STRUCTURE AND BONE MINERAL DENSITY OF BABOON VERTEBRAE

YOSHIYUKI TOHNO[1)], SETSUKO TOHNO[1)], KAZUHIKO FURUTA[2)], MAMORU MORIMOTO[2)], YUMI MORIWAKE[1)], CHO AZUMA[1)], MASA-OKI YAMADA[1)] and MOTOHARU HAYASHI[3)]

1) *Department of Anatomy and*
2) *Department of Orthopedic Surgery, Nara Medical University*
3) *Department of Cellular and Molecular Biology, Primate Research Institute, Kyoto University*
Received June 4, 2003

Abstract : The authors dissected a 5-year-old male baboon and examined the structure and bone mineral density (BMD) of the vertebrae. The baboon backbone consisted of 7 cervical, 12 thoracic, 7 lumbar, 3 sacral, and 19 coccygeal vertebrae. It was observed that long accessory processes were present in the 10th-12th thoracic and the 1st-5th lumbar vertebrae. The superior articular process was held between the accessory and inferior articular processes of the adjacent vertebra. Therefore, the rotary movement of the vertebral column was restricted in the range between the 10th thoracic and 5th lumbar vertebrae. Regarding the intervertebral joint, the position of axis for rotation was shifted from ventral to dorsal direction on the superior and inferior views of the 10th thoracic vertebra. The average BMD of the vertebrae was the highest in the cervical vertebrae, and decreased in the order of the lower thoracic, lumbar, and upper thoracic vertebrae.

Key words : Baboon, vertebra, bone mineral density, accessory process, intervertebral joint

INTRODUCTION

The mineral content was previously examined in the cervical, thoracic, and lumbar vertebrae of humans[1,2] and it was reported that the content of calcium and phosphorus was the highest in the cervical vertebrae, and decreased in the order of the upper thoracic, lower thoracic, and lumbar vertebrae. There are some reports regarding the structure of vertebrae[3,4] and the bone mineral density of lumbar vertebrae in monkeys[5-10]. However, there are few reports examining the bone mineral density of the cervical, thoracic, and lumbar vertebrae of Primates.

The authors had an opportunity to dissect and examine the structure and bone mineral density of baboon vertebrae. It was observed that long accessory processes were present in the last three thoracic vertebrae and the 1st-5th lumbar vertebrae, and it was found that the bone mineral density of the vertebral body was higher in the order of the cervical, lower

Correspondence to : Professor Yoshiyuki Tohno, Department of Anatomy, Nara Medical University, Kashihara, Nara 634-8521, Japan TEL No.: 0744-22-3051 FAX No.: 0744-24-8432 E-MAIL: ytohno@naramed-u.ac.jp

thoracic, lumbar, and upper thoracic vertebrae.

MATERIALS AND METHODS

Materials

The animal experiment was carried out in accordance with the US NIH Guide for the care and use of laboratory animals. The baboon, a 5-year-old male, was raised at the Primate Research Institute, Kyoto University. It was pretreated with intramuscular injection of ketamine hydrochloride (10 mg/kg), deeply anesthetized by intravenous administration of pentobarbital sodium (Nembutal; 30 mg/kg), and sacrificed by severing the common carotid artery. The vertebrae were resected from the spinal column after adhered muscles and ligaments were removed.

Measurement of Bone Mineral Density (BMD)

BMD of the vertebral bodies was measured by dual-energy X-ray absorptiometry (DPX-L X-Ray Bone Densitometer, Lunar Corporation, Madison, WI, USA). Scans were carried out in accordance with the manufacturer's recommendations using small animal appendicular options software (Lunar Corporation). The mode of measurement was performed at a pixel size of 0.15 x 0.30 mm[11].

X-Ray Examination of Vertebrae

The vertebrae were photographed with a soft X-ray apparatus (Softex type E40, Softex Co., Osaka, Japan) as described previously[12].

