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ORIGINAL ARTICLE

Weight regulation and bone mass: a comparison between professional jockeys, elite amateur boxers, and age, gender and BMI matched controls

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Abstract The aim of this study was to compare bone mass between two groups of jockeys (flat: $n = 14$; national hunt: $n = 16$); boxers ($n = 14$) and age, gender and BMI matched controls ($n = 14$). All subjects underwent dual energy X-ray absorptiometry (DXA) scanning for assessment of bone mass, with measurements made of the total body, vertebra L2–4 and femoral neck. Body composition and the relative contribution of fat and lean mass were extrapolated from the results. Data were analysed in accordance with differences in body composition, in particular, height, lean mass, fat mass and age. Both jockey groups were shown to display lower bone mass than either the boxers or control group at a number of sites including total body bone mineral density (BMD) (1.019 ± 0.06 and 1.17 ± 1.05 vs. 1.26 ± 0.01 and 1.26 ± 0.06 g cm^{-2} for flat, national hunt, boxer and control, respectively), total body bone mineral content (BMC) less head, L2–4 BMD and femoral neck BMD and BMC ($p < 0.05$). Regression analysis revealed that lean mass and height were the primary predictors of total body BMC, although additional group-specific influences were present which reduced bone mass in the flat jockey group and enhanced it in the boxers ($R^2 = 0.814$). Reduced bone mass in jockeys may be a consequence of reduced energy availability in response to chronic weight restriction and could have particular implications for these athletes in light of the high risk nature of the sport. In contrast, the high intensity, high impact training associated with boxing may have conveyed an osteogenic stimulus on these athletes.

Keywords Weight category athletes · Bone mass · Boxers · Jockeys

Introduction

Jockeys and amateur boxers are examples of weight category athletes and both must weigh-in at a designated body mass in order to compete. It has previously been suggested that the severe energy restrictions which accompany acute weight loss may have consequences for bone health in weight category athletes [1, 2], and it is thought that this may be due to energy and micronutrient deficiencies, and to the hormonal readjustments which occur as a result of reduced energy availability [2, 3]. Boxers have, however, previously been identified as having high bone mass in comparison to controls [4, 5], which is likely to be due to the high-impact nature of training and competition. Conversely, jockeys have recently been suggested as having low bone mass [6, 7] and it was suggested that this may have occurred in response to the life of chronic weight cycling typically associated with this population [8]. In theory the demands associated with "making weight" for competition in both these groups of athletes should be similar. In practice, however, the challenges which are encountered are quite different. The main difference between horse-racing and the majority of other weight category sports such as boxing is that while weight loss occurs in all cases, boxers are required to weigh-in prior to

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competition only. This weigh-in may take place up to 12 h prior to competition, thereby allowing the athlete time to replenish energy and fluid stores depleted when making weight [9]. This opportunity is not afforded to jockeys who are required to weigh-in immediately before and after each race that they ride. The situation is further compounded by the virtue that jockeys race at weight throughout the week, and in many cases over a 10–12 month period. In contrast, boxers appear to have a defined competitive season which may last approximately 4–6 months and contains a small number of major competitions so allowing these athletes to regain some body mass between competitions and in the off-season. In addition jockeys are required to align their own body mass with that allocated to the mount that they are riding in each individual race, which may be as many as 5–7 races per day. The large variability and lack of predictability related to the specific weight targets which jockeys must meet can result in rapid and acute weight loss and chronic weight cycling which may increase the physiological and metabolic strain placed on this athletic population [6]. This may be related to the low bone mass previously identified in jockeys; however, a major flaw of previous research is that findings were reported in accordance with World Health Organisation T scores only, which were formulated based on Caucasian women over the age of 50 years, and so may have limited application to a younger male athletic group [10]. In addition bone mineral density as indicated by DXA scanning is unable to fully account for differences in body size, with a tendency toward under and over-estimation in those of smaller and larger stature respectively [11, 12]. This occurs due to an inherent technical inability to measure bone depth, and therefore, true volumetric bone density. While the study by Warrington et al. [6] provided some very interesting data, further research was required so to assess whether bone mass is actually reduced in this group, and if so to more fully elucidate the potential mechanisms involved. The aim of this study, therefore, was to compare bone mass between a group of flat and national hunt jockeys, elite amateur boxers, and age, gender and BMI matched controls.

