硼对去卵巢大鼠骨质疏松症发生的减缓作用

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摘要 硼是人和动物的可能必需微量元素, 具有多种生理调控作用, 特别是对骨代谢. 本研究建立大鼠卵巢摘除骨质疏松模型, 通过长达22周的饮水补硼实验, 研究硼元素对骨质疏松症的影响. 84只大鼠随机分为7组, 去卵巢组(ovariectomized group, OVX group)大鼠摘除卵巢, 随机分为阴性对照组(蒸馏水, OVX)、阳性对照组(饮水中添加雌激素(estrogen, Est), OVX+Est)、3个补硼组(饮水中分别添加20、40、80 mg/L硼, OVX+B20、OVX+B40、OVX+B80); 假手术组(Sham group)大鼠不摘除卵巢, 仅摘除卵巢周围等量的脂肪, 随机分为空白组(蒸馏水, Sham)和补硼组(饮水中添加40 mg/L硼, Sham+B40). 实验期间, 大鼠自由饮水和饮食, 于补硼后第9、22周取样. 研究结果显示, 硼可以促进幼稚软骨细胞数以及同源细胞群细胞数增加, 减缓股骨干骺端组织显微结构的破坏, 提高机体碱性磷酸酶活性、降低抗酒石酸酸性磷酸酶活性, 维持血清Ca、P、Mg含量, 并降低体内丙二醛含量, 提高机体抗氧化酶水平. 因此, 硼元素可以减缓但不能完全阻止去卵巢大鼠骨质疏松症的发生.

关键词 硼, 去卵巢大鼠, 骨质疏松症, 骨代谢, 软骨细胞, 抗氧化能力

骨质疏松症是继心血管系统疾病的第二大威胁人类健康的疾病, 不仅威胁绝经后女性的健康, 而且严重影响其生活质量. 该病是代谢性骨骼系统疾病, 以骨矿物质大量丢失、骨组织结构破坏和容易骨折为主要临床特征, 其本质是骨形成和骨吸收之间的动态平衡被打破, 导致骨吸收大于骨形成. 人们在关注预防骨质疏松症的同时, 将关注点主要放在各种维生素和常量元素上, 却忽视了“硼”(boron, B)这个作用广泛的微量元素. 硼是一种非金属元素, 独特的理化性质使其广泛应用于工业、农业、医药卫生等领域^[1,2], 并广泛参与人和动物机体代谢调节活动. 已有研究认为硼是人和动物的必需微量元素^[3,4]. 大量研究表明, 适量硼对动物的免疫功能^[5]、抗氧化能力^[6~10]、矿物质和激素代

谢^[11,12]、生长和生产性能等有促进作用, 尤其是在骨代谢方面. 早在1987年, 研究发现, 硼可以降低绝经后女性尿中钙、镁、磷含量、提高血清激素含量^[13]. 硼缺乏会影响人和动物骨组织器官的结构和功能: 大鼠腰椎断层扫描发现, 硼缺乏会降低骨体积分数和骨小梁厚度, 增加骨小梁分离和结构模型指数^[14], 导致牙槽骨修复能力和牙齿表面釉质厚度降低^[15,16]. 而适量补充硼, 对人和动物骨骼生长和骨量维持有促进作用. 禽类日粮中添加适量硼可提高胫骨和股骨剪切力^[17]; 可增加大鼠股骨重量、骨密度、骨小梁数量和骨小梁厚度^[18]; 可刺激大鼠牙齿的骨形成^[19]; 可在增强骨强度的同时优化骨中矿物质的比例^[12]. 此外, 硼元素可调节与骨矿化相关的胞外基质蛋白mRNA的表达, 进而提高

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钙化组织相关的成骨细胞前体蛋白表达,促进小鼠成骨细胞矿化小结的形成^[20]。本研究采用经典常用的去卵巢方法建立骨质疏松症动物模型^[21],通过饮水添加硼元素,研究硼对骨质疏松症的调节作用,希望为防治以骨质疏松为代表的骨代谢疾病提供理论依据。

1 材料与方法

1.1 动物饲养与实验设计

无特定病原(specific pathogen free, SPF)级3月龄雌性斯泼雷格·多累(Sprague Dawley, SD)大鼠84只,体重200±20 g;由安徽医科大学实验动物中心提供。动物合格证号为34000200000429;动物许可证号为scxk(皖)2011-002。大鼠饲养于全膜终端过滤独立送风系统(the film terminal individual ventilated cage, IVC)笼具,饲养管理严格按照IVC标准化操作规范进行(室温18~26℃,湿度40%~65%),适应环境1周以后进行摘除卵巢手术。

