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A preliminary study on age estimation using epiphyses union of vertebrae

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Abstract Estimating age at death through ossification morphology in vertebrae is effective for adolescents and young adults but has not been studied in Japanese populations. In this study, the timing of fusion of the four kinds of secondary centers in the vertebrae in recent Japanese individuals was investigated to determine whether there was any relationship with age. In addition, for comparison, the fusion status of the sternal end of the clavicle and the Suchey-Brooks method for the pubic symphysis was investigated in the same sample. The number of Japanese samples was 99 individuals of known age and sex; however, because there were few females, the analysis was conducted using pooled sexes. As a result, it was determined that the correlation between the age at death and the stages of all epiphyses was significant and that the epiphyseal rings of the vertebrae could be estimated to the same degree as the sternal end of the clavicle. It was also found that the neurocentral cartilage was more suitable for slightly younger age groups than the age range investigated in this study and that the epiphyses on the transverse and mammillary processes and spinous processes showed slightly lower correlations than the epiphyseal rings.
Key Words: age estimation, epiphyses union of vertebrae, recent Japanese

Introduction

In the fields of physical anthropology and legal medicine, estimating age at death is an important task. Some methods have been developed for the morphology of several parts of human skeletal remains, including the pubic symphysis, auricular surface, and cranial sutures (Todd, 1920; Lovejoy *et al.*, 1985; Meindl and Lovejoy, 1985; Katz and Suchey, 1986; Brooks and Suchey,1990). However, when these parts are not preserved in human remains discovered in the fields of forensic science and physical anthropology, estimation of age at death is almost impossible. Even if these parts are preserved, it is important to utilize multiple age estimation methods to increase accuracy.

Considering that vertebral bones are often preserved, age estimation with the vertebrae might be useful. Age estimation methods using morphology of vertebral bones can be classified into two types: one for younger individuals with the fusion of the secondary centers of ossification in the cervical, thoracic, and lumbar vertebrae epiphysial rings (McKern and Stewart,1957; Buikstra *et al.*, 1984; Albert and Maples, 1995; Albert *et al.*, 2010; Cardoso and Rios, 2010; Albert and Maier, 2013), and one for older individuals with osteophyte formation (Stewart, 1958; Watanabe and Terazawa, 2006). In previous studies, the timing of union in the vertebral epiphyses was useful for estimating the ages of adolescents and young adults. Unfortunately, these studies used American and Portuguese people as samples but did not analyze a Japanese population.

Thus, the purpose of this preliminary investigation was to determine the relationship between age at death and the epiphyseal fusion status of the secondary centers of vertebral ossification in the Japanese population.

Material and Methods

The samples used in this study were the vertebrae of 99 recent Japanese skeletal remains (72 males and 27 females) with recorded sex and age at death that were

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Table 1. Age distribution of samples in this study.

Age	＜10	10–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	Sum
Female	4	6	0	6	5	2	0	1	3	27
Male	0	5	15	10	15	5	4	9	9	72
Sum	4	11	15	16	20	7	4	10	12	99

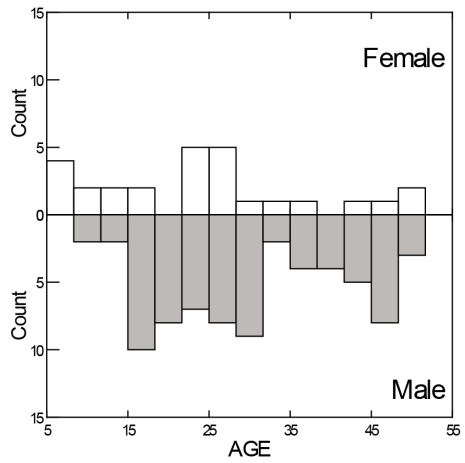

Figure 1. Age and sex distribution of the sample.

stored at the University Museum, the University of Tokyo, and the Department of Anatomy and Shinshu University Graduate School of Medicine. The samples were selected on the basis of age range of the samples was 6–50 years, with all of their vertebrae observable and no variation in the number of vertebrae. The distributions of the samples are presented in Table 1 and Figure 1. Although it would be better to analyze the data separately by sex, previous studies have reported that there are no significant differences by sex (Cardoso and Rios, 2010), and the number of females in these data is considerably lower than that of males; therefore, this study did not take sex into account.

