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医学生物物理

能谱CT评估生物力学的初步研究

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【摘 要】目的:通过分析能谱CT定量参数与生物力学的相关性,探讨能谱CT定量参数评估骨强度的价值。**方法:**采用能谱CT成像扫描36个羊腰椎椎体,测定每个椎体的骨松质、骨皮质及皮质+松质的能谱CT基物质对(铁-水、钙-水、羟基磷灰石-水)密度,然后将各个椎体去除附件对应编号,行腰椎压缩实验。将能谱不同基物质对(铁-水、钙-水、羟基磷灰石-水)密度值与生物力学测得的最大载荷和最大应力进行相关性分析。**结果:**能谱CT基物质对密度值与生物力学相关性分析可得,在松质+皮质时钙-水、羟基磷灰石-水与最大应力呈强相关(R^2=0.508, P<0.05; R^2=0.507, P<0.05),与最大载荷呈中等程度相关(R^2=0.454, P<0.05; R^2=0.451, P<0.05),而铁-水相关性较低;皮质、松质的3个基物质对密度值与生物力学值相关性较差。**结论:**能谱CT定量参数可以用来评价骨强度。

【关键词】能谱CT;骨质疏松;生物力学;骨强度
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Preliminary study of evaluating biomechanics with energy spectral computed tomography

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Abstract: Objective To analyze the correlations between energy spectral computed tomography (CT) quantitative parameters and biomechanics, and explore the value of energy spectral CT quantitative parameters in the assessment of bone strength. **Methods** Energy spectral CT scanning was performed on 36 vertebral bodies to determine the density of CT-based material pairs (iron-water, calcium-water and hydroxyl-phosphorus) in cancellous, cortex and cortico-cancellous in each vertebral body of the sheep. Then the corresponding number of each vertebral body was removed, and lumbar compression experiment was conducted. The correlations between the density values of different pairs (iron-water, calcium-water and hydroxyapatite-water) and the maximum load and maximum stress measured by biomechanics were analyzed. **Results** The analysis of the correlations between density values and biomechanical properties of energy spectral CT-based materials showed that for cortico-cancellous, calcium-water and hydroxyapatite-water were strongly correlated with the maximum stress (R^2=0.508, P<0.05; R^2=0.507, P<0.05), and moderately correlated with the maximum load (R^2=0.454, P<0.05; R^2=0.451, P<0.05), while the iron-water correlation was relatively lower. The 3 CT-based material pairs of cortex and cancellous had poor correlations between density values and biomechanical properties. **Conclusion** Energy spectral CT quantitative parameters can be used to evaluate bone strength.

Keywords: energy spectrum computed tomography; osteoporosis; biomechanics; bone strength

前 言

骨质疏松症是一种以系统骨矿含量、骨强度下降及骨微结构损害为特征,常导致骨折风险增加的疾病。由于骨质疏松的诊断及检测往往存在着不足,常常导致骨质疏松性骨折对患者的生活质量造成严重影响。目前双能X线吸收法(Dual-energy X-ray Absorptiometry, DXA)仍然为学术界公认的诊断骨质疏松的"金标准",但DXA在测量骨密度(Bone Mineral Density, BMD)时存在诸多局限性,且骨强度

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的代表不止有BMD,还有骨生物力学。Guler Okyay等[1]认为在评估骨折风险中与矿物含量相比,骨的生物力学质量具有更重要的作用。但生物力学测定无法在在体情况下实现[2-3],因此寻找出一种可以在体评估生物力学的检查方法,将对临床骨质疏松患者的诊断及治疗提供巨大帮助。能谱CT在常规CT扫描图像的基础上可以得到不同单能量条件下物质衰减图像,实现了能量分辨率和理化性质分辨率。另外能谱CT利用基物质配对原理可以定量分析组织中特定成分的种类及含量[4-6],且已有研究证实能谱CT定量参数可以用来评估诊断骨质疏松,且较DXA更为准确[7-8]。因此本研究应用能谱CT基物质成像技术与生物力学值进行相关性分析,以期能谱CT定量参数能够为骨强度的评估提供参考。