大鼠随机分为去卵巢组和假手术组,术后恢复1周,开始补硼(硼酸, H₃BO₃)实验。去卵巢组(ovariectomized group, OVX)大鼠摘除卵巢,随机分为阴性对照组(蒸馏水, OVX)、阳性对照组(饮水中添加雌激素(estrogen, Est), OVX+Est)、3个补硼组(饮水中分别添加20、40、80 mg/L硼, OVX+B20、OVX+B40、OVX+B80);假手术组(Sham group)大鼠不摘除卵巢,仅摘除卵巢周围等量的脂肪,随机分为空白组(蒸馏水, Sham)和补硼组(饮水中添加40 mg/L硼, Sham+B40)。实验期间,大鼠自由进水和饮食,于补硼后第9、22周取样。

1.2 样本采集

大鼠过夜禁食,经乙醚麻醉后称量体重,打开胸腔,心脏采血致死,3000 r/min离心15 min,分离的血清于-20℃保存;取大鼠右侧股骨头,除去其他组织,于多聚甲醛中保存备用。

1.3 血清指标检测

分别采用ARⅢ法、紫外直接法、甲基麝香草酚蓝(methyl thymol blue, MTB)法、2-氨基-2-甲基-1-丙醇(2-amino-2-methyl-1-propanol, AMP)缓冲液法检测血清钙、磷、镁的含量及碱性磷酸酶(alkaline phosphatase, ALP)的活性;分别采用可见光、羟胺法、TBA法、比色法、比色法测定过氧化氢酶(catalase, CAT)、总超氧

化物歧化酶(total superoxide dismutase, T-SOD)、丙二醛(malondialdehyde, MDA)、谷胱甘肽过氧化物酶(glutathione peroxidase, GSH-Px)、抗酒石酸酸性磷酸酶(tartrate resistant acid phosphatase, TRAP)的活性。血清指标检测完全试剂按照说明书操作进行。

1.4 骨组织切片制作

将多聚甲醛中固定好的骨组织取出,放入乙二胺四乙酸(ethylene diamine tetraacetic acid, EDTA)脱钙液进行脱钙,然后放入无机酸溶液(无机酸脱钙液配制:取浓盐酸10 mL、甲酸6 mL、氯化钙8 g,加入蒸馏水100 mL溶解混匀)的容器中继续脱钙,容器置于水浴锅中,保持水温在55~60℃,脱钙18~24 h。骨组织脱钙完全后,流水冲洗6 h左右,梯度乙醇脱水后,转入3:1的氯仿-无水乙醇混合液内12 h,然后转入氯仿内48 h。放入已融化的高熔点蜡中浸蜡5~6 h后包埋。常规切片,HE(hematoxylin-eosin)染色,显微观察、拍照并分析统计。

1.5 数据处理与分析

利用SPSS 20.0统计软件对数据进行单因素组间方差分析和比较,结果以“平均值±标准差”(x±SD)表示,数据显著水平设定:0.01 < P ≤ 0.05时差异显著, P ≤ 0.01时差异极显著。利用Graphpad Prism 5制图。

2 结果与讨论

2.1 硼对去卵巢大鼠股骨干骺端组织形态学的影响

骨组织形态学观察是在骨代谢领域中的重要研究技术,是评价骨组织显微结构的有效研究手段。软骨内成骨是哺乳动物长骨生成生长的主要途径,其本质是软骨细胞增殖、分化、凋亡并最终矿化,即骨组织替代软骨组织的过程。鼠类软骨内形成骨过程经历静止期、增殖期和肥大期,其中静止期软骨细胞即幼稚软骨细胞,小而圆,与软骨表面平行;成熟软骨细胞位于软骨中部,成群存在形成同源细胞群,细胞排列具有明显的方向性,与长骨发育方向相关;停止增殖后的软骨细胞分化成肥大细胞,为最后形成初级骨小梁的组织提供细胞支架^[22]。本实验结果显示(图1),3种不同浓度硼均可极显著提高幼稚软骨细胞数量,特别是40 mg/L浓度下,且在骨质疏松发生的早期阶段(9周)补充效果最佳;同时,硼元素可以增加软骨细胞增殖过程中同源细胞群中细胞数量,而软骨形成与骨形成的过程在时