To examine the state of epiphyseal fusion of the secondary centers of ossification in the vertebrae, four types of ossification were examined: epiphyseal rings of the superior and inferior vertebral bodies, ossification of the neurocentral cartilage, epiphyseal tips for transverse processes of the thoracic vertebrae and mammillary processes of the lumbar vertebrae, and epiphyseal tips of spinous processes from the seventh cervical vertebra to the fifth lumbar vertebra. Although there are other epiphyses on the vertebrae, such as those on the superior and inferior costal facets and the transverse process of the cervical and lumbar vertebrae (Scheuer and Black, 2000), they have not been investigated here because of difficulties in identification with the naked eye. The following evaluation criteria were established for the four variables using the four scoring methods. As in Cardoso and Rios (2010), when the bilateral difference of stages in the neurocentral cartilage and transverse and mammillary processes was evaluated, the younger stage was selected.

1) Criteria for superior and inferior epiphyseal rings (Fig. 2)

Stage 0: No union without any adherence of epiphysis.

Stage 1: Partial union with a wide gap between the epiphyseal ring and the vertebral body. The epiphyseal ring is not circular.

Stage 2: Partial union with a narrower gap between the ring and body. The epiphyseal ring has a closed circular shape. The vertebra, with a faint line or groove between the epiphysis and centrum, is contained in this stage, as described by Albert *et al.* (2010).

Stage 3: Complete union.

2) Criteria for ossification of neurocentral cartilage in the superior view (Fig. 3)

Stage 0: No union.

Stage 1: Partial union with a wide gap between the pedicles of the vertebral arch and body.

Stage 2: Almost union with epiphyseal line.

Stage 3: Complete union without any line or groove between pedicles and body.

3) Criteria for transverse and mammillary processes (Fig. 4)

Stage 0: No union.

Stage 1: Partial union with the epiphysis is partially stuck in the process in a granular form. The epiphy-

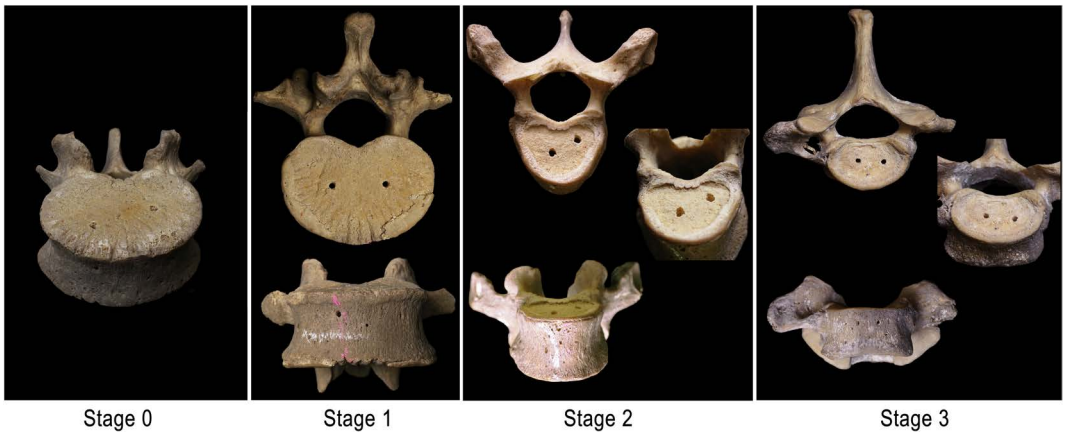

Figure 2. Illustrations of each stage of the epiphyseal ring

Figure 3. Illustrations of each stage of neurocentral cartilage ossification.

sis was smaller than the area of the epiphyseal facet in the process.
Stage 2: Almost union with epiphyseal line.
Stage 3: Complete union.

4) Criteria for the spinous process (Fig. 5)
Stage 0: No union.
Stage 1: Partial union with the epiphysis is partially stuck in the process in a granular form. The epiphysis was smaller than the area of the epiphyseal facet in the process.
Stage 2: Almost union with epiphyseal line.
Stage 3: Complete union.

In addition, for comparison with the epiphyseal fusion of the vertebrae, the fusion of the sternal end of the clavicle and pubic symphysis of the Suhey-Brooks system were also analyzed using the same samples.

The epiphyseal union of the sternal end of the clavicle is utilized for the estimation of age at death in adolescents and young adults because this epiphysis does not complete fusion until the late 20s or early 30s (Scheuer and Black, 2000; Webb and Suchey, 1985). The Suchey-Brooks system of age estimation with the pubic symphysis was developed with large samples from various populations, including the Japanese, and these morphological changes were strongly correlated with age at death (Katz and Suchey, 1989: Hoppa, 2000: Sakaue, 2005). The evaluation criteria for the forms were as follows:

5) Criteria for the sternal end of the clavicle

Figure 4. Illustrations of epiphyses in the transverse and mammillary processes.