RESULTS

Structure of Baboon Vertebrae

The backbone of the male baboon was composed of 7 cervical, 12 thoracic, 7 lumbar, 3 sacral, and 19 coccygeal vertebrae. As shown in Fig. 1, long and slender accessory processes were present in the range from the 10th thoracic to the 5th lumbar vertebrae. The accessory process was a trace in the last two lumbar vertebrae of the 6th and 7th lumbar vertebrae. The transverse process of the thoracic vertebrae above the 8th thoracic vertebra projected horizontally, but it declined gradually and perpendicularly in the thoracic and lumbar vertebrae below the 8th thoracic vertebra (Figs. 1 and 2). Although the superior articular process was not tightly held in the 11th and 12th thoracic vertebrae (Figs. 1A and 1B), it was tightly held between the accessory and inferior articular processes of the adjacent vertebra in the 1st-5th lumbar vertebrae (Fig. 3). Therefore, the rotation of the vertebral column was much restricted in the range between the 1st and 5th lumbar vertebrae.

Rotation Movement of Intervertebral Joint

The axis of rotation at the intervertebral joint was examined in the thoracic and lumbar vertebrae. Figure 4 indicates that the position of axis for rotation at the intervertebral joint is shifted from ventral to dorsal direction on the superior and inferior views of the 10th

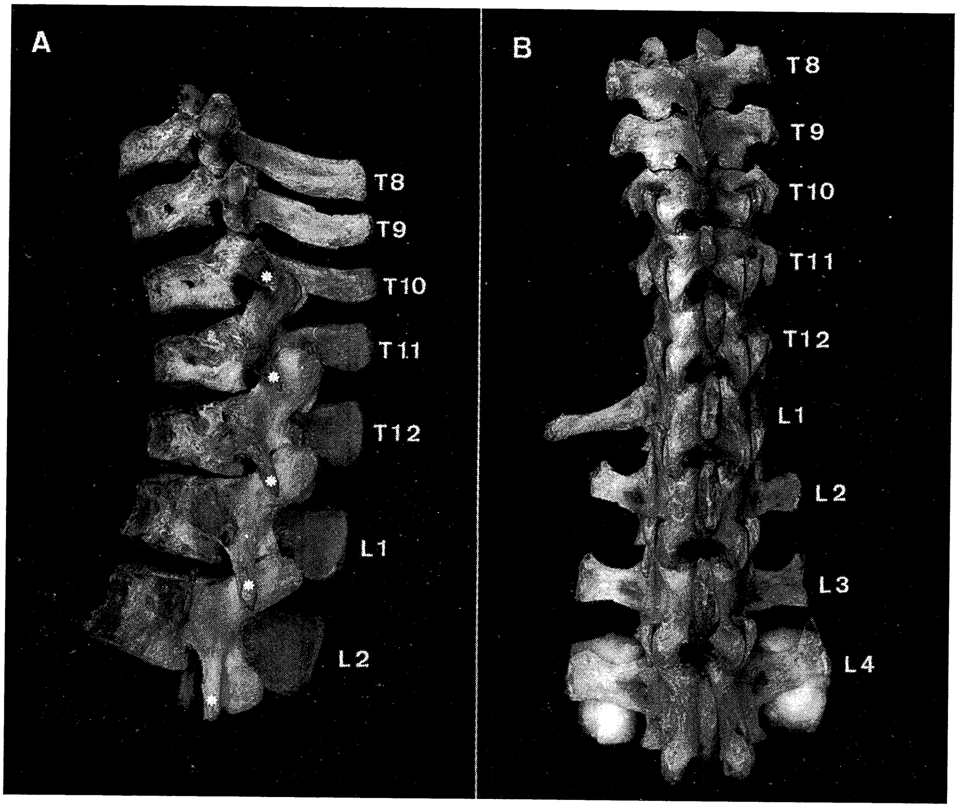

Fig. 1.

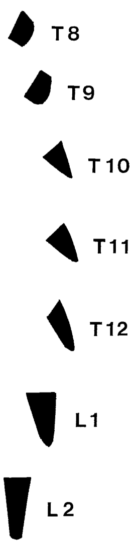

Fig. 2.

Fig. 1. Lateral (A) and posterior (B) views of the lower thoracic and upper lumbar vertebrae. The asterisk in Fig. 1A indicates the long accessory process.

