Structure of Human Vertebral Lamellar Bone in Age-Associated Involution and Osteoporosis

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We compared the structure of lamellar bone in anterolateral zones of vertebral bodies in adult and senile subjects in health and osteoporosis. The appearance of structural signs of age-related osteopenia and enlargement of coplanar consolidations of the bone matrix crystals were noted. Osteopenia was more pronounced in osteoporosis, while the structural organization of the mineral component did not differ from that in age-matched controls.

Key Words: *lamellar bone; vertebra; bone mineral crystals; osteoporosis*

Osteoporosis is a prevalent disease of the skeleton responsible for bone fractures and leading to disability [1,5]. Recent studies demonstrated that osteoporosis, apart from the loss of bone matter, is associated with changes in the ultrastructure and physico-chemical characteristics of the bone matrix (BM) [12]. These factors impair functional characteristics and adaptation potentialities of bones [11]. However, quantitative comparative analysis in such studies is impeded by scanty and contradictory data on the normal structure of BM components [17]. In light of this, structural analysis of specimens of the anterolateral zones of human vertebral bodies, where osteoporosis clinically manifests at early stages, attracts special interest [7].

We studied the microstructure of the lamellar bone and ultrastructural organization of BM mineral component in health and osteoporosis.

MATERIALS AND METHODS

Specimens of compact and spongy substance from the anterolateral zones of lumbar vertebrae I and II from. Group 1 comprised 36 male cadavers without bone pathologies and belonging to age groups IV (19-44 years) and VII (75-89 years) [4]. Group 2 comprised 5 male cadavers with osteoporosis (bone specimens were kindly provided by Prof. J. Dequeker, Louvene University, Belgium, within the framework of scientific cooperation "Biomed I: Evaluation of Bone Quality in Osteoporosis"). The diagnosis was made clinically and by double X-ray absorptiometry.

The samples were prepared for light, scanning (SEM), and transmission (TEM) electron microscopy by standard methods [8]. Some bone samples were deorganified in NaOCl solution. Specimens (3-5 mm thick) were cut out from the vertebrae of the anterolateral zone for histomorphometric analysis. Bone fragments for morphometrical studies were prepared routinely [2]. SEM was carried out using a Philips SEM-515 scanning electron microscope. Mineral particles obtained after mechanical disintegration [13] were studied by TEM. Bone mineral ultrastructures were studied by cryofractography [3]. Mineralization front of natural bone surface was studied without fracturing. The study was carried out under a Philips EM-420 transmission electron microscope.

RESULTS

Examination of group 1 specimens showed that the mineralization front of the vertebral anterolateral surface in age group IV was formed by fibrillar structures integrated in the surface bone plate and perforating ligamental fibers. The thickness of the cortical layer usually varies from 523 to 203 μ. The spongy sub-

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stance in the pericortical zones of the vertebrae in adult humans consists of bent planar trabeculae and few cylindrical structures lying between them. The number of cylindrical structures increases from periphery to the center of the vertebra.

The mineral component of the vertebrae is formed by prismatic crystals. They are integrated in the intrafibrillar, extrafibrillar crystal pools, and the crystal pool coating the formed bone surfaces. Mineral crystals inside the bone and on its surface lay individually (Fig. 1, *a*) or form coplanar consolidations with clearly seen interface. Coplanar consolidations of crystals form layers or compact groups (Fig. 1, *b*). The mean size of crystals and their groups are presented in Table 1.

In age group VII the thickness of compact layer is 290-116 μ. The trabecular architecture is changed: bone trabeculae are thinned or disappear. The number of horizontal (planar) structures decreases to a greater extent compared to vertical (cylindrical) structures (which become predominant). The mean relative volume of the bone decreased, trabeculae are thinned, and the intertrabecular spaces are extended (Table 2).

The coplanar crystal consolidations in BM of senile individuals are longer and wider compared to those in adult humans, while their thickness remained unchanged.