Materials and methods

Participants

Fifty-eight male participants were recruited to take part in this study (14 flat jockeys; 16 national hunt jockeys; 14 elite amateur boxers and 14 healthy, recreationally active controls). Flat jockeys compete in races of 5–20 furlongs (1 furlong = 0.201 km) and consist of a run with no obstacles. Flat jockeys compete within a weight range of 52.7–64 kg. National hunt races are at least 3.2 km long throughout which the horse must jump a number of obstacles. National hunt jockeys compete within a weight range of 62–76 kg. Inclusion criteria for jockeys included male jockeys who currently held a full-time racing license. Participants were recruited via mass mailing and advertisement at race-tracks. Participants were recruited on a volunteer basis, following a screening process. Elite amateur boxers compete in 11 different Olympic weight classifications. Participants for this study were all members of the National Amateur Squad; however, participants recruited were restricted to those boxers who participated in weight categories corresponding to the weight ranges within which jockeys compete. Control participants were recruited by mass e-mailing to all staff and students in a local university. All participants were recreationally active, fit and healthy but were not involved in any organized, structured sporting activity any more than twice a week. All participants within this study were matched for age, gender and BMI. In addition the national hunt jockeys, boxers and controls were body mass matched. It was not possible to match body mass of all groups as flat jockeys compete in a distinctly different weight range than national hunt riders. Ethical approval for this study was granted by the Dublin City University Research Ethics Committee. All participants provided written informed consent and medical history prior to participation in this study. Anyone with a reported medical condition known to affect bone health was excluded from this study.

Assessment of bone mass and body composition

Bone mass was determined by dual energy X-ray absorptiometry (DXA) scanning using the GE Lunar Prodigy Advance Scanner ($CV < 1\%$) (GE Medical Systems, UK). Scans were performed in order to measure bone mass of the total body, lumbar spine (vertebra L2–4) and femoral neck. Positioning for all scans was completed in accordance with manufacturer instructions. Bone mineral density (BMD) was reported as grams of absolute bone mineral content (BMC) per cm^2 of projected bone area (BA). Bone mineral apparent density (BMAD) was calculated so to provide an estimation of volumetric bone density, using previously described equations [13, 14].

$$\mathrm{L2{-}4BMAD} = \left(\left(\mathrm{BMD}^2\right)/\mathrm{BMC}\right) \times \left(4/(\pi \times \mathrm{width})\right)$$

$$\mathrm{FNBMAD} = \left(\left(\mathrm{BMD}^2\right)/\mathrm{BMC}\right) \times (4k/\pi)$$

(where $k = 1.5\,\mathrm{cm}$, i.e. the fixed length along the femoral neck)

The relative contributions of fat and lean mass were extrapolated from the results of the total body scan. Height and body mass were measured in a standing position wearing minimal clothing following standardized procedures. Body mass index (BMI), fat mass index (FMI) and lean mass index (LMI) were calculated as weight in kilograms (kg) divided by height in meters squared (kg m^{-2}).

Statistical analysis

Data were analysed using SPSS for Windows, version 17.0. Data distribution were assessed through use of the Shapiro Wilks test. Any variable which did not meet parametric assumptions was log transformed to ensure normalisation of data distribution. One way independent samples ANOVA was used to identify differences between the groups for all parameters. General linear modelling using univariate analysis of covariance (ANCOVA) was used to identify significant covariates of total body, lumbar spine (L2–4) and femoral neck BMC and BA, so to assess those variables which had a significant influence on the dependant variable in question, i.e. the bone mass variables. Group, lean mass, height, age, fat mass and interaction effects were included as potential covariates in each case. All variables were entered into this analysis in their log transformed state. Variables identified as being significant covariates to each of the relevant bone mass variables were then entered stepwise into a linear regression model. This model was used to identify the relationship between the significant covariates which best explained or predicted the behaviour of the dependent variables. A "dummy variable" was included within this analysis, whereby a standard value representing the interaction between the most significant covariate and group was included in the analysis, in order to identify group specific effects. Regression equations and R^2 values were generated from the results.

