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Bone quality in the lumbar spine in high-performance athletes

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Abstract Little is known about the influence of high-performance training on the bone quality of the lumbar spine, in particular, the effects on bone mineral density (BMD) in athletes with high weight-bearing demands on the spine. Measurements were therefore performed in internationally top-ranked high-performance athletes of different disciplines (weight lifters, boxers, and endurance-cyclists). The measurements were carried out by dual-energy X-ray absorptiometry, and the results compared with the measurements of 21 age-matched male controls. The BMD of the high-performance weight lifters was greater than that of the controls by 24% (0.252 g/cm^2) on the AP view and by 23% (0.200 g/cm^2) on the lateral view ($P < 0.01$), while difference in BMD between the boxers and the controls was +17% (0.174 g/cm^2) on the AP view and +19% (0.174 g/cm^2) on the lateral view. The BMD of the lumbar spine in all endurance cyclists was lower than that in the controls (AP view –10%, 0.105 g/cm^2; lateral view –8%, 0.067 g/cm^2; $P > 0.05$). The results show that training program stressing axial loads of the skeleton may lead to a significant increase of BMD in the lumbar spine of young individuals. Other authors' findings that the BMD of endurance athletes may decrease are confirmed. Nevertheless the 10% BMD loss of cyclists was surprisingly high.

Key words Bone mineral density · Dual-energy X-ray absorptiometry · High-performance athletes · Osteoporosis treatment · Osteoporosis prevention

Introduction

As osteoporosis and osteoporosis-related fractures lead to both severe reduction of quality of life and tremendous costs to the community [6], various training and rehabilitation programs have been introduced to prevent the disease or to treat patients suffering from osteoporosis [5, 7, 28]. A positive correlation between physical activity and bone mineral density (BMD) was hypothesized previously [25]. Other authors showed that BMD can be improved by physical training within a few months [17]. On the other hand, bone mineral loss in endurance athletes (mainly female long-distance runners) was reported [23, 35]. Hence, to optimize training programs for prevention and treatment of vertebral osteoporosis, more data on the intensity of training are required [25, 26].

We therefore examined the effect of highly demanding training programs on bone quality in internationally top-ranked athletes performing in different disciplines (weight lifting, boxing, and endurance cycling) and correlated the athletes' values to the BMD of age-matched controls.

Subjects and methods

Forty male athletes, recruited by the German National Training Center (Bundesleistungszentrum, Heidelberg), were inlcuded in the study. They comprised 28 weight lifters (mean age 22.3 ± 3.9 years, mean body weight 89.4 ± 20.5 kg, mean height 173.5 ± 9.1 cm), 6 boxers (mean age 21.5 ± 2.4 years, mean body weight 77.3 ± 3.8 kg, mean height 179 ± 3.8 cm), and 6 endurance cyclists (mean age 26 ± 2.2 years, mean body weight 70.2 ± 4.3 kg, mean height 178.2 ± 3.9 cm). All the athletes were internationally top ranked (weight lifters: two Olympic champions, five world champions, two European champions, national league members; boxers: national league members; cyclists: professionals, Tour-de France participants), and were training under full specific competition-training conditions at the time of measurement. In weight-lifting training the skeleton is exposed to enormous static loads: a ground lift of 305 kg results in a load on the lumbar vertebrae of 22.9 kN [12], and the athletes work with loads of 68 tons per week on average. The boxers' training, however, is more varied [10]: body and muscle building is as important as training in fighting techniques, swiftness, and endurance [2]. The cyclists, on the other hand, mostly perform pure endurance training [3]. In the pre-competition period they cover distances of 3,000–10,000 km in low and middle gears [20].

As BMD reference values are not available for all age groups, we established a data base on 21 male controls (mean age 24 ± 1.8 years, mean body weight 73.6 ± 11.1 kg, mean height 178.7 ± 6.4 cm, mixed-discipline sports activity 2.4 h per week).

Qualifications and current health status of athletes and controls were registered on a questionnaire. Only individuals without severe injury or other cause for breaking off training over the 6 weeks immediately preceding the measurements were included in this study.

