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Bone mineral density, rib pain and other features of the female athlete triad in elite lightweight rowers: new concepts for injury prevention

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The Triad in elite female lightweight rowers

ABSTRACT

Objective: To determine bone mineral density (BMD) and the associations among BMD, menstrual history, disordered eating (DE), training history, intentional weight loss and rib pain for the first time in female lightweight rowers.

Methods: Dual-energy X-ray absorptiometry measured total body (TB) composition and BMD at the spine, femoral neck (FN), radius and TB. Questionnaires (EAT-26) measured DE, oligo/amenorrhea years, rib pain, training history and nutritional support provision in 21 elite female lightweight rowers (12 active, 9 retired).

Results: DE was reported in 6 of the rowers. The active with DE started rowing younger (P<0.05) than those without, and their amount of intentional weight loss (IWL) was associated with EAT-26 score (P<0.05). Some participants reported a history of oligo/amenorrhea 17 (76%) and/or rib pain 7 (32%) with those with rib pain having lower spine and TB Z-scores (P<0.05) than those without. Those with oligo/amenorrhea had lower spine Z-scores (P<0.01) than those without. Twelve participants had low BMD; three at spine; one at FN; and eight at radius. 13% of mean total training hours (18.6 ±9.1h.week^{-1}) were spent strength training (2.4 ±2.2h.week^{-1}). **Conclusions:** Upper-body exercises incorporating multidimensional high peak bone strain were not reported and may need to be considered in their strength training to improve radial BMD. Results suggest IWL and high-level training at a young age increases the likelihood of DE and there may be a lack of quality nutritional support for these athletes.

Strengths and limitations of this study

- The first multidisciplinary study to investigate the distribution of BMD, compared to parameters established in healthy non-athletic women, in association to rib stress fractures in UK elite active and retired female lightweight rowers.
- The first study to suggest that lightweight rowing rules may be partly responsible for the development of the Triad, and perhaps changing the weight rules to discourage unhealthy weight loss practices could prevent injury.
- The first study that contrasts with the sport-specificity theorem and highlights the importance of supplemental non-sport specific exercises in the training programmes of rowers and other athletes, that particularly suffer from low radius BMD, to elicit bone health and possibly reduce the incidence of skeletal fractures later in life.
- Generalisations for elite female lightweight rowers are limited by the small sample size.
- The validity of self-reported questionnaires has been critiqued on the credibility of honest responses.

Introduction

Rowing is an Olympic sport with two weight categories: open (no weight restriction) and lightweight. To qualify for racing lightweight, female rowers must weigh-in at no more than 59kg with a crew average of no more than 57kg (International Rowing Federation). The majority of lightweight rowers restrict their diet to meet weight restrictions using both acute and chronic methods of weight-loss [1, 2]. This could lead to disordered eating (DE), chronic energy deficiency, and subsequently menstrual dysfunction and low bone mineral density (BMD) [3, 4, 5]. The latter two are associated with bone stress injuries [6] and endothelial dysfunction, a concern for future cardiovascular risk [7]. The Female Athlete Triad (the Triad) according to the American College of Sports Medicine (ACSM) revised position statement; is an association between energy availability, menstrual function, and BMD, which may have clinical manifestations including eating disorders, amenorrhea, and osteoporosis [5]. Low energy availability, with or without disordered eating, can cause amenorrhea and reduced BMD due to reductions in leptin [8], insulin like growth factor (IGF-1) [9], and oestrogen production [10]. It has been reported that when severely restricted energy availability is prolonged, from either dietary restriction or increased expenditure, irreversible reductions in BMD could result [11]. Even less severe energy restrictions could suppress bone formation, and possibly prevent young women from achieving their genetic potential for peak BMD [11].

The Triad is also associated with increased incidence of musculoskeletal injuries and higher stress fracture risk [12] and is prevalent in sports where leanness is considered important [5]. The existence of the Triad is documented in dancers [13, 14], triathletes [15], distance runners [16, 17] and swimmers [18] but not in female lightweight rowers,

who commonly have a higher risk for rib stress fractures [19], and where leanness and weight control determine eligibility to compete and participate in the sport.

Disordered eating may describe the array of abnormal and harmful sub-clinical eating attitudes used to lose weight or maintain low weight, and is thought to affect up to two-thirds of young female athletes [20]. Sundgot-Borgen and Torstveit's, [21] more recent and large study on 572 elite female athletes showed a 20% prevalence of eating disorders, indicating a significant clinical issue for the health of a great amount of athletes. Eating disorders have one of the highest mortality rates of mental illnesses [22], and have been reported to be more prevalent (31%) in elite female athletes involved in sports emphasising leanness compared to those athletes (8%) involved in sports with less emphasis on leanness [23]. Studies on rowing have shown that lightweights are at a higher eating disorder risk than heavyweights, as identified by the Eating Attitudes Test-26 (EAT-26), [24, 25]. This is in accord with the higher prevalence of DE in "weight-category" sports which was reported by Sundgot-Borgen's, [26] study on 522 elite female athletes from 35 sports and 448 nonathletic controls. An incidence of 12% [24] and 16.2% [25] of DE has been reported in lightweight rowers in the past. The interlinked nature between DE, menstrual dysfunction and BMD is demonstrated in studies that established a relationship between DE and menstrual dysfunction [4, 16], between menstrual dysfunction and low BMD [3, 27] and between DE and low BMD in the absence of menstrual dysfunction [4, 16, 27]. Low BMD is also linked with increased incidence of stress fractures in male and female Marine recruits [28] and with exercise-induced rib stress fractures in male lightweight rowers [29]. Although one of the most common injuries in female rowers is rib stress fractures, its aetiology remains

unclear [19]. Rib stress fractures are less common in men [30], suggesting that low oestrogen levels, low BMD or factors associated with the Triad might be causative for rib stress fractures in female rowers.

To date, no studies have investigated BMD in relation to rib stress fractures in female lightweight rowers. This reinforces the view of [31], that the pathology and prevention of rib stress fractures is a worthy area of research in rowing. Little is known about the possible long-term implications of the Triad but it appears that the effects on BMD might be partially irreversible [13, 32, 33].

The aims of the present study were therefore to investigate: 1) The distribution of BMD for the first time in UK elite active and retired female lightweight rowers compared to the parameters established in healthy non-athletic women; 2) the associations among BMD, menstrual history, training history, DE, intentional weight loss and rib pain and 3) assess whether any past DE symptoms and menstrual dysfunction continue after retirement.

Methods

Ethics

This study was approved by the Health Studies Ethics Committee at Middlesex University. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. Details of the study's methods and testing procedures were explained to each participant, before a written, informed consent was obtained.

Participants

Participants were recruited from responses to recruitment advertisements in rowing clubs and a rowing magazine. No mention of DE, menstrual disorders and other aspects of the Triad were included in the advert to avoid possible sample selection bias. The year of this study only 79 UK female lightweight rowers were identified to participate in national and international level competitions. Twenty-nine Caucasian female lightweight rowers, from 9 different clubs volunteered to participate in this study. Only 21 (12 active, 9 retired) met the study's criteria and volunteered for the study. Inclusion criteria were females aged over 18 years who had rowed competitively in lightweight category for no less than one year. Participants were excluded if they had a history of bone disease, used medications known to influence BMD (e.g., corticosteroids, antidepressants, thiazolidinediones, bisphosphonates, NSAIDS and chemotherapy) or if they were pregnant, lactating or post-menopausal. Two rowers were excluded and six withdraw for logistic reasons. Rowing competition level was: 5 international (2 active) and 16 national (10 active) level. All were non-smokers and their mean weekly alcohol consumption was 5.8 ±1.2 units per week. None reported vitamin D and calcium supplements intake and all but two did not regularly (3-4/week) eat products containing calcium.

Questionnaires:

EAT-26 and Pathogenic Weight Control Strategies

Symptoms and characteristics of eating disorders were assessed by the EAT-26, a 26-item inventory with strong psychometric properties [34]. Thirteen items relate to "dieting" behaviour, six to "Bulimia and Food Preoccupation" and seven to "Oral

Control". The 26 items of the EAT-26 inventory were rated on a 6-point response scale as described in Garner et al. [34]. The score can range from 0-78. A score of 20 or above is considered indicative of DE [34].

Self-reported questionnaires assessed whether participants had been engaged in any pathogenic weight control strategies such as vomiting and/or use of laxatives to induce weight loss within the last 6 months. Present or past engagement in binge-eating behaviour, eating more than other people would in the same situation [35] and whether they had previously been diagnosed with an eating disorder were also assessed. Retired rowers were assessed to observe whether any past pathogenic weight control strategies continued after retirement.

Menstrual History Questionnaire

All rowers reported their age of menarche and number of menses for each year after menarche choosing from the following options: amenorrhea (0-3), oligomenorrhea (4-9) and eumenorrhea (10-13) [16]. Total lifetime menses (years) and number of years of amenorrhea, and oligomenorrhea was calculated as described in Cobb et al. [16] and normalised for age by dividing the number of years of each of the above menstrual variables with current age. Due to the small sample size, menstrual history status was categorised into two groups of oligo/amenorrheic (those with history of oligo/amenorrhea) and eumenorrheic (those without). Retired rowers were assessed to observe whether any history of oligo/amenorrhea continued after retirement.

Additional Questionnaires

Self-reported questionnaires assessed demographic data, including details of sporting history, mode of training including type of resistance training exercises and average weekly training volume (hours) at highest competitive level for both retired and active rowers, level of competition, medical history, use of medications, supplements and oral contraceptives (OCA), smoking, alcohol intake and weight loss. Duration of OCA use was normalised for gynecological age by dividing the number of years of OCA use with gynecological age. History of injury was reported by drawing the area of symptoms on a body chart and answering questions about cause of injury, duration of symptoms, and diagnosis. History, duration and cause of rib pain were also recorded. Participants were also asked whether they had ever been provided with nutritional and/or weight management advice from coach/club. Retired rowers gave details of physical activity since retiring from lightweight rowing. Questionnaire details were verbally explained to each participant in conjunction with written instructions. Whilst participants were completing the questionnaires investigators were present to clarify any issues/questions and tried to ensure that the answers were as accurate as possible.

Physical and Bone Measurements

Bone mineral density ($g.cm^{-2}$) at the posterior anterior (PA) L2-4 lumbar spine (LS); PA femoral neck (FN); dominant arm distal radius; total body and body composition (lean and fat mass) were measured by DXA (fan beam, Lunar DPX-L series GE Medical systems, Lunar Madison, WI USA). The in-house coefficient of variation of the BMD measurements ranged from 0.5-0-1.4%. The scanner was calibrated using a spine phantom at the start of each day of testing and its performance was followed with the labs quality assurance protocol. Z-scores were calculated using the manufacturer-supplied reference data (Lunar enCORE© USA/European reference data) set to compare individuals BMD values to age and sex-matched controls. The ACSM defines the term 'low BMD' as a Z-score between -1 and -2, and 'osteoporosis' a Z-score ≤ -2 together with secondary risk factors for fracture (e.g., chronic malnutrition, eating disorders, hypoestrogenism, hypogonadism, glucocorticoid exposure, and previous fractures,[3]).

All participants were requested to refrain from heavy physical activity 24 h before screening to minimize the effect of fluctuations in hydration status on body composition measurements. Participants' height (m) and body mass (kg) were measured using standard stadiometers and balance beam scales, respectively. Body mass index (BMI) was calculated as kilograms per square meter ($kg.m^{-2}$). All anthropometric measurements, scanning and analyses were performed by the same technician using the same equipment.

Statistical Analyses

Statistical analyses were performed using SPSS version 16.0. Values are reported as means ± SD. Statistical significance was set at $P<0.05$. Levene's test was used to assess equality of variances in the different groups. Violations of the equality of variances assumption were corrected using the P-value calculated for equal variances not assumed. A General Linear Model was used to determine whether Z-scores, years of training, age of menarche, and amount of intentional weight loss differ: 1) between rowers with and without history of oligo/amenorrhea or rib pain, and 2) between active rowers that scored ≥20 and active rowers that scored <20 on the EAT-26. When the Z-scores were analysed to assess for differences between participants, data was adjusted/controlled for BMI [36], by fitting an ANCOVA to the data.

Z-scores were used in the statistical analyses, as they are normative values for chronological age. Pearson's correlation coefficient was used to determine significant relationships between variables of interest. Any analysis performed between Z-scores and other specific variables was controlled for BMI. Correlation analysis between EAT-26 score and amount of intentional weight loss and duration of OCA use was applied only in the data of active rowers. The retired were excluded because their weight loss data refers to the past whilst the EAT-26 data refers to their current DE attitudes.

Results

The anthropometric characteristics, training and menstrual history details and OCA use of the lightweight rowers is summarized in Table 1.

