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ORIGINAL ARTICLE

Growth-dependent effects of dietary protein concentration and quality on the biomechanical properties of the diaphyseal rat femur

Rosa M. Alippi[a], Emilio Picasso[b], Patricia Huygens[a], Carlos E. Bozzini[a,*], Clarisa Bozzini[a]

[a] *Department of Physiology, Faculty of Odontology, University of Buenos Aires, Buenos Aires 1122, Argentina*
[b] *Department of Statistics, Faculty of Engineering, University of Buenos Aires, Buenos Aires 1122, Argentina*

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KEYWORDS
Diet;
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Abstract
Objectives: This study compares the effects of feeding growing rats with increasing concentrations of casein (C) and wheat gluten (G), proteins that show different biological qualities, on the morphometrical and biomechanical properties of the femoral diaphysis.
Materials and methods: Female rats were fed with one of ten diets containing different concentrations (5–30%) of C and G between the 30th and 90th days of life (Control = C-20%). Biomechanical structural properties of the right femur middiaphysis were estimated using a 3-point bending mechanical test with calculation of some indicators of bone material properties.
Results: Body weight and length were affected by treatments, values being highest in rats fed the C-20% diet. G diets affected negatively both parameters. Changes in cross-sectional geometry (mid-diaphyseal cross-sectional and cortical areas, femoral volume, and rectangular moment of inertia) were positively related to the C content of the diet, while they were severely and negatively affected by G diets. Similar behaviors were observed in the bone structural properties (fracture load, yielding load, diaphyseal stiffness and elastic energy absorption). When values of strength and stiffness were normalized for body weight, the differences disappeared. The bone material quality indicators (elastic modulus, yielding stress, elastic energy absorption/volume) did not differ significantly among all studied groups. Femoral calcium concentration in ashes was not significantly different among groups.
Conclusion: The clear differences in strength and stiffness of bone beams induced by dietary protein concentration and quality seemed to be the result of an induced subnormal gain in bone structural properties as a consequence of a correlative subnormal gain in bone growth and mass, yet not in bone material properties.
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* Corresponding author.
E-mail address: cebozi@fisio.odon.uba.ar (C.E. Bozzini).

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PALABRAS CLAVE
Dieta;
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Crecimiento;
Biomecánica ósea

Efectos de la concentración y calidad de las proteínas dietarias sobre la calidad ósea de la diáfisis femoral de la rata asociados con el crecimiento

Resumen
Objetivos: Este estudio compara los efectos sobre las propiedades morfométricas y biomecánicas de la diáfisis femoral de ratas en edad de crecimiento de dos proteínas dietarias, caseína (C) y gluten de trigo (G), que muestran características biológicas diferentes, ofrecidas en concentraciones crecientes en las dietas utilizadas.
Material y métodos: Ratas hembras fueron alimentadas entre los días 30 y 90 de sus vidas con una de diez dietas que contenían concentraciones diferentes (5-30%) de C y G (Controles = C al 20%). Se estimaron las propiedades biomecánicas estructurales de la parte media de la diáfisis del fémur derecho mediante la prueba mecánica de flexión a tres puntos calculándose, además, algunos indicadores de las propiedades biomecánicas del material óseo.
Resultados: Los tratamientos afectaron al peso corporal y a la talla, con valores más elevados en aquellas ratas alimentadas con la dieta C al 20%. Las dietas conteniendo G afectaron en forma negativa a ambos parámetros. Los cambios en la geometría de la sección transversal (áreas de la sección transversal de la parte media de la diáfisis y cortical, volumen del fémur y momento rectangular de inercia) mostraron una correlación positiva con la concentración de C en las dietas, mientras que fueron severa y negativamente afectados por la presencia de G en las mismas. Se observaron comportamientos similares en las propiedades estructurales del hueso (carga o resistencia a fractura, punto de cesión, rigidez diafisaria y absorción de energía durante el período elástico). Cuando los valores de rigidez y resistencia diafisarias fueron normalizados por el peso corporal, desaparecieron las diferencias. Los indicadores de la calidad biomecánica del material óseo (módulo de elasticidad, estrés elástico límite, absorción elástica de energía/volumen óseo) no fueron estadísticamente diferentes entre los grupos estudiados. La concentración de calcio femoral no mostró diferencias entre grupos.
Conclusión: Las diferencias significativas de rigidez y resistencia entre las diáfisis femorales inducidas por la concentración y calidad de las proteínas dietarias parecieran ser el resultado de la ganancia subnormal de las mismas como consecuencia de una ganancia también subnormal del crecimiento y de la masa ósea, sin alteraciones de las propiedades materiales.
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Introduction

During evolution, the skeleton of vertebrates developed an important property, the resistance to deformation, and indirectly to fracture that was adapted to the physiological mechanical demands of the environment. The criterion for adequate support function is the formation and maintenance of sufficient quantity and quality of bone adequately distributed to support the body throughout life and to withstand ordinary stresses to which skeletal components are subjected.[1]

It is assumed that the mechanical properties of bones integrated as organs (*structural properties*) are directly related to both the amount (*bone mass*) and the architectural distribution of the mineralized tissue (*geometric properties*) and to the mechanical quality of bone material (*material properties*).[2,3] The structural stiffness, measured as a load/deformation ratio, is usually kept high enough to withstand to everyday bone deformation to avoid damage, and hence fracture. The structural stiffness, and indirectly the strength of bones, is thought to be controlled by a ''*bone mechanostast*''.[4] This is a feedback mechanism that optimizes the bone design through a permanent re-distribution of the mineralized tissue.

Several factors have been recognized to play an important physiological role in determining bone stiffness and strength and its resistance to spontaneous and traumatic fractures. Both body weight and somatic muscles contractions could be considered as the most important ''*mechanical factors*'' in the determination of bone strength.[5] However, other ''*nonmechanical factors*'' also exist that can *modulate* bone physiology, by either establishing or maintaining the mechanical competence of bones.

Several years ago, we reported the biomechanical repercussion of a severe protein restriction on the shaft of long bones and on cortical tissue in growing rats.[6] A great reduction in growth-related gains in bone stiffness and strength with respect to well-nourished controls was found. The alterations described correlated with very low values of the cross-sectional bone mass indicators and moments of inertia and the calcium content of bone tissue. The additive effects of protein and energy deficiencies were also demonstrated.[7] These findings were partially confirmed later by other investigators.[8–10] In general, these later studies, which were performed in adult rats, demonstrated that isocaloric protein undernutrition decreased bone mineral mass and strength and/or negatively affected intrinsic tissue properties of bone. In these studies, the effects of protein restriction on bone biomechanics were thus isolated from the concomitant effects on body growth seen in young animals, which could also secondarily alter bone biomechanical properties.

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