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# A Radiographic Analysis on Human Lumbar Vertebrae in the Aged

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*Summary.* Radiographic analysis was made on human lumbar vertebrae (1st to 3rd) from 101 autopsy cases (54 males, 47 females) without primary and secondary osteopathy. The materials consisted with 11 control cases (28–59 yr) and 90 cases of the aged subjects (60–92 yr). The aged subjects were divided into four groups by decades. One vertebral body was removed from the vertebral column and three bone specimens, one mid-sagittal (Plane A) and two mid-horizontal (Plane BL and BR) sections, of about 10 mm in thickness were prepared by a hand saw. Contact radiographs taken on films by a radiographic apparatus were analyzed.

Radiographic images of Plane A in control showed a typical checker pattern consisting of vertical and horizontal trabeculae within a rim of a transversely elongated square. Planes B showed a uniform ring pattern of about 1.0 to 1.3 mm in diameter within a semi-circular dense cortical margin. The trabecular image of the male was somewhat denser and wider than those of the female. Radiographically the aged vertebrae were classified into four types. Type I was a trabecular pattern indistinguishable from that of the control. Type IV was the most advanced from of vertebral atrophy. Type II and III were intermediate forms between previous two types. Early trabecular atrophy, which was characterized by slight decrease in trabecular density in Plane A and widened ring pattern in Planes B, was seen in Type II. In Type III, these features were further exaggerated. Horizontal trabeculae in Plane A became indiscernible and the ring pattern in Planes B widened more significantly. In Type IV, the typical trabecular pattern was no longer seen. Only a few trabeculae ran vertically crossing irregular horizontal trabeculae of thin appearance. These alterations appeared to be age-dependent as evident by an increasing percentage of Type III and IV in higher age groups: *Group less than 60 yr* (9 cases), Type I 72%, Type II 9%, unclassified 9%; *Group 6 decades* (12 cases), Type I 8%, Type II 84%, Type III 8%; *Group 7 decades* (40 cases), Type I 5%, Type II 25%, Type III 47.5%, Type IV 20%, unclassified 2.5%; *Group 8 decades* (37 cases), Type I 0%, Type II 19%, Type III 32.4%, Type IV 43.2%, unclassified 6.4%; *Group 9 decades* (1 case), one in Type III. Sex difference was not clearly appreciated. In addition, two types of trabecular alterations; (a) diffuse trabecular reinforcement, dominant in vertical direction, in vertebrae with advanced atrophy and (b) focal rarefaction in less atrophic vertebrae, were noted. Unusual trabeculae not seen in control specimens were recongnized in highly atrophic vertebrae. They may have been formed by remodelling of the cancellous bones against increasing weight stress on local tissues created by diminishing normal trabeculae.

Age-unrelated alterations were also noted. They were; (a) focal compact bone formation in both compact and cancellous bones, (b) exostosis and (c) fracture and flattening of the vertebral body. These changes may be seen more frequently in vertebrae with advanced atrophy; however, relation to ageing was inconsistent. The presence of a local fracture of both upper and lower rims without deformation of the vertebral body was distinguished. The significance of these radiographic alterations will be studied by a comparative histological examination on the same specimens used in radiography in future.

*Key words:* Vertebrae — Ageing — Radiography.

The skeletal tissue is one of the most popular organs for the study of the ageing phenomenon since various striking alterations, with or without clinical manifestations, are known to occur during senescence. Much information is available on the quantitative aspect of the changes, particulary in relation to senescence and metabolic impairments (Delling, 1973). Recent trends in investigation stress the quantitative evaluation of bone histology shown in undemineralized specimens obtained by iliac biopsy (Delling, 1973). Though an exhausting study on various human skeletal tissues, exclusion of vertebrae, in decalcified, paraffin-embedded specimens has been made by Dominok (1968), qualitative analyses of skeletal alterations related to ageing are fewer possiblly because the ageing phenomenon occuring in skeletal tissue is insignificant and less clearly revealed by histological examination.

Observations on human vertebrae by Eder (1960), Casuccio (1962), Atkinson (1967) and Arnold (1970) described interesting alterations of trabecular pattern in senescence. These studies stimulated us to a further analysis of the vertebral trabeculae in aged subjects. Since the skeletal structure is seen best by a x-ray examination, radiographic analysis was chosen as a preferrable method for this purpose. Bone preparations of about 10 mm in thickness using mid-sagittal and mid-horizontal plane preparations were used for this study based on an assumption that much information may be available from thick preparations, particulary in atrophic bone. This communication illustrates the architectural alterations in the vertebrae revealed by radiographic analysis of 101 autopsy cases ranging from 28 yr to 92 yr.

## Materials and Methods

One hundred and one lumbar vertebrae (1st to 3rd) from autopsy subjects, with excluding primary and metastatic osteopathy and ranging from 28 yr to 92 yr were studied radiographycally. The aged specimens were obtained from the autopsy cases of Yoikuin Hospital, Itabashi, Tokyo during 1973. Control specimens from younger subjects were obtained from the St. Lukes Hospital, Sumida, Tokyo. Age and sex of the materials used are listed in Table 1.