图1 硼对去卵巢大鼠股骨干骺端幼稚软骨细胞数量和软骨细胞同源细胞群内细胞数量的影响。(a) 幼稚软骨细胞数量; (b) 软骨细胞同源细胞群内细胞数量。与Sham组比较, *表示差异显著($P \leq 0.05$); **表示差异极显著($P \leq 0.01$); 与OVX组比较, \$表示差异显著($P \leq 0.05$); \$\$表示差异极显著($P \leq 0.01$)

Figure 1 Effects of boron on the number of young chondrocyte and isogenous groups cell in OVX rats. (a) Number of young chondrocyte; (b) number of isogenous groups cell in chondrocyte. Compared with Sham group, * indicates a significant difference ($P \leq 0.05$), and ** indicates an extreme significant difference ($P \leq 0.01$); compared with OVX group, \$ indicates a significant difference ($P \leq 0.05$), and \$\$ indicates an extreme significant difference ($P \leq 0.01$)

间和空间上存在紧密的联系, 且幼稚软骨细胞数量以及同源细胞群中细胞数量与骨小梁组织形态结构成正相关。骨小梁厚度、骨小梁间隙等指标反映骨小梁连接状况和骨小梁本身的结构特征, 反映骨结构的参数。骨组织显微结构越优化, 骨骼系统的抗骨折能力就越强^[23]。本实验结果表明(图2), 9周时, Sham组骨小梁粗壮、壁厚, 形态结构完整, 排列紧密有序且交织成网, 密度、面积正常, 骨小梁间隙小; 特别是Sham+B40组骨小梁更加粗壮致密, 两组假手术组骨小梁生长方向均顺应骨力学方向。OVX组骨小梁变细、变薄, 排列稀疏、无序, 骨小梁间隙增大; OVX+Est组骨小梁排列较稀疏、稍紊乱, 基本交织成网; OVX+B各组骨小梁排列较稀疏, 但骨小梁排列有序、交织成网。与Sham组比较, OVX+B各组骨小梁排列虽较稀疏、但排列有序; 与OVX组比较, OVX+B各组骨小梁排列较紧密、有序, 骨小梁略有增粗。在22周时, Sham和Sham+B40这

两组的骨小梁保持其结构完整, 排列致密有序、交织成网, 骨小梁间隙小。OVX组骨微结构损坏严重, 骨小梁变细、变薄, 甚至断裂, 不能保持完整性, 间隙较大; 与Sham组比较, OVX+B各组骨小梁变细、变薄, 排列稀疏, 但较OVX组, 骨小梁结构相对略粗, OVX+B80组尚能保持骨小梁结构完整性。骨小梁的形成与成骨细胞有密切关系。有研究表明, 硼可以通过调节I型胶原(COL I)、骨桥蛋白(osteopontin, OPN)、骨唾液蛋白(bone sialoprotein, BSP)、骨钙蛋白(osteocalcin, OCN)和RunX2(mRNA水平)以及骨形态发生蛋白-4、-6和-7(蛋白质水平)的表达, 促进成骨细胞的骨形成作用^[20]。同时卵巢摘除导致大鼠体内雌激素严重缺乏, 虽然研究表明硼元素具有类雌激素作用^[24], 仅能弥补雌激素的缺乏但不能完全替代雌激素, 但硼元素的补充延缓了大鼠体内骨矿物的丢失以及骨组织结构的破坏, 进而减缓骨质疏松症的发生。

