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Insights into relationships between body mass, composition and bone: findings in elite rugby players

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Abstract

Recent reports indicate that bone strength is not proportional to body weight in obese populations. Elite rugby players have a similar body mass index (BMI) to obese individuals, but differ markedly with low body fat, high lean mass and frequent skeletal exposure to loading through weight-bearing exercise. The purpose of this study was to determine relationships between body weight, composition and bone strength in male rugby players characterised by high BMI and high lean mass. Fifty two elite male rugby players and 32 non-athletic, age-matched controls differing in BMI (30.2±3.2 *v* 24.1±2.1 kg.m^{-2}; p=0.02) received one total body and one total hip DXA scan. Hip Structural Analysis of the proximal femur was used to determine bone mineral density (BMD) and cross-sectional bone geometry. Multiple linear regression was computed to identify independent variables associated with total hip and femoral neck BMD and HSA-derived bone geometry parameters. Analysis of covariance was used to explore differences between groups. Further comparisons between groups were performed after normalising parameters to body weight and to lean mass. There was a trend for a positive fat-bone relationship in rugby players, and a negative relationship in controls, although neither reached statistical significance. Correlations with lean mass were stronger for bone geometry (r^2=0.408-0.520) than for BMD (r^2=0.267-0.293).Relative to body weight, BMD was 6.7% lower in rugby players than controls (p<0.05). Rugby players were heavier than controls, with greater lean mass and BMD (p<0.01). Relative to lean mass, BMD was 10-14.3% lower in rugby players (p<0.001). All bone geometry measures except cross-sectional area, were proportional to body weight and lean mass. To conclude, BMD in elite rugby players was reduced in proportion to body weight and lean mass. However, their superior bone geometry suggests that overall bone strength may be adequate for loading demands. Fat-bone interactions in athletes engaged in high impact sports require further exploration.

Key words: athlete; bone strength; lean; fat; hip geometry; mechanical loading

Introduction

There remains controversy over the relative relationships between high body mass index (BMI), bone strength and fracture risk. Body weight *per se* is positively associated with bone mineral density (BMD) (1), and both obese populations (2,3) and elite rugby players have demonstrated greater absolute BMD compared to age- and sex-matched controls (4,5). Never-the-less, recent studies of obese groups are reporting reduced bone strength relative to their greater body weight (2,3), and an elevated risk of site-specific fracture (6-8). One hypothesis given is that bone is negatively influenced by greater adiposity and lower lean mass composition of body weight in obesity (3). This suggests a crucial role for lean mass in the maintenance of bone strength and resistance against fracture. It is unclear if the relationship between bone strength and body weight is more balanced in high BMI individuals with body weight comprised of substantial lean mass and low fat mass.

Elite rugby players typically present with high BMI (~30 $kg.m^{-2}$), substantial lean mass, and low body fat (4,5,9). In contrast to adipose tissue, muscles load bone directly, to the extent that individuals of identical body weight and body fat, but differing lean mass, might be expected to exhibit proportionally different bone masses. The sport of rugby exposes the skeleton to repeated high magnitude ground and joint reaction forces which are additionally osteogenic. The purpose of this study therefore, was to ascertain if markers of bone strength at the hip are proportional to the greater body weight and lean mass of elite rugby players compared to normal weight controls. In doing so, we adopted a similar approach to that previously utilised in studies of obese groups (3). We also aimed to explore relationships between body composition and bone, to provide unique insights into the muscle-bone link in a group typically at the higher end of the lean mass scale.

Materials and Methods

Elite male rugby players (n=52) and non athletic controls (n=32), aged 22 to 36 years, participated in the study. Rugby players were recruited from one Super League team and one English Premiership rugby union team, and all scans were performed in the pre-season for each code. The non athletic, normal BMI, age- and sex-matched controls were recruited from university-wide emails. The University Faculty Research Ethics Committee approved the study and informed consent was obtained from all participants prior to testing.

Physical measures

Participants wore light-weight clothing and removed shoes and jewellery for all measurements, which were conducted in a dedicated research unit. Standing height was measured using a stadiometer (SECA, Birmingham, UK) and recorded to the nearest millimetre. Weight was measured with calibrated electronic scales (SECA, Birmingham, UK) and recorded in kilograms (kg) to the nearest 0.1 kg. Body mass index (BMI), (body mass / height ^{2} (kg.m^{-2})) was calculated for the purposes of comparison with obesity tables. Body composition indices of total lean mass and fat mass percentage were obtained from a dual energy X-ray absorptiometry (iDXA, GE Lunar, Madison, WI) scan of the total body. Precision errors for lean and fat mass measurements in our Unit are 0.5 and 0.9% respectively (mean age 34.6 years) (10).