Table 1. Age and sex of the material examined

| | Male | Female | Total |
|---|---|---|---|
| Less than 60 years | 8 | 3 | 11 |
| 6 decades | 9 | 3 | 12 |
| 7 decades | 17 | 23 | 40 |
| 8 decades | 20 | 17 | 37 |
| 9 decades | 0 | 1 | 1 |
| Total | 54 | 47 | 101 |

One vertebral body was removed from the vertebral column by cutting off intervertebral discs and pedicles (radix arcus vertebrae). This procedure created frequently a defective body at the dorsal wall. The materials of which defect exceeded more than one fourths of the total ventro-dorsal length were not used for this investigation. Bone preparations of about 10 mm in thickness were prepared by a hand saw following the schedule illustrated in Fig. 1. By this method, the thickness of the majority (92% of the total) of the specimens fell within $10 \pm 1$ mm. As illustrated in Fig. 1, the specimens consisted of one mid-sagittal (Plane A) and a pair of mid-horizontal (Plane BL and BR) plane sections. The macroscopic appearance

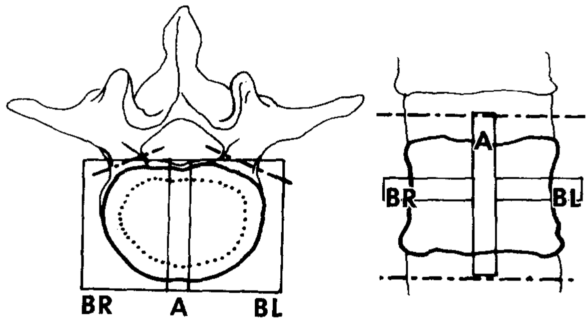



Fig. 1. A schema illustrating the schedule of bone preparation used for radiographic analysis. An upper horizontal view of a vertebra with processes on left and a frontal view of a vertebra with intervertebral discs on right. *A* mid-sagittal section (Plane A); *BL* and *BR* mid-horizontal sections (Plane B)

of these preparations was recorded photographically so as to compare with the radiographic images. Contact radiographs were taken on films (Fuji Softex Film FG, Fuji Photo Film Co., Tokyo) using a radiographic apparatus, Softex CMB (Softex Co., Tokyo). Photographic conditions were as follows; focal distance 40 cm, microfocus, secondary voltage 30 kv, current 2.5 mA, exposure 40 sec, developed by Sofdol (Fuji Photo Film Co., Tokyo) for 5 minutes at 20° C.

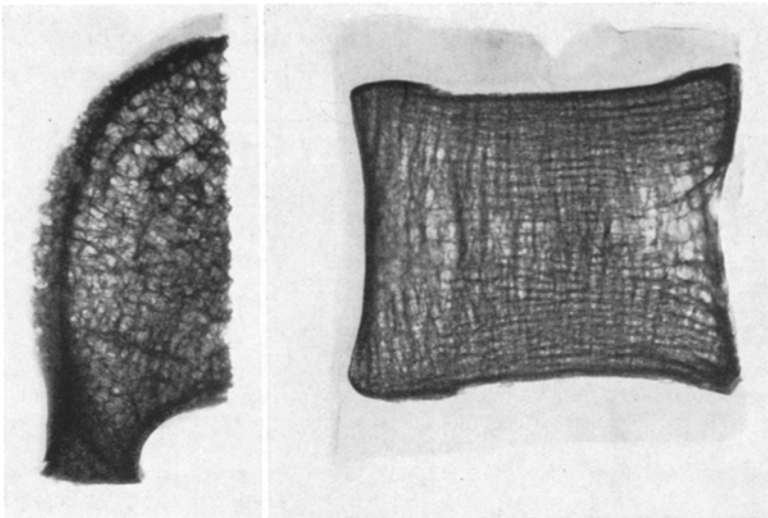
## Observations

### *1. Controls* (Fig. 2)

Radiographs of the vertebral specimens consisted of an opaque outer margin and a spongy internal portion. The former corresponded to the anatomical substantia compacta and the latter to the pars spongiosa. There was little deformation of the entire body structure.

#### A. Plane A

The opaque outer margin formed horizontally elongated square. Each wall concaved slightly inwards showing a smooth surface. Both upper and lower wall showed slight depression at the center corresponding to the face to intervertebral discs. Histologically these areas were covered by hyaline cartilage. The posterior wall was opened frequently due to the presence of a large venous vessel which runs horizontally at this level. The pars spongiosa of Plane A showed a lattice pattern made of vertical and horizontal trabeculae. In thin preparations, this feature has been described already (Atkinson, 1967; Arnold, 1970). Horizontal trabeculae may be classified into three zones, two end-zones and one mid-zone (Eder, 1960; Casuccio, 1962; Atkinson, 1967; Arnold, 1970). In radiographs of the control specimens, the end zones were not clearly distinguished possibly due to greater thickness of the preparation used in this study. The vertical trabeculae became less distinctive at the dorso-ventral margin near the middle level. In general the trabecular pattern of male vertebrae was thicker and denser than that of the female.