Examination of group 2 specimens showed that the thickness of the cortical layer in patients with osteoporosis did not exceed 233 μ and sometimes can decrease to 87 μ. In some cases it is virtually entirely occupied by cavities (Fig. 2, *a*). The mean relative volume of spongy substance can decrease to 54%. The thickness of trabeculae in group 2 is 18-45% lower than in age-matched controls. Horizontal trabeculae virtually completely disappear (Fig. 2, *b*), while intertrabecular spaces increase by 17-32%. Spatial distri-

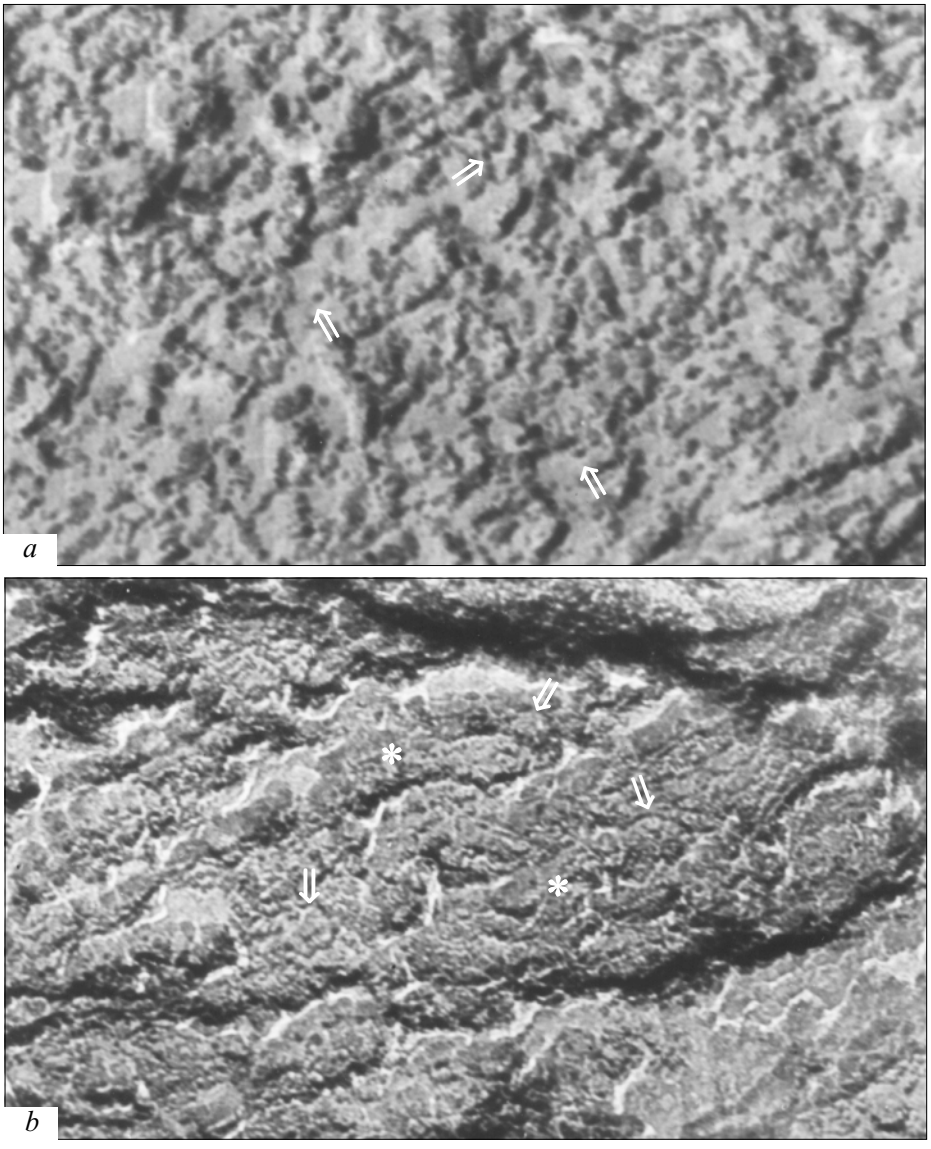

Fig. 1. Ultrastructural organization of mineral component of vertebrae. *a*) Individual mineral crystals on bone surface (arrows). Replica. TEM, ×292,400; *b*) compact groups (asterisks) of coplanar amalgamations of crystals (arrows) in the bone matrix. Replica. TEM, ×187,498.