Results

Anthropometric and descriptive data

All groups were age, gender and BMI matched, with no significant differences apparent. Differences were shown between the groups for a number of other indices of body composition as illustrated in Table 1. Both the boxer group and controls had a significantly greater amount of lean mass than the flat jockey group. No differences were shown between the groups in relation to lean mass expressed relative to height (kg m^{-2}). The national hunt and control groups had a greater fat mass, FMI and % body fat than either the flat jockey or boxer group.

Bone mass characteristics

Bone mass characteristics of all groups are presented in Table 2. Groups consistently followed the same pattern for each variable measured, with flat jockeys displaying the lowest measure, followed by national hunt and control subjects, while the boxer group consistently displayed the greatest amount of bone. These differences reached significance between the groups for a number of variables, with both jockey groups (flat and national hunt) displaying significantly lower bone content than either of the control or boxer group in relation to total body BMD, total body BMC less head, L2–4 BMD and femoral neck BMD and BMC (see Table 2). A tendency toward significance was shown between national hunt and control group for L2–4 BMC and L2–4 BA ($p = 0.07$ and 0.054 respectively). Consideration of a ratio of total body BMC to lean mass (g kg^{-1}) showed that the flat jockey group had significantly lower TBBMC:LM than either the boxer or control group.

Predictors of bone mass

General linear modelling was used to identify significant covariates of each of the bone mass variables ($p < 0.05$). Lean mass (kg), height (m) and an interaction effect between lean mass and group were most consistently identified as covariates to the different bone mass variables. All significant covariates were then entered into a stepwise linear regression model and prediction equations and R^2 values for each variable were calculated. Resultant equations are presented in Table 3.

Discussion

Results from this study indicate that both jockey groups appear to have reduced bone mass at a number of sites when compared to an age, gender and BMI matched control and boxer group. Subsequent analysis revealed that much of the difference in bone mass could be explained by variations in height and the amount of lean mass present, with lean mass apparent as the primary predictor. Additional influences were, however, present which reduced bone mass in the jockey group and enhanced it in the boxer group. Reported results appear to support previous research which suggests low bone mass in jockeys [6, 7].

Differences in bone mass between both jockey groups versus the boxer and control groups reached statistical significance for total body BMD and BMC less head, L2–4 BMD and femoral neck BMD and BMC. Flat jockeys appeared to be most affected at all sites (see Table 2). Bone mass, as assessed through DXA scanning, has been indicated as the most relevant and predictive independent factor available for identification of fracture risk [15, 16]. Horseracing has previously been identified as a high risk sport [17, 18]. Recent research in a group of Irish jockeys showed that mean reported racing-related fractures for flat and national

Table 1 Descriptive and anthropometric data

	Flat ($n = 14$)	National hunt ($n = 16$)	Boxers ($n = 14$)	Control ($n = 14$)
Age (years)	25 ± 7	25 ± 4	21 ± 2	23 ± 4
Height (m)	1.65 ± 0.06	1.72 ± 0.05*	1.74 ± 0.1*	1.79 ± 0.045*◆
Body mass (kg)	54.63 ± 3.6	64.3 ± 3.34*	65.3 ± 12.2*	69.18 ± 4.98*
BMI (kg m^{-2})	20.18 ± 1.6	21.92 ± 1.2	21.56 ± 2.27	21.7 ± 1.88
Lean mass (kg)	49.39 ± 3.8	53.74 ± 4.34	58.06 ± 8.3*	58.03 ± 5.12*
LMI (kg m^{-2})	18.19 ± 1.3	18.25 ± 1.23	19.22 ± 1.6	18.17 ± 1.4
Fat mass (kg)	4.43 ± 1.5	8.67 ± 3.9*	6.66 ± 4.1	9.26 ± 3.84*
FMI (kg m^{-2})	1.65 ± 0.62	2.97 ± 1.46*	2.14 ± 1.07	2.94 ± 1.32*
Body fat (%)	8.26 ± 2.9	13.84 ± 6.02*	9.76 ± 4.14	13.66 ± 5.06*