Bone mineral density assessment and advanced hip structural analysis

Measurements of total hip and femoral neck BMD (non dominant side) were performed using DXA. From those scans, advanced hip structural analysis (AHSA) data were derived. The GE Encore AHSA software, version 13.0, provides a line of pixels traversing the bone axis which gives a projection of the surface area of bone in the cross-section of the narrow neck region of the femur. Cross-sectional area (CSA) (cm^2; exclusive of soft tissue spaces), cross-sectional moment of inertia (cm^4) (CSMI), section modulus, and femoral strength index (FSI) were obtained using HSA. CSA is an indicator of axial strength and is taken following the y axis along the narrow neck region (y is the distance from the centre of mass to the superior neck margin). CSMI is a measurement of density and the distribution of the density around the femoral neck. The measure reflects periosteal apposition that deposits bone mineral further away from the central axis, thus higher values indicate greater bone strength. SM is computed as the CSMI divided by the maximum distance of the centre of mass to the medial and lateral profile margin, and is a marker of bending strength. FSI is calculated from BMD, geometry, age, height and body mass data to indicate the risk of fracture for forces generated during a fall on the greater trochanter, where stress is: moment * y /cross-sectional moment of inertia + force /cross-sectional area (11). Short term *in-vivo* precision coefficients of variation derived from our Unit are 0.5%, 0.9%, 3.8%, 3.1%, 4.5%, and 9.2% for total hip BMD, femoral neck BMD, CSA, CSMI, SM and FSI respectively (12).

Statistical analysis

Statistical tests were performed using SPSS version 21.0 (LEAD Technologies Inc©). The Kolmogorov-Smirnov test indicated that all data were normally distributed, with a kurtosis equal to zero and therefore parametric models were utilised. Initial exploration of the data was computed using stepwise multiple linear regression to identify independent variables with a significant influence on total hip and femoral neck BMD and HSA-derived bone geometry parameters. This analysis was conducted for the complete group and for rugby players and controls separately in order to determine whether there were any differences between groups in terms of associations between bone phenotypes and lean mass. Independent variables included age, height, body weight, BMI, lean mass, and percentage fat mass. Differences in descriptive characteristics between rugby players and controls were explored using independent T-tests. To further evaluate differences between groups in BMD and bone geometry, we used analysis of covariance (ANCOVA) and Bonferroni comparisons, given that the groups of data studied were equal in variance. Age, height and lean mass were incorporated as covariates based on actual relationships to variables as determined using step-wise multiple linear regression. To evaluate how the bone parameters vary in proportion to the body weight and lean mass, group comparisons were repeated after dividing individual values successively by body weight and lean mass and the differences were expressed in percentage of the mean values of NW controls, as described elsewhere (3). Normalisation of bone parameters to lean mass was conducted separately, using the same method. Differences were expressed as a percentage of the mean values of age-matched, normal weight controls. The level of significance for all tests was set at $p<0.05$.

Results

Descriptive results are given in Table 1. All variables were normally distributed. Rugby players were heavier with greater lean mass than controls ($p<0.01$). Given that the controls were in the healthy range for body fat, there were no significant differences in body fat between the two groups. Despite an average body fat of 18%, rugby player BMI fell in the 'obese' range, whereas control BMI fell in the 'healthy' range. All BMD and bone geometry values were greater in rugby players ($p<0.001$). There were no significant differences between groups in FSI, which incorporates body weight into the algorithm.

Table 2 shows the standardised β coefficients for the stepwise multiple linear regression. For the whole group, only age, height and lean mass contributed significantly to the models. In controls, only body weight and lean mass contributed to models, and in rugby players, height and lean mass. Relationships between bone and body composition were also explored using bivariate correlation analyses. In separate analyses of the rugby players and controls, there were no correlations between lean mass or body fat and BMD. Analyses for the two groups combined revealed small, negative relationships between body fat, total hip (r^2= -0.071) and femoral neck BMD (r^2=-0.67, p=0.016), and positive relationships between lean mass, total hip (r^2=0.293) and femoral neck BMD (r^2=0.299, both $p<0.001$), and, as illustrated in Figures 1 and 2 respectively. We observed higher BMD in rugby players than controls, despite similar levels of body fat (Figure 1). Additionally, on visual inspection of the scatter plots, a similar BMD in some rugby players and controls appeared to exist despite greater lean mass in the rugby players (Figure 2).

Associations between lean mass and hip geometry were more pronounced than those with BMD. In rugby players, lean mass was positively associated with section modulus (r^2=0.121, *p*=0.015), CSMI (r^2=0.182, *p*=0.002) and CSA (r^2=0.149, *p*=0.006). In controls, lean mass was positively associated with CSMI (r^2=0.204, *p*=0.014) and CSA (r^2=0.150, *p*=0.038). There were no associations between body fat and bone geometry in either group, or when both groups were combined.

Table 3 presents the differences in bone parameters between groups, after adjustment for covariates based on actual relationships with those parameters. Total hip BMD was greater in rugby players ($p<0.05$). Bone parameters are presented in proportion to body weight (Table 4), and to lean mass (Table 5). Following normalisation for body weight, total hip and femoral neck BMD were lower in rugby players than in controls (both -6.7%; $p<0.05$). Relative to lean mass, total hip BMD and femoral neck BMD were 14.3% and 10.0% lower in rugby players than controls respectively ($p<0.001$). CSA was lower in rugby players in proportion to lean mass (-7.2; p=0.01). There were no differences in section modulus and CSMI, but there was a trend for greater section modulus in rugby players relative to body weight and to lean mass.