Table 1. Anthropometric characteristics, training and menstrual history details and oral contraceptive use of lightweight rowers

Variable	Active N =12	Retired N=9	Both N=21
Age (yr)	26.6 ±2.0	31.6 ±5.0	28.7 ±4.3 (23-39)*
Stature (cm)	171.8 ±5.5	165.7±2.8	169.2±5.4 (162.0-179.5)
Body mass (kg)	61.2±1.8	61.5±5.4	61.3 ±3.7 (56.8-73)
Body fat (%)	21.4±5.8	23.1±7.2	22.1 ±6.4 (11.6-35.1)
BMI ($kg.m^{-2}$)	20.8±1.1	22.3 ±2.6	21.4±2.0 (19.5-27.8)
Age at onset of exercising (yr)	15.1±5.7	11.3 ±4.6	13.5 ±5.6 (4-26)
Years playing sports	11.5±5.2	20.2 ±5.0	15.2 ±6.7 (2-31)*
Years training at lightweight category	2.5 ±1.1	6.0 ±3.8	4.0 ±3.1 (1-12)*
Training per week (h)	15.3 ±4.1	22.9 ±12	18.6 ±9.0 (10-53)
Strength and power training per week (h)	1.7 ±1.6	3.3 ±2.6	2.4 ±2.2 (0-10)
Water rower training per week (h)	8.8 ±2.8	11.1 ±2.7	9.8 ±3.0 (5-16)
Cardiovascular training (i.e., cycling, running, ergometer rowing) per week (h)	4.8 ±2.2	8.6 ±9.8	6.4 ±6.7 (1-33.5)
Age at onset of retirement (yr)	NA	28.6±5.6	NA
Years since retirement	NA	3.0 ±1.9	NA
OCA (yr)	4.3±3.1	2.4±1.4	3.9 ±2.7 (1-9)
Years with oligo/amenorrhea	4.5 ±3.9	4.2 ±4.4	4.4±4.0 (0-13)
Menarcheal age (yr)	13.4 ±1.1	13.0 ±1.2	13.2±1.1 (11-15)
Oligo/amenorrhic (N)	10	7	17
Gynaecological age (yr)	13.2±2.2	18.5±5.1	15.5±4.5 (10-27)*
Total lifetime menses (yr)	10.8±2.3	14.6±5.4	12.4±4.3 (4.9-25.3)

Values are mean ± SD. *P<0.05 between active and retired rowers. Gynecological age is years since menarche; OCA is length of oral contraceptive use in years; all oligo/amenorrhea years were secondary (occurred after menarche).

Bone Mineral Density

Three participants had low BMD at LS (Z-scores -1.5, -1.2 and -1.1), one at FN (Z-score -1.1) and eight at radius. Three of these had Z-scores below -2 at radius (Z-scores -2.3, -2.1 and -2.3). As depicted in Figure 1, the mean Z-scores of the oligo/amenorrheic, active and retired rowers was significantly lower at LS (AD=1.75, $F(2,21) = 11.455$, $P < 0.01$, $\eta p^2=0.560$) compared to the eumenorrheic rowers. Total lifetime menses (controlled for BMI values) was positively associated with Z-scores at LS (r=0.516, P<0.05) and at FN (r=0.438, P<0.05).

Furthermore, when the retired were looked at separately, the results revealed that the oligo/amenorrheic rowers had significantly lower Z-scores at LS (AD=2.7, $F(2,9) = 17.307$, $P < 0.01$, $\eta p^2=0.852$) and total body (AD=1.47, $F(2,9) = 26.756$, $P < 0.01$, $\eta p^2=0.899$) compared to the eumenorrheic retired rowers. Mean Z-scores of eumenorrheic retired were above normal at all sites.

Disordered Eating, Pathogenic Weight Control Strategies

All active rowers reported engagement in intentional weight loss to qualify for lightweight racing. Both active and retired rowers reported DE attitudes (EAT-26 score >20) and pathogenic weight control strategies (Table 2).

Independent sample T-tests showed that active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), (t=-3.088, P<0.05). The EAT-26 score was associated with the amount of intentional weight loss (r=0.720, P<0.05), see Figure 2, and duration of OCA use (r=0.908, *P*<0.001).

Table 2. Reported eating attitudes in lightweight rowers

	Active N =12	Retired N=9	Overall N=21
DE symptoms N (%)	5 42	1 11	6 29
Binge eating episodes N (%)	8 67	0	8 38
Induced vomiting N (%)	3 25	0	3 14
Use of laxatives N (%)	4 33	2 22≠	6 29
Intentional weight loss N (%)(Mean loss SD)	12 100 (5.8 ±1.9kg)	8 89 (6.3 ±4.5kg) †	20 95 (6.0 ±3.2kg)

≠past laxative use during their rowing career

†past intentional weight loss to qualify for racing lightweight during their rowing career

Rib Pain

Seven participants (32%) reported a history of rib pain lasting between 2 to 10 weeks. As depicted in Figure 3, the Z-scores at total body and LS were significantly lower (P<0.05) in rowers with history of rib pain compared to those without. Additionally, rowers with rib pain reported to train more hours per week, (21 vs. 17h, P>0.05), and to have higher oligo/amenorrhea years (8.8 vs. 4yr, P>0.05) than those without.

There is no additional data available.

Discussion

This study confirms the co-existence of reduced BMD, oligo/amenorrhea, disordered eating and intentional weight loss, in UK elite female lightweight rowers. The association between total lifetime menses and BMD supports the notion that BMD declines as the number of missed menstrual cycles accumulates [32].

A novel, but concerning finding in this study was that total EAT-26 score was associated with the amount of intentional weight loss in active rowers which suggests that intentional weight loss increases the likelihood of engaging in DE behaviours. Furthermore, active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), which suggests involvement in high level training at a young and vulnerable age (all rowers achieved national and international level) is significantly associated with risk to DE attitudes [37]. A meta-analysis of 34 studies (2459 athletes) supports these findings, which showed an increased risk of DE in elite athletes compared to non-elite [38]. Additionally, a higher prevalence of eating disorders among adolescent elite athletes than controls has been reported in a most recent study by Martinsen and Sundgot-Borgen, [39]. Binge eating was also a common finding among the active rowers (67%), which compares to 52% encountered by Thiel et al. [40]. Pathogenic weight control strategies and symptoms of DE and binge eating were more prevalent in the active than the retired rowers of this study, and in earlier studies on elite rowers [24, 25].

Furthermore, only 2/12 (17%) active compared to 4/9 (44%) retired reported to have received professional nutritional support for rowing and weight management. The importance of nutritional guidance to help in the prevention and treatment of DE has been evident to this study and is in agreement with Beals and Manore, [41] who stated that one of the issues that leads athletes to fail to meet their exercise energy requirements is lack of appropriate nutritional knowledge. Sundgot-Burgen and Klungland,[42], reported that the prevalence of DE was reduced from 33% to 15% in cross-country skiers over an 8-year DE preventative programme. Therefore, quality nutritional guidance should be offered from a young age to possibly minimize DE and the health related risks [4, 16, 43]. Youth rowing coach education on DE and Triad risk or perhaps even weight category rule change consideration may also needed to prevent DE, the Triad and associated unhealthy conditions in developing lightweight female rowers.

Weight loss is predominantly the result of negative energy balance, however, methods of intentional weight loss such as the use of laxatives, which was reported in this study, or other dehydration methods do not necessarily mean low energy availability [44] or a symptom of DE. In this study no association was found between symptoms of DE and BMD, which is contrary to previous studies [4, 16]. However, DE is not necessarily a component of the Triad whereas low energy availability is [5]. Assessment of DE is also an important medical consideration, and can help identify psychopathological individuals with the Triad, in addition to indirectly establishing the possibility of low energy availability.

Prevalence of DE in lightweight rowers, as assessed by a score ≥20 on the EAT-26 questionnaire, has been reported to be between 12 and 16% [24, 25] compared to 29% in this study. These results suggest that the rowers from the above research studies and the present study are considered "at risk" for clinical eating disorders [45]. This percentage could have been even higher as athletes tend to under report symptoms of DE [20, 26] due to denial and secrecy which are hallmarks of DE [22], and because do not consider eating habits as DE, but as "part of the game" in season. Denying DE symptoms has clinical implications for these athletes including delayed facilitation of appropriate therapy.

In ballet dancers and runners, the reproductive hormonal changes caused by excessive exercise and low energy availability may result in low BMD at LS [16, 46]. The mechanical stresses of rowing appear to exert protection on the lumbar BMD [47]. The eumenorrheic rowers in this study demonstrated elevated BMD measurements compared to their age and sex-matched reference data, particularly at LS, which is in accord with Wolman et al. [48]. However, the mean lumbar BMD of the oligo/amenorrheic rowers in this study was not elevated compared to their age and sex-matched reference data, suggesting that oligo/amenorrhea has a negative effect on BMD [32]. This can be further supported by the significantly lower Z-score observed at LS in the rowers with history of oligo/amenorrhea compared to those without, and the positive association between total lifetime menses and Z-scores at LS and FN found in this study. Previous studies have shown similar findings [4, 46].

In line with the practices of coaches working with rowers in Great Britain [49], the rowers in this study engaged in strength and power training, predominately consisting of squats, cleans and lower-body plyometrics. The nature of the sport, and the direction of force application, dictates that these pulling movements and closed chain exercises are indeed rational and explains their routine recommendation [50]. Specifically, Ebben [51] reported that an 8-week strength and power programme using these, improved time, power and power per stroke during 2000m ergometer rowing. Unsurprisingly, pushing based strength exercises for the upper-body, such as the bench press, rank quite low on importance, and upper-body plyometrics generally do not feature [49]. From a training specificity and performance-based point of view, the reasons for this appear sound. However, of a bone health perspective, such a focused approach may be contested. The results of this study and that of others [17, 52] have reported low BMD in the radius of athletes, suggesting that current training paradigms may not address this appropriately and perhaps fitness coaches should also address the current and future health of their athletes. At times, this will require a non-sport specific approach.

Specifically, in this study eight rowers had low BMD at the radius (Z<-1) and it has been recommended that a Z-score of <-1.0 in an athlete warrants further investigation, even in the absence of prior fracture [5]. The marked incidence of low BMD at radius might suggest that the stress applied on the upper limb skeleton through joint-reaction forces, generated during the rowing and/or the strength and power training undertaken by the rowers in this study were not sufficient to elicit an increase in BMD or maintain it to normal physiological levels [53]. It might also suggest that these tensile forces were insufficient to counteract the negative effects of low energy availability on BMD [3-5, 11] possibly induced by intentional weight loss methods, a common practice in lightweight rowers as seen here and in previous research [1, 36]. Furthermore, low radius BMD might reflect the dissipation/diversion of BMD to weight-bearing sites, at the expense of non-weight bearing sites, such as the radius [52]. These findings reinforce the tenet that bone mineral acquisition obeys a principle of specificity [52, 54] and that the effects of joint reaction forces on bone formation are not as effective as those observed through ground reaction forces generated during dynamic sports and /or activities like running, jumping, kicking, tennis, punching and plyometrics which can incorporate multidimensional (non-conventional) high peak loading compressing strains distribution into the bone [53-55].

In summary, exercises that directly target the arms such as the bench press and plyometric push-ups for example, may help in the modelling/remodeling of the bone. This comes into contrast with the sport-specificity theorem and the authors of this study strongly recommend the implementation of supplemental non-sport specific exercises in the training programmes of rowers and other athletes, that particularly suffer from low radius BMD, could be a promising means of maximizing bone accrual and health, and possibly reducing the incidence of skeletal fractures later in life.

Little is known about the long-term effects of DE and oligo/amenorrhea on BMD. In retired rowers with a history of oligo/amenorrhea, despite resuming normal menses, their Z-scores at LS and total body were significantly lower than those who had always been eumenorrheic. This corroborates existing body of knowledge, which suggests that deficits in BMD may be irreversible [13, 32, 33]. Longitudinal study on a higher number of female lightweight rowers is required to understand this issue more adequately.

An incidence of rib stress fractures in male rowers of up to 12% has been reported [29]. Seven (32%) of participants in this study had history of rib pain lasting 2-8wk (5.1 ±2.9wk). Whilst these participants had no radiographic evidence to confirm diagnosis of rib stress fracture, our study suggests the incidence of rib pain is a common complaint in female lightweight rowers (2.7 times more common than male rowers) and chronic chest wall pain in rowers is almost always the result of rib stress fractures as suggested by Strayer [56]. However, a subsequent study reported that athletes tend to self-report a higher percentage on stress fractures (14.0%) compared to those diagnosed with stress fractures (8.1%) ($P< 0.001$), indicating that self-reporting of stress fractures has low validity [57]. Due to the retrospective nature of this study in terms of assessing rib stress fractures incidence, it was not possible to make a clinical diagnosis. In this study active and retired rowers with history of rib pain had significantly lower LS and total body Z-score values than those without history, which possibly suggests that low BMD may play a role in the aetiology of exercise-induced rib stress fractures in female lightweight rowers. Interestingly, Nevill et al. [52] reported significant correlations ($P<0.05$) between BMD recorded at ribs, thoracic and lumbar spine, pelvis, legs, hip and arms. This study's results are in agreement with others [19, 29, 30], although the association between low BMD and fractures has been established in postmenopausal women with osteoporosis [58] and not in premenopausal.