Prior to the measurements, routine quality control was carried out using an anthropomorphic spine phantom (spine phantom 1179, Hologic) to check the precision of the measuring technique. Informed consent was obtained from all subjects and controls.

BMD was measured with a "second-generation" dual-energy X-ray absorptiometry (DEXA) device (QDR 2000, Siemens) using a high-resolution array scan. The measurements were evaluated with an interactive software program (Hologic). As scientific discussion concerning the most meaningful, precise, and sensitive technique and view is still in progress [11, 31], measurements from both the AP and lateral view of the lumbar spine and the proximal femur were performed. On the AP view of the lumbar spine, L1–L4 is depicted; however, the lateral view is restricted to L2–L4 because of occlusion by the ribs [27]. In elderly individuals L4 may be difficult to evaluate correctly because of overlay by the pelvis. The lateral view enables us to evaluate the whole vertebral body with its cortical frame (LAT value) or a central region of interest (ROI) covering the cancellous bone only (MID value).

The results of BMD measurements were expressed in units of grams per square centimeter. Normal distribution was assessed by Kolmogorov-Smirnov-test. The results are expressed as a mean with standard deviation. For statistical difference testing, unpaired Student's t-test was used. The level of statistical significance used in this study was $P < 0.05$.

Results

Quality control

Between January 1993 and July 1994, 177 high-resolution array scans of the spine phantom were performed. The average BMD value of the spine phantom was 1.046 ± 0.005 g/cm^2. The coefficient of variation *(cV)* was 0.47% (Fig. 1).

Control individuals

The BMD values of the lumbar spine of our controls were lower than the values of the preinstalled software kit, which was based on 3,000 North Americans. The mean control BMD in L1–L4 was 93.9 ± 10.9% of the mean value on the preinstalled data base. A statistical difference in the BMD of the lumbar spine is assumed ($P < 0.05$), as the 95% confidence limits of our control measurements did not reach the 100% line of the references (Fig. 2). Statistical analysis was not performed, as the reference data of Hologic is not accessible.

Body mass index (BMI)

The body mass index (BMI), calculated as weight/height^2 [24], was correlated with the BMD of the lumbar spine. In

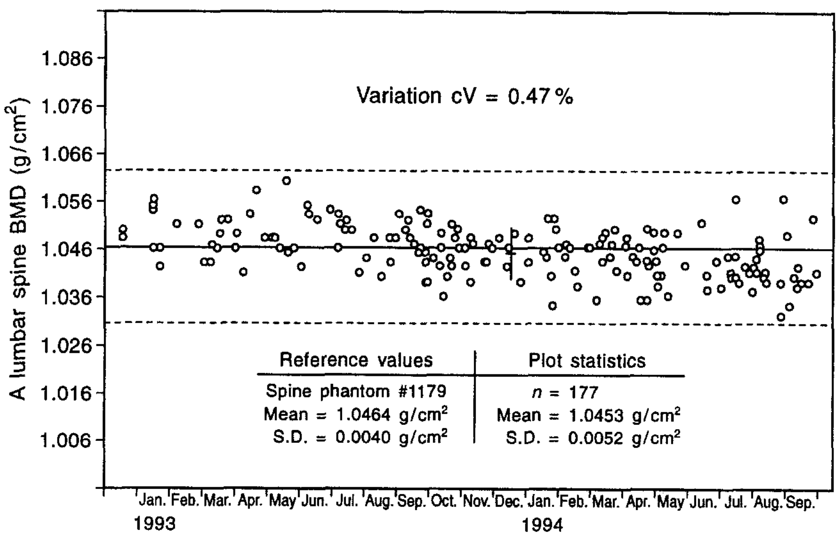

Fig. 1 Quality control. Results of 177 high-resolution array scans of the anthropomorphic spine phantom (spine phantom 1179, Hologic). Mean, 1.046 ± 0.005 g/cm^2; coefficient of variation *(cV)*, 0.47%