Figure 5. Illustrations of epiphyses on spinous processes.

Stage 0: No union.
Stage 1: Partial union with the epiphysis is partially stuck in the process, and the epiphysis is smaller than the epiphyseal facet on the shaft of the clavicle.
Stage 2: Almost union with epiphyseal line.
Stage 3: Complete union.

6) Criteria for pubic symphysis

Phases 1–5 were classified based on the Suchey-Book system (Brooks and Suchey, 1990: Sakaue, 2005). Among the samples in this study, there were no individuals in phase 6.

The relationship between age and stage was examined using the Spearman rank correlation for six variables. A survey was also conducted using the correlation ratios. All statistical analyses were performed using SYSTAT 13 and Microsoft Excel for Microsoft 365 software.

Results and Discussion

Table 2 shows the basic statistics, the Spearman rank correlation coefficients between age at death and each stage or phase, and the correlation ratios for the fusion stage of the sternal end of the clavicle and the pubic symphysis in this study, and Figure 6 shows box plots.

Spearman rank correlation coefficients between age and each score (phase) for the clavicle and pubic symphysis were 0.822 and 0.847 respectively, indicating statistically significant values at the 1% level. The correlation ratios were also quite high, at 0.626 for the clavicle and 0.706 for the pubic symphysis, and both were statistically significant at the 1% level.

The maximum age for a score of 0 in the clavicle was 27 years, which is very high among the minimum and maximum ages for each stage of the clavicle. This 27-year-old individual shows outlier values in the vertebral epiphyseal rings described below, and it is possible that this individual did not grow normally or that there was a problem with specimen management. The

Table 2. Basic statistics, Spearman rank correlation coefficients, and correlation ratios for the fusion stages (phases) of the sternal end of the clavicle and pubic symphysis.

	Sternal end of the clavicle				Pubic symphysis				
	Stage 0	Stage 1	Stage 2	Stage 3	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
N.	37	3	12	47	17	20	19	36	7
Means	16.7	23.5	28.6	37.4	19.3	25.1	30.8	38.2	46.7
S.D.	5.6	2.1	7.0	9.0	4.0	3.0	5.2	8.5	2.9
Min. age	6	22	19	20	10	19	20	21	41
Max. age	27	25	34	50	26	30	41	50	49
Correlation coefficient between ages and stages (phases)									
	0.822				0.847				
P	P＜0.01				P＜0.01				
Correlation ratio $\eta 2$									
	0.626				0.706				
P	P＜0.01				P＜0.01				

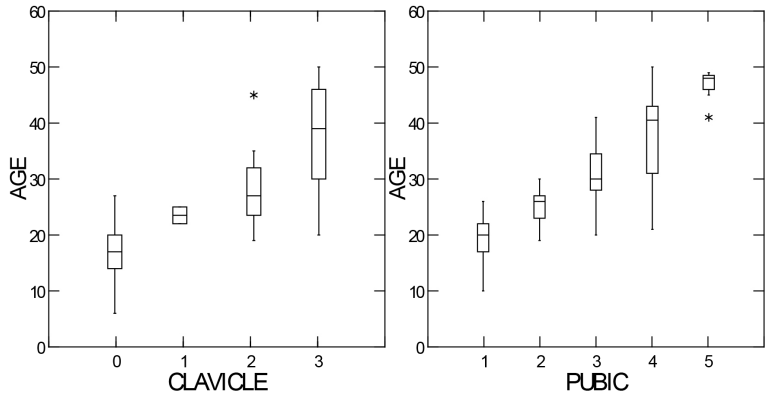

Figure 6. Box plots of each stage of the clavicle and each phase of the pubic symphysis.

next oldest individual in the stage 0 of the clavicle was 23 years old. This value indicates the true age range. The minimum age for stage 1 was 22 years, and the maximum age was 25 years, the minimum age for stage 2 was 19 years, and the maximum age was 34 years. The minimum age for stage 3, in which the epiphyses were completely fused, was 20 years. The average age for stage 0 was 16.7 years old, stage 1 was 23.5 years old, stage 2 was 28.6 years old, and stage 3 was 37.4 years old. There was no overlap between the mean ages of the adjacent stages. As shown in the box plot in Figure 6, there was relatively little overlap between the stages, and the distributions of each stage were gradual. These results confirmed those of previous studies that "if the sternal end of the clavicle is in the process of fusion, it is in its 20s, and if it is completely fused, it is over 30 years old (Scheuer and Black, 2004).