Generalisations for elite female lightweight rowers are limited by the small sample size, however, lightweight rowing is a "minority" sport reflected by the relatively small number (79) of female lightweight rowers identified to participate in National level competition during the study year. Therefore, further research is required to verify the findings from this study. However, future research should focus on measuring energy input versus energy output and assess in more detail, calcium, anti-inflammatory medications, vitamin A and D supplemental intake and the methods and behaviours associated with IWL. The establishment of normal BMD reference ranges in athletes is needed since the application of a reference range based on the general non-athletic population may not be appropriate [17]. Finally, the effect of upper body resistance and plyometrics training on BMD should be investigated to determine if this could counter the negative effects of DE and oligo/amenorrhea.

This study suggests that lightweight rowing rules may be partly responsible for resultant high levels of DE, high rates of oligo/amenorrhea, BMD deficiencies which are correlated with number of lifetime menses, and the tendency to have DE after retirement. Apparent DE vulnerability of lightweight female rowers commencing training at a younger age is of great concern. Lightweight female rowing rules mean that any athlete above the height of 175cm meeting the mean target weight of 57kg would be underweight with a BMI of <18.5. We would therefore encourage lightweight rowing to embrace sports injury prevention and provide coaches and athletes with appropriate multidisciplinary nutritional and psychological support to prevent DE and the development of the Triad, and perhaps to also consider changing the weight rules to discourage unhealthy weight loss practices.

What are the new findings

- This study confirms the co-existence of reduced BMD, oligo/amenorrhea, disordered eating and intentional weight loss, in UK elite female lightweight rowers.
- EAT-26 scores were associated with the amount of intentional weight loss, which suggests that intentional weight loss increases the likelihood of engaging in DE behaviours in active rowers.
- Active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), which suggests involvement in high level training at a young and vulnerable age (all rowers achieved national and international level) is significantly associated with risk to DE attitudes.
- Only 2/12 (17%) active compared to 4/9 (44%) retired reported to have received professional nutritional support for rowing and weight management.

How might it impact on clinical practice in the near future

- Individuals considering rowing in a lightweight category may benefit from assessment and monitoring for physical and psychological health risk and their suitability and sport participation safety by a trained sports medicine physician/scientist.
- If considered that they can safely achieve the required weight loss then they should be supported with nutritional guidance and regular monitoring of energy availability, DE and assessment of menstrual function.

- Athletes and coaches should be educated about the risks of DE, low energy availability and menstrual dysfunction on systemic health to help in the prevention and treatment of the Triad in lightweight rowers.
- Nutritional guidance and psychological support should be offered at a young age to minimize DE and health related risks, and supplemental strength and conditioning training that involves non-sport specific exercises that distribute multidimensional high peak strains on the upper body skeleton is likely to elicit bone health and performance benefits for female lightweight rowers.

Contributorship statement:
LD, AR and RL-S conceived the idea for the study and prepared the methods. LD completed the scanning and analysed it. LD, AR and RL-S collected the data and analysed it. LD, AR and RL-S drafted the initial paper and RW, AT, LH and NJ contributed with further critical drafting. All authors critically revised and approved the final version of the manuscript.

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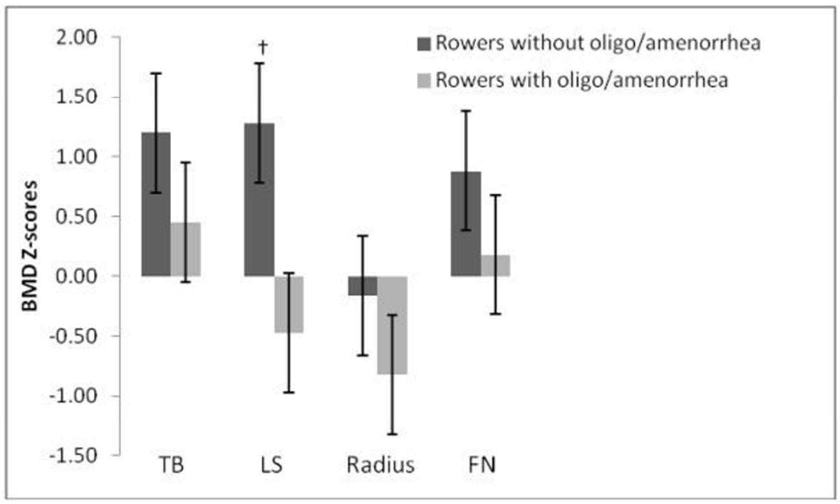
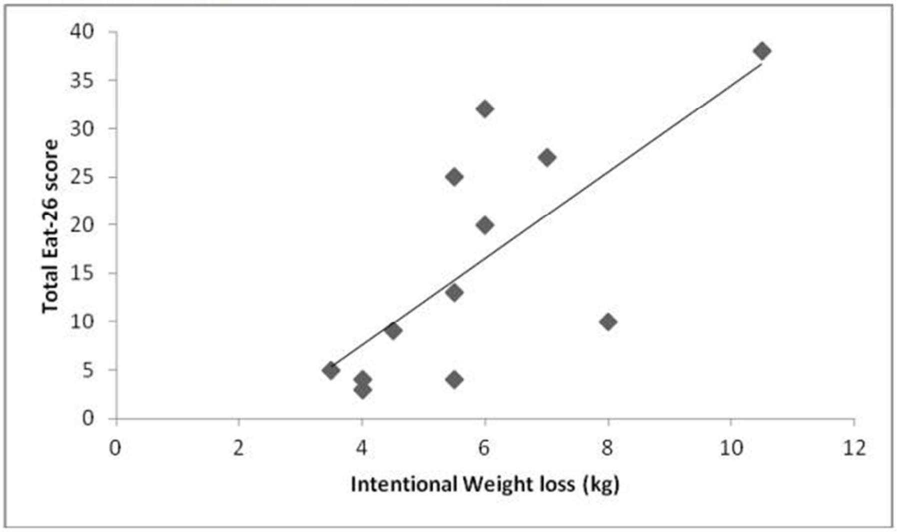
Figure 1. BMD Z-scores (Mean ±SD) at total body (TB), lumbar spine (LS), radius and neck of femur (NF) in rowers with and without a history of oligo/ammenorrhea.



†Significant difference ($p<0.001$) between rowers with and without a history of oligo/ammenorrhea.

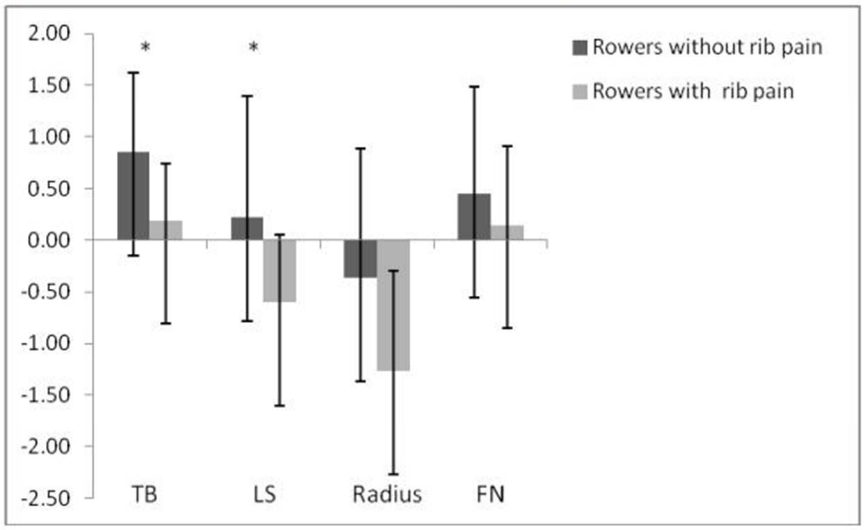
BMD Z-scores (Mean ±SD) at total body (TB), lumbar spine (LS), radius and neck of femur (NF) in rowers with and without a history of oligo/ammenorrhea.
254x190mm (72 x 72 DPI)

Figure 2. Relationship between the amount of intentional weight loss and EAT-26 score, a measure of DE, in active rowers, (r=0.720, p<0.05).



254x190mm (72 x 72 DPI)

Figure 3. BMD Z-scores (Mean ±SD) at total body (TB), lumbar spine (LS), radius and neck of femur (NF) in rowers with and without a history of rib pain.



*Significant difference (P<0.05) between rowers with and without a history of rib pain.

*Significant difference (P<0.05) between rowers with and without a history of rib pain.
254x190mm (72 x 72 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	
Bias	9	Describe any efforts to address potential sources of bias	6,7
Study size	10	Explain how the study size was arrived at	5,6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10
		(*b*) Describe any methods used to examine subgroups and interactions	NA
		(*c*) Explain how missing data were addressed	5-10

		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5,6
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-13
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	Figures and tables, 10-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18-20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-18
Generalisability	21	Discuss the generalisability (external validity) of the study results	19,20
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	No funding.20.

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Bone mineral density, rib pain and other features of the female athlete triad in elite lightweight rowers

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Bone mineral density, rib pain and other features of the female athlete triad in elite lightweight rowers.

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The Triad in elite female lightweight rowers

ABSTRACT

Objective: To determine bone mineral density (BMD) and the associations among BMD, menstrual history, disordered eating (DE), training history, intentional weight loss and rib pain for the first time in female lightweight rowers.

Methods: Dual-energy X-ray absorptiometry measured total body (TB) composition and BMD at the spine, femoral neck (FN), radius and TB. Questionnaires (EAT-26) measured DE, oligo/amenorrhea years, rib pain, training history and nutritional support provision in 21 elite female lightweight rowers (12 active, 9 retired).

Results: DE was reported in 6 of the rowers. The active with DE started rowing younger ($P<0.05$) than those without, and their amount of intentional weight loss (IWL) was associated with EAT-26 score ($P<0.05$). Some participants reported a history of oligo/amenorrhea 17 (76%) and/or rib pain 7 (32%) with those with rib pain having lower spine and TB Z-scores ($P<0.05$) than those without. Those with oligo/amenorrhea had lower spine Z-scores ($P<0.01$) than those without. Twelve participants had low BMD; three at spine; one at FN; and eight at radius. 13% of mean total training hours ($18.6 \pm 9.1 h.week^{-1}$) were spent strength training ($2.4 \pm 2.2 h.week^{-1}$). **Conclusions:** Upper-body exercises incorporating multidimensional high peak bone strain were not reported and may need to be considered in their strength training to improve radial BMD. Results suggest IWL and high-level training at a young age increases the likelihood of DE and there may be a lack of quality nutritional support for these athletes.

Key words: DXA, menstrual dysfunction, exercise, dieting, skeletal health, fractures

Strengths and limitations of this study

- The first multidisciplinary study to investigate the distribution of BMD, compared to parameters established in healthy non-athletic women, in association to rib pain in UK elite active and retired female lightweight rowers.
- The first multidisciplinary study that examined BMD and TB composition via DXA, menstrual history, disordered eating (DE), training history, intentional weight loss and rib pain in lightweight rowing which is a "minority" sport and understudied.
- The first study that contrasts with the sport-specificity theorem and highlights the importance of supplemental non-sport specific exercises in the training programmes of rowers and other athletes, that particularly suffer from low radius BMD, to elicit bone health and possibly reduce the incidence of skeletal fractures later in life.
- Generalisations for elite female lightweight rowers are limited by the small sample size.
- The validity of self-reported questionnaires has been critiqued on the credibility of honest responses.

Introduction

Rowing is an Olympic sport with two weight categories: open (no weight restriction) and lightweight. To qualify for racing lightweight, female rowers must weigh-in at no more than 59kg with a crew average of no more than 57kg (International Rowing Federation). The majority of lightweight rowers restrict their diet to meet weight restrictions using both acute and chronic methods of weight-loss [1, 2]. This could lead to disordered eating (DE), chronic energy deficiency, and subsequently menstrual dysfunction and low bone mineral density (BMD) [3, 4, 5]. The latter two are associated with bone stress injuries [6] and endothelial dysfunction, a concern for future cardiovascular risk [7]. The Female Athlete Triad (the Triad) according to the American College of Sports Medicine (ACSM) revised position statement; is an association between energy availability, menstrual function, and BMD, which may have clinical manifestations including eating disorders, amenorrhea, and osteoporosis [5]. Low energy availability, with or without disordered eating, can cause amenorrhea and reduced BMD due to reductions in leptin [8], insulin like growth factor (IGF-1) [9], and oestrogen production [10]. It has been reported that when severely restricted energy availability is prolonged, from either dietary restriction or increased expenditure, irreversible reductions in BMD could result [11]. Even less severe energy restrictions could suppress bone formation, and possibly prevent young women from achieving their genetic potential for peak BMD [11].