1 材料与方法

1.1 实验材料

购买新鲜市售羊椎体4副,每副选取腰椎(6个),共36个椎体,每个椎体进行编号。能谱CT扫描采用美国GE公司生产的Discovery CT750 HD能谱CT对实验椎体进行扫描;骨生物力学测定(电子万能试验机,AG-X 50KN型,日本岛津公司)。

1.2 能谱CT扫描

选用GSI扫描,扫描模式为轴向扫描,探测器宽度20 mm,扫描层厚0.62 mm,矩阵大小:512×512;重建算法为Stand,自适应统计迭代重建(Adaptive Statistical Iterative Recon, ASIR)。扫描完成后,进入AW 4.6工作站进行分析,于每个椎体中间层面的皮质、松质、松质+皮质范围放置感兴趣区(Region of Interest, ROI),ROI面积2.90 mm^2,测得每个ROI的铁-水、钙-水、羟基磷灰石-水基物质密度,单位为mg/cm^3。

1.3 生物力学测定

将标记好的各个椎体去除椎体附件及周围软组织,用细纱纸将每个椎体打磨成上下两个面平行的圆柱体,用游标卡尺测量椎体矢状径、冠状径,将打磨好的椎体置于压缩工作台中心位置上,以1 mm/min的实验速度对试样施加压应力,直至腰椎椎体破坏,记录载荷-位移曲线并得到最大载荷并计算出最大应力。

1.4 统计学分析

应用SPSS 23.0软件,对所有数据进行统计学描述及分析。所有计量数据用均数±标准差表示;能谱CT定量参数值与生物力学值相关性分析采用Pearson相关分析,检验水准α=0.05。

2 结 果

2.1 不同区域能谱CT测量结果

不同区域羟基磷灰石-水及钙-水的含量具有一定差异,即能谱CT可以区分不同区域的物质含量,如图1所示。图1a为能谱CT羟基磷灰石含量分布伪彩图(亮度越高代表羟基磷灰石含量越高);图1b为3个不同测量区域ROI的放置:L1骨皮质、L2骨皮质+骨松质、L3骨松质;图1c和图1d分别为为3个不同区域羟基磷灰石和钙的含量分布散点图。

2.2 能谱CT参数与生物力学相关性分析

能谱CT测得椎体不同区域的不同能谱参数与生物力学值的相关性分析结果如图2所示。由图2可知,能谱CT测量所得皮质+松质区域的3个基物质浓度值与生物力学值呈正相关(P<0.05),即能谱CT测得的基物质浓度值的变化趋势与生物力学值(最大应力)变化一致;钙-水与羟基磷灰石-水两基物质对与生物力学值之间的决定系数R^2分别为:0.508、0.507,高于铁-水基物质密度值与生物力学值(最大应力)之间的决定系数(R^2=0.426);3个基物质浓度值(铁-水、钙-水、羟基磷灰石-水)与生物力学值(最大载荷)变化一致,但相关性较低,决定系数R^2分别为:0.388、0.454、0.451;单纯松质和皮质所得能谱CT基物质浓度值与生物力学值均无相关性。

3 讨 论

能谱CT采用高低电压瞬时切换技术,得到比常规CT图像更多的能量信息,其在医学各个领域的应用已有较多报道[9-14],在物质定量分析等方面也取得一定成果[15-16]。由于骨折是骨质疏松症的主要并发症,且DXA在临床应用有较多局限性例如:① 其测量结果是区域内的二维密度,含有骨的皮质和松质,难以分别,所以早期发生于骨松质的骨钙降低难以发现;② DXA的测量受很多外部因素(骨折、人体软组织厚度,动脉壁钙化等)影响,导致其测量值偏离真实BMD;③ 在老年患者出现骨质增生等退行性改变后,其测量值往往较真实值偏大,不能及时诊断骨质疏松症。这些局限可由能谱CT填补,有研究证明能谱CT测量BMD的准确性高于DXA[17],而能谱CT定量参数与骨强度之间的关系未见报道。