Regarding the pubic symphysis, the specimen analyzed in this study is part of the specimen analyzed by Sakaue (2005), and the results are consistent with those of previous studies. As shown in the box plot in Figure 6, the boxes were distributed gradually as the stages progressed.

Epiphyseal ring of vertebrae

Table 3 shows the basic statistics, the Spearman rank correlation coefficient for age and each stage, and correlation ratios for the state of fusion of epiphyseal rings of the cervical, thoracic, and lumbar vertebrae, and Figure 7 shows the box plots.

The correlation coefficients of all vertebrae with age

Table 3. Basic statistics, Spearman rank correlation coefficients, and correlation ratios for fusion stages of epiphyseal rings.

	C2 I				C3 S				C3 I				C4 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	20	4	12	63	21	6	13	59	23	11	8	57	21	6	12	59
Means	13.1	16.5	23.3	34.2	14.3	18.2	24.1	34.6	13.7	20.5	26.0	35.4	13.9	19.0	25.0	34.5
S.D.	4.2	2.4	4.5	9.6	4.8	3.7	8.2	9.6	4.7	2.4	3.2	9.4	4.9	2.9	6.9	9.9
Min. age	6	14	17	18	6	14	17	20	6	17	23	20	6	15	17	15
Max. age	21	19	34	50	27	23	42	50	27	25	32	50	27	23	42	50
Correlation coefficient between ages and stages																
	0.785				0.764				0.820				0.758			
P	P<0.01				P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$																
	0.549				0.523				0.606				0.517			
P	P<0.01				P<0.01				P<0.01				P<0.01			

	C4 I				C5 S				C5 I				C6 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	22	11	11	54	22	6	11	60	24	10	13	52	20	10	15	54
Means	13.5	21.4	29.4	34.9	13.8	18.7	22.4	35.1	14.0	20.9	27.2	35.9	13.2	19.3	29.9	34.4
S.D.	3.9	2.7	7.8	10.0	4.9	2.7	3.0	9.2	4.7	3.0	6.1	9.3	4.1	4.6	8.5	9.7
Min. age	6	17	17	20	6	15	17	20	6	17	20	20	6	14	20	20
Max. age	19	27	45	50	27	22	27	50	27	27	39	50	19	27	46	50
Correlation coefficient between ages and stages																
	0.767				0.822				0.819				0.736			
P	P<0.01				P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$																
	0.547				0.595				0.608				0.534			
P	P<0.01				P<0.01				P<0.01				P<0.01			

Table 3. Continued

	C6 I				C7 S				C7 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	23	8	22	46	21	7	27	44	21	11	30	37
Means	13.4	21.8	27.8	36.3	13.1	19.6	28.8	35.8	13.1	20.4	29.0	37.7
S.D.	3.9	3.9	7.4	9.4	3.9	4.2	7.6	9.9	4.0	3.7	7.0	9.6
Min. age	6	17	19	20	6	15	19	20	6	14	19	20
Max. age	19	27	46	50	19	27	46	50	19	27	46	50
Correlation coefficient between ages and stages												
	0.807				0.759				0.814			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.602				0.561				0.629			
P	P<0.01				P<0.01				P<0.01			

	Th1 S				Th1 I				Th2 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	26	4	30	39	26	7	31	35	26	7	28	38
Means	14.3	20.8	28.1	37.6	14.3	21.1	29.0	38.4	14.6	19.4	28.7	38.1
S.D.	4.8	2.9	6.6	9.6	4.8	2.3	6.5	9.6	4.9	3.2	5.8	9.5
Min. age	6	17	19	20	6	17	19	20	6	14	22	20
Max. age	27	23	45	50	27	23	45	50	27	23	42	50
Correlation coefficient between ages and stages												
	0.805				0.820				0.827			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.619				0.643				0.648			
P	P<0.01				P<0.01				P<0.01			

Table 3. Continued

	Th2 I				Th3 S				Th3 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	28	5	30	36	27	7	26	39	29	4	27	39
Means	14.6	21.8	28.5	38.6	14.8	20.1	28.0	38.4	15.0	20.8	27.7	38.4
S.D.	4.7	1.6	5.8	9.4	5.1	2.8	5.2	9.3	5.0	2.9	5.3	9.2
Min. age	6	20	19	20	6	16	19	20	6	17	19	20
Max. age	27	23	42	50	27	23	42	50	27	23	42	50
Correlation coefficient between ages and stages												
	0.834				0.836				0.839			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.662				0.665				0.667			
P	P<0.01				P<0.01				P<0.01			