The Triad is also associated with increased incidence of musculoskeletal injuries and higher stress fracture risk [12] and is prevalent in sports where leanness is considered important [5]. The existence of the Triad is documented in dancers [13, 14], triathletes [15], distance runners [16, 17] and swimmers [18] but not in female lightweight rowers,

who commonly have a higher risk for rib stress fractures [19], and where leanness and weight control determine eligibility to compete and participate in the sport.

Disordered eating may describe the array of abnormal and harmful sub-clinical eating attitudes used to lose weight or maintain low weight, and is thought to affect up to two-thirds of young female athletes [20]. Sundgot-Borgen and Torstveit's, [21] more recent and large study on 572 elite female athletes showed a 20% prevalence of eating disorders, indicating a significant clinical issue for the health of a great amount of athletes. Eating disorders have one of the highest mortality rates of mental illnesses [22], and have been reported to be more prevalent (31%) in elite female athletes involved in sports emphasising leanness compared to those athletes (8%) involved in sports with less emphasis on leanness [23]. Studies on rowing have shown that lightweights are at a higher eating disorder risk than heavyweights, as identified by the Eating Attitudes Test-26 (EAT-26), [24, 25]. This is in accord with the higher prevalence of DE in "weight-category" sports which was reported by Sundgot-Borgen's, [26] study on 522 elite female athletes from 35 sports and 448 nonathletic controls. An incidence of 12% [24] and 16.2% [25] of DE has been reported in lightweight rowers in the past. The interlinked nature between DE, menstrual dysfunction and BMD is demonstrated in studies that established a relationship between DE and menstrual dysfunction [4, 16], between menstrual dysfunction and low BMD [3, 27] and between DE and low BMD in the absence of menstrual dysfunction [4, 16, 27]. Low BMD is also linked with increased incidence of stress fractures in male and female Marine recruits [28] and with exercise-induced rib stress fractures in male lightweight rowers [29]. Although one of the most common injuries in female rowers is rib stress fractures, its aetiology remains

unclear [19]. Rib stress fractures are less common in men [30], suggesting that low oestrogen levels, low BMD or factors associated with the Triad might be causative for rib stress fractures in female rowers.

To date, no studies have investigated BMD in relation to rib stress fractures in female lightweight rowers. This reinforces the view of [31], that the pathology and prevention of rib stress fractures is a worthy area of research in rowing. Little is known about the possible long-term implications of the Triad but it appears that the effects on BMD might be partially irreversible [13, 32, 33].

The aims of the present study were therefore to investigate: 1) The distribution of BMD for the first time in UK elite active and retired female lightweight rowers compared to the parameters established in healthy non-athletic women; 2) the associations among BMD, menstrual history, training history, DE, intentional weight loss and rib pain and 3) assess whether any past DE symptoms and menstrual dysfunction continue after retirement.

Methods

Ethics

This study was approved by the Health Studies Ethics Committee at Middlesex University. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. Details of the study's aims, methods and testing procedures were explained to each participant, before a written, informed consent was obtained.

Participants

Participants were recruited from responses to recruitment advertisements for current and retired lightweight rowers offering free determination of BMD and TB composition in rowing clubs and a rowing magazine. No mention of DE, menstrual disorders and other aspects of the Triad were included in the advert to avoid possible sample selection bias. The year of this study only 79 UK female lightweight rowers were identified to participate in national and international level competitions. Twenty-nine Caucasian female lightweight rowers, from 9 different clubs volunteered to participate in this study. Only 21 (12 active, 9 retired) met the study's criteria and volunteered for the study. Inclusion criteria were females aged over 18 years who had rowed competitively in lightweight category for no less than one year. Participants were excluded if they had a history of bone disease, used medications known to influence BMD (e.g., corticosteroids, antidepressants, thiazolidinediones, bisphosphonates, NSAIDS and chemotherapy) or if they were pregnant, lactating or post-menopausal. Two rowers were excluded and six withdraw for logistic reasons. Rowing competition level was: 5 international (2 active) and 16 national (10 active) level. All were non-smokers and their mean weekly alcohol consumption was 5.8 ±1.2 units per week. None reported vitamin D and calcium supplements intake and all but two did not regularly (3-4/week) eat products containing calcium.

Questionnaires:

EAT-26 and Pathogenic Weight Control Strategies

Symptoms and characteristics of eating disorders were assessed by the EAT-26, a 26-item inventory with strong psychometric properties [34]. Thirteen items relate to “dieting” behaviour, six to “Bulimia and Food Preoccupation” and seven to “Oral Control”. The 26 items of the EAT-26 inventory were rated on a 6-point response scale as described in Garner et al. [34]. The score can range from 0-78. A score of 20 or above is considered indicative of DE [34].

Self-reported questionnaires assessed whether participants had been engaged in any pathogenic weight control strategies such as vomiting and/or use of laxatives to induce weight loss within the last 6 months. Present or past engagement in binge-eating behaviour, eating more than other people would in the same situation [35] and whether they had previously been diagnosed with an eating disorder were also assessed. Retired rowers were assessed to observe whether any past pathogenic weight control strategies continued after retirement.

Menstrual History Questionnaire

All rowers reported their age of menarche and number of menses for each year after menarche choosing from the following options: amenorrhea (0-3), oligomenorrhea (4-9) and eumenorrhea (10-13) [16]. Total lifetime menses (years) and number of years of amenorrhea, and oligomenorrhea was calculated as described in Cobb et al. [16] and normalised for age by dividing the number of years of each of the above menstrual variables with current age. Due to the small sample size, menstrual history status was categorised into two groups of oligo/amenorrheic (those with history of oligo/amenorrhea) and eumenorrheic (those without). Retired rowers were assessed to observe whether any history of oligo/amenorrhea continued after retirement.

Additional Questionnaires

Self-reported questionnaires assessed demographic data, including details of sporting history, mode of training including type of resistance training exercises and average weekly training volume (hours) at highest competitive level for both retired and active rowers, level of competition, medical history, use of medications, supplements and oral contraceptives (OCA), smoking, alcohol intake and weight loss. Duration of OCA use was normalised for gynecological age by dividing the number of years of OCA use with gynecological age. History of injury was reported by drawing the area of symptoms on a body chart and answering questions about cause of injury, duration of symptoms, and diagnosis. History, duration and cause of rib pain were also recorded. Participants were also asked whether they had ever been provided with nutritional and/or weight management advice from coach/club. Retired rowers gave details of physical activity since retiring from lightweight rowing. Questionnaire details were verbally explained to each participant in conjunction with written instructions. Whilst participants were completing the questionnaires investigators were present to clarify any issues/questions and tried to ensure that the answers were as accurate as possible.

Physical and Bone Measurements

Bone mineral density ($g.cm^{-2}$) at the posterior anterior (PA) L2-4 lumbar spine (LS); PA femoral neck (FN); dominant arm distal radius; total body and body composition (lean and fat mass) were measured by DXA (fan beam, Lunar DPX-L series GE Medical systems, Lunar Madison, WI USA). The in-house coefficient of variation of the BMD measurements ranged from 0.5-0-1.4%. The scanner was calibrated using a spine phantom at the start of each day of testing and its performance was followed with the labs quality assurance protocol. Z-scores were calculated using the manufacturer-supplied reference data (Lunar enCORE© USA/European reference data) set to compare individuals BMD values to age and sex-matched controls. The ACSM defines the term 'low BMD' as a Z-score between -1 and -2, and 'osteoporosis' a Z-score ≤ -2 together with secondary risk factors for fracture (e.g., chronic malnutrition, eating disorders, hypoestrogenism, hypogonadism, glucocorticoid exposure, and previous fractures,[3]).

All participants were requested to refrain from heavy physical activity 24 h before screening to minimize the effect of fluctuations in hydration status on body composition measurements. Participants' height (m) and body mass (kg) were measured using standard stadiometers and balance beam scales, respectively. Body mass index (BMI) was calculated as kilograms per square meter ($kg.m^{-2}$). All anthropometric measurements, scanning and analyses were performed by the same technician using the same equipment.

Statistical Analyses

Statistical analyses were performed using SPSS version 16.0. Values are reported as means ± SD. Statistical significance was set at $P<0.05$. Levene's test was used to assess equality of variances in the different groups. Violations of the equality of variances assumption were corrected using the P-value calculated for equal variances not assumed. A General Linear Model was used to determine whether Z-scores, years of training, age of menarche, and amount of intentional weight loss differ: 1) between rowers with and without history of oligo/amenorrhea or rib pain, and 2) between active rowers that scored ≥20 and active rowers that scored <20 on the EAT-26. When the Z-scores were analysed to assess for differences between participants, data was adjusted/controlled for BMI [36], by fitting an ANCOVA to the data.

Z-scores were used in the statistical analyses, as they are normative values for chronological age. Pearson's correlation coefficient was used to determine significant relationships between variables of interest. Any analysis performed between Z-scores and other specific variables was controlled for BMI. Correlation analysis between EAT-26 score and amount of intentional weight loss and duration of OCA use was applied only in the data of active rowers. The retired were excluded because their weight loss data refers to the past whilst the EAT-26 data refers to their current DE attitudes.

Results

The anthropometric characteristics, training and menstrual history details and OCA use of the lightweight rowers is summarized in Table 1.

Table 1. Anthropometric characteristics, training and menstrual history details and oral contraceptive use of lightweight rowers

Variable	Active N =12	Retired N=9	Both N=21
Age (yr)	26.6 ±2.0	31.6 ±5.0	28.7 ±4.3 (23-39)*
Stature (cm)	171.8 ±5.5	165.7±2.8	169.2±5.4 (162.0-179.5)
Body mass (kg)	61.2±1.8	61.5±5.4	61.3 ±3.7 (56.8-73)
Body fat (%)	21.4±5.8	23.1±7.2	22.1 ±6.4 (11.6-35.1)
BMI ($kg.m^{-2}$)	20.8±1.1	22.3 ±2.6	21.4±2.0 (19.5-27.8)
Age at onset of exercising (yr)	15.1±5.7	11.3 ±4.6	13.5 ±5.6 (4-26)
Years playing sports	11.5±5.2	20.2 ±5.0	15.2 ±6.7 (2-31)*
Years training at lightweight category	2.5 ±1.1	6.0 ±3.8	4.0 ±3.1 (1-12)*
Training per week (h)†	15.3 ±4.1	22.9 ±12	18.6 ±9.0 (10-53)
Strength and power training per week (h)†	1.7 ±1.6	3.3 ±2.6	2.4 ±2.2 (0-10)
Water rower training per week (h)†	8.8 ±2.8	11.1 ±2.7	9.8 ±3.0 (5-16)
Cardiovascular training (i.e., cycling, running, ergometer rowing) per week (h)†	4.8 ±2.2	8.6 ±9.8	6.4 ±6.7 (1-33.5)
Age at onset of retirement (yr)	NA	28.6±5.6	NA
Years since retirement	NA	3.0 ±1.9	NA
OCA (yr)	4.3±3.1	2.4±1.4	3.9 ±2.7 (1-9)
Years with oligo/amenorrhea	4.5 ±3.9	4.2 ±4.4	4.4±4.0 (0-13)
Menarcheal age (yr)	13.4 ±1.1	13.0 ±1.2	13.2±1.1 (11-15)
Oligo/amenorrhic (N)	10	7	17
Gynaecological age (yr)	13.2±2.2	18.5±5.1	15.5±4.5 (10-27)*
Total lifetime menses (yr)	10.8±2.3	14.6±5.4	12.4±4.3 (4.9-25.3)

Values are mean ± SD. *P<0.05 between active and retired rowers; † at highest competitive level; gynecological age is years since menarche; OCA is length of oral contraceptive use in years; all oligo/amenorrhea years were secondary (occurred after menarche).

Bone Mineral Density

Three participants had low BMD at LS (Z-scores -1.5, -1.2 and -1.1), one at FN (Z-score -1.1) and eight at radius. Three of these had Z-scores below -2 at radius (Z-scores -2.3, -2.1 and -2.3). As depicted in Figure 1, the mean Z-scores of the oligo/amenorrheic, active and retired rowers was significantly lower at LS (AD=1.75, $F(2,21) = 11.455$, $P <0.01$, $\eta p^2=0.560$) compared to the eumenorrheic rowers. Total lifetime menses (controlled for BMI values) was positively associated with Z-scores at LS (r=0.516, P<0.05) and at FN (r=0.438, P<0.05).

Furthermore, when the retired were looked at separately, the results revealed that the oligo/amenorrheic rowers had significantly lower Z-scores at LS (AD=2.7, $F(2,9) = 17.307$, $P <0.01$, $\eta p^2=0.852$) and total body (AD=1.47, $F(2,9) = 26.756$, $P <0.01$, $\eta p^2=0.899$) compared to the eumenorrheic retired rowers. Mean Z-scores of eumenorrheic retired were above normal at all sites.