在衡量骨的质量时,常用生物力学来测试。骨强度是由BMD和骨质量构成,而骨质量是由骨的材料特性和骨的结构特性决定[18],材料特性为骨的固有特性,而骨的结构特性与骨的形状及骨小梁结构及空间形态分布有关[19]。本研究选用骨的材料特性(最大载荷)、骨的结构特性(最大应力)两种代表性指标与能谱CT定量参数进行相关性分析发现,在皮

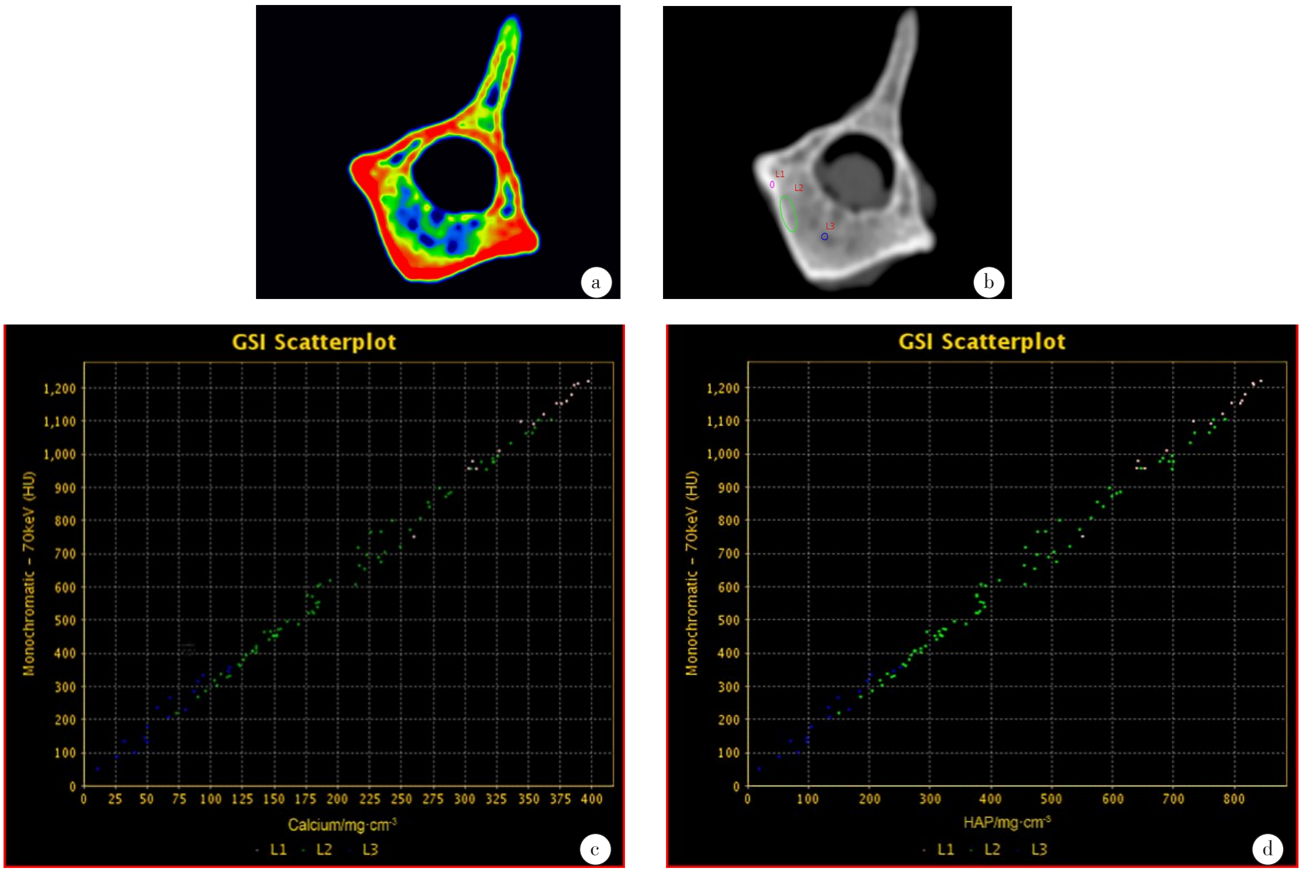

图1 能谱CT所测区域

Fig.1 Areas scanned by energy spectral computed tomography (CT)