2.2 硼对去卵巢大鼠血清钙、磷、镁含量的影响

人和动物骨骼富含各种矿物盐, 而骨骼硬度是由无机矿物盐含量决定的。无机质主要成分是钙(Ca)、磷(P)、镁(Mg)等矿物质盐, 血清中Ca、P和Mg的检测可间接反映骨矿物质变化情况。本研究结果显示, 不同浓度的硼, 在不同时间对去卵巢大鼠血清中Ca、P和Mg含量的影响无显著变化($P > 0.05$), 与Xu等人^[25,26]的研究结果一致。研究发现, 硼可以减少尿钙、尿磷的排出, 这可能与骨组织中的骨细胞具有维持钙、磷稳态作用有关^[3,27-30], 骨细胞主要源于成骨细胞, 而成骨细胞受ALP的调控。摘除卵巢早期(第9周), 硼可以提高ALP活性, 减少尿中矿物元素的排出, 维持血清中Ca、P和Mg的含量。本试验结果表明(图3), 大鼠摘除卵巢后期(第22周), 血清中矿物元素仍处于动态平衡状态(血清矿物元素主要来源于肠道吸收以及骨骼系统释放, 沉积于骨骼系统或者通过粪尿途径排出)。无论是在摘除卵巢的早期还是晚期, 与Sham组相比, OVX组大鼠体内都会有大量矿物元素的丢失, 因此, 尽管硼可以减少Ca、P和Mg矿物元素的排出, 但并不能完全阻止其排出。这与开展的硼对骨质疏松症大鼠牙槽骨骨量的丢失的结果一致^[31,32]。可能原因是, 当血清矿物元素减少时就会动员骨骼系统中相应的无机盐, 因此大鼠长期处于丢失Ca、P和Mg的状态, 长此以往, 导致去卵巢大鼠骨矿元素的大量丢失, 进而发生骨质疏松症。

图 2 (网络版彩色)硼对去卵巢大鼠股骨干骺端组织形态学的影响。(a)~(g) 9周去卵巢大鼠股骨干骺端组织; (h)~(n) 22周去卵巢大鼠股骨干骺端组织。(a), (h) Sham组; (b), (i) Sham+B40组; (c), (j) OVX组; (d), (k) OVX+Est组; (e), (l) OVX+B20组; (f), (m) OVX+B40组; (g), (n) OVX+B80组。“★”指示为幼稚软骨细胞;“▲”指示为软骨细胞同源细胞群;“◆”指示为骨小梁

Figure 2 (Color online) Effects of boron on the histomorphology of femoral metaphysis in OVX rats. (a)~(g) Femoral metaphysis tissue of OVX rats at the 9th week after ovariectomy; (h)~(n) femoral metaphysis tissue of OVX rats at the 22nd week after ovariectomy. (a), (h) Sham group; (b), (i) Sham+B40 group; (c), (j) OVX group; (d), (k) OVX+Est group; (e), (l) OVX+B20 group; (f), (m) OVX+B40 group; (g), (n) OVX+B80 group. “★” indicates young chondrocyte; “▲” indicates isogenous groups cell; “◆” indicates trabecular bone

2.3 硼对去卵巢大鼠骨代谢酶活性的影响

骨转换过程是成骨细胞形成新骨和破骨细胞清除旧骨之间的动态平衡过程。当这个动态平衡被打破, 出现骨吸收大于骨形成时, 就会出现骨质疏松症^[33]。骨代谢标志物是骨基质或各类骨骼组织细胞分泌的代谢指标, 其中ALP是骨形成相关的重要标志物, 不仅是成骨细胞生长和发育早期的重要标志, 同时也是成骨细胞功能状态的体现。本实验结果显示(图4), 9周时, 与OVX组相比, 20、40 mg/L浓度硼可以显著地提高去卵巢大鼠血清中ALP活性, 80 mg/L时也可以提高ALP活性, 但是差异不显著; 与Sham比较, 摘除卵巢的5组大

鼠血清中ALP活性均极显著提高, 而在22周时不同浓度的硼对ALP活性无明显影响。TRAP是衡量骨吸收能力的重要代谢指标, 而硼对去卵巢大鼠血清中TRAP活性的影响较大: 9周时40、80 mg/L浓度硼可以显著地抑制去卵巢大鼠血清TRAP活性, 但在22周时20($P \leq 0.01$)、40($P \leq 0.01$)和80 mg/L($P \leq 0.05$)可以不同程度抑制其活性; 与Sham组相比, 仅OVX组极显著地升高, 其他摘除卵巢组TRAP活性也有升高趋势, 但是差异不显著。结果表明, 早期阶段(9周), 由于摘除大鼠卵巢导致其骨转换过程加快, 骨吸收过程加剧, 推测机体代偿性地引起骨形成过程加速, ALP进入血液导致其活性增加; 同时硼元素具有抑制TRAP活性的作用, 降低骨