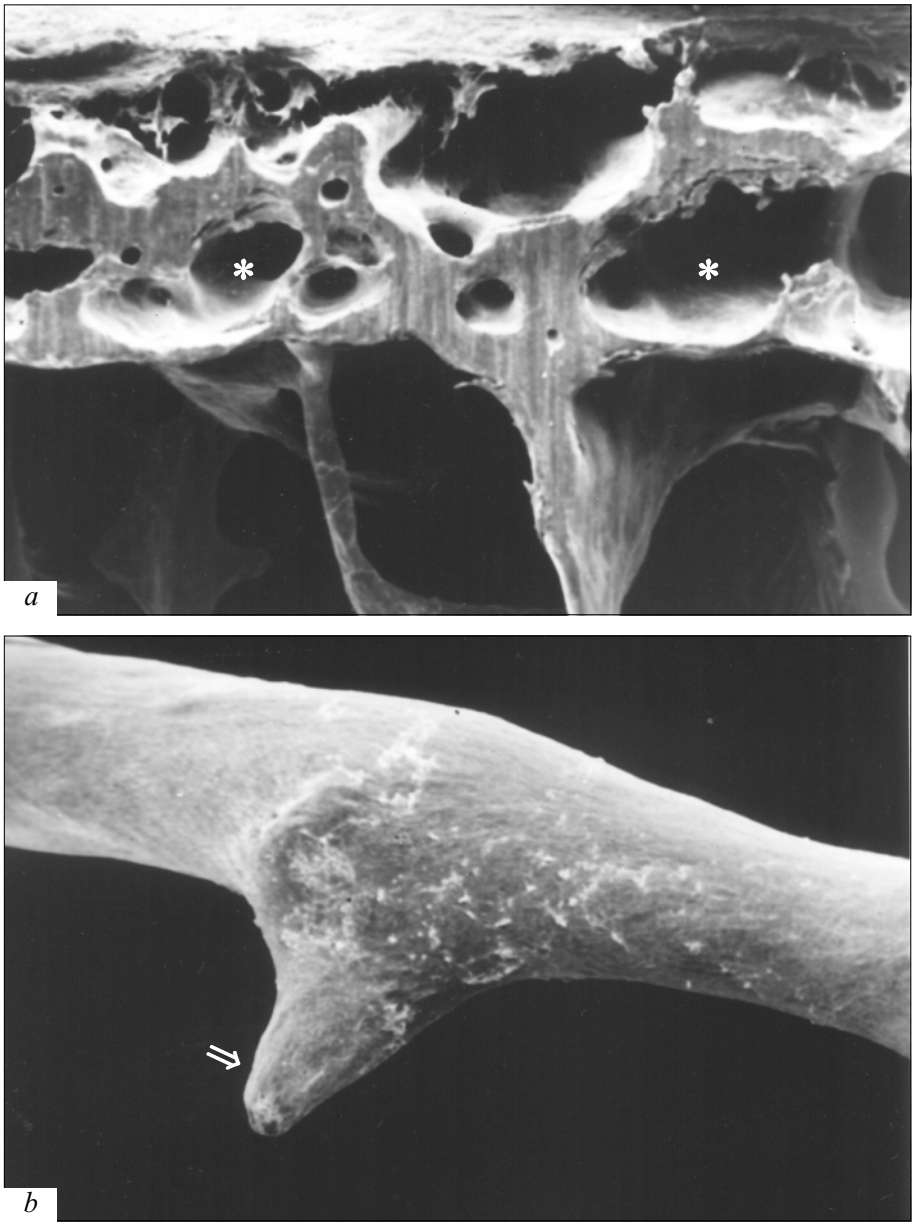

Fig. 2. Changes in the anterolateral zone of vertebrae in osteoporosis. *a*) numerous large cavities in the compact substance layer (asterisks). SEM, ×37; *b*) the remainder of resorbed horizontal bone beam (arrow) in spongy substance. SEM, ×222.