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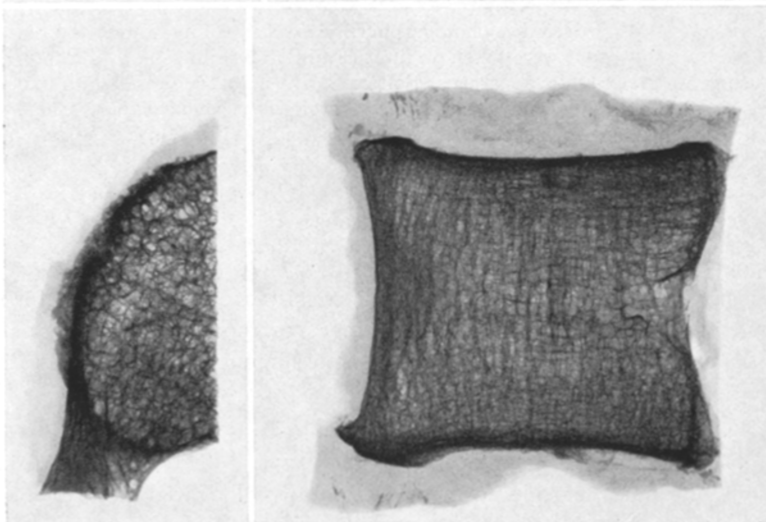

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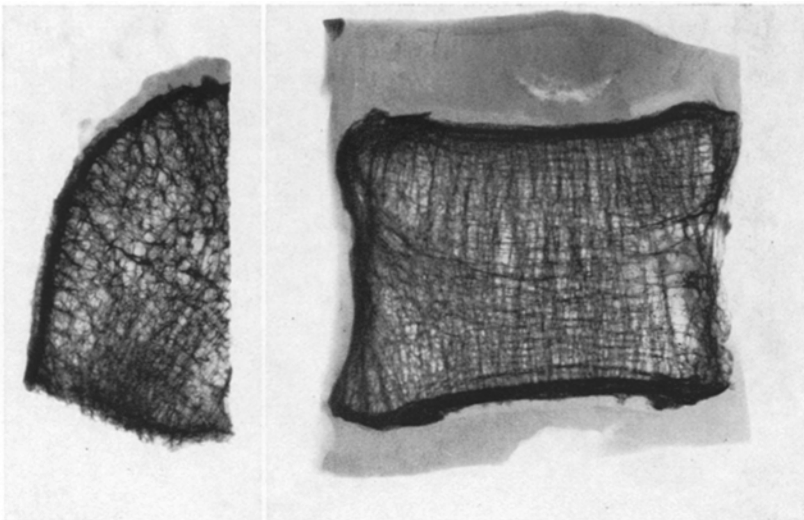
All radiographs are enlarged to 1.5 times from the original contact negatives

Fig. 2. Radiograph of Plane A (right, ventral side on left) and Plane B (left, ventral side on top) from a control case (37 yr male, thickness 10.0 mm). Note the typical checker pattern consisted with vertical and horizontal trabeculae in Plane A. Vertical struts are not clearly seen at ventral and dorsal margins. Plane B shows irregularly, but, fairly uniform ring pattern corresponded to pars spongiosa

Fig. 3. Type I: Well preserved vertebral trabeculae with minor local alterations uncommon in younger controls (deposition of opaque materials in intervertebral disc for an example). In Plane B, the ring pattern is not distinguishable from that of control. From a 75 yr female (thickness 10.5 mm)

### B. Plane BL and BR

Planes B showed nearly similar patterns. In perfect specimens they formed a semi-circle with radix projection at the dorsolateral site. A compact cortical rim



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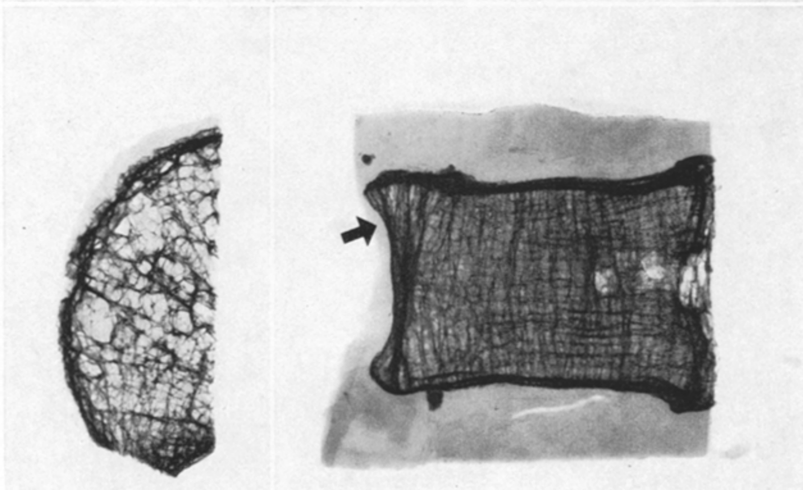