	Th4 S				Th4 I				Th5 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	30	3	33	33	29	6	24	40	30	5	20	44
Means	15.3	20.0	30.1	38.0	15.0	20.8	27.9	38.4	15.2	20.8	28.0	37.4
S.D.	5.1	3.0	8.2	9.1	5.0	2.6	5.3	8.9	5.0	1.6	5.1	9.2
Min. age	6	17	19	20	6	17	20	21	6	19	22	20
Max. age	27	23	42	49	27	23	42	50	27	23	42	50
Correlation coefficient between ages and stages												
	0.798				0.852				0.836			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.604				0.678				0.648			
P	P<0.01				P<0.01				P<0.01			

Table 3. Continued

	Th5 I				Th6 S				Th6 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	29	5	26	39	29	6	22	42	28	5	25	41
Means	14.9	21.2	27.9	38.5	15.0	22.2	28.4	37.5	14.7	22.8	26.8	38.3
S.D.	4.9	1.8	5.4	9.0	5.0	4.1	6.3	9.3	4.9	2.7	5.5	8.8
Min. age	6	19	20	21	6	19	22	20	6	20	19	21
Max. age	27	23	42	50	27	30	45	50	27	27	42	50
Correlation coefficient between ages and stages												
	0.850				0.824				0.850			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.679				0.633				0.676			
P	P<0.01				P<0.01				P<0.01			

	Th7 S				Th7 I				Th8 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	29	3	25	42	28	4	29	38	29	4	22	44
Means	15.0	21.3	26.3	38.3	14.6	22.3	26.9	39.1	15.0	20.5	25.8	38.2
S.D.	5.0	1.5	5.1	8.7	4.7	1.5	5.6	8.5	5.0	1.7	3.3	8.8
Min. age	6	20	19	20	6	20	19	21	6	19	20	20
Max. age	27	23	45	50	27	23	42	50	27	23	34	50
Correlation coefficient between ages and stages												
	0.857				0.869				0.865			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.682				0.704				0.696			
P	P<0.01				P<0.01				P<0.01			

Table 3. Continued

	Th8 I				Th9 S				Th9 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	28	3	27	41	29	3	25	42	28	4	24	43
Means	14.8	22.0	26.4	38.3	14.8	23.0	26.3	38.3	14.6	22.3	26.3	38.0
S.D.	4.9	1.7	5.7	8.7	4.8	0.0	4.4	8.9	4.7	1.5	5.2	8.8
Min. age	6	20	19	21	6	23	19	20	6	20	19	21
Max. age	27	23	42	50	27	23	38	50	27	23	39	50
Correlation coefficient between ages and stages												
	0.856				0.855				0.858			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.677				0.688				0.679			
P	P<0.01				P<0.01				P<0.01			

	Th10 S				Th10 I				Th11 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	27	5	23	44	27	5	22	45	27	6	22	44
Means	14.4	21.8	27.1	37.3	14.4	21.8	26.3	37.5	14.4	21.5	27.8	37.1
S.D.	4.7	1.6	5.5	9.3	4.7	1.6	5.4	8.9	4.7	1.6	5.4	9.5
Min. age	6	20	19	20	6	20	19	21	6	20	19	20
Max. age	27	23	42	50	27	23	39	50	27	23	39	50
Correlation coefficient between ages and stages												
	0.829				0.851				0.822			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.644				0.662				0.635			
P	P<0.01				P<0.01				P<0.01			

Table 3. Continued

	Th11 I				Th12 S				Th12 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	27	6	21	45	27	6	20	46	27	4	21	47
Means	14.4	21.5	26.9	37.4	14.4	21.5	28.3	36.5	14.4	21.5	26.4	36.9
S.D.	4.7	1.6	6.1	8.9	4.7	1.6	6.2	9.6	4.7	1.7	5.4	9.2
Min. age	6	20	19	21	6	20	19	20	6	20	19	21
Max. age	27	23	42	50	27	23	42	50	27	23	42	50
Correlation coefficient between ages and stages												
	0.852				0.809				0.831			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.657				0.612				0.638			
P	P<0.01				P<0.01				P<0.01			

	L1 S				L1 I				L2 S			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	28	6	21	44	26	6	21	46	27	6	19	47
Means	14.9	21.5	26.2	38.0	14.2	21.7	25.5	37.6	14.4	21.5	24.7	37.8
S.D.	5.1	1.6	4.7	8.8	4.6	1.5	3.9	8.9	4.7	1.6	3.0	8.5
Min. age	6	20	19	21	6	20	19	21	6	20	19	21
Max. age	27	23	39	50	27	23	34	50	27	23	31	50
Correlation coefficient between ages and stages												
	0.857				0.861				0.882			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.680				0.686				0.709			
P	P<0.01				P<0.01				P<0.01			