Fig. 2. Tracing of the accessory processes in the lower thoracic and upper lumbar vertebrae shown in Figure 1A.

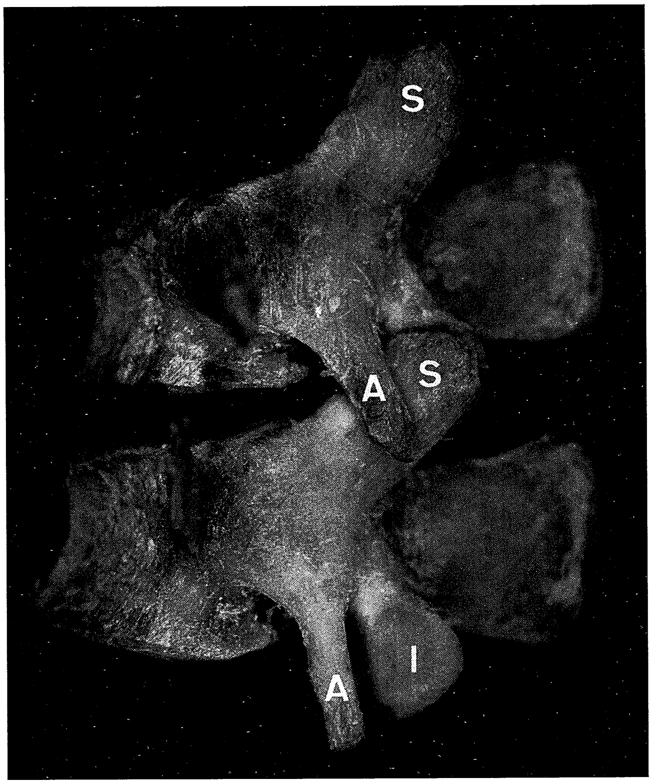

Fig. 3. Lateral views of the 1st and 2nd lumbar vertebrae. A, I, and S denote the accessory, inferior articular, and superior articular processes, respectively.

thoracic vertebra. The position of axis for rotation at the intervertebral joint was ventral in the thoracic vertebrae above the 10th thoracic vertebra, whereas it was dorsal in the 11th and 12th thoracic and the lumbar vertebrae below the 10th thoracic vertebra.

Bone Mineral Density of Vertebrae

The BMD was measured in the vertebral bodies of the cervical, thoracic, and lumbar vertebrae. As shown in Fig. 5, the BMD was highest in the upper cervical vertebrae and was lowest in the upper thoracic vertebrae, with some exceptions. Table 1 indicates that the average BMD is higher in the order of the cervical, lower thoracic, lumbar, and upper thoracic vertebrae. It should be noted that the average BMD was slightly higher in the lower thoracic and lumbar vertebrae in comparison with that of the upper thoracic vertebrae.

Figure 6 shows the radiographs of the lower thoracic and lumbar vertebrae in the baboon. The vertebral bodies of the lumbar vertebrae seemed to be moderately dense. As shown in Fig. 6, the vertebral bodies of the lumbar vertebrae were trigonal prism.

Figure 5 also shows the ratio of length of the accessory process to mean height of the vertebral body. The ratio was highest at the 12th thoracic and the 1st lumbar vertebrae, and decreased thereafter.