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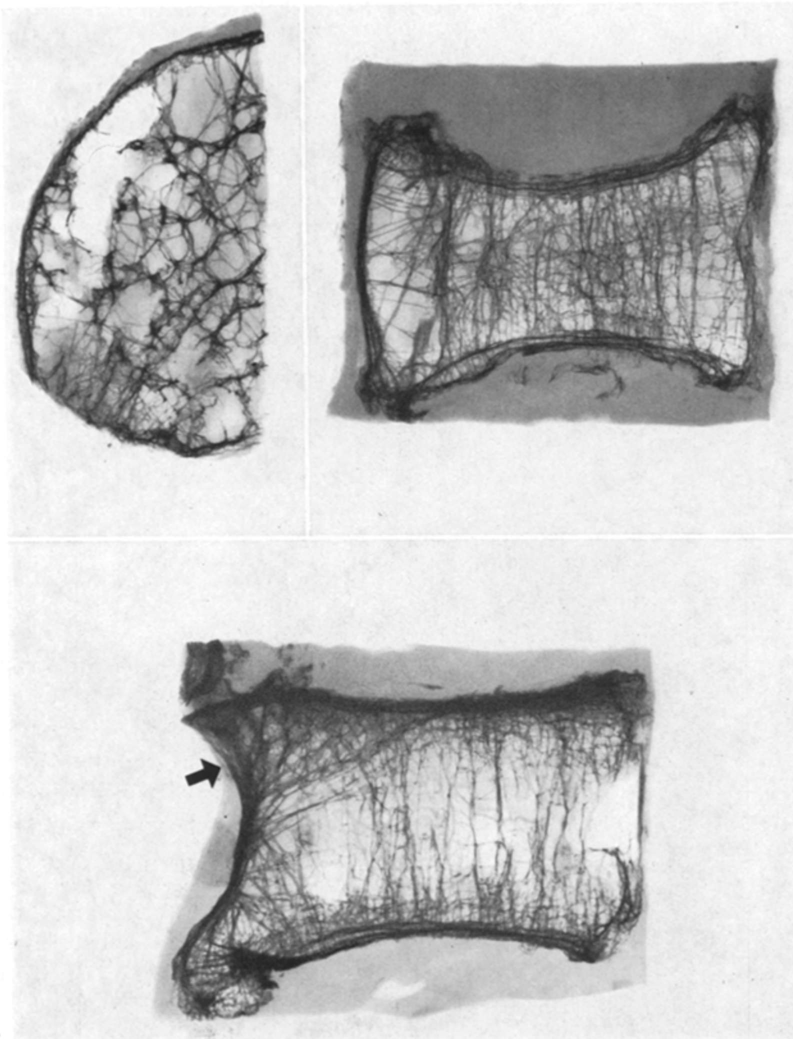
Fig. 4. Type II, intermediate form. Note slightly widened ring pattern in Plane B and decreased trabecular density in Plane A. From a 75 yr male (thickness 10.2 mm)

Fig. 5. Type III, advanced intermediate form. Widened ring pattern in Plane B. In Plane A, horizontal trabeculae at ventral margin, particularly of the upper side, are not clearly seen. Unusual vertical trabeculae (arrow) at the same position. From a 73 yr female (thickness 10.7 mm)

encircled the spongy bones at the lateral margin. The sawn-off face of the pars spongiosa was exposed at the median surface. The compact rim showed a smooth surfaced except for short spicules at the lateral margin. These spicules were created by superimposed images of a wider base of a rhomboid specimen. The pars spongiosa consisted of multiple ring patterns of about 1.0 to 1.3 mm in diameter formed by vertical and horizontal trabeculae. In closer observations,



a

b

Fig. 6 a and b. Type IV, advanced form. (a) Extremely widened ring pattern in Plane B and completely disappearance of normal horizontal trabeculae in Plane A. Irregular horizontal trabeculae and a few vertical struts are only seen. From a 83 yr male (thickness 9.9 mm). (b) This picture demonstrates the presence of abnormal trabeculae at upper ventral edge (arrow). Significant exostosis at upper and lower ventral edges is also seen. From a 84 yr male (thickness 7.7 mm)

two major streams were distinguished in horizontal trabeculae; one radiated from the center of the vertebral body and the other was arranged concentrically along the vertebral margin. The latter pattern became denser at the dorsal portion and transformed eventually into the central trabeculae of the radix projection.

*2. Vertebrae of the Aged* (Fig. 3 through 14)

In the aged subjects, skeletal alteration is appreciated best in the pars spongiosa (Atkinson, 1967; Arnold, 1970). Alteration in the substantia compacta was rather insignificant except in highly deformed vertebrae resulting from either fracture or exostosis.

A. Alterations of the Pars Spongiosa

The trabecular pattern of the pars spongiosa revealed by radiography may be classified into the following four types.

*(i) Type I* (Fig. 3). Trabecular pattern of this group showed essentially little difference from that of the control. However, certain age-related phenomena, such as less distinctive horizontal trabeculae, slight deformation of entire vertebral shape or deposition of opaque materials in the intervertebral discs may be seen. Fig. 3 is a vertebra of Type I noted in a 75 yr female.

*(ii) Type II and Type III* (Figs. 4, 5). These types formed an intermediate stage between Type I and Type IV, and the latter included the most advanced form of vertebral atrophy. Because of a rather wide range in alterations, the intermediate stage was divided into two types. The first type, defined as Type II, was characterized radiographically by appreciable but a slight decrease in trabecular density both vertically and horizontally in Plane A, and a widended ring pattern in Planes B. An example is shown in Fig. 4. This type, as in the later types, showed occasionally advanced deformation of the vertebral body and local alterations as described later. The second type (Fig. 5), Type III, may be defined as the advanced intermediate type. The alteration may be characterized by further widened ring pattern in Planes B and diminishing horizontal trabeculae in Plane A. The latter change is well in accordance with the observations on aged vertebrae by others (Atkinson, 1967; Arnold, 1970). Fig. 5 illustrates one of such examples. Both local and general deformations of the vertebral body were more frequently seen in this type (85% of Type III) than in Type II (37%).