Fig.1a was pseudocolor image of the content distribution of hydroxyapatite in energy spectral CT. The higher the brightness is, the higher the hydroxyapatite content is. Fig.1b was the placement of the region of interest in 3 different measurement areas, namely L1 cortical bone, L2 cortical bone + bone pine, and L3 cancellous bone. Fig.1c and 1d were the scatter plots of hydroxyapatite and calcium in 3 different areas, respectively.

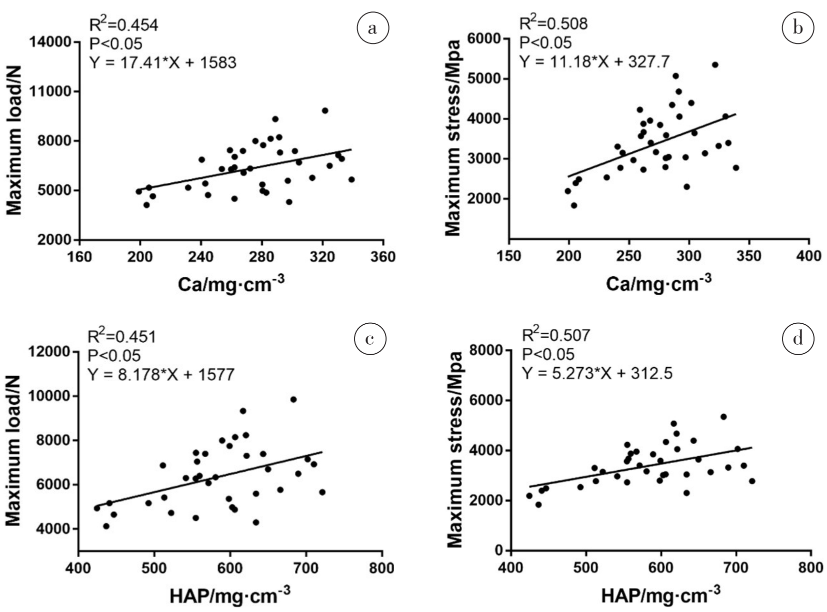

图2 皮质+松质能谱定量参数与生物力学值相关性分析

Fig.2 Correlations between energy spectral CT quantitative parameters and biomechanical properties of cortico-cancellous

Fig.2a was the correlation analysis of calcium (Ca)-water-based material pairs and the maximum load; Fig.2b was the correlation analysis of calcium (Ca)-water-based material pairs and the maximum stress; Fig.2c was the correlation analysis of hydroxyapatite (HAP)-water-based material pairs and the maximum load; Fig.2d was the correlation analysis of hydroxyapatite (HAP)-water-based material pairs and the maximum stress.

质＋松质这一区域时,能谱CT基物质对浓度钙-水、羟基磷灰石-水值与最大应力呈显著正相关,而与最大载荷呈弱相关,这一结果表明骨强度与骨的结构特性更为密切。单纯的皮质和松质的能谱CT定量参数与生物力学值之间无相关性,是因为骨强度是由骨皮质和骨松质的共同骨密度及骨质量构成的,因此单一区域的基物质浓度值并不能反映整体的骨强度,骨强度的评估需要对皮质和松质进行综合测量。

综上所述,能谱CT在采用钙-水和羟基磷灰石-水基物质对时,其与生物力学具有明显的正相关,可以作为无创评估骨强度的一种新方法。

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