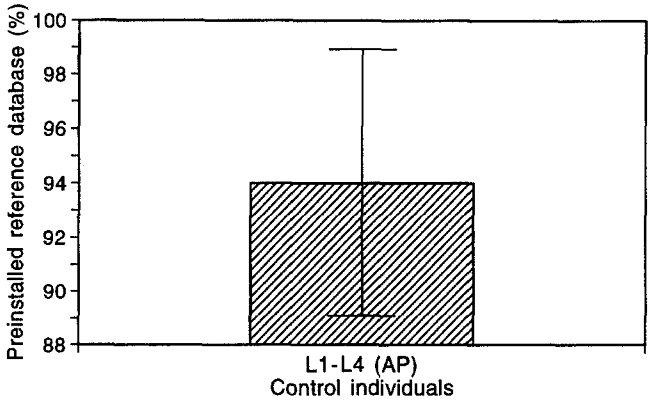

Fig. 2 Comparison of the mean bone mineral density (BMD) of the 28 controls (L1–L4 AP) with the preinstalled reference data base (= 100%) of Hologic. *Vertical line* standard error of the mean

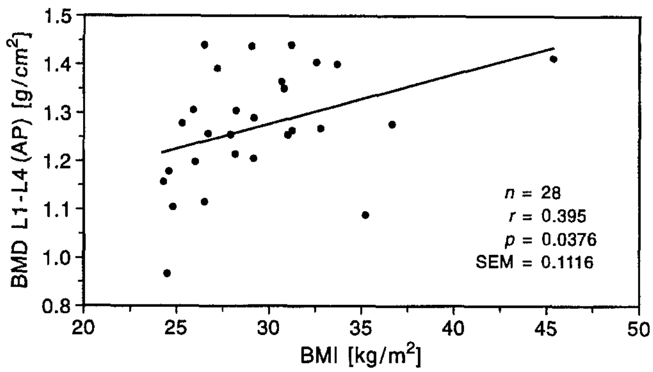

Fig. 3 A significant positive correlation (r = 0.395, Pearsons correlation coefficient) is shown between the body mass index (BMI) and the BMD of the lumbar spine (AP) in weight lifters. *SEM* standard error of mean

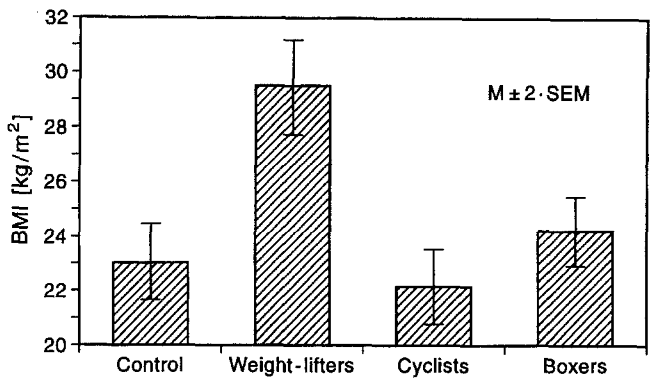

Fig. 4 The BMI of weight lifters was greater than that of the controls, boxers, and cyclists ($P < 0.01$). *M* mean