*(iii) Type IV* (Fig. 6a, b). As previously described, this type included the most advanced form of atrophic vertebrae. The skeletal trabeculae of this type were so thin and highly irregular that nearly 90% of the vertebral body was highly deformed. Fig. 6a shows a radiograph of this type with slight deformation. In this type, the typical lattice pattern in Plane A was no longer discernible (Fig. 6a, b). Horizontal trabeculae had nearly all disappeared and several vertical struts were seen left near the centre. These trabeculae appeared to be thinner and arranged irregularly. There were unusual trabeculae run randomly in the entire body. In Planes B, the ring pattern was widened significantly. Peculiar trabeculae appeared as if they were supporting an hanging edge of the upper ventral surface were seen frequently (Fig. 6b). These trabeculae were not seen in the control specimen and may be created in response to unusual local stress in highly atrophic vertebrae.

The alterations of cancellous bones observed radiographically in the aged vertebrae are illustraed schematically in Fig. 7.

Two types of trabecular alterations not included in the previous types were distinguished (Figs. 8, 9). They may not be related to the ageing phenomenon. The first type is the trabecular pattern consisted with diffuse increase in fibrillar

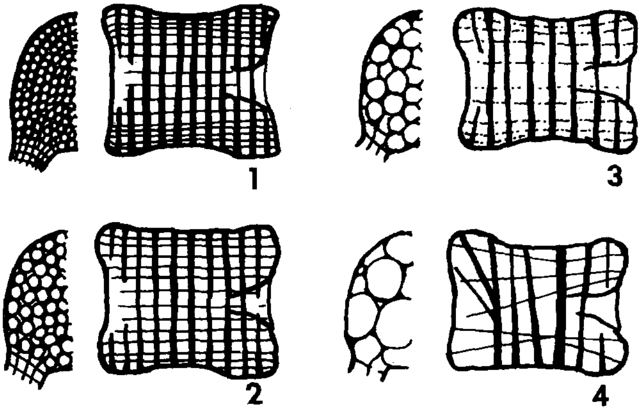



Fig. 7. Radiographic trabecular patterns appeared in each type are schematically illustrated. 1. Type I, checker pattern in Plane A and small uniform ring pattern in Plane B. 2. Type II, slightly distended ring pattern in Plane B and slight decrease in trabecular density in Plane A. 3. Type III, widened rign pattern in Plane B and partly disappeared horizontal trabeculae in Plane A. 4. Type IV, extremely distended ring pattern in Plane B and significantly decrease in trabecular density in Plane A

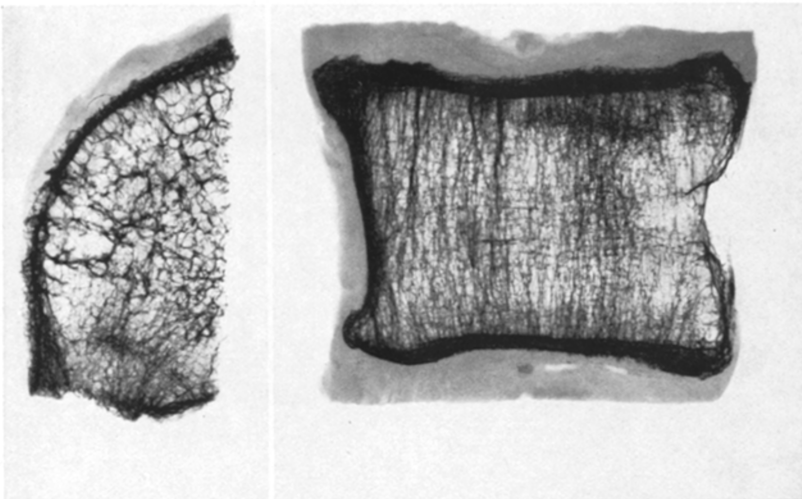
trabeculae throughout the entire vertebral body (Fig. 8). Trabecular increase may occur in both vertical and horizontal directions, but, vertical feature is usually prominent. The original trabecular pattern, if discernible any, showed insignificant disarrangement. Fine fibrillar trabeculae, which may be interpreted as reactive bone formation, were seen locally near or around the fracture site. Radiographic images of such reactive bone formation are essentially similar to the present alteration. This trabecular alteration may be interpreted as a reinforcement of trabeculae in atrophic vertebrae. The second type (Fig. 9) is the pattern consisted with focal rarefaction in a less atrophic cancellous bone. As seen in Fig. 9, larger clear zones scattered among smaller ring pattern. This alteration may be interpreted as advanced local rarefaction in a less atrophic vertebra.

B. Local and Entire Deformations of the Vertebrae

Local and entire deformation of the vertebrae were noted in many occasions. The deformation occurred in both compact and cancellous bones. The change may be unrelated to the ageing.