Disordered Eating, Pathogenic Weight Control Strategies

All active rowers reported engagement in intentional weight loss to qualify for lightweight racing. Both active and retired rowers reported DE attitudes (EAT-26 score >20) and pathogenic weight control strategies (Table 2).

Independent sample T-tests showed that active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), (t=-3.088, P<0.05). The EAT-26 score was associated with the amount of intentional weight loss (r=0.720, P<0.05), see Figure 2, and duration of OCA use (r=0.908, *P*<0.001).

Table 2. Reported eating attitudes in lightweight rowers

	Active N =12	Retired N=9	Overall N=21
DE symptoms N (%)	5 42	1 11	6 29
Binge eating episodes N (%)	8 67*	0*≠	8 38
Induced vomiting N (%)	3 25*	0*≠	3 14
Use of laxatives N (%)	4 33*	0* 2 22≠	6 29
Intentional weight loss N (%)(Mean loss SD)	12 100 (5.8 ±1.9kg)	8 89 (6.3 ±4.5kg) †	20 95 (6.0 ±3.2kg)

*within the last 6 months; ≠past reported symptomsduring their rowing career; †past intentional weight loss to qualify for racing lightweight during their rowing career

Rib Pain

Seven participants (32%) reported a history of rib pain lasting between 2 to 10 weeks. As depicted in Figure 3, the Z-scores at total body and LS were significantly lower (P<0.05) in rowers with history of rib pain compared to those without. Additionally, rowers with rib pain reported to train more hours per week, (21 vs. 17h, P>0.05), and to have higher oligo/amenorrhea years (8.8 vs. 4yr, P>0.05) than those without.

There is no additional data available.

Discussion

This study confirms the co-existence of reduced BMD, oligo/amenorrhea, disordered eating and intentional weight loss, in UK elite female lightweight rowers. The association between total lifetime menses and BMD supports the notion that BMD declines as the number of missed menstrual cycles accumulates [32].

A novel, but concerning finding in this study was that total EAT-26 score was associated with the amount of intentional weight loss in active rowers which suggests that intentional weight loss increases the likelihood of engaging in DE behaviours. Furthermore, active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), which suggests involvement in high level training at a young and vulnerable age (all rowers achieved national and international level) is significantly associated with risk to DE attitudes [37]. A meta-analysis of 34 studies (2459 athletes) supports these findings, which showed an increased risk of DE in elite athletes compared to non-elite [38]. Additionally, a higher prevalence of eating disorders among adolescent elite athletes than controls has been reported in a most recent study by Martinsen and Sundgot-Borgen, [39]. Binge eating was also a common finding among the active rowers (67%), which compares to 52% encountered by Thiel et al. [40]. Pathogenic weight control strategies and symptoms of DE and binge eating were more prevalent in the active than the retired rowers of this study, and in earlier studies on elite rowers [24, 25].

Furthermore, only 2/12 (17%) active compared to 4/9 (44%) retired reported to have received professional nutritional support for rowing and weight management. The importance of nutritional guidance to help in the prevention and treatment of DE has been evident to this study and is in agreement with Beals and Manore, [41] who stated that one of the issues that leads athletes to fail to meet their exercise energy requirements is lack of appropriate nutritional knowledge. Sundgot-Burgen and Klungland,[42], reported that the prevalence of DE was reduced from 33% to 15% in cross-country skiers over an 8-year DE preventative programme. Therefore, quality nutritional guidance should be offered from a young age to possibly minimize DE and the health related risks [4, 16, 43]. Youth rowing coach education on DE and Triad risk or perhaps even weight category rule change consideration may also needed to prevent DE, the Triad and associated unhealthy conditions in developing lightweight female rowers.

Weight loss is predominantly the result of negative energy balance, however, methods of intentional weight loss such as the use of laxatives, which was reported in this study, or other dehydration methods do not necessarily mean low energy availability [44] or a symptom of DE. In this study no association was found between symptoms of DE and BMD, which is contrary to previous studies [4, 16]. However, these studies determined energy deficiency, and assessed DE with the Eating Disorder Inventory instead. Possibly, DE is not necessarily a component of the Triad whereas low energy availability is [5]. Assessment of DE is also an important medical consideration, and can help identify psychopathological individuals with the Triad, in addition to indirectly establishing the possibility of low energy availability.

Prevalence of DE in lightweight rowers, as assessed by a score ≥20 on the EAT-26 questionnaire, has been reported to be between 12 and 16% [24, 25] compared to 29% in this study. These results suggest that the rowers from the above research studies and the present study are considered “at risk” for clinical eating disorders [45]. This percentage could have been even higher as athletes tend to under report symptoms of DE [20, 26] due to denial and secrecy which are hallmarks of DE [22], and because do not consider eating habits as DE, but as “part of the game” in season. Denying DE symptoms has clinical implications for these athletes including delayed facilitation of appropriate therapy. Furthermore, the validity of self-reported questionnaires has been critiqued on the credibility of honest responses. Therefore, the use of questionnaires alone to assess symptoms of DE would be best if complimented with a clinical interview in future studies.

In ballet dancers and runners, the reproductive hormonal changes caused by excessive exercise and low energy availability may result in low BMD at LS [16, 46]. The mechanical stresses of rowing appear to exert protection on the lumbar BMD [47]. The eumenorrheic rowers in this study demonstrated elevated BMD measurements compared to their age and sex-matched reference data, particularly at LS, which is in accord with Wolman et al. [48]. However, the mean lumbar BMD of the oligo/amenorrheic rowers in this study was not elevated compared to their age and sex-matched reference data, suggesting that oligo/amenorrhea has a negative effect on BMD [32]. This can be further supported by the significantly lower Z-score observed at LS in the rowers with history of oligo/amenorrhea compared to those without, and the positive association between total lifetime menses and Z-scores at LS and FN found in this study. Previous studies have shown similar findings [4, 46].

In line with the practices of coaches working with rowers in Great Britain [49], the rowers in this study engaged in strength and power training, predominately consisting of squats, cleans and lower-body plyometrics. The nature of the sport, and the direction of force application, dictates that these pulling movements and closed chain exercises are indeed rational and explains their routine recommendation [50]. Specifically, Ebben [51] reported that an 8-week strength and power programme using these, improved time, power and power per stroke during 2000m ergometer rowing. Unsurprisingly, pushing based strength exercises for the upper-body, such as the bench press, rank quite low on importance, and upper-body plyometrics generally do not feature [49]. From a training specificity and performance-based point of view, the reasons for this appear sound. However, of a bone health perspective, such a focused approach may be contested. The results of this study and that of others [17, 52] have reported low BMD in the radius of athletes, suggesting that current training paradigms may not address this appropriately and perhaps fitness coaches should also address the current and future health of their athletes. At times, this will require a non-sport specific approach.

Furthermore, to support bone health, general health, injury prevention and sporting performance, current training paradigms should be supported with effective nutritional guidance and psychological support, when required, to educate, prevent, recognise, support and manage weight loss and DE in lightweight female rowers [53].

Specifically, in this study eight rowers had low BMD at the radius ($Z<-1$) and it has been recommended that a Z-score of <-1.0 in an athlete warrants further clinical investigation and management, even in the absence of prior fracture [5]. The marked incidence of low BMD at radius might suggest that the stress applied on the upper limb skeleton through joint-reaction forces, generated during the rowing and/or the strength and power training undertaken by the rowers in this study were not sufficient to elicit an increase in BMD or maintain it to normal physiological levels [54]. It might also suggest that these tensile forces were insufficient to counteract the negative effects of low energy availability on BMD [3-5, 11] possibly induced by intentional weight loss methods, a common practice in lightweight rowers as seen here and in previous research [1, 36]. Furthermore, low radius BMD might reflect the dissipation/diversion of BMD to weight-bearing sites, at the expense of non-weight bearing sites, such as the radius [52]. These findings reinforce the tenet that bone mineral acquisition obeys a principle of specificity [52, 55] and that the effects of joint reaction forces on bone formation are not as effective as those observed through ground reaction forces generated during dynamic sports and /or activities like running, jumping, kicking, tennis, punching and plyometrics which can incorporate multidimensional (non-conventional) high peak loading compressing strains distribution into the bone [54-56].

In summary, exercises that directly target the arms such as the bench press and plyometric push-ups for example, may help in the modelling/remodeling of the bone. This comes into contrast with the sport-specificity theorem and the authors of this study strongly recommend the implementation of supplemental non-sport specific exercises in the training programmes of rowers and other athletes, that particularly suffer from low radius BMD, could be a promising means of maximizing bone accrual and health, and possibly reducing the incidence of skeletal fractures later in life. This is the first study that contrasts with the sport-specificity theorem.

Little is known about the long-term effects of DE and oligo/amenorrhea on BMD. In retired rowers with a history of oligo/amenorrhea, despite resuming normal menses, their Z-scores at LS and total body were significantly lower than those who had always been eumenorrheic. This corroborates existing body of knowledge, which suggests that deficits in BMD may be irreversible [13, 32, 33]. Longitudinal study on a higher number of female lightweight rowers is required to understand this issue more adequately.

An incidence of rib stress fractures in male rowers of up to 12% has been reported [29]. Seven (32%) of participants in this study had history of rib pain lasting 2-8wk (5.1 ±2.9wk). Whilst these participants had no radiographic evidence to confirm diagnosis of rib stress fracture, our study suggests the incidence of rib pain is a common complaint in female lightweight rowers (2.7 times more common than male rowers) and chronic chest wall pain in rowers is almost always the result of rib stress fractures as suggested by Strayer [57]. However, a subsequent study reported that athletes tend to self-report a higher percentage on stress fractures (14.0%) compared to those diagnosed with stress fractures (8.1%) ($P< 0.001$), indicating that self-reporting of stress fractures has low validity [58]. Due to the retrospective nature of this study in terms of assessing rib stress fractures incidence, it was not possible to make a clinical diagnosis. In this study active and retired rowers with history of rib pain had significantly lower LS and total body Z-score values than those without history, which possibly suggests that low BMD may play a role in the aetiology of exercise-induced rib stress fractures in female lightweight rowers. Interestingly, Nevill et al. [52] reported significant correlations ($P<0.05$) between BMD recorded at ribs, thoracic and lumbar spine, pelvis, legs, hip and arms.

This study's results are in agreement with others [19, 29, 30], although the association between low BMD and fractures has been established in postmenopausal women with osteoporosis [59] and not in premenopausal.

Generalisations for elite female lightweight rowers are limited by the small sample size, however, lightweight rowing is a "minority" sport reflected by the relatively small number (79) of female lightweight rowers identified to participate in National level competition during the study year. Therefore, further research that recruits a larger sample of lightweights and a control group of either non-athletes, athletes from other sports, or non-lightweight rowers is recommended to further substantiate the findings of this study. However, future research should focus on measuring energy input versus energy output and assess in more detail, calcium, anti-inflammatory medications, vitamin A and D supplemental intake and the methods and behaviours associated with IWL. The establishment of normal BMD reference ranges in athletes is needed since the application of a reference range based on the general non-athletic population may not be appropriate [17]. Finally, the effect of upper body resistance and plyometrics training on BMD should be investigated to determine if this could counter the negative effects of DE and oligo/amenorrhea.

This study suggests that lightweight rowing rules may be partly responsible for resultant high levels of DE, high rates of oligo/amenorrhea, BMD deficiencies which are correlated with number of lifetime menses, and the tendency to have DE after retirement. Apparent DE vulnerability of lightweight female rowers commencing training at a younger age is of great concern. Lightweight female rowing rules mean that any athlete above the height of 175cm meeting the mean target weight of 57kg would be underweight with a BMI of <18.5. We would therefore encourage lightweight rowing to embrace sports injury prevention and provide coaches and athletes with appropriate multidisciplinary nutritional and psychological support to prevent DE and the development of the Triad, and perhaps to also consider changing the weight rules to discourage unhealthy weight loss practices. Previous research suggests that rowing performance is strongly correlated to body height (related to arm and leg length), as well as body mass [60, 61, 62, 63]. Our study would therefore support competitive categories being explored by height, rather than weight to help avoid detrimental health and performance issues identified in our study related to DE and the Triad.

Contributorship statement:

LD, AR and RL-S conceived the idea for the study and prepared the methods. LD completed the scanning and analysed it. LD, AR and RL-S collected the data and analysed it. LD, AR and RL-S drafted the initial paper and RW, AT, LH and NJ contributed with further critical drafting. All authors critically revised and approved the final version of the manuscript.

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What are the new findings

- This study confirms the co-existence of reduced BMD, oligo/amenorrhea, disordered eating and intentional weight loss, in UK elite female lightweight rowers.