TABLE 1. Size of Mineral Crystals and Their Coplanar Amalgamations in BM of Normal Humans and Patients with Osteoporosis, TEM ($M \pm m$, $n \geq 100$)

Age group, years		Object of examination	Crystal size, nm		Size of coplanar consolidations of crystals, nm		
			length	width	length	width	thickness
IV, 19-44	normal value	IMP	13.49±0.44	7.44±0.54	29.94±1.28	18.83±1.16	3.49±0.19
		PCR	13.26±0.45	7.62±0.37	32.03±1.67	19.71±0.96	—
	osteoporosis	IMP	13.37±0.49	7.50±0.46	30.17±1.81	20.64±1.03	3.49±0.22
		PCR	13.66±0.41	7.79±0.37	30.99±1.11	19.77±0.82	—
VII, 75-89	normal value	IMP	13.31±0.39	7.61±0.37	37.33±1.36	21.57±1.20	3.55±0.25
		PCR	13.26±0.48	7.62±0.46	37.32±2.81	21.92±1.64	—
	osteoporosis	IMP	13.50±0.52	7.62±0.49	37.15±1.18	22.27±0.84	3.49±0.19
		PCR	13.55±0.43	7.79±0.28	38.20±3.45	22.91±1.85	—

Note. IMP: individual mineral particles; PCR: platinum-carbon replicas.

bution of the mineral component, shape and linear parameters of crystals and their consolidations in BM were not changed in osteoporosis (Table 1).

Hence, our findings indicate that the thickness of the compact substance layer and trabeculae decrease and the spongy substance is loosened and restructured during age involution in the anterolateral zone of the lumbar vertebral bodies. This can be explained by disorders in the bone remodeling cycle. For example, elongation of erosive lacunae and appearance of numerous lacunae without signs of BM filling in senile individuals indicate prolongation of the reversion phase and decreased bone formation activity, which can lead to the above-described changes in the compact and spongy substances of the vertebral bodies. Decreased number of trabeculae in the spongy substance can be compensated by greater thickness of vertical bone trabeculae [13].

These changes in the compact and spongy substances of the bone are more pronounced in osteoporosis. In the layer of compact substance this is due to deeper resorption on the endosteal surface [6]. In the spongy layer the reversion phase of remodeling process can be prolonged and the rate of bone formation decreases.

Mineral particles formed by bone mineral crystal are larger in senile individuals than in adult subjects. This difference can serve as a factor promoting BM mineralization during aging against the background of decreased content of organic component and water, increased Ca^{2+}/P^{5+} ratio, and numerous defects in the crystal network in BM [9].

Our study showed that the structural organization and spatial distribution of mineral components in BM in osteoporosis did not differ from those in age-matched control. This is at variance with the data of some scientists [14], who observed enlargement of mineral particles in this disease. This disagreement can be explained by the choice of material for this study [14] (vertebrae were collected from burial places, where they remained during 100-300 years under unknown conditions).

TABLE 2. Morphometric Characteristics of Spongy Substance of Bone Specimens ($M \pm m$)

Parameter	Age group (years)	
	IV (19-44)	VII (75-89)
Mean thickness of trabeculae, μ	147±5	96±19
Mean width of intertrabecular spaces, μ	1060±52	2078±209
Mean volume of bone, %	16.9±0.86	7.3±1.5

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