Data presented as mean ± SD

LMI lean mass index, *FMI* fat mass index

* $p < 0.05$ from flat; ◆ $p < 0.05$ from national hunt

Table 2 Bone mass characteristics

	Flat ($n = 14$)	National hunt ($n = 17$)	Boxer ($n = 14$)	Control ($n = 14$)
TB BMD (g cm^{-2})	1.09 ± 0.06	1.17 ± 0.05*	1.29 ± 0.1*◆	1.26 ± 0.06*◆
TB BMC (g)	2373 ± 255	2791 ± 226*	3268 ± 612*◆	3128 ± 327*
TB BMCLH (g)	1941 ± 227	2314 ± 208*	2751 ± 560*◆	2649 ± 277*◆
TB BA (cm^2)	2172 ± 163	2399 ± 147*	2516 ± 299*	2502 ± 147*
TB BALH (cm^2)	1950 ± 161	2167 ± 145*	2285 ± 295*	2266 ± 142*
L2–4 BMD (g cm^{-2})	1.10 ± 0.09	1.15 ± 0.1	1.48 ± 0.16*◆†	1.26 ± 0.14*
L2–4 BMC (g)	47.28 ± 6.9	51.76 ± 9	74.35 ± 15.1*◆	63.66 ± 11.24*◆
L2–4 BA (cm^2)	42.72 ± 4.2	44.89 ± 5.3	49.84 ± 6.7*	50.13 ± 4.4*◆
L2–4 BMAD (g cm^{-3})	0.14 ± 0.01	0.14 ± 0.01	0.18 ± 0.02*◆†	0.143 ± 0.014
FN BMD (g cm^{-2})	1.05 ± 0.07	1.07 ± 0.11	1.25 ± 0.11*◆	1.19 ± 0.15*◆
FN BMC (g)	5.4 ± 0.55	5.76 ± 0.72	6.85 ± 0.82*◆	6.55 ± 0.7*◆
FN BA (cm^2)	5.15 ± 0.4	5.39 ± 0.35	5.46 ± 0.32	5.5 ± 0.35
FN BMAD (g cm^{-3})	0.39 ± 0.04	0.38 ± 0.05	0.44 ± 0.04◆	0.42 ± 0.07
TBBMC:LM (g kg^{-1})	48.1 ± 3.5	52.1 ± 4.4	56.0 ± 3.8	54.0 ± 5.1

Data are presented as mean ± SD

TB total body, *BMD* bone mineral density, *BMC* bone mineral concentration, *BMCLH* bone mineral content less head, *BA* bone area, *BALH* bone area less head, *BMAD* bone mineral apparent density, *L2–4* lumbar vertebrae 2–4, *FN* femoral neck, *LM* lean mass

* $p < 0.05$ from Flat; ◆ $p < 0.05$ from National Hunt; † $p < 0.05$ from Control

Table 3 Bone mass prediction equations

Variable	Prediction equation	R^2
TBBMC (g)	$4.763 + (\text{LBM}^{0.634}) - (\text{LBMFlat}^{0.024}) + (\text{Ht}^{1.204}) + (\text{LBMBoxer}^{0.020})$	0.814
TBBA (cm^2)	$5.460 + (\text{LBM}^{0.425}) + (\text{Ht}^{1.044}) + (\text{FM}^{0.035}) - (\text{LBMControl}^{0.010})$	0.914
L2–4 BMC (g)	$2.239 + (\text{Ht}^{3.212}) + (\text{LBMBoxer}^{0.066})$	0.692
L2–4 BA (cm^2)	$2.239 + (\text{Ht}^{3.212}) + (\text{LBMBoxer}^{0.066})$	0.692
FN BMC (g)	$-0.669 + (\text{LBM}^{0.816}) - (\text{Age}^{0.249})$	0.562
FN BA (cm^2)	$0.284 + (\text{LBM}^{0.349})$	0.362

Table represents prediction equations for all dependent variables, generated using a stepwise linear regression model and including all relevant covariates as identified by general linear modelling

TBBMC total body bone mineral content, *TBBA* total body bone area, *FN* femoral neck, *LBM* lean body mass, *FM* fat mass

hunt jockeys were 2.3 ± 2.9 and 4.5 ± 3.5 respectively. Of the participants, 78% had experienced a racing-related fracture at the time of this study [6]. The finding of low bone mass in the group of jockeys in the current study and assumed increase in fracture susceptibility [19], therefore, may have particular implications for jockeys.