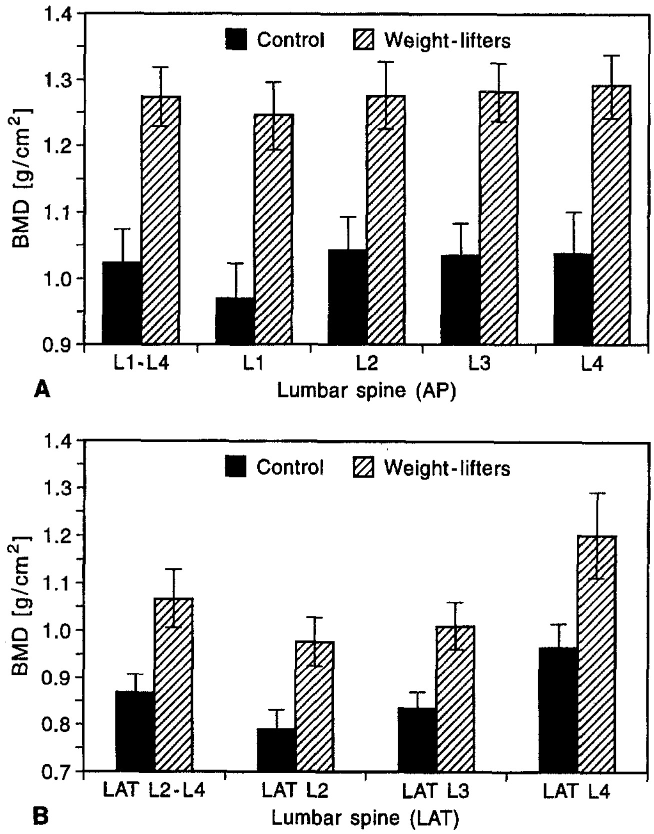

Fig. 5 **A** The BMD of the 28 weight lifters was greater than that of the 21 controls on the AP view of the lumbar spine (difference +24%, $P < 0.01$). **B** the difference between the values on the lateral view (LAT) was +23% ($P < 0.01$)

the 21 controls, BMD in the lateral spine (LAT, MID) and all ROIs in the 28 weight lifters (LAT, MID, AP) showed a positive correlation with the BMI (Fig. 3). The weight lifters' BMI differed from the BMI of the controls, the boxers, and the cyclists ($P < 0.01$), and this was statistically significant (Fig. 4).

Weight lifters

BMD of the lumbar spine in total (L1–L4) in the AP view was 24% (0.252 g/cm²) higher in weight lifters than in the controls (L1 +28%, L2 +22%, L3 +24%, L4 +24%, $P < 0.01$) (Fig. 5A). The lateral view showed similar results: BMD of L2–L4 (whole vertebrae measurement LAT) was 23% (0.200 g/cm²) higher (L2 +24%, L3 +21%, L4 +25%, $P < 0.01$) (Fig. 5b). In the spongious bone ROIs (MID) the difference was +30% (0.236 g/cm²; L2 +26%, L3 +28%, L4 +34%, $P < 0.01$).

Boxers

The BMD of the boxers was 17% (0.174 g/cm²) higher than that of the controls in the AP view of the lumbar spine (L1 +18%, L2 ±16%, L3 +19%, $P < 0.01$; L4 +15%, $P < 0.05$) (Fig. 6A) and 19% (0.174 g/cm²) in the lateral view (LAT: L2 +29%, L3 +16%, $P < 0.01$; L4 +13%, $P < 0.05$) (Fig. 6B). Though the measurements were less consistent, BMD of the spongious areas of the boxers' vertebral bodies were 17% (0.132 g/cm²) higher than in the

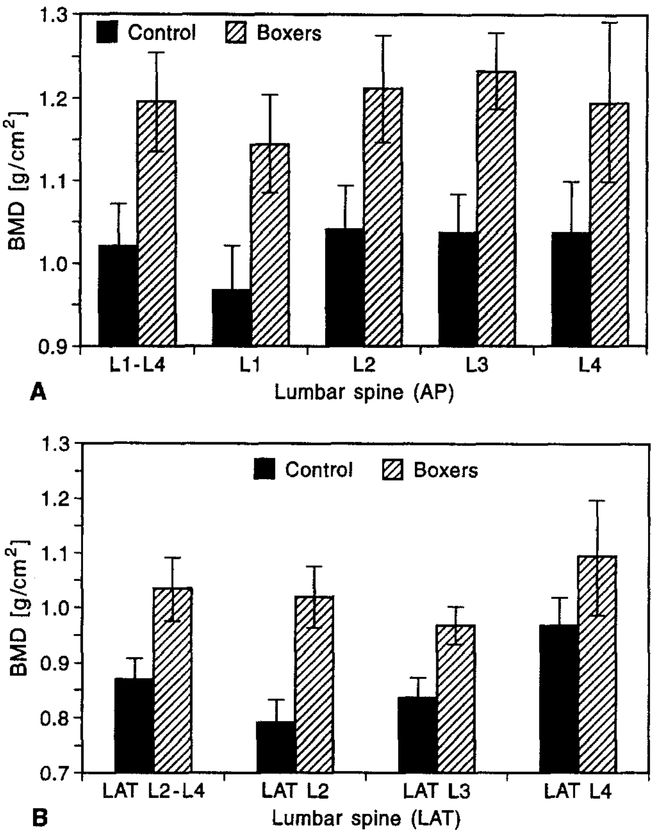

Fig. 6 **A** The BMD of the 6 boxers was greater than that of the 21 controls on the AP view of the lumbar spine (difference +17%, $P < 0.01$). **B** The difference between the values on the lateral view (LAT) was +19%, ($P < 0.01$)