Table 3. Continued

	L2 I				L3 S				L3 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	27	4	22	46	27	5	19	48	25	5	21	48
Means	14.4	21.5	25.4	37.6	14.4	21.2	25.6	37.1	14.1	20.2	25.3	37.1
S.D.	4.7	1.7	4.4	8.8	4.7	1.6	4.4	8.9	4.7	2.2	4.5	9.0
Min. age	6	20	19	21	6	20	19	21	6	17	19	21
Max. age	27	23	39	50	27	23	39	50	27	23	39	50
Correlation coefficient between ages and stages												
	0.863				0.854				0.851			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.682				0.664				0.663			
P	P<0.01				P<0.01				P<0.01			

	L4 S				L4 I				L5 S				L5 I			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	27	4	17	51	26	2	17	54	25	2	17	55	26	3	15	55
Means	14.4	22.0	24.4	36.7	14.3	18.5	24.5	35.9	14.2	17.0	23.3	36.0	14.3	21.0	23.2	36.0
S.D.	4.7	1.4	3.5	9.0	4.8	2.1	4.8	9.2	4.8	0.0	3.0	9.1	4.8	3.5	3.2	9.0
Min. age	6	20	19	21	6	17	19	21	6	17	19	21	6	17	19	21
Max. age	27	23	30	50	27	20	39	50	27	17	29	50	27	23	29	50
Correlation coefficient between ages and stages																
	0.851				0.830				0.842				0.844			
P	P<0.01				P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$																
	0.657				0.616				0.633				0.634			
P	P<0.01				P<0.01				P<0.01				P<0.01			

and each stage were statistically significant at the 1% level, with the lowest and highest values being 0.738 and 0.882. The average correlation coefficients for the cervical, thoracic, and lumbar vertebrae were 0.786, 0.836, and 0.853, respectively. The correlation ratios were all significant at the 1% level, with those for the cervical vertebrae being 0.517–0.629 (average 0.570), those for the thoracic vertebrae being 0.604–0.704 (average 0.658), and those for the lumbar vertebrae being 0.616–0.709 (average 0.662), showing a slightly lower tendency for the cervical vertebrae; however, all values were very high. Therefore, it can be said that morphological changes in the epiphyseal ring of all vertebrae are significantly related to age. These values are similar to those of the clavicle and pubic symphysis.

At the average ages of cervical vertebrae for each stage, stage 0 is between the ages of 13.1 and 14.3, stage 1 is between 16.5 and 21.8, stage 2 is between 22.4 and 29.9, and stage 3 is between 34.2 and 37.7, at those of thoracic vertebrae, stage 0 is between the ages of 14.3 and 15.3, stage 1 is between 19.4 and 23.0, stage 2 is between 25.8 and 30.1, and stage 3 is between 36.5 and 39.1, and at those of lumbar vertebrae, stage 0 is between the ages of 14.1 and 14.9, stage 1 is between 17.0 and 22.0, stage 2 is between 23.2 and 26.2, and Stage 3 is between 35.9 and 39.0. These data indicate that the average ages did not overlap with those of adjacent stages. In stage 0, there were 39 variables with a maximum age of 27 years, but all were from the same individual mentioned above, and the next highest age for this individual was 19 or 23 years. In stage 1, the minimum age was 14 years, and the maximum age was 30 years; in stage 2, the minimum age was 17 years, and the maximum age was 46 years. In Stage 3, the minimum age was 15 years. Although there is an overlap between the minimum and maximum values for age, as seen in box plots in Figure 7, it can be said that there is relatively little overlap between stages and that the distribution is gradual.

In summary, although there are variations depending on the vertebra, it can generally be said that "individuals with no epiphyseal ring fusion (stage 0) are those who are in their early teens or younger," "individuals with an epiphyseal ring in the process of fus-