*(i) Local Condensation of Bone* (Figs. 10a, b). Local condensation of bone may be seen in the substantia compacta and the pars spongiosa. The change was seen more frequently in the former structure. This may or may not be related to fracture of the local tissue.

*(ii) Exostosis* (Spondylosis deformans) (Figs. 6b, 11). Significant exostosis may be seen in vertebrae of the aged. The change occurred most frequently on the ventral margin of the vertebral body particularly at both upper and lower edges (Figs. 6b, 11). In the extreme case, a bone projection from the lower edge reached to a similar projection from the upper edge of the next low vertebra.



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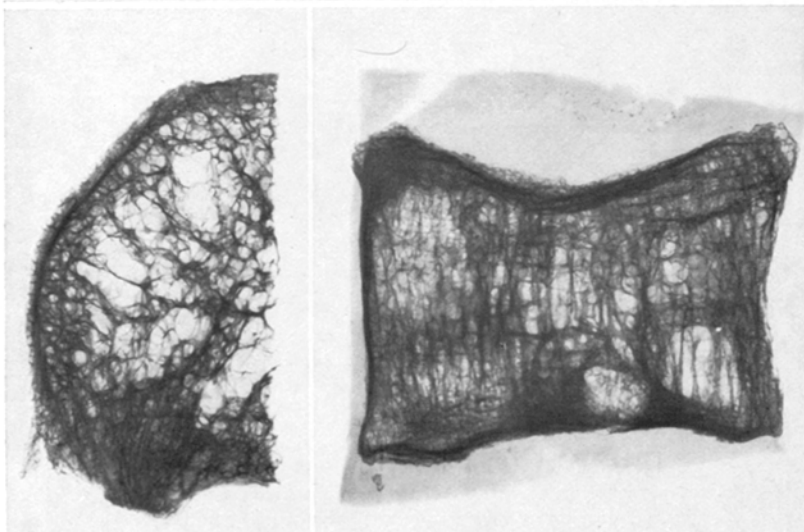

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Fig. 8 and 9. Unusual trabecular patterns not included in previous four types

Fig. 8. Diffuse increase in fibrillar trabeculae. Note absence of fracture and well preserved ring pattern in Plane B. From a 92 yr female

Fig. 9. Local rarefaction in less atrophic vertebra. The change is seen well in Plane B. From a 83 yr male

*(iii) Fracture* (Figs. 12, 13a, b). Fracture of the vertebral body was seen quite frequently. This is the major cause of significant vertebral deformation. Two types may be classified. The first type (Fig. 12) is a local fracture without deformation of the entire vertebral body. Radiographs of this type appeared as local condensation of trabeculae with pattern disarrangement. Sometimes local increase of thin trabeculae described in the previous section may be associated. Histo-

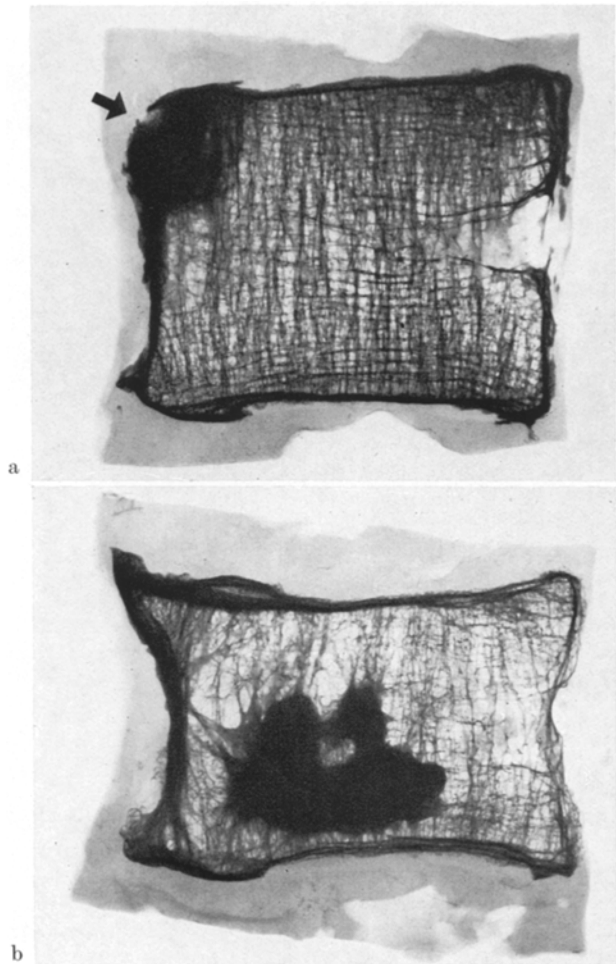

Fig. 10. (a) Focal condensation of cortical bone (arrow). From a 86 yr male. (b) Focal condensation in pars spongiosa. From a 85 yr male

logical examination revealed a fracture of cortical bone, invasion of hyaline cartilage in cancellous bone and reactive bone formation, which suggest a preceding fracture at this locus. The fracture of this type occurred at both upper and lower rims of vertebral body near the center. Both rims were affected equally, however, incidence of upper rim fracture was higher in vertebrae with advanced atrophy (Type IV). The next type is a large fracture leading significant body deformation (Fig. 13a, b) and may include a compression fracture of clinical entity. Both upper and lower rims were affected. Fracture of the vertebral body was more frequently seen in the vertebra with advanced atrophy; 17% in Type II, 27% in Type III and 58% in Type IV. The fine trabeculae, reactive bone formation, were seen commonly in the fractured vertebral body. Increase of fine trabe-