图3 硼对去卵巢大鼠血清钙、磷、镁含量的影响。(a) 血清钙含量;(b) 血清磷含量;(c) 血清镁含量。与Sham组比较,*表示差异显著($P \leq 0.05$);**表示差异极显著($P \leq 0.01$);与OVX组比较,\$表示差异显著($P \leq 0.05$);\$\$表示差异极显著($P \leq 0.01$)

Figure 3 Effects of boron on serum calcium, phosphorus and magnesium level in ovariectomized rats. (a) Serum calcium level; (b) serum phosphorus level; (c) serum magnesium level. Compared with Sham group, * indicates a significant difference ($P \leq 0.05$), and ** indicates an extreme significant difference ($P \leq 0.01$); compared with OVX group, \$ indicates a significant difference ($P \leq 0.05$), and \$\$ indicates an extreme significant difference ($P \leq 0.01$)

吸收过程,使得骨量丢失较少。但到后期(22周)时,即使在补硼的状态下,虽然硼具有抑制TRAP活性的作用,降低骨吸收过程,但是摘除卵巢大鼠骨代谢(骨吸收和骨形成)已进入稳态,ALP活性依旧下降,成骨作用减弱,骨质疏松症状最终出现。

2.4 硼对去卵巢大鼠抗氧化能力的影响

绝经后骨质疏松症发生的主要机制是活性氧自由基的增加^[34]。自由基攻击体内脂肪产生的氧化产物MDA是衡量机体氧化损伤程度的重要指标,而机体内

图4 硼对去卵巢大鼠骨代谢酶活性的影响。(a) 血清ALP活性;(b) 血清TRAP活性。与Sham组比较,*表示差异显著($P \leq 0.05$);**表示差异极显著($P \leq 0.01$);与OVX组比较,\$表示差异显著($P \leq 0.05$);\$\$表示差异极显著($P \leq 0.01$)

Figure 4 Effects of boron on the activity of bone metabolism enzymes in ovariectomized rats. (a) Serum ALP activity; (b) serum TRAP activity. Compared with Sham group, * indicates a significant difference ($P \leq 0.05$), and ** indicates an extreme significant difference ($P \leq 0.01$); compared with OVX group, \$ indicates a significant difference ($P \leq 0.05$), and \$\$ indicates an extreme significant difference ($P \leq 0.01$)

清除自由基和MDA主要依赖机体内的抗氧化系统,主要包括总超氧化物歧化酶(T-SOD)、还原型谷胱甘肽(GSH-Px)、过氧化氢酶(CAT)。本研究中OVX组大鼠血清中MDA含量一直较高,特别是在早期阶段,提示大鼠摘除卵巢后机体内一直处于氧化应激状态,机体内抗氧化系统能力的降低和MDA含量增高降低了大鼠体内成骨细胞数量,减弱了骨形成作用;但促进了破骨细胞分化、增殖和成熟,加快骨组织脱矿降解过程。本试验结果显示(图5),与OVX组相比,其他各组大鼠血清中MDA含量不同程度降低,特别是在早期阶段(9周),OVX+B20和OVX+B40组极显著降低;而在22周时,虽有下降但差异不显著,硼对MDA的产生具有抑制作用。硼是如何起到保护机体不受自由基攻击?本研究检测大鼠体内3种抗氧化酶活性。结果显示,OVX组中的T-SOD、CAT、GSH-Px活性,无论是在9周还是22周时,3种抗氧化酶活性均最低。与OVX组相比,9周时OVX+B40($P \leq 0.01$)组以及22周时OVX+B20($P \leq 0.05$)和

图5 硼对去卵巢大鼠抗氧化能力的影响。(a) 血清MDA水平; (b) 血清T-SOD活性; (c) 血清CAT活性; (d) 血清GSH-Px活性。与Sham组比较, *表示差异显著($P \leq 0.05$); **表示差异极显著($P \leq 0.01$); 与OVX组比较, \$表示差异显著($P \leq 0.05$); \$\$表示差异极显著($P \leq 0.01$)

Figure 5 Effect of boron on antioxidant capacity in OVX rats. (a) Serum MDA level; (b) serum T-SOD activity; (c) serum CAT activity; (d) serum GSH-Px activity. Compared with Sham group, * indicates a significant difference ($P \leq 0.05$), and ** indicates an extreme significant difference ($P \leq 0.01$); compared with OVX group, \$ indicates a significant difference ($P \leq 0.05$), and \$\$ indicates an extreme significant difference ($P \leq 0.01$)