- EAT-26 scores were associated with the amount of intentional weight loss, which suggests that intentional weight loss increases the likelihood of engaging in DE behaviours in active rowers.
- Active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), which suggests involvement in high level training at a young and vulnerable age (all rowers achieved national and international level) is significantly associated with risk to DE attitudes.
- Only 2/12 (17%) active compared to 4/9 (44%) retired reported to have received professional nutritional support for rowing and weight management.

How might it impact on clinical practice in the near future

- Individuals considering rowing in a lightweight category may benefit from assessment and monitoring for physical and psychological health risk and their suitability and sport participation safety by a trained sports medicine physician/scientist.
- If considered that they can safely achieve the required weight loss then they should be supported with nutritional guidance and regular monitoring of energy availability, DE and assessment of menstrual function.
- Athletes and coaches should be educated about the risks of DE, low energy availability and menstrual dysfunction on systemic health to help in the prevention and treatment of the Triad in lightweight rowers.
- Nutritional guidance and psychological support should be offered at a young age

to minimize DE and health related risks, and supplemental strength and conditioning training that involves non-sport specific exercises that distribute multidimensional high peak strains on the upper body skeleton is likely to elicit bone health and performance benefits for female lightweight rowers.

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Bone mineral density, rib pain and other features of the female athlete triad in elite lightweight rowers.~~: new concepts for injury prevention~~

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The Triad in elite female lightweight rowers

ABSTRACT

Objective: To determine bone mineral density (BMD) and the associations among BMD, menstrual history, disordered eating (DE), training history, intentional weight loss and rib pain for the first time in female lightweight rowers.

Methods: Dual-energy X-ray absorptiometry measured total body (TB) composition and BMD at the spine, femoral neck (FN), radius and TB. Questionnaires (EAT-26) measured DE, oligo/amenorrhea years, rib pain, training history and nutritional support provision in 21 elite female lightweight rowers (12 active, 9 retired).

Results: DE was reported in 6 of the rowers. The active with DE started rowing younger ($P<0.05$) than those without, and their amount of intentional weight loss (IWL) was associated with EAT-26 score ($P<0.05$). Some participants reported a history of oligo/amenorrhea 17 (76%) and/or rib pain 7 (32%) with those with rib pain having lower spine and TB Z-scores ($P<0.05$) than those without. Those with oligo/amenorrhea had lower spine Z-scores ($P<0.01$) than those without. Twelve participants had low BMD; three at spine; one at FN; and eight at radius. 13% of mean total training hours ($18.6 \pm 9.1 h.week^{-1}$) were spent strength training ($2.4 \pm 2.2 h.week^{-1}$). **Conclusions:** Upper-body exercises incorporating multidimensional high peak bone strain were not reported and may need to be considered in their strength training to improve radial BMD. Results suggest IWL and high-level training at a young age increases the likelihood of DE and there may be a lack of quality nutritional support for these athletes.

Key words: DXA, menstrual dysfunction, exercise, dieting, skeletal health, fractures

Strengths and limitations of this study

- The first multidisciplinary study to investigate the distribution of BMD, compared to parameters established in healthy non-athletic women, in association to rib painstress fractures in UK elite active and retired female lightweight rowers.
- The first multidisciplinary study that examined BMD and TB composition via DXA, menstrual history, disordered eating (DE), training history, intentional weight loss and rib pain in lightweight rowing which is a "minority" sport and understudied.
- The first study to suggest that lightweight rowing rules may be partly responsible for the development of the Triad, and perhaps changing the weight rules to discourage unhealthy weight loss practices could prevent injury.
- The first study that contrasts with the sport-specificity theorem and highlights the importance of supplemental non-sport specific exercises in the training programmes of rowers and other athletes, that particularly suffer from low radius BMD, to elicit bone health and possibly reduce the incidence of skeletal fractures later in life.
- Generalisations for elite female lightweight rowers are limited by the small sample size.
- The validity of self-reported questionnaires has been critiqued on the credibility of honest responses.

Introduction

Rowing is an Olympic sport with two weight categories: open (no weight restriction) and lightweight. To qualify for racing lightweight, female rowers must weigh-in at no more than 59kg with a crew average of no more than 57kg (International Rowing Federation). The majority of lightweight rowers restrict their diet to meet weight restrictions using both acute and chronic methods of weight-loss [1, 2]. This could lead to disordered eating (DE), chronic energy deficiency, and subsequently menstrual dysfunction and low bone mineral density (BMD) [3, 4, 5]. The latter two are associated with bone stress injuries [6] and endothelial dysfunction, a concern for future cardiovascular risk [7]. The Female Athlete Triad (the Triad) according to the American College of Sports Medicine (ACSM) revised position statement; is an association between energy availability, menstrual function, and BMD, which may have clinical manifestations including eating disorders, amenorrhea, and osteoporosis [5]. Low energy availability, with or without disordered eating, can cause amenorrhea and reduced BMD due to reductions in leptin [8], insulin like growth factor (IGF-1) [9], and oestrogen production [10]. It has been reported that when severely restricted energy availability is prolonged, from either dietary restriction or increased expenditure, irreversible reductions in BMD could result [11]. Even less severe energy restrictions could suppress bone formation, and possibly prevent young women from achieving their genetic potential for peak BMD [11].

The Triad is also associated with increased incidence of musculoskeletal injuries and higher stress fracture risk [12] and is prevalent in sports where leanness is considered important [5]. The existence of the Triad is documented in dancers [13, 14], triathletes [15], distance runners [16, 17] and swimmers [18] but not in female lightweight rowers,

who commonly have a higher risk for rib stress fractures [19], and where leanness and weight control determine eligibility to compete and participate in the sport.

Disordered eating may describe the array of abnormal and harmful sub-clinical eating attitudes used to lose weight or maintain low weight, and is thought to affect up to two-thirds of young female athletes [20]. Sundgot-Borgen and Torstveit's, [21] more recent and large study on 572 elite female athletes showed a 20% prevalence of eating disorders, indicating a significant clinical issue for the health of a great amount of athletes. Eating disorders have one of the highest mortality rates of mental illnesses [22], and have been reported to be more prevalent (31%) in elite female athletes involved in sports emphasising leanness compared to those athletes (8%) involved in sports with less emphasis on leanness [23]. Studies on rowing have shown that lightweights are at a higher eating disorder risk than heavyweights, as identified by the Eating Attitudes Test-26 (EAT-26), [24, 25]. This is in accord with the higher prevalence of DE in "weight-category" sports which was reported by Sundgot-Borgen's, [26] study on 522 elite female athletes from 35 sports and 448 nonathletic controls. An incidence of 12% [24] and 16.2% [25] of DE has been reported in lightweight rowers in the past. The interlinked nature between DE, menstrual dysfunction and BMD is demonstrated in studies that established a relationship between DE and menstrual dysfunction [4, 16], between menstrual dysfunction and low BMD [3, 27] and between DE and low BMD in the absence of menstrual dysfunction [4, 16, 27]. Low BMD is also linked with increased incidence of stress fractures in male and female Marine recruits [28] and with exercise-induced rib stress fractures in male lightweight rowers [29]. Although one of the most common injuries in female rowers is rib stress fractures, its aetiology remains

unclear [19]. Rib stress fractures are less common in men [30], suggesting that low oestrogen levels, low BMD or factors associated with the Triad might be causative for rib stress fractures in female rowers.

To date, no studies have investigated BMD in relation to rib stress fractures in female lightweight rowers. This reinforces the view of [31], that the pathology and prevention of rib stress fractures is a worthy area of research in rowing. Little is known about the possible long-term implications of the Triad but it appears that the effects on BMD might be partially irreversible [13, 32, 33].

The aims of the present study were therefore to investigate: 1) The distribution of BMD for the first time in UK elite active and retired female lightweight rowers compared to the parameters established in healthy non-athletic women; 2) the associations among BMD, menstrual history, training history, DE, intentional weight loss and rib pain and 3) assess whether any past DE symptoms and menstrual dysfunction continue after retirement.

Methods

Ethics

This study was approved by the Health Studies Ethics Committee at Middlesex University. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. Details of the study's aims, methods and testing procedures were explained to each participant, before a written, informed consent was obtained.

Participants

Participants were recruited from responses to recruitment advertisements for current and retired lightweight rowers offering free determination of BMD and TB composition in rowing clubs and a rowing magazine. No mention of DE, menstrual disorders and other aspects of the Triad were included in the advert to avoid possible sample selection bias. The year of this study only 79 UK female lightweight rowers were identified to participate in national and international level competitions. Twenty-nine Caucasian female lightweight rowers, from 9 different clubs volunteered to participate in this study. Only 21 (12 active, 9 retired) met the study's criteria and volunteered for the study. Inclusion criteria were females aged over 18 years who had rowed competitively in lightweight category for no less than one year. Participants were excluded if they had a history of bone disease, used medications known to influence BMD (e.g., corticosteroids, antidepressants, thiazolidinediones, bisphosphonates, NSAIDS and chemotherapy) or if they were pregnant, lactating or post-menopausal. Two rowers were excluded and six withdraw for logistic reasons. Rowing competition level was: 5 international (2 active) and 16 national (10 active) level. All were non-smokers and their mean weekly alcohol consumption was 5.8 ±1.2 units per week. None reported vitamin D and calcium supplements intake and all but two did not regularly (3-4/week) eat products containing calcium.

Questionnaires:

EAT-26 and Pathogenic Weight Control Strategies

Symptoms and characteristics of eating disorders were assessed by the EAT-26, a 26-item inventory with strong psychometric properties [34]. Thirteen items relate to "dieting" behaviour, six to "Bulimia and Food Preoccupation" and seven to "Oral Control". The 26 items of the EAT-26 inventory were rated on a 6-point response scale as described in Garner et al. [34]. The score can range from 0-78. A score of 20 or above is considered indicative of DE [34].

Self-reported questionnaires assessed whether participants had been engaged in any pathogenic weight control strategies such as vomiting and/or use of laxatives to induce weight loss within the last 6 months. Present or past engagement in binge-eating behaviour, eating more than other people would in the same situation [35] and whether they had previously been diagnosed with an eating disorder were also assessed. Retired rowers were assessed to observe whether any past pathogenic weight control strategies continued after retirement.

Menstrual History Questionnaire

All rowers reported their age of menarche and number of menses for each year after menarche choosing from the following options: amenorrhea (0-3), oligomenorrhea (4-9) and eumenorrhea (10-13) [16]. Total lifetime menses (years) and number of years of amenorrhea, and oligomenorrhea was calculated as described in Cobb et al. [16] and normalised for age by dividing the number of years of each of the above menstrual variables with current age. Due to the small sample size, menstrual history status was categorised into two groups of oligo/amenorrheic (those with history of oligo/amenorrhea) and eumenorrheic (those without). Retired rowers were assessed to observe whether any history of oligo/amenorrhea continued after retirement.

Additional Questionnaires

Self-reported questionnaires assessed demographic data, including details of sporting history, mode of training including type of resistance training exercises and average weekly training volume (hours) at highest competitive level for both retired and active rowers, level of competition, medical history, use of medications, supplements and oral contraceptives (OCA), smoking, alcohol intake and weight loss. Duration of OCA use was normalised for gynecological age by dividing the number of years of OCA use with gynecological age. History of injury was reported by drawing the area of symptoms on a body chart and answering questions about cause of injury, duration of symptoms, and diagnosis. History, duration and cause of rib pain were also recorded. Participants were also asked whether they had ever been provided with nutritional and/or weight management advice from coach/club. Retired rowers gave details of physical activity since retiring from lightweight rowing. Questionnaire details were verbally explained to each participant in conjunction with written instructions. Whilst participants were completing the questionnaires investigators were present to clarify any issues/questions and tried to ensure that the answers were as accurate as possible.

Physical and Bone Measurements

Bone mineral density ($g.cm^{-2}$) at the posterior anterior (PA) L2-4 lumbar spine (LS); PA femoral neck (FN); dominant arm distal radius; total body and body composition (lean and fat mass) were measured by DXA (fan beam, Lunar DPX-L series GE Medical systems, Lunar Madison, WI USA). The in-house coefficient of variation of the BMD measurements ranged from 0.5-0-1.4%. The scanner was calibrated using a spine phantom at the start of each day of testing and its performance was followed with the labs quality assurance protocol. Z-scores were calculated using the manufacturer-supplied reference data (Lunar enCORE© USA/European reference data) set to compare individuals BMD values to age and sex-matched controls. The ACSM defines the term ‘low BMD’ as a Z-score between -1 and -2, and ‘osteoporosis’ a Z-score ≤ -2 together with secondary risk factors for fracture (e.g., chronic malnutrition, eating disorders, hypoestrogenism, hypogonadism, glucocorticoid exposure, and previous fractures,[3]).

All participants were requested to refrain from heavy physical activity 24 h before screening to minimize the effect of fluctuations in hydration status on body composition measurements. Participants’ height (m) and body mass (kg) were measured using standard stadiometers and balance beam scales, respectively. Body mass index (BMI) was calculated as kilograms per square meter ($kg.m^{-2}$). All anthropometric measurements, scanning and analyses were performed by the same technician using the same equipment.