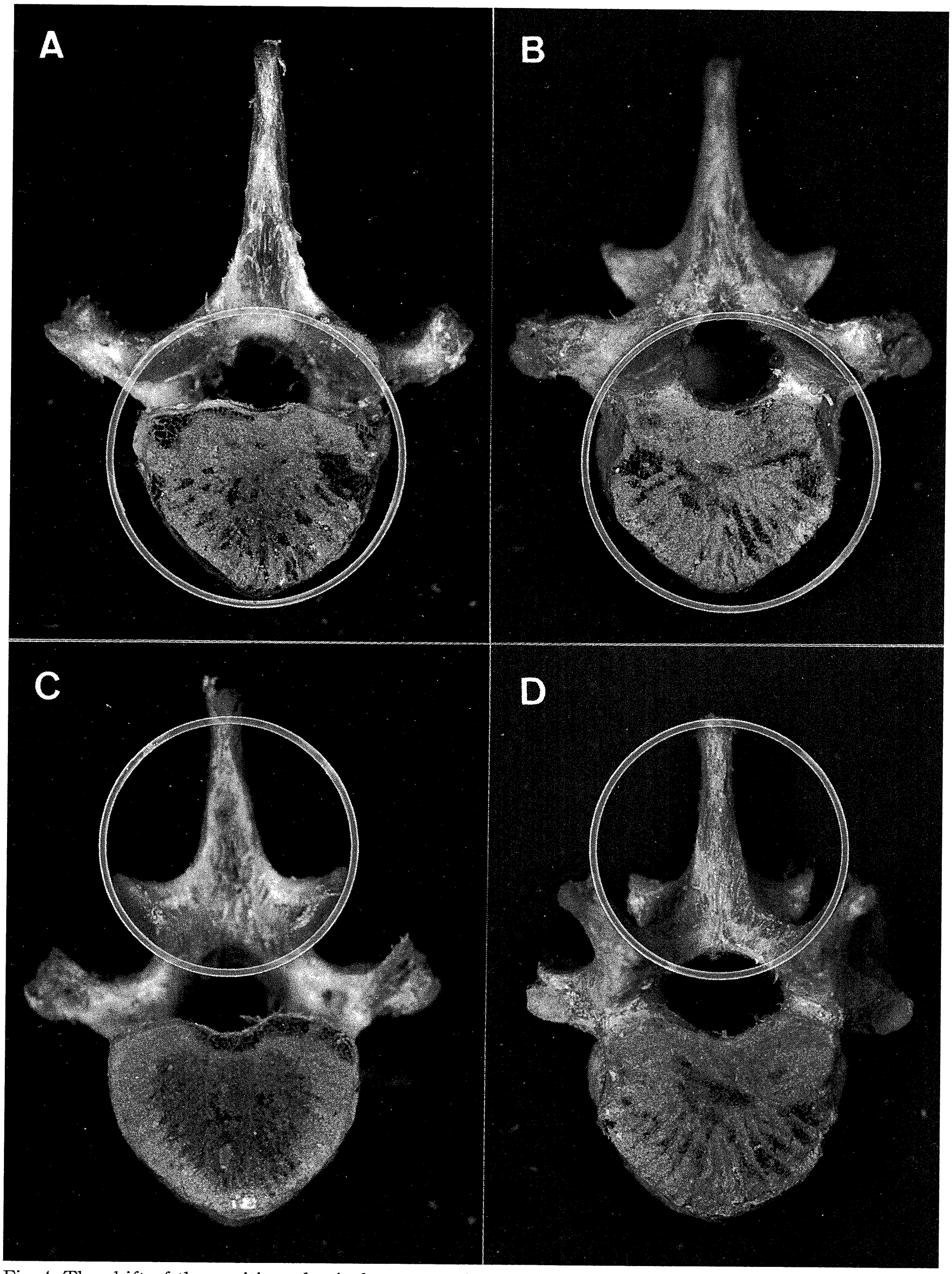

Fig. 4. The shift of the position of axis from ventral to dorsal direction for rotation at the intervertebral joints. The white circles show the rotary movement at the intervertebral joint. A, inferior view of the 9th thoracic vertebra; B, superior view of the 10th thoracic vertebra; C, inferior view of the 10th thoracic vertebra; and D, superior view of the 11th thoracic vertebra.