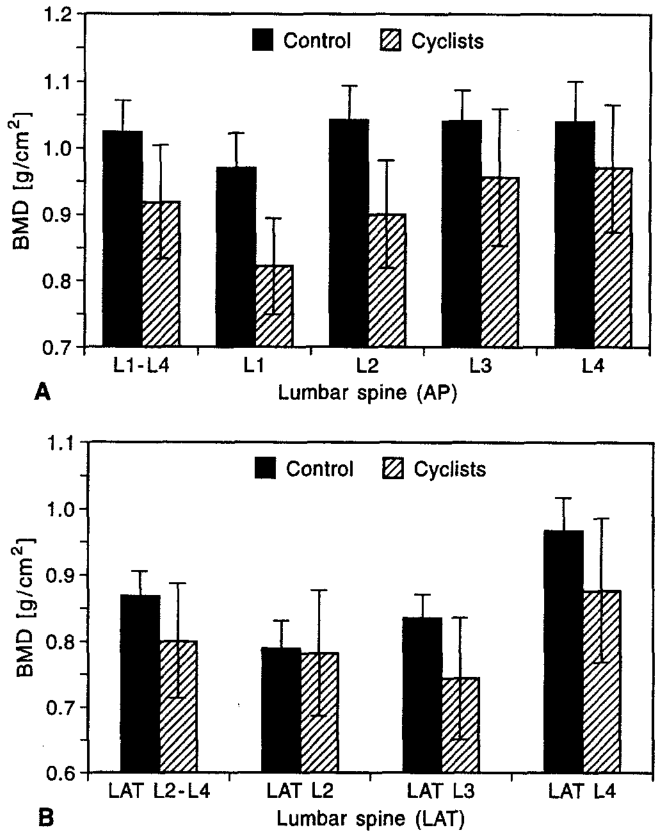

Fig. 7 **A** The BMD of the 6 cyclists was less than that of the 21 controls on the AP view of the lumbar spine (difference –10%, $P > 0.05$). **B** The difference between the values on the lateral view (LAT) was –8% ($P > 0.05$)

controls (MID: L2 +36%, $P < 0.01$; L3 +15%, $P < 0.05$; L4 +6%, $P > 0.05$).

Cyclists

All cyclists' BMD levels were lower in most ROIs than those of the controls. The lumbar spine showed 10% (0.105 g/cm^2, $P > 0.05$) lower values in the AP view (L1 –15%, $P < 0.05$; L2 –14%, $P < 0.05$; L3 -8%, $P > 0.05$; L4 –7%, $P > 0.05$) (Fig. 7A) and 8% (0.067 g/cm^2, $P > 0.05$) lower values in the lateral view (LAT: L2 –1%, $P < 0.05$; L3 –11%, $P > 0.05$; L4 –10%, $P > 0.05$) (Fig. 7B). All MID values except L2 were also decreased, in total by 6% (0.046 g/cm^2, $P > 0.05$; L2 +9%, $P > 0.05$; L3 –11%, $P > 0.05$; L4 –6%, $P > 0.05$).

Lumbar spine: MID vs LAT

To compare the vertebrae's spongious bone with the cortical frame, the difference between the changes was calculated. A positive value indicates a predominant change of the MID value, while a negative value means a predominant change of the LAT value. In weight lifters, the mean difference amounted to +6.6 ± 5.1% ($P < 0.0001$), in boxers it was –2.3 ± 0.01% ($P < 0.01$), and in cyclists it was –1.9 ± 3.0% ($P > 0.05$).

