to some studies, stature loss with age starts as early as the 20s (i.e. when people are between 20 and 30 years of age), whereas other studies indicate it does not commence until people are in their 40s (see review in Sorkin et al., 1999). After commencing, stature loss follows a quadratic pattern with a gradually increasing rate (Cline et al., 1989). Stature loss is in part caused by reductions in muscle and bone strength associated with age (Hannan et al., 2012; Fernihough and McGovern, 2015); there is thus a considerable amount of variation between individuals. Physically active and healthy individuals generally experience less stature loss than more sedentary and less healthy individuals (Sagiv et al., 2000; Moayyeri et al., 2008; Fernihough and McGovern, 2015). Variation between populations in stature loss with age is thus also expected, and this naturally has some effect on applying various age corrections (e.g., age term in Equation 1 of Raxter et al., 2006) in estimating stature of middle aged and older adults.

An increase with age in bi-iliac breadth of adults is well documented. A longitudinal anthropometric study of male physique changes reveals that male bi-iliac breadth (including soft tissue) increases considerably to the 40s (0.8 mm/year) and more gradually thereafter (Friedlaender et al., 1977). A cross-sectional study based on computed tomography scans reveals that bi-iliac breadth of both sexes increases throughout adult life, with male bi-iliac breadth increasing 0.398 mm/year and female bi-iliac breadth 0.330 mm/year between ages 20 and 80 (Berger et al., 2011). Age-related increase in adipose and connective tissue is expected to further increase living (anthropometric) bi-iliac breadth relative to skeletal bi-iliac breadth, i.e., the living bi-iliac breadth may increase more than the skeletal one with age.

1.3. Effects of age on body mass and body composition

Aging significantly affects body composition as there is increase in fat mass (FM) and reduction in lean body mass (LBM) in older adults (Chumlea et al., 2002). As a general rule, in both industrialized and non-industrialized human populations, LBM increases through adolescence and early adulthood until the 30s or 40s and starts to decline in the late 40s or early 50s. There is a great deal of inter-population variation in age-related development of adiposity (FM). In industrialized societies, FM tends to increase until the mid-50s (Chumlea et al., 2002; Kyle et al., 2004). In highly mobile non-industrialized societies it may even decline throughout adult life (e.g., nomadic Turkana, see Campbell et al., 2005:their Fig. 1). As a result of these combined age changes in LBM and FM, total body mass (TBM) is expected to exhibit a curvilinear pattern with age in all societies, reaching a peak in middle adulthood, but the exact pattern of this change may vary between populations.

In this study, we focus on examining how age changes in body mass, body composition, stature, and bi-iliac breadth affect body mass estimations using the stature/bi-iliac method of Ruff et al. (2005) in the light of cross-sectional and longitudinal anthropometric data from the literature, as well as data derived from skeletal samples. The focus is on males, as all available and relevant longitudinal research data are based on male study samples and we wanted especially to utilize longitudinal data in this study.

We first examined age changes in LBM index and fat percentage. Then we constructed simulation datasets based on dimensions (stature and bi-iliac breadth) from the pooled skeletal sample, together with age changes in LBM and percent FM estimated under three different assumptions. Resulting body masses in the three simulations were compared with those estimated from the standard stature/bi-iliac equation (Ruff et al., 2005). We also carried out comparisons with Friedlaender et al.'s (1977) data.

2. Materials and methods

2.1. Materials

We used three datasets to conduct our study: 1) skeletal (Table 1), 2) published anthropometric cross-sectional (Table 2), and 3) published anthropometric (Friedlander et al., 1977; Table 3). Bi-iliac breadth and maximum femoral length of males of known age and European ancestry from two collections, the Robert J. Terry Anatomical Skeletal Collection at the National Museum of Natural History of the Smithsonian Institution (Hunt and Albanese, 2005) and the W.M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville (https://fac.utk.edu/wm-bass-donated-skeletal-collection/), were included in the skeletal dataset. A total of 59 males from the Terry sample and 76 from the Bass sample were studied, with the individual specimens detailed in the Supplementary Online Material (SOM). Published information on body mass, body composition, stature, and bi-iliac breadth changes with age were included in the cross-sectional dataset, which comprised cross-sectional data on American males of European, African, and Mexican ancestry from the NHANES III study (Chumlea et al., 2002), Swiss males (Kyle et al., 2004), and Turkana males (Campbell et al., 2005; subsamples listed in Table 2). Settled and nomadic Turkana males were pooled due to relatively small age-group-specific sample sizes. The Turkana sample, representing “non-industrial” males, includes individuals who were likely subject to acute and/or chronic undernutrition (Campbell et al., 2005).