OVX+B40($P \leq 0.05$)组血清T-SOD活性显著或极显著性升高。与OVX组相比,其他各组大鼠血清中CAT活性不同程度升高,尤其是22周OVX+B80($P \leq 0.01$)活性极显著地升高;与OVX组相比,GSH-Px活性在9、22周的OVX+B40($P \leq 0.05$)组显著性升高,其他各组血清中GSH-Px活性升高无差异($P > 0.05$)。硼的添加可以提高大鼠特别是摘除卵巢后的大鼠体内抗氧化能力,尤其是T-SOD以及GSH-Px活性。这与本课题组^[6]早期研究结果以及Türkez等人^[35]和Korkmaz等人^[36]的研究结果一致。而去卵巢大鼠体内抗氧化能力的提高,则可以减缓氧化应激对成骨细胞、骨细胞的损伤,抑制破骨细

胞的分化增殖,降低卵巢摘除引起的氧化应激对骨骼系统的破坏,延缓骨质疏松症的发生。

3 结论

硼元素是一种具有多种生物学作用的微量元素,特别是对人和动物的骨代谢具有重要的调节作用。硼可以减缓股骨干骺端组织显微结构的破坏,提高机体ALP活性、降低TRAP活性,维持血清Ca、P和Mg含量,并降低体内MDA含量,提高机体内抗氧化酶水平。因此,硼元素可以减缓但不能完全阻止去卵巢大鼠骨质疏松症的发生。

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Summary for “硼对去卵巢大鼠骨质疏松症发生的减缓作用”

The mitigation effect of boron on the occurrence of osteoporosis in ovariectomized rats

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In recent years, unhealthy lifestyles and diet habits have resulted in poor bone growth and development, as well as bone metabolism disorders in adolescents. At the same time, bone metabolism disorder represented by osteoporosis has become the second disease that threatens human health after cardiovascular disease. The bone metabolism disease is a persistent problem in the livestock husbandry and pet industry, which has caused the death and elimination of livestock and poultry and has brought huge economic losses. Therefore, bone metabolic diseases not only threaten human health, but also seriously affect the economic benefits of the pet industry and livestock husbandry. While people focus on the prevention of animal bone metabolism diseases, they mainly focus on various vitamins and major elements, but ignore the trace element “boron” with a wide range of uses. Boron is a non-metal element, and its unique physical and chemical properties make it widely involved in the metabolic regulation activities of human and animal bodies. It promotes the immune function, antioxidant capacity, mineral and hormone metabolism, growth and production performance of animals, especially in bone metabolism which is essential trace element. A large number of studies have shown that boron deficiency will not only lead to bone dysplasia and even deformity, but also lead to bone structural changes, and disorders in bone formation and bone repair. Appropriate boron supplementation has positive effects on bone development and bone maintenance of humans and animals.

In this study, the ovariectomized (OVX) rats were selected to establish an osteoporosis model, and the effects of boron on osteoporosis were studied by boron supplementation in drinking water during 22 weeks. Through the microscopic observation of the femoral metaphysis tissue structure in different periods (the 9th and 22nd week after boron supplementation), boron could slow down but not completely prevent the occurrence of osteoporosis. For a long time after the rats' ovaries were removed, the removal of the ovaries resulted in severe estrogen deficiency in rats. Although studies have shown that boron has an estrogen-like effect and could make up for the lack of estrogen, but not completely replace estrogen. Boron could inhibit the TRAP activity and reduce the bone resorption process, but the bone metabolism including bone resorption and bone formation of the OVX rat has also entered a steady state, ALP activity was still decreased and the osteogenesis effect was weakened. In addition, boron supplementation maintained the content of the serum Ca, P and Mg in the OVX rats, and those three elements mainly derived from the bone minerals of the skeletal system. Therefore, the rat body has been in a state of losing Ca, P, and Mg for a long time, and bone minerals loss will lead to osteoporosis if it goes on. The improvement of antioxidant capacity in OVX rats in the boron supplementation groups could slow down the damage of oxidative stress to osteoblasts and osteocytes, inhibit the differentiation and proliferation of osteoclasts, reduce the damage to the skeletal system, and delay the occurrence of osteoporosis. Therefore, boron could slow down but not completely prevent the occurrence of osteoporosis in OVX rats.

boron, ovariectomized rats, osteoporosis, bone metabolism, chondrocytes, antioxidant capacity

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