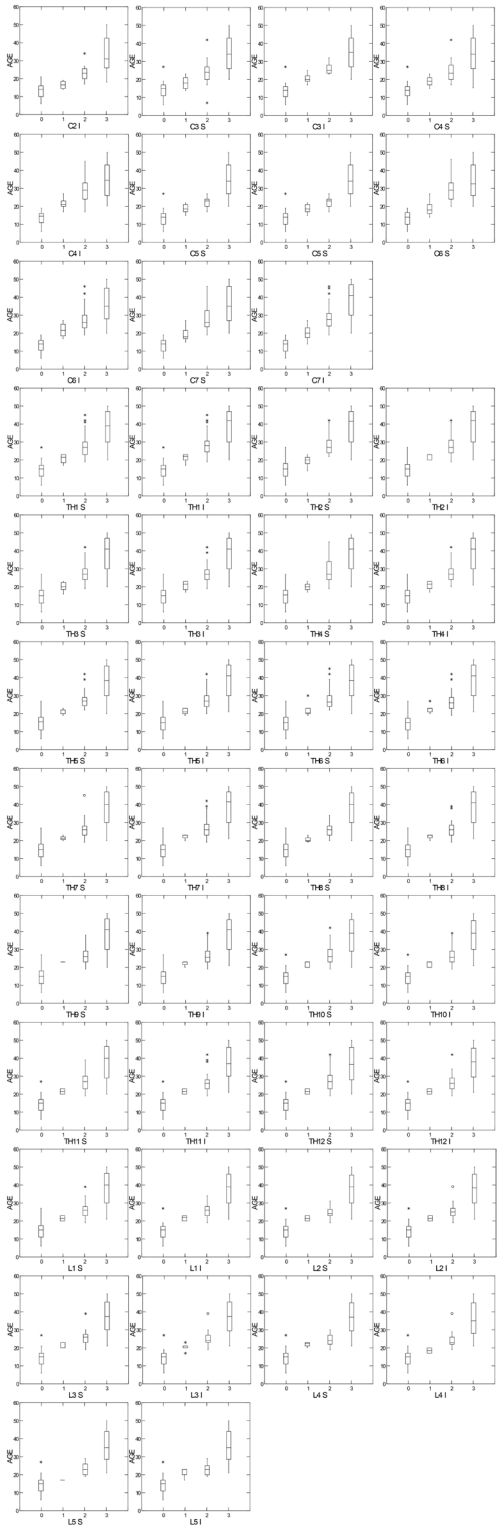

Figure 7. Box plots of each stage of epiphyseal rings.

ing with the vertebra (stage 1 and stage 2) are those in their late teens to their 20s," and "individuals with a completely fused epiphyseal ring (stage 3) are those who are 30 or older." This trend is similar to that of the sternal end of the clavicle, and the distribution of the box plot also shows that the epiphyseal ring and clavicle are similar, as shown in Figures 6 and 7.

Ossification of neurocentral cartilage

Table 4 shows the basic statistics, the Spearman rank correlation coefficients for age and each stage, and correlation ratios for the ossification of the neurocentral cartilage of the cervical, thoracic, and lumbar vertebrae, and Figure 8 shows the box plot.

All the correlation coefficients were statistically significant at the 5% level. The average correlation coefficient for the cervical vertebrae was 0.275, that for the thoracic vertebrae was 0.752, and that for the lumbar vertebrae was 0.529, which was clearly lower than that of the epiphyseal rings. Although the correlation ratios were all significant at the 5% level, the results were quite low for the cervical vertebrae, ranging from 0.061 to 0.135 (average 0.083); slightly high for the thoracic vertebrae, ranging from 0.333 to 0.584 (average 0.510); and low for the lumbar vertebrae, ranging from 0.192 to 0.312 (average 0.251). This finding may be due to the small sample size of individuals with stage 0 or 1 cervical and lumbar vertebrae. The number of individuals assigned to stage 0 was zero for the cervical vertebrae, and there was one individual each for the first and fifth lumbar vertebrae. Only one individual showed stage 1 for the sixth cervical vertebra and one for the fifth lumbar vertebra. The highest number of individuals with a score of 2 was 5 in the cervical vertebrae and 19 in the lumbar vertebrae. This finding could indicate that in the age group of this study, ossification of the neurocentral cartilage was completed in most individuals in the cervical and lumbar vertebrae. A previous study also showed that fusion of the vertebral arch and vertebral body of the cervical vertebrae begins before the age of six (Scheuer and Black, 2000). Interestingly, although the number of individuals showing stage 1 in the thoracic vertebrae was small (0–6), the number of individuals showing stage 2 was considerably higher (20–36) than that in the cervical and lumbar vertebrae. This finding indicates that ossification of the neurocentral cartilage of the thoracic vertebrae occurs later than that of the cervical or lumbar vertebrae.

At the average age of the thoracic vertebrae for each stage, stage 2 is between the ages of 14.3 and 18.7, and stage 3 is between 31.4 and 35.3. The maximum age for stage 2 was 30 years, and the minimum age for stage 3 was 11 years; therefore, there was an overlap in the age range between stages 2 and 3. As shown in Figure 8, there was relatively little overlap between the stages of the thoracic vertebrae.