Although BMD has previously been identified as one of the most relevant and quantifiable determinants of fracture risk available [16] it is important to note that bone mineral density is a two dimensional measure (g cm^{-2}) and so cannot provide a true approximation of volumetric bone density due to its failure to detect bone depth [12]. In fact, it has been suggested that the protective effect of high BMD may not actually be due to bone density per se, but may be related to the biomechanical advantage which an increased cross sectional area may convey [20]. Estimation of volumetric bone density through the calculation of bone mineral apparent density (BMAD) aims to correct for this factor [21] and has been suggested as being less reliant on body size than BMD [22]. Bone mineral apparent density (BMAD) was estimated in this group according to previously described calculations [13, 14]. Results revealed that the boxer group had significantly higher L2–4 BMAD than any other group, but that both jockey groups were similar to the control group, indicating that actual bone density differences between these groups may in fact be largely dependent on differences in body size.

In order to more fully explore the relationship between DXA derived measures of bone mass and other aspects of body composition, univariate analysis was used to identify significant covariates of BMC and BA of the total body, lumbar spine and femoral neck. Identified covariates were taken as those which had a significant influence or role to play in the determination of each of the measured bone mass variables. Lean mass, height and an interaction effect between group and lean mass were consistently identified as independently significant predictors of bone mass, particularly in the case of total body BMC. Lean mass consistently emerged as the primary predictor of bone mass. This finding is unsurprising given the allometric relationship which exists between these compartments of body composition. The “mechanostat” theory states that the skeletal system will adjust and adapt in accordance with its physical environment, so enabling it to cope with the typical voluntary muscle loads placed on it [23]. The finding that lean mass is the primary determinant of bone mass in this study is well supported by the literature as lean mass and the associated muscular forces which this measure represents characterize the extent of mechanical loading by which bone is regulated [24]. The consistent identification of a significant group × lean mass effect suggests however that additional group-specific influences may be present. The equation ‘‘$\mathrm{TBBMC} = 4.763 + \left(\mathrm{LBM}^{0.634}\right) - \left(\mathrm{LBMFlat}^{0.024}\right) + \left(\mathrm{Ht}^{1.204}\right) + \left(\mathrm{LBMBoxer}^{0.020}\right)$’’ suggests that some unidentified factor, along with height and the amount of lean mass present exists which enhances total body bone mineral content in the boxer group and reduces BMC of the flat group (see Table 3). Examination of a ratio of BMC to lean mass (g kg^{-1}) supports this result. It has previously been suggested that consideration of the proportionality between bone and lean mass may aid in the identification of causal mechanisms of low bone mass [25]. It is thought that a proportional amount of bone mass to lean mass, as displayed by the national hunt jockey group (see Table 2), may indicate that reduced bone mass in this group is a consequence of reduced lean mass, and the associated anthropometric and biomechanical osteogenic enhancements which it may convey. That the flat jockey group had a lower proportion of BMC relative to their lean mass suggests that additional metabolic or systemic influences may be present which caused a reduction of bone mineral content in this group [25]. Recent research suggests that jockeys may habitually operate with an energy availability below that required to maintain usual metabolic function [8], i.e. 30 kcal kg LBM^{-1}. It has been reported that bone turnover may be disrupted in favour of a resorptive state at an energy availability below this threshold, an effect which appears to occur in a dose–response fashion [26]. This may at least in part be due to the endocrine action of various energy regulating hormones such as leptin [27]. It is possible that chronic exposure to low levels of energy availability may have impaired the development of bone (and lean) mass in this group. The athlete triad is a condition defined by the presence of three inter-related conditions, i.e. low energy availability, reduced BMD and disrupted reproductive function [28]. Although this condition is more commonly associated with female athletes, it appears that this group of male jockeys may be susceptible to at least two of its elements, i.e. reduced BMD and low energy availability [8]. No information is currently available regarding reproductive function in this group. Further research, including an analysis of related endocrine and nutritional factors may be required in order to identify the interplay of factors which are involved in the development of the different body composition compartments within these groups of weight category athletes.