Statistical Analyses

Statistical analyses were performed using SPSS version 16.0. Values are reported as means ± SD. Statistical significance was set at $P<0.05$. Levene’s test was used to assess equality of variances in the different groups. Violations of the equality of variances assumption were corrected using the P-value calculated for equal variances not assumed. A General Linear Model was used to determine whether Z-scores, years of training, age of menarche, and amount of intentional weight loss differ: 1) between rowers with and without history of oligo/amenorrhea or rib pain, and 2) between active rowers that scored ≥20 and active rowers that scored <20 on the EAT-26. When the Z-scores were analysed to assess for differences between participants, data was adjusted/controlled for BMI [36], by fitting an ANCOVA to the data.

Z-scores were used in the statistical analyses, as they are normative values for chronological age. Pearson's correlation coefficient was used to determine significant relationships between variables of interest. Any analysis performed between Z-scores and other specific variables was controlled for BMI. Correlation analysis between EAT-26 score and amount of intentional weight loss and duration of OCA use was applied only in the data of active rowers. The retired were excluded because their weight loss data refers to the past whilst the EAT-26 data refers to their current DE attitudes.

Results

The anthropometric characteristics, training and menstrual history details and OCA use of the lightweight rowers is summarized in Table 1.

Table 1. Anthropometric characteristics, training and menstrual history details and oral contraceptive use of lightweight rowers

Variable	Active N =12	Retired N=9	Both N=21
Age (yr)	26.6 ±2.0	31.6 ±5.0	28.7 ±4.3 (23-39)*
Stature (cm)	171.8 ±5.5	165.7±2.8	169.2±5.4 (162.0-179.5)
Body mass (kg)	61.2±1.8	61.5±5.4	61.3 ±3.7 (56.8-73)
Body fat (%)	21.4±5.8	23.1±7.2	22.1 ±6.4 (11.6-35.1)
BMI ($kg.m^{-2}$)	20.8±1.1	22.3 ±2.6	21.4±2.0 (19.5-27.8)
Age at onset of exercising (yr)	15.1±5.7	11.3 ±4.6	13.5 ±5.6 (4-26)
Years playing sports	11.5±5.2	20.2 ±5.0	15.2 ±6.7 (2-31)*
Years training at lightweight category	2.5 ±1.1	6.0 ±3.8	4.0 ±3.1 (1-12)*
Training per week (h)†	15.3 ±4.1	22.9 ±12	18.6 ±9.0 (10-53)
Strength and power training per week (h)†	1.7 ±1.6	3.3 ±2.6	2.4 ±2.2 (0-10)
Water rower training per week (h)†	8.8 ±2.8	11.1 ±2.7	9.8 ±3.0 (5-16)
Cardiovascular training (i.e., cycling, running, ergometer rowing) per week (h)†	4.8 ±2.2	8.6 ±9.8	6.4 ±6.7 (1-33.5)
Age at onset of retirement (yr)	NA	28.6±5.6	NA
Years since retirement	NA	3.0 ±1.9	NA
OCA (yr)	4.3±3.1	2.4±1.4	3.9 ±2.7 (1-9)
Years with oligo/amenorrhea	4.5 ±3.9	4.2 ±4.4	4.4±4.0 (0-13)
Menarcheal age (yr)	13.4 ±1.1	13.0 ±1.2	13.2±1.1 (11-15)
Oligo/amenorrhic (N)	10	7	17
Gynaecological age (yr)	13.2±2.2	18.5±5.1	15.5±4.5 (10-27)*
Total lifetime menses (yr)	10.8±2.3	14.6±5.4	12.4±4.3 (4.9-25.3)

Values are mean ± SD. *P<0.05 between active and retired rowers;. † at highest competitive level; gynecological age is years since menarche; OCA is length of oral contraceptive use in years; all oligo/amenorrhea years were secondary (occurred after menarche).

Bone Mineral Density

Three participants had low BMD at LS (Z-scores -1.5, -1.2 and -1.1), one at FN (Z-score -1.1) and eight at radius. Three of these had Z-scores below -2 at radius (Z-scores -2.3, -2.1 and -2.3). As depicted in Figure 1, the mean Z-scores of the oligo/amenorrheic, active and retired rowers was significantly lower at LS (AD=1.75, $F(2,21) = 11.455$, $P < 0.01$, $\eta p^2=0.560$) compared to the eumenorrheic rowers. Total lifetime menses (controlled for BMI values) was positively associated with Z-scores at LS (r=0.516, P<0.05) and at FN (r=0.438, P<0.05).

Furthermore, when the retired were looked at separately, the results revealed that the oligo/amenorrheic rowers had significantly lower Z-scores at LS (AD=2.7, $F(2,9) = 17.307$, $P < 0.01$, $\eta p^2=0.852$) and total body (AD=1.47, $F(2,9) = 26.756$, $P < 0.01$, $\eta p^2=0.899$) compared to the eumenorrheic retired rowers. Mean Z-scores of eumenorrheic retired were above normal at all sites.

Disordered Eating, Pathogenic Weight Control Strategies

All active rowers reported engagement in intentional weight loss to qualify for lightweight racing. Both active and retired rowers reported DE attitudes (EAT-26 score >20) and pathogenic weight control strategies (Table 2).

Independent sample T-tests showed that active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), (t=-3.088, P<0.05). The EAT-26 score was associated with the amount of intentional weight loss (r=0.720, P<0.05), see Figure 2, and duration of OCA use (r=0.908, *P*<0.001).

Table 2. Reported eating attitudes in lightweight rowers

	Active N =12	Retired N=9	Overall N=21
DE symptoms N (%)	5 42	1 11	6 29
Binge eating episodes N (%)	8 67*	0*≠	8 38
Induced vomiting N (%)	3 25*	0*≠	3 14
Use of laxatives N (%)	4 33*	0* 2 22≠	6 29
Intentional weight loss N (%)(Mean loss SD)	12 100 (5.8 ±1.9kg)	8 89 (6.3 ±4.5kg) †	20 95 (6.0 ±3.2kg)

*within the last 6 months; ≠past reported symptoms ~~laxative use~~ during their rowing career; †past intentional weight loss to qualify for racing lightweight during their rowing career

Rib Pain

Seven participants (32%) reported a history of rib pain lasting between 2 to 10 weeks. As depicted in Figure 3, the Z-scores at total body and LS were significantly lower (P<0.05) in rowers with history of rib pain compared to those without. Additionally, rowers with rib pain reported to train more hours per week, (21 vs. 17h, P>0.05), and to have higher oligo/amenorrhea years (8.8 vs. 4yr, P>0.05) than those without.

There is no additional data available.

Discussion

This study confirms the co-existence of reduced BMD, oligo/amenorrhea, disordered eating and intentional weight loss, in UK elite female lightweight rowers. The association between total lifetime menses and BMD supports the notion that BMD declines as the number of missed menstrual cycles accumulates [32].

A novel, but concerning finding in this study was that total EAT-26 score was associated with the amount of intentional weight loss in active rowers which suggests that intentional weight loss increases the likelihood of engaging in DE behaviours. Furthermore, active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), which suggests involvement in high level training at a young and vulnerable age (all rowers achieved national and international level) is significantly associated with risk to DE attitudes [37]. A meta-analysis of 34 studies (2459 athletes) supports these findings, which showed an increased risk of DE in elite athletes compared to non-elite [38]. Additionally, a higher prevalence of eating disorders among adolescent elite athletes than controls has been reported in a most recent study by Martinsen and Sundgot-Borgen, [39]. Binge eating was also a common finding among the active rowers (67%), which compares to 52% encountered by Thiel et al. [40]. Pathogenic weight control strategies and symptoms of DE and binge eating were more prevalent in the active than the retired rowers of this study, and in earlier studies on elite rowers [24, 25].

Furthermore, only 2/12 (17%) active compared to 4/9 (44%) retired reported to have received professional nutritional support for rowing and weight management. The importance of nutritional guidance to help in the prevention and treatment of DE has been evident to this study and is in agreement with Beals and Manore, [41] who stated that one of the issues that leads athletes to fail to meet their exercise energy requirements is lack of appropriate nutritional knowledge. Sundgot-Burgen and Klungland,[42], reported that the prevalence of DE was reduced from 33% to 15% in cross-country skiers over an 8-year DE preventative programme. Therefore, quality nutritional guidance should be offered from a young age to possibly minimize DE and the health related risks [4, 16, 43]. Youth rowing coach education on DE and Triad risk or perhaps even weight category rule change consideration may also needed to prevent DE, the Triad and associated unhealthy conditions in developing lightweight female rowers.

Weight loss is predominantly the result of negative energy balance, however, methods of intentional weight loss such as the use of laxatives, which was reported in this study, or other dehydration methods do not necessarily mean low energy availability [44] or a symptom of DE. In this study no association was found between symptoms of DE and BMD, which is contrary to previous studies [4, 16]. However, these studies determined energy deficiency, and assessed DE with the Eating Disorder Inventory instead. Possibly, DE is not necessarily a component of the Triad whereas low energy availability is [5]. Assessment of DE is also an important medical consideration, and can help identify psychopathological individuals with the Triad, in addition to indirectly establishing the possibility of low energy availability.

Comment [MU1]: The authors need to (in the discussion) discuss the validity of the EAT as a screening instrument for DE in this sample. Specifically also take this into consideration when arguing (p 16, l. 38-40) that "in this study no association was found between symptoms of DE and BMD, which is contrary to previous studies (4, 16). In the referred studies different methods to assess DE and energy deficiency was used. This has to be taken into consideration and will probably effect the author's statement.

We believe that the highlighted paragraph addresses this comment, and the validity of EAT-26 as a screening instrument is addressed below in pg 17, line 9.

Prevalence of DE in lightweight rowers, as assessed by a score ≥20 on the EAT-26 questionnaire, has been reported to be between 12 and 16% [24, 25] compared to 29% in this study. These results suggest that the rowers from the above research studies and the present study are considered "at risk" for clinical eating disorders [45]. This percentage could have been even higher as athletes tend to under report symptoms of DE [20, 26] due to denial and secrecy which are hallmarks of DE [22], and because do not consider eating habits as DE, but as "part of the game" in season. Denying DE symptoms has clinical implications for these athletes including delayed facilitation of appropriate therapy. Furthermore, the validity of self-reported questionnaires has been critiqued on the credibility of honest responses. Therefore, the use of questionnaires alone to assess symptoms of DE would be best if complimented with a clinical interview in future studies.

Comment [MU2]: This has already been stated in strengths and limitations but you have asked us to mention it in the discussion.

In ballet dancers and runners, the reproductive hormonal changes caused by excessive exercise and low energy availability may result in low BMD at LS [16, 46]. The mechanical stresses of rowing appear to exert protection on the lumbar BMD [47]. The eumenorrheic rowers in this study demonstrated elevated BMD measurements compared to their age and sex-matched reference data, particularly at LS, which is in accord with Wolman et al. [48]. However, the mean lumbar BMD of the oligo/amenorrheic rowers in this study was not elevated compared to their age and sex-matched reference data, suggesting that oligo/amenorrhea has a negative effect on BMD [32]. This can be further supported by the significantly lower Z-score observed at LS in the rowers with history of oligo/amenorrhea compared to those without, and the positive association between total lifetime menses and Z-scores at LS and FN found in this study. Previous studies have shown similar findings [4, 46].

In line with the practices of coaches working with rowers in Great Britain [49], the rowers in this study engaged in strength and power training, predominately consisting of squats, cleans and lower-body plyometrics. The nature of the sport, and the direction of force application, dictates that these pulling movements and closed chain exercises are indeed rational and explains their routine recommendation [50]. Specifically, Ebben [51] reported that an 8-week strength and power programme using these, improved time, power and power per stroke during 2000m ergometer rowing. Unsurprisingly, pushing based strength exercises for the upper-body, such as the bench press, rank quite low on importance, and upper-body plyometrics generally do not feature [49]. From a training specificity and performance-based point of view, the reasons for this appear sound. However, of a bone health perspective, such a focused approach may be contested. The results of this study and that of others [17, 52] have reported low BMD in the radius of athletes, suggesting that current training paradigms may not address this appropriately and perhaps fitness coaches should also address the current and future health of their athletes. At times, this will require a non-sport specific approach.

Furthermore, to support bone health, general health, injury prevention and sporting performance, current training paradigms should be supported with effective nutritional guidance and psychological support, when required, to educate, prevent, recognise, support and manage weight loss and DE in lightweight female rowers [53].