Discussion

In agreement with previous reports (4,5), elite rugby players had greater absolute total hip and femoral neck BMD compared to controls. However, although body size (height) and lean mass accounted for all the variance in bone strength parameters between rugby players and controls, the increment in BMD was not proportional to their higher body weight. Our findings emulate those recently reported in obese groups (2,3), despite considerable differences in body composition between large, muscular athletes and obese individuals. For bone geometry, absolute values were greater in rugby players than controls, except for FSI which includes an adjustment for body weight in its derivative algorithm. All bone geometrical measures were proportional to body weight and lean mass in the rugby players, except CSA, a marker of resistance against axial loads, which was reduced relative to increased lean mass.

Whereas obesity is characterised by excess fat mass (2,3), the high BMI of the elite rugby players reflects a substantial component of lean mass, as demonstrated in the current study and others (4,5,13). Unlike fat mass, which provides only indirect biomechanical advantage, lean mass exerts an additional direct and positive influence on bone (14-17). In consideration of the Mechanostat theory, we expected that bone parameters would be proportional to lean mass in mesomorphic rugby players. Instead, we observed lower BMD relative to body weight in this group. As expected lean mass was higher in the rugby players, however, the relationship between lean mass and BMD was not as apparent for rugby players as it was for controls. Our findings suggest that the positive effect of lean mass on bone may plateau after a certain point, and that the relationship is not in fact linear, and the greater absolute BMD observed in rugby players, may reflect a more pronounced influence of skeletal loading through impact sport. Additionally, elite rugby players engage in intensive strength training programmes and manipulate their diet in order to maximise the amount of lean mass they can accumulate. Therefore, it is also possible that large, rapid increases in lean mass may occur at a rate greater than that which would allow for concurrent bone adaptation.

Our results demonstrated that CSA was lower relative to lean mass in rugby players. CSA is predictive of fracture risk (18), however the short term risk for fracture in elite rugby players due to axial loading of the femoral neck is minimal. Injury audits support this, with a very low occurrence of fractures to the hip reported in this group, and soft tissue injuries accounting for most of those reported (19). Despite this, the substantial lean mass of players, may offer protection at this skeletal site, just as it has been suggested fat mass provides site-specific protection to obese individuals. It is also likely that loading at the hip during rugby, does not exceed what can be accommodated by the already greatly enhanced bone strength at this site which they exhibit. It should be considered that the findings of the current study are specific to the hip region, and therefore not applicable to other sites such as the spine. Recent research has reported a high prevalence of vertebral fracture in elite male rugby players, suggesting that this site is less protected from excessive impacts in comparison to the hip (13).

There were clear associations between lean mass and all bone geometry parameters. SM and CSMI are estimates of bending strength, and were well-matched to body weight and lean mass in elite rugby players. The associations between lean mass and bone geometry were more pronounced than those with BMD, and this finding is similar to those reported in obese groups (3). SM increases as the femur expands in diameter by subperiosteal apposition, an effect reported following weight-bearing exercise interventions (20) and in observational studies of athletes compared to controls (21). Given the superior bone geometrical properties in rugby players, overall bone strength in this group is likely to be adequate for their loading demands. The greater SM and CSMI in rugby players could in part reflect the influence of skeletal loading through impacts and bone strain generated at the hip region during rugby training and competition, and a through the direct influence of muscle on bone.

There exists some degree of controversy over the role of fat in bone health. Body fat levels were similar between the rugby players and controls in our study, likely reflecting that our controls were normally-active young adults. The relationship between fat and bone however appeared different between the two groups, evident on visual inspection of the scatter plots. In rugby players, body fat was more positively associated with BMD than in controls, where a clear negative relationship was observed (Figure 1). Indeed it has been suggested that fat exerts a positive effect on bone metabolism at a biochemical level, for example through hormones such as leptin (22). Future research exploring the role of fat in bone health of athletes would be valuable.

In this study, participants were male, and therefore our findings should not be applied to women. Research elsewhere however, suggests that HSA is superior in both young adult women and men athletes, with women athletes demonstrating greater strength indices than non-athletic men (23). HSA was utilised to derive values of bone geometry. This method relies on two-dimensional DXA with the same mass distribution curve as a BMD measurement, rather than a three-dimensional measure. Nonetheless, HSA has been validated against volumetric qualitative computed tomography (24), and has numerous practical advantages including being more cost effective, with lower radiation, and enabling DXA-derived data to be expressed in ways that are more biomechanically interpretable than BMD alone.

Conclusions

Despite greater absolute values, BMD is not proportional to the higher body weight and lean mass of elite male rugby players. Our findings suggest that the positive influence of lean mass and loading may plateau after a certain point in mesomorphic athletes. Lean mass was more predictive of BMD in controls, and fat may have a contributory, positive role on bone in athletes, but further research is required. Lean mass is important for all bone geometry properties in young adult men, particularly section modulus.

There are no conflicts of interest to declare.

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