Boxing is primarily a speed and power type sport involving accelerated movement in multiple directions [29, 30] and may be considered typical of the type of physical activity known to convey an osteogenic benefit [31–35]. For example, participation in rugby, a high intensity high impact sport, has recently been shown to be associated with high BMD levels in elite players. This finding was accompanied by a metabolic balance favoring bone formation [33]. The nature of loading associated with boxing likely accounts for the increased bone mass identified in this group. The high levels of bone mass identified in the boxing group in this study (see Table 3) are consistent with those previously reported in groups of competitive boxers [4, 5]. That an effect independent of lean mass and height was identified as being instrumental in the development of total body BMC in the boxing group is consistent with the assertion that the osteogenic benefits associated with high impact activity may outweigh the benefits associated with lean mass alone [36].

An interesting finding from this study was that control subjects appeared to have a lower total body cross sectional bone area than either of the two athletic groups once the effects of height, lean mass and fat mass were accounted for (see Table 3). A potential explanation for this finding may be that extended participation in sport caused increased periosteal apposition in both athletic groups, as a greater cross sectional area may convey a biomechanical advantage to bone breaking strength [21]. Mineral accrual appeared to lag behind periosteal apposition in the jockey group however, resulting in the low BMD values reported within this study.

Results from the present study neither support nor refute the contention that participation in weight category sports may place the bone health of these athletes at risk [2] and it is likely that the mechanical properties and specific attributes of each sport in question may be the primary determinant of bone mass development. It has previously been suggested that participation in high impact sports may convey a protective effect on bone mass, which may overcome the negative osteogenic effects of rapidly reducing body mass [1]. Proteau et al. demonstrated a bone resorptive state in a group of elite judoists who were actively reducing body mass for competition. Weight regain between competition however, coupled with the high impact nature of judo appeared to be reflected by an overall osteogenic balance favouring bone formation and a high bone mass in comparison to controls, demonstrating the protective effect of high impact activity. This theory is supported by a study which examined a group of female boxers who were shown to have high levels of bone density in comparison to a control group despite displaying low levels of body fat, high energy expenditure and a high incidence of oligomenorrhea [5]. These findings support the high bone mass results reported in the boxer group in this study. The protective effect of high-impact activity does not appear to be afforded to jockeys however [37] and it is possible that repeated exposure to low levels of energy availability and the chronic nature of weight cycling associated with these athletes may have affected the development of lean and bone mass in this group.

There are a number of limitations in this study which may have affected interpretation of results. Sample size is small, so limiting the power of the statistical model employed. DXA scanning though widely used provides an incomplete view of actual bone health and strength, as it measures bone mass alone and cannot account for additional elements such as bone architecture, geometry, tissue properties or the amount of micro-damage present. Further research involving alternative bone scanning techniques such as quantitative computer tomography (QCT) may be of benefit as this technique provides a cross-sectional image of long bones and may provide a more comprehensive view of bone architecture and strength [38]. Inferences have been made regarding the dietary and physical activity habits of jockeys and boxers and their potential impact on bone health. These variables were not directly measured however and so conclusions drawn on the effect of such elements remains speculation pending further research.

In conclusion, results from this study appear to show low bone mass in both jockey groups and high bone mass in the boxer group, when compared to an age, gender and BMI matched control group. Statistical analysis indicates lean mass primarily, along with height to be the primary predictors of bone mass. This finding supports the strong body of literature available suggesting an allometric relationship between the development of lean and bone mass. Regression analysis did however show that additional group specific effects are present, which appear to reduce bone mass in the flat jockey group and to enhance it in the boxer group. The degree of high intensity mechanical loading associated with boxing may account for this result, while it is speculated that chronic exposure to a lifestyle of habitual weight cycling may have affected the development of bone (and lean) mass in the flat jockey group. Further research may be required so to identify the interaction of genetic and lifestyle factors which may have influenced bone mass findings observed within the present study.

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