Specifically, in this study eight rowers had low BMD at the radius (Z<-1) and it has been recommended that a Z-score of <-1.0 in an athlete warrants further clinical investigation and management, even in the absence of prior fracture [5]. The marked incidence of low BMD at radius might suggest that the stress applied on the upper limb skeleton through joint-reaction forces, generated during the rowing and/or the strength and power training undertaken by the rowers in this study were not sufficient to elicit an increase in BMD or maintain it to normal physiological levels [54]. It might also suggest that these tensile forces were insufficient to counteract the negative effects of low energy availability on BMD [3-5, 11] possibly induced by intentional weight loss methods, a common practice in lightweight rowers as seen here and in previous research [1, 36]. Furthermore, low radius BMD might reflect the dissipation/diversion of BMD to weight-bearing sites, at the expense of non-weight bearing sites, such as the radius [52]. These findings reinforce the tenet that bone mineral acquisition obeys a principle of specificity [52, 55] and that the effects of joint reaction forces on bone formation are not as effective as those observed through ground reaction forces generated during dynamic sports and /or activities like running, jumping, kicking, tennis, punching and plyometrics which can incorporate multidimensional (non-conventional) high peak loading compressing strains distribution into the bone [54-56].

In summary, exercises that directly target the arms such as the bench press and plyometric push-ups for example, may help in the modelling/remodeling of the bone. This comes into contrast with the sport-specificity theorem and the authors of this study strongly recommend the implementation of supplemental non-sport specific exercises in the training programmes of rowers and other athletes, that particularly suffer from low radius BMD, could be a promising means of maximizing bone accrual and health, and possibly reducing the incidence of skeletal fractures later in life. This is the first study that contrasts with the sport-specificity theorem.

Little is known about the long-term effects of DE and oligo/amenorrhea on BMD. In retired rowers with a history of oligo/amenorrhea, despite resuming normal menses, their Z-scores at LS and total body were significantly lower than those who had always been eumenorrheic. This corroborates existing body of knowledge, which suggests that deficits in BMD may be irreversible [13, 32, 33]. Longitudinal study on a higher number of female lightweight rowers is required to understand this issue more adequately.

An incidence of rib stress fractures in male rowers of up to 12% has been reported [29]. Seven (32%) of participants in this study had history of rib pain lasting 2-8wk (5.1 ±2.9wk). Whilst these participants had no radiographic evidence to confirm diagnosis of rib stress fracture, our study suggests the incidence of rib pain is a common complaint in female lightweight rowers (2.7 times more common than male rowers) and chronic chest wall pain in rowers is almost always the result of rib stress fractures as suggested by Strayer [57]. However, a subsequent study reported that athletes tend to self-report a higher percentage on stress fractures (14.0%) compared to those diagnosed with stress fractures (8.1%) ($P < 0.001$), indicating that self-reporting of stress fractures has low validity [58]. Due to the retrospective nature of this study in terms of assessing rib stress fractures incidence, it was not possible to make a clinical diagnosis. In this study active and retired rowers with history of rib pain had significantly lower LS and total body Z-score values than those without history, which possibly suggests that low BMD may play a role in the aetiology of exercise-induced rib stress fractures in female lightweight rowers. Interestingly, Nevill et al. [52] reported significant correlations ($P<0.05$) between BMD recorded at ribs, thoracic and lumbar spine, pelvis, legs, hip and arms. This study's results are in agreement with others [19, 29, 30], although the association between low BMD and fractures has been established in postmenopausal women with osteoporosis [59] and not in premenopausal.

Generalisations for elite female lightweight rowers are limited by the small sample size, however, lightweight rowing is a "minority" sport reflected by the relatively small number (79) of female lightweight rowers identified to participate in National level competition during the study year. Therefore, further research that recruits a larger sample of lightweights and ~~is required to verify the findings from this study.~~ a control group of either non-athletes, athletes from other sports, or non-lightweight rowers is recommended to further substantiate the findings of this study. However, future research should focus on measuring energy input versus energy output and assess in more detail, calcium, anti-inflammatory medications, vitamin A and D supplemental intake and the methods and behaviours associated with IWL. The establishment of normal BMD reference ranges in athletes is needed since the application of a reference range based on the general non-athletic population may not be appropriate [17]. Finally, the effect of upper body resistance and plyometrics training on BMD should be investigated to determine if this could counter the negative effects of DE and oligo/amenorrhea.

This study suggests that lightweight rowing rules may be partly responsible for resultant high levels of DE, high rates of oligo/amenorrhea, BMD deficiencies which are correlated with number of lifetime menses, and the tendency to have DE after retirement. Apparent DE vulnerability of lightweight female rowers commencing training at a younger age is of great concern. Lightweight female rowing rules mean that any athlete above the height of 175cm meeting the mean target weight of 57kg would be underweight with a BMI of <18.5. We would therefore encourage lightweight rowing to embrace sports injury prevention and provide coaches and athletes with appropriate multidisciplinary nutritional and psychological support to prevent DE and the development of the Triad, and perhaps to also consider changing the weight rules to discourage unhealthy weight loss practices. Previous research suggests that rowing performance is strongly correlated to body height (related to arm and leg length), as well as body mass [60, 61, 62, 63]. Our study would therefore support competitive categories being explored by height, rather than weight to help avoid detrimental health and performance issues identified in our study related to DE and the Triad.

Contributorship statement:

LD, AR and RL-S conceived the idea for the study and prepared the methods. LD completed the scanning and analysed it. LD, AR and RL-S collected the data and analysed it. LD, AR and RL-S drafted the initial paper and RW, AT, LH and NJ contributed with further critical drafting. All authors critically revised and approved the final version of the manuscript.

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What are the new findings

- This study confirms the co-existence of reduced BMD, oligo/amenorrhea, disordered eating and intentional weight loss, in UK elite female lightweight rowers.
- EAT-26 scores were associated with the amount of intentional weight loss, which suggests that intentional weight loss increases the likelihood of engaging in DE behaviours in active rowers.
- Active rowers with DE symptoms, had started rowing at a significantly younger age (10.6 ±3.1yr) than those without DE (18.3 ±4.9yr), which suggests involvement in high level training at a young and vulnerable age (all rowers achieved national and international level) is significantly associated with risk to DE attitudes.
- Only 2/12 (17%) active compared to 4/9 (44%) retired reported to have received professional nutritional support for rowing and weight management.

How might it impact on clinical practice in the near future

- Individuals considering rowing in a lightweight category may benefit from assessment and monitoring for physical and psychological health risk and their suitability and sport participation safety by a trained sports medicine physician/scientist.
- If considered that they can safely achieve the required weight loss then they should be supported with nutritional guidance and regular monitoring of energy availability, DE and assessment of menstrual function.
- Athletes and coaches should be educated about the risks of DE, low energy

availability and menstrual dysfunction on systemic health to help in the prevention and treatment of the Triad in lightweight rowers.

- Nutritional guidance and psychological support should be offered at a young age to minimize DE and health related risks, and supplemental strength and conditioning training that involves non-sport specific exercises that distribute multidimensional high peak strains on the upper body skeleton is likely to elicit bone health and performance benefits for female lightweight rowers.

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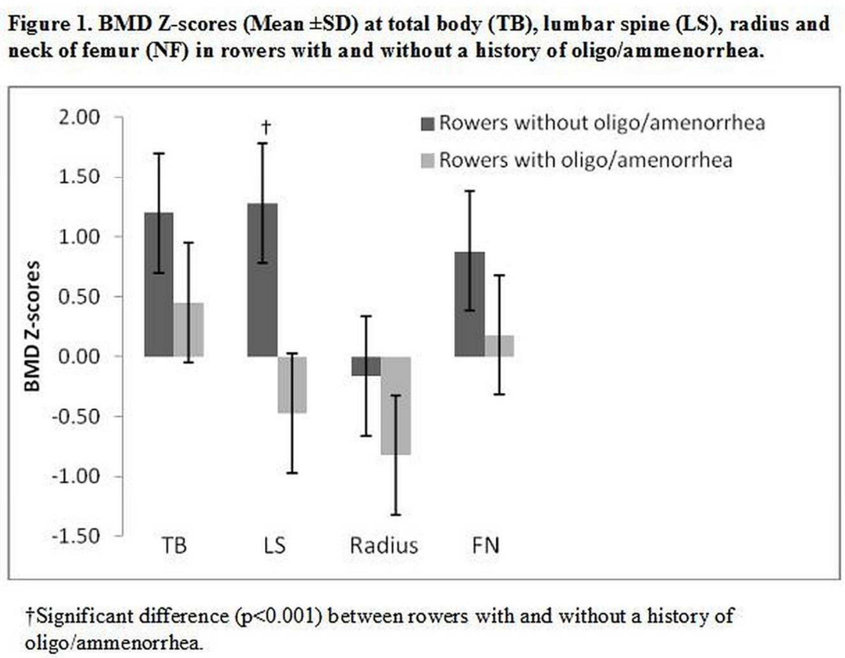
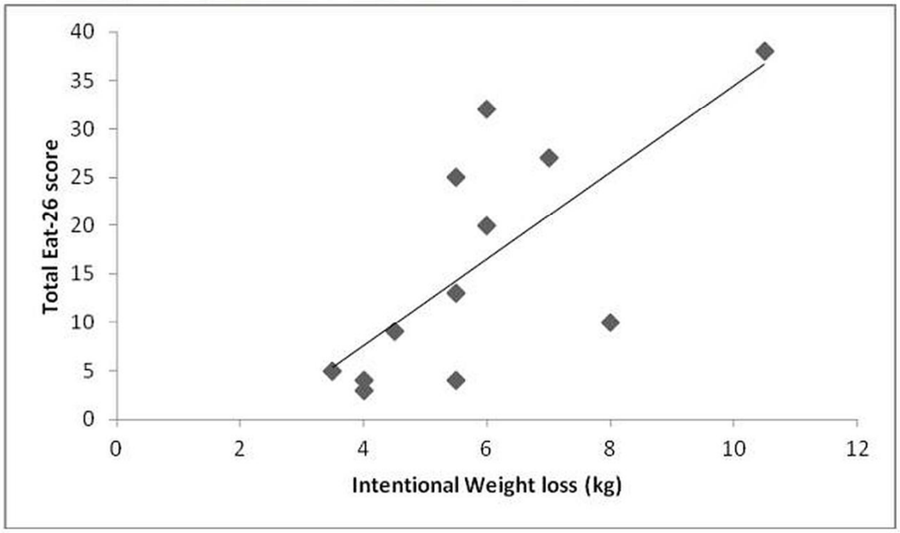


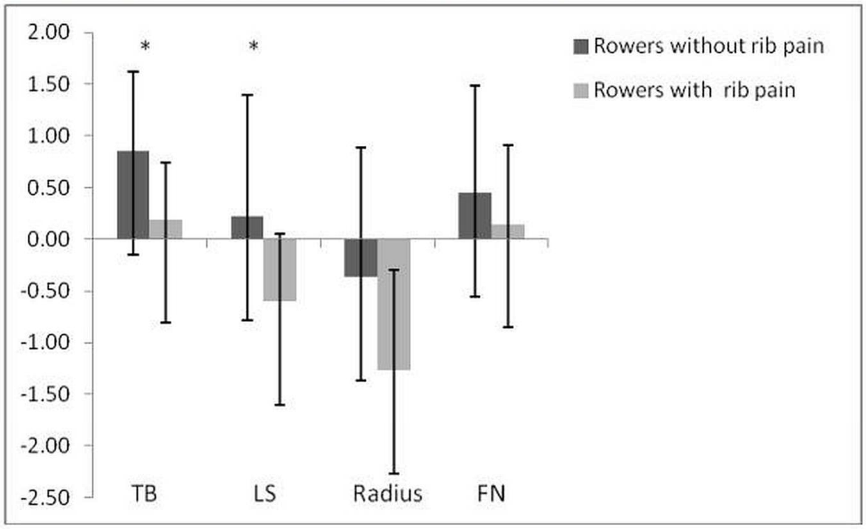
BMD Z-scores (Mean ±SD) at total body (TB), lumbar spine (LS), radius and neck of femur (NF) in rowers with and without a history of oligo/ammenorrhea.
119x90mm (300 x 300 DPI)

Figure 2. Relationship between the amount of intentional weight loss and EAT-26 score, a measure of DE, in active rowers, (r=0.720, p<0.05).



119x90mm (300 x 300 DPI)

Figure 3. BMD Z-scores (Mean ±SD) at total body (TB), lumbar spine (LS), radius and neck of femur (NF) in rowers with and without a history of rib pain.



*Significant difference (P<0.05) between rowers with and without a history of rib pain.

*Significant difference (P<0.05) between rowers with and without a history of rib pain.
119x90mm (300 x 300 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	
Bias	9	Describe any efforts to address potential sources of bias	6,7
Study size	10	Explain how the study size was arrived at	5,6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10
		(*b*) Describe any methods used to examine subgroups and interactions	NA
		(*c*) Explain how missing data were addressed	5-10

		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5,6
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-13
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	Figures and tables, 10-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18-20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-18
Generalisability	21	Discuss the generalisability (external validity) of the study results	19,20
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	No funding.20.

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.