Discussion

BMD measurement with DEXA is a widely accepted procedure [9], as the precision of the method is excellent; 0.47% for the high-resolution array in our quality control. Moreover, at 1 μ Sievert, radiation exposure to the patient is very low [18]. The controls' BMDs differend from the preinstalled reference data values of the lumbar spine significantly (–6.1%, $P < 0.05$). We herewith emphasize other authors' findings that reference data based on other populations should not be accepted indiscriminately [1].

In all ROIs the weight lifters had a significantly higher BMD than the controls; their BMD values were also the highest among the athletes. Though beneficial the effect of training on bone quality has been taken for granted since the fundamental work on the reagibility of bone by

Julius Wolff at the end of the last century, and though many authors have contributed to this subject [7, 25, 26, 32], the influence of physical training has not been sufficiently quantified yet. Previous BMD measurements in athletes were mostly performed with single photon absorptiometry (SPA) or dual photon absorptiometry (DPA) [12, 32]. The most recent work with DEXA, by Karlsson et al., reported a BMD increase of 16% in the lumbar spine in weight lifters [19]. Our weight lifters had an average BMD in the lumbar spine 24% higher than that of the controls. The better training conditions of these athletes, who are mainly European or world champions in their weight category, may be the reason for the remarkable differences between Karlsson's and our findings. To our knowledge, BMD changes as extreme and statistically significant as those found in our weight lifters have not been reported yet.

No reference to the BMD of boxers is known of. This athlete group also showed significant increase in BMD of the lumbar spine (AP view +17%, lateral view +19%, $P < 0.05$), but to a lesser extent than the weight lifters, who bear more static loads in training and competition.

In endurance athletes, mainly in long-distance runners, BMD decrease has been described [14] with DPA. We confirm these findings with DEXA in endurance cyclists (BMD lumbar spine –10%). As our cyclist group was relatively small ($n = 6$), comparison with the controls is of no statistical significance, but shows a statistical trend.

This study cannot clarify the reason for the loss of mineralization in endurance athletes. But it is supposed that changes in hormone levels, predominantly testosterone decrease and cortisol increase, are the main cause of BMD changes [4, 23]. Low testosterone levels were found in endurance athletes [13, 29, 33] as well as in male patients with osteoporosis [30]. Chronically high cortisol levels will also lead to osteoporosis [14]. Precise measurements in athletes described higher endogenous cortisol outputs [21, 22], others showed a relation between cortisol output and distance of running in training [34].

We also reconfirm findings that the body mass index (BMI) may be correlated to the BMD, at least in heavy people [15, 16]. A positive correlation between the mass of the psoas muscle and the ashes weight of vertebra L3 was stated by Doyle [8]. In our study a positive correlation was also found in the weight lifters, but not in the boxers or cyclists. The boxers' mean BMI was similar to that of the controls. It is therefore obvious that the higher BMD in the weight lifters group depends on higher body mass only to a certain extent.

Though differentiation between the BMD of spongious and cortical bone is the domain of quantitative CT [9], the difference between the changes in the MID and LAT values of the lumbar spine may be instructive. A positive difference in the changes could be seen only in the weight lifters (+6.6%); it was negative in the boxers (–2.3%) and cyclists (–1.9%). This intensive reaction of the spongious bone in the vertebrae (MID value) in weight lifters may be explained by their specific training program with extreme axial loads. Possibly the high BMI in the weight lifters did cause artefacts resulting in high BMD MID values.

In studies of this type one has to be aware that results may be biased by self-selection of one group: it is possible that individuals chose particular disciplines because of their preexisting physical characteristics. This bias can only be eliminated by performing a longitudinal study where the BMD is measured before and after separate training regimes. To design and carry out a study like this would be extraordinarily demanding. To our knowledge, this effort is not under way in any research center. Therefore, we feel that results of this cross-sectional study give a good impression of the influence of physical training effects on bone and justify our conclusions.

Conclusion

BMD in the lumbar spine in high-performance athletes is correlated specifically with the performed discipline. Weight lifters' BMD is significantly higher than that of boxers and controls. Endurance athletes, in this case endurance cyclists, may develop severe loss of BMD, supposedly because of hormonal changes. This data should be taken as a basis for modifying osteoporosis training programs, though our results cannot easily be adapted to elderly patients.

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