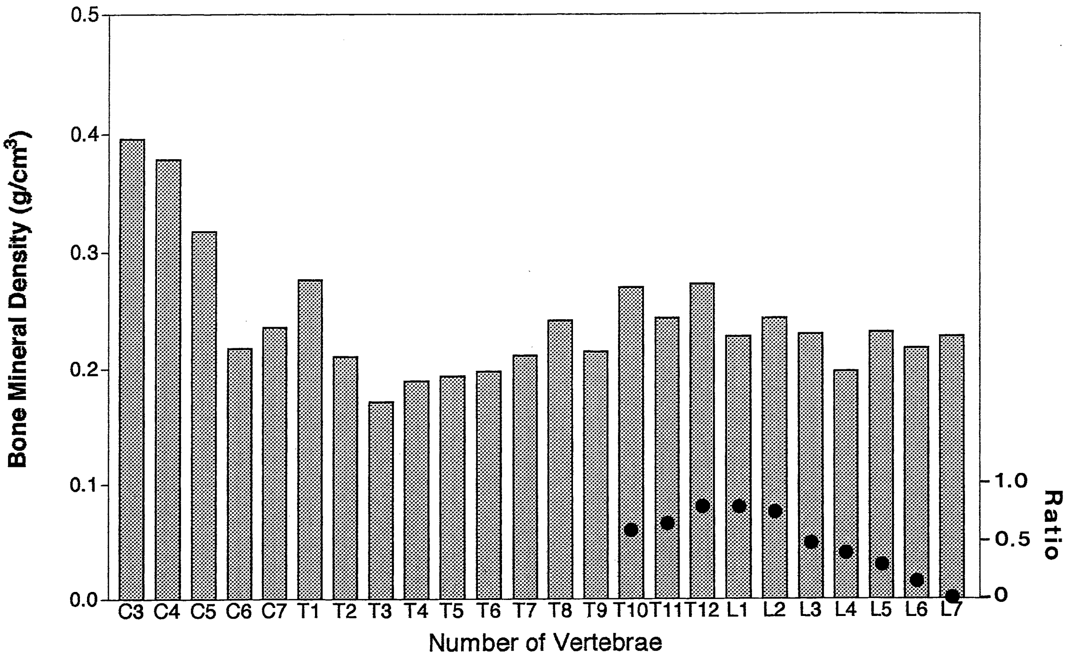

Fig. 5. The BMD of the baboon vertebrae. The bars and solid circles indicate the BMD of the vertebrae and the ratio of length of the accessory process to mean height of the vertebral body, respectively.

Table 1. Average BMD of Baboon Vertebrae

Vertebra	Average BMD (g/cm^3)
Cervical	0.309 ± 0.081
Upper Thoracic (1-6)	0.207 ± 0.037
Lower Thoracic (7-12)	0.243 ± 0.026
Lumbar	0.225 ± 0.014

DISCUSSION

The present study revealed that long and slender accessory processes were present in the range from the 10th thoracic to the 5th lumbar vertebrae in the baboon.

Kimura et al.[4] studied the vertebrae of crab-eating monkeys (Macaca fascicularis) and reported that the last two thoracic and the 1st–5th lumbar vertebrae had a distinct accessory process ventral to the inferior articular process, and that the superior articular and mamillary processes were tightly held between the accessory and inferior articular processes of the adjacent vertebra. Except for the 10th thoracic vertebra, long and slender accessory processes in the baboon were present in the same vertebrae as the crab-eating monkey. They were morphologically similar to each other. In humans, the accessory process of the lumbar vertebrae is much shorter. Therefore, it is able to rotate slightly at the intervertebral joint in the lumbar vertebrae of humans[13].

In the baboon, the position of axis for rotation at the intervertebral joint was shifted from