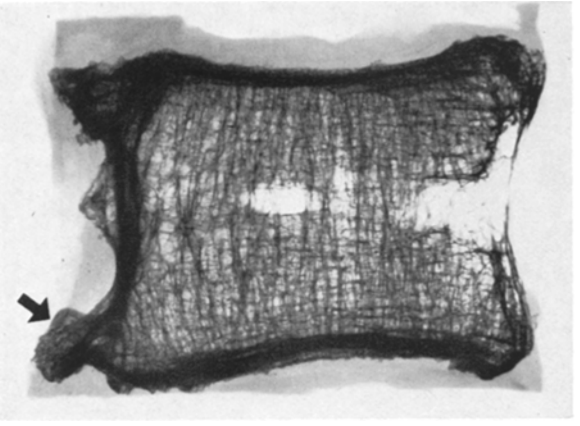

Fig. 11. Exostosis (arrow). From a 79 yr male

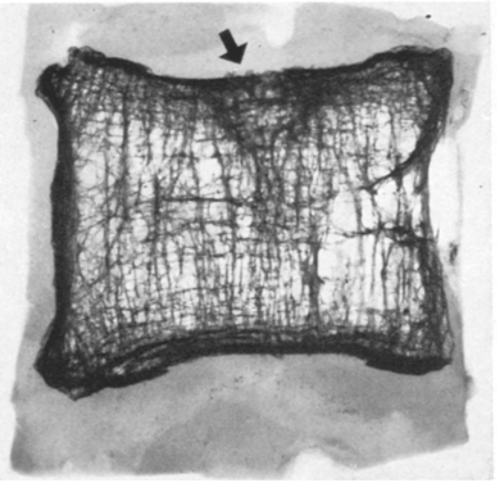

Fig. 12. A local fracture (arrow) of an atrophic vertebra without deformation. From a 86 yr female

culae were sometimes so significant that the original trabecular pattern became indistinctive (Fig. 13a). In a few occasions, fractured vertebrae did not show reactive bone formation as illustrated in Fig. 13b. Absence of reactive trabeculae suggested insufficiency in local reaction either by time cause or biological activity.

*(iv) Deposition of Opaque Materials in the Intervertebral Disc* (Fig. 14). Deposition of opaque material, possibly calcification, may be seen in the intervertebral discs. The pattern and extend of material deposition varied considerably in cases and there was no apparent relation to the grade of vertebral atrophy.

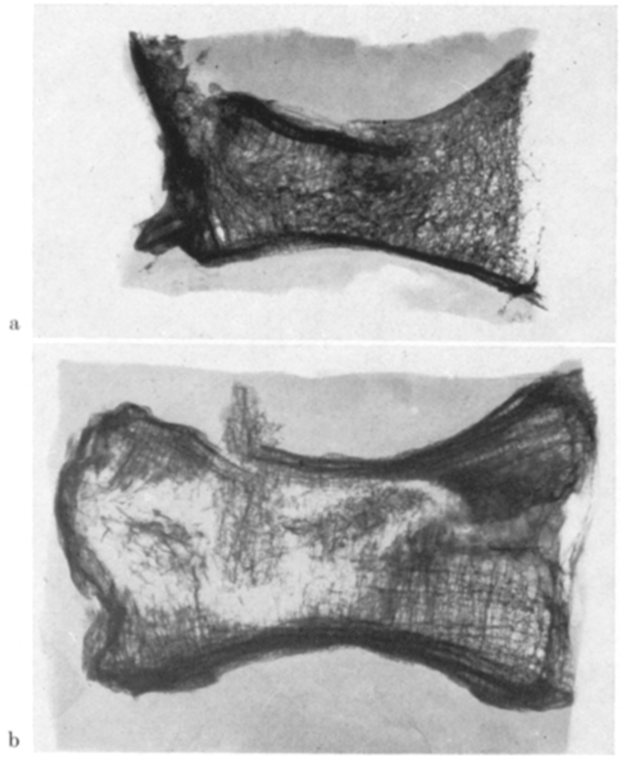

Fig. 13a and b. Fractures with significant body deformation. (a) With reactive bone formation. Note the presence of irregularly distended trabeculae in the fractured body. From a 89 yr male. (b) Without reactive bone formation. Note the absence of reactive bone formation in the fractured bone. From a 69 yr male

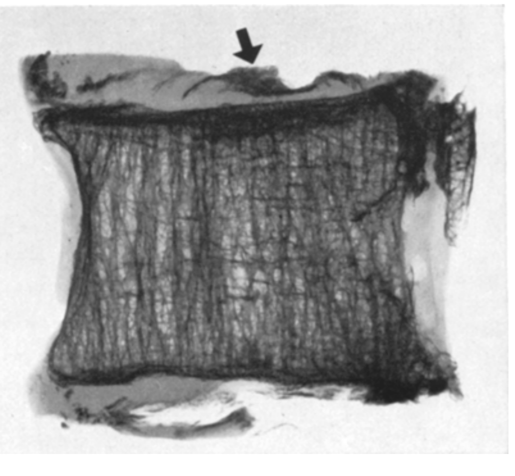

Fig.14. Deposition of x-ray opaque material in the intervertebral discs (arrow)