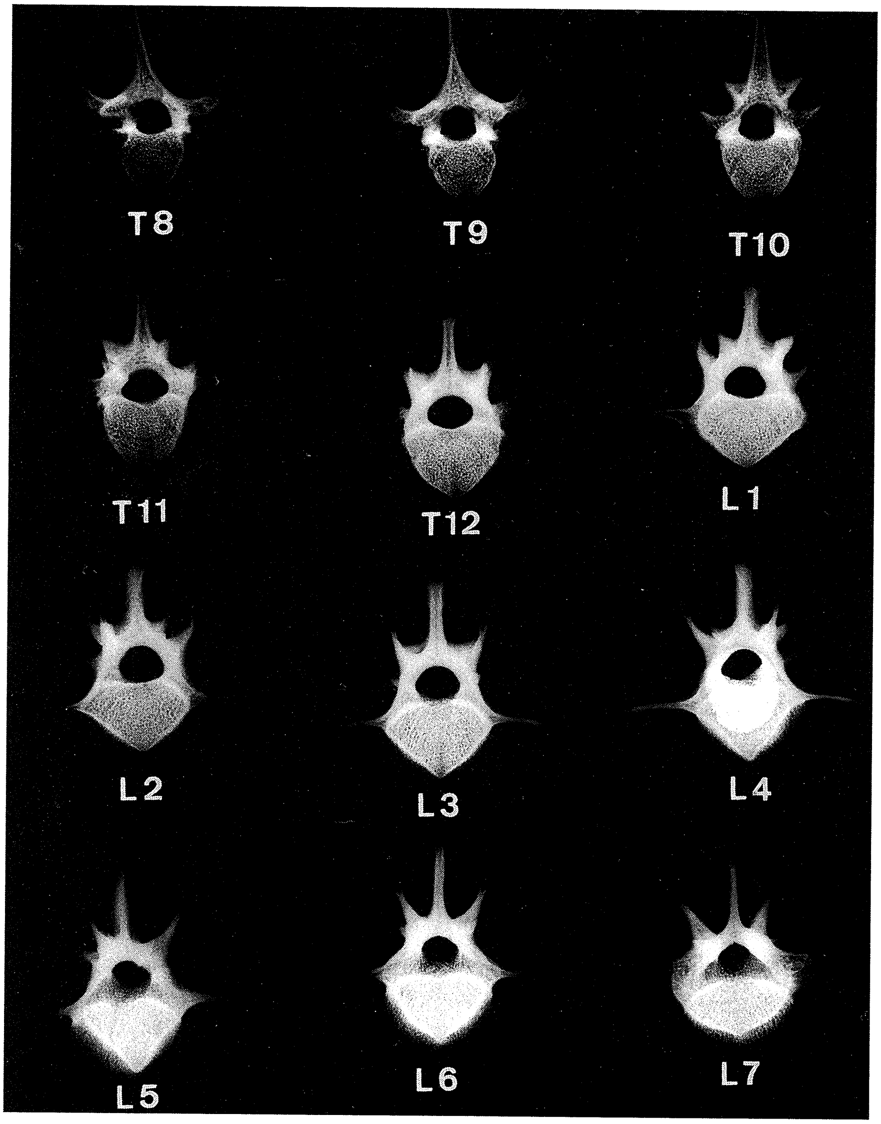

Fig. 6. Radiographs of the lower thoracic and lumbar vertebrae in the baboon.

ventral to dorsal direction on the superior and inferior views of the 10th thoracic vertebra. In most cases of the crab-eating monkeys[4], the position of axis for rotation at the intervertebral joint was shifted from ventral to dorsal direction on the superior and inferior views of the 10th thoracic vertebra. Yamada et al. (unpublished data) examined 17 cases of human spines and found that the position of axis for rotation at the intervertebral joint was shifted in 12 cases from ventral to dorsal direction on the superior and inferior views of the 12th thoracic vertebra, whereas it was shifted in 5 cases on the superior and inferior views of the 11th thoracic vertebra.

In the baboon and most cases of the crab-eating monkeys, the position of axis for rotation at the intervertebral joint was shifted from ventral to dorsal direction on the superior and inferior views of the 10th thoracic vertebra. This vertebra in the baboon had a long accessory process, which held the superior articular process of the adjacent vertebra. In the human spine, however, the position of axis for rotation at the intervertebral joint was shifted from ventral to dorsal direction on the superior and inferior views of the 11th or 12th thoracic vertebra that a long and slender accessory process was absent. Therefore, it is clear that a shift of the position of axis for rotation at the intervertebral joint is not related with the presence of a long and slender accessory process.

Based on these findings, there is a possibility that the position of axis for rotation at the intervertebral joint is related to the curvature of the spine, namely, it is ventral in vertebrae of kyphosis, whereas it is dorsal in the vertebrae of lordosis.

The authors[1,2] previously examined the mineral contents in the human cervical, thoracic, and lumbar vertebrae from 11 subjects of 46 to 99 years old at death and found that the content of calcium and phosphorus was the highest in the cervical vertebrae and decreased in the order of the upper thoracic, lower thoracic, and lumbar vertebrae. It is noteworthy that the human vertebrae are different from those of the baboon with regard to the mineral content of the lower thoracic and lumbar vertebrae, in which the BMD was slightly higher in comparison with that in the upper thoracic vertebrae.

Acknowledgment. This study was done under the Cooperation Research Program of the Primate Research Institute, Kyoto University.

REFERENCES

1) **Tohno, Y., Tohno, S., Nishiwaki, F., Utsumi, M., Yamada, M.-o., Minami, T., Ichii, M.** and **Okazaki, Y. :** Gradient of mineral contents of vertebral column with special reference to intervertebral discs. Acta Anat. Nippon. **69** : 734-741, 1994.

2) **Tohno, Y., Tohno, S., Utsumi, M., Minami, T., Ichii, M., Okazaki, Y., Nishiwaki, F., Moriwake, Y., Naganuma, T., Yamada, M.-o.** and **Araki, T. :** Age-indepedent constancy of mineral contents in human vertebra and auditory ossicle. Biol. Trace Element Res. **59** : 167-175, 1997.

3) **Schultz, A.H. :** Vertebral column and thorax. Primatol. 4 : 1-66, 1961.

4) **Kimura, K., Konishi, M., Takahashi, Y.** and **Iwamoto, S. :** The skeletal system of Macaca fascicularis - Description and measurement. Part III. The Vertebrae. J. Natl. Def. Med. Coll. **11** : 19-34, 1986.

5) **Pope, N.S., Gould, K.G., Anderson, D.C.** and **Mann, D.R. :** Effects of age and sex on bone density in the Rhesus monkey. Bone **10** : 109-112, 1989.

6) **Champ, J.E., Binkley, N., Havighurst, T., Colman, R.J., Kemnitz, J.W.** and **Roecker, E.B.:** The effect of advancing age on bone mineral content of female rhesus monkeys. Bone **19** : 485-492, 1996.

7) **Yamada, G., Nakamura, S., Fukuzaki, K., Izumi, H., Horai, N., Nagata, R., Minami, T., Tohno, Y., Miyado, K., Toyoda, T., Izpisua-Belmonte, J.C., Maruyama, I.** and **Kitajima, I. :** Dysregulation of trace element composition in ovariectomied Cynomolgus monkey bones. Cell. Mol. Biol. **44** : 1205-1213, 1998.

8) **Colman, R.J., Lane, M.A., Binkley, N., Wegner, F.H.** and **Kemnitz, J.W. :** Skeletal effects of aging in male rhesus monkeys. Bone **24** : 17-23, 1999.

9) **Cerroni, A. M., Tomlinson, G. A., Turnquist, J. E.** and **Grynpas, M. D. :** Bone mineral density, osteopenia,

and osteoporosis in the rhesus macaques of Cayo Santiago. Am. J. Phys. Anthropol. **113** : 389–410, 2000.

10) **Chen, Y., Shimizu, M., Sato, K., Koto, M., Tsunemi, K., Yoshida, T.** and **Yoshikawa, Y. :** Effects of aging on bone mineral content and bone biomarkers in female cynomolgus monkeys. Exp. Anim. **49** : 163–170, 2000.

11) **Morimoto, M., Utsumi, M., Tohno, Y., Tohno, S., Moriwake, Y., Sugimoto, K., Yamada, M., Furuta, K., Takano, Y.** and **Takakura, Y. :** Age-related changes of bone mineral density in human calcaneus, talus, and scaphoid bone. Biol. Trace Element Res. **82** : 53–60, 2001.

12) **Tohno, Y., Tohno, S., Matsumoto, H.** and **Naito, K. :** A trial of introducing soft X-ray apparatus into dissection practice for students. J. Nara Med. Assoc. **36** : 365–370, 1985.

13) **White, A. A.** and **Panjabi, M. M. :** The basic kinematics of the human spine. A review of past and current knowledge. Spine **3** : 12–20, 1978.