## Discussion

Radiographic analysis on thicker vertebral preparations of the aged subjects appeared to confirm the earlier observations made by others (Eder, 1960; Casuccio, 1962; Atkinson, 1967; Arnold, 1970). Diminishing entire skeletal volume by loss of cancellous bones, prominent in horizontal trabeculae, and irregular thickening of vertical struts have been accounted as the typical features of vertebral alterations in the aged (Atkinson, 1967; Arnold, 1970). Such alterations were recognized fully by this present investigation. In addition, peculiar trabecular pattern in highly atrophic vertebrae (Fig. 6a, b), fine reactive bone formation in fractured (Fig. 13a) and intact vertebrae (Fig. 8), local fracture of upper and lower rims (Fig. 12), focal bone formation (Fig. 10a, b) and focal rarefaction in less atrophic bones (Fig. 9) are new observations not recorded in the previous reports. These alterations may be difficult to distinguish by the previous methods in which macroscopic observation on thin (a few millimeters in thickness) macerated specimens were selected. Thicker preparations were easily made from highly atrophic bone without significant detoriation of the original structure. More trabeculae included in thicker preparation may serve for better, perhaps more precise, understanding of trabecular alterations in highly atrophic vertebrae. Additional studies on horizontal plane sections contributed to detect slight widening of the ring pattern. By these reasons radiographic analysis on thicker preparations may be the most suitable method for morphological analysis of the aged vertebrae. Comparative histological examination on the same bone preparations used for radiographical studies, which is under progress in our laboratory, might strength the precise interpretation of skeletal alterations in the aged. However, some of these features may not be fully adequate for the study of normal vertebrae as examplified by a failure in demonstrating the specific trabecular pattern, the end zone of Arnold's classification (Arnold, 1970), in less atrophic bones. This is apparently due to difficulty in separating overlapped images of the trabeculae in less atrophic specimens.

As shown in Table 2, the alterations of trabeculae classified into four types showed a close relation to the ageing. Difference in relation to either sex or primary diseases was not clear. It has been accepted that advancing skeletal rarefaction in the aged is produced by imbalanced activity of bone remodelling due to significant reduction in new bone formation in contrast to less affected activity of bone resorption (Delling, 1973). An age-related, characteristic histological sequence may be seen in various bones (Dominok, 1968). Mechanical factors such as less important activity of horizontal structs in supporting the body weight may determine the reduction sequence of bone trabeculae (Atkinson, 1967). Addition to the earlier conclusion by others, which usually stressed resorption of trabeculae during senescence, the author likes to emphasize the persistent remodelling activity, though insignificant, in the senile bone as seen in appearance of unusual trabeculae and reactive bone formation. It is unlikely that such unusual trabeculae are formed by simple dislocation or deformation of preexisting normal trabeculae. Rather they may be formed to support increasing weight stress on local tissues created by diminishing important trabeculae during senescence.

Table 2. Incidence of radiographical types in each age group

| Age group | Sex | Radiographical types | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | uc[a] | |
| Less than 60 years | m | 5 | 1 | — | — | 2 | 8 |
| | f | 3 | — | — | — | — | 3 |
| 6 decades | m | — | 8 | 1 | — | — | 9 |
| | f | 1 | 2 | — | — | — | 3 |
| 7 decades | m | 1 | 4 | 12 | — | — | 17 |
| | f | 1 | 6 | 7 | 8 | 1 | 23 |
| 8 decades | m | — | 7 | 3 | 8 | 2 | 20 |
| | f | — | — | 9 | 8 | — | 17 |
| 9 decades | m | — | — | — | — | — | 0 |
| | f | — | — | 1 | — | — | 1 |
| Total | | 11 | 28 | 33 | 24 | 5 | 101 |

[a] uc = unclassified.

Advanced decrease in skeletal volume results general osteoporosity. When skeletal porosity reached to a pathological level detectable clinically in radiographs, the diagnosis of osteoporosis is made. In contrast to similar change in young addults, pathological porosity in the aged is not easily distinguished from a physiological involutional change. Such difficulty invites a delicate difference in interpretation of senile osteoporosis. Atkinson and Woodhead (1973) have stated that senile osteoporosis could be merely an extension of the development process rather than a degenerative process. This view is, perhaps, favored by many at present. Arnold *et al.* (1966) have distinguished clearly senile osteoporosis from physiological involutional changes by macroscopic study on vertebral morphology. Type IV of the present classification corresponded apparently to senile osteoporosis of Arnold's description. However the presence of various intermediates between Type I and Type IV suggests that Type IV is not specific form of porosity only detectable in the senile vertebrae, at least at morphological level. Fibrillar bone formation noted in atrophic vertebrae without fracture is of interesting. They may be reinforcement of porous bones rather than repair of deformation. Failure or insufficiency of the reaction may lead further deformation and porosity of the vertebra. The problems relating to senile osteoporosis will be analyzed in future study using comparative histological examination on the same specimens used in radiography.

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