From the above, it is considered that the ossification of the neurocentral cartilage is not appropriate for age estimation for populations aged 6–50 years and that it can only be used for the thoracic vertebrae. Thus, it can be said that "individuals with an epiphyseal line of the neurocentral cartilage (stage 2) are those who are in their late teens to 20s."

Epiphyses on transverse and mammillary processes

Table 5 shows the basic statistics, the Spearman rank correlation coefficients for age and each stage, and correlation ratios for the state of epiphyses on the transverse processes of the thoracic vertebrae and mammillary processes of the lumbar vertebrae, and Figure 9 shows the box plots.

The correlation coefficients of all vertebrae with age and stage were statistically significant at the 1% level. The average correlation coefficient for the thoracic vertebrae was 0.760, and that for the lumbar vertebrae was 0.747, which was slightly lower than that of the epiphyseal rings. All correlation ratios were significant at the 1% level, with those for the thoracic vertebrae being 0.458–0.553 (average 0.501) and for the lumbar vertebrae being 0.462–0.515 (average 0.487). All values were high. Therefore, it can be said that the morphological changes in epiphyses on transverse and mammillary processes are significantly related to age. However, only one individual in the first lumbar vertebra had stage 1, and stage 2 was confirmed in only a small number of individuals (11 or fewer). In contrast, stage 0 was confirmed in 15–25 individuals, and stage 3 was confirmed in 67–75 individuals. This finding indicated that there were few individuals in the fusion process. However, the reason for this finding remains unclear. This may be because the period during which

Table 4. Basic statistics, Spearman rank correlation coefficients, and correlation ratios for the ossification of the neurocentral cartilage.

	C3_Root		C4_Root		C5_Root		C6_Root			C7_Root	
	Stage 2	Stage 3	Stage 2	Stage 3	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 2	Stage 3
N.	2	97	2	96	2	97	1	3	95	5	94
Means	7.5	28.4	7.5	28.4	7.0	28.4	17.0	8.3	28.7	9.0	28.9
S.D.	0.7	11.7	0.7	11.8	0.0	11.7	—	2.3	11.6	3.4	11.4
Min. age	7	6	7	6	7	6	17	7	6	6	8
Max. age	8	50	8	50	7	50	17	11	50	14	50
Correlation coefficient between ages and stages											
	0.235		0.236		0.239		0.300			0.364	
P	P<0.05		P<0.05		P<0.05		P<0.01			P<0.01	
Correlation ratio $\eta 2$											
	0.061		0.061		0.064		0.095			0.135	
P	P<0.05		P<0.05		P<0.05		P<0.01			P<0.01	

	Th1_Root		Th2_Root				Th3_Root				Th4_Root		
	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	20	79	1	1	26	71	1	2	28	68	3	33	63
Means	14.3	31.4	7.0	6.0	16.5	32.7	7.0	6.5	16.8	33.4	6.7	17.5	34.4
S.D.	5.4	10.6	—	—	5.1	10.3	—	0.7	4.9	9.8	0.6	5.1	9.5
Min. age	6	13	7	6	7	10	7	6	8	17	6	8	20
Max. age	23	50	7	6	27	50	7	7	27	50	7	30	50
Correlation coefficient between ages and stages													
	0.608		0.686				0.739				0.777		
P	P<0.01		P<0.01				P<0.01				P<0.01		
Correlation ratio $\eta 2$													
	0.333		0.422				0.491				0.543		
P	P<0.01		P<0.01				P<0.01				P<0.01		

Table 4. Continued

	Th5_Root				Th6_Root				Th7_Root		
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
N.	2	1	34	62	3	2	32	62	5	34	60
Means	6.5	7.0	17.5	34.7	6.7	11.0	18.1	34.6	8.4	18.4	35.0
S.D.	0.7	—	4.9	9.3	0.6	4.2	5.1	9.4	3.2	5.0	9.4
Min. age	6	7	8	20	6	8	10	20	6	10	20
Max. age	7	7	27	50	7	14	30	50	14	30	50
Correlation coefficient between ages and stages											
					0.781				0.792		
P					P<0.01				P<0.01		
Correlation ratio $\eta 2$											
	0.563				0.553				0.568		
P	P<0.01				P<0.01				P<0.01		

	Th8_Root				Th9_Root				Th10_Root			
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	1	4	36	58	1	3	36	59	1	4	31	63
Means	7.0	8.8	18.7	35.3	7.0	9.0	18.1	35.3	7.0	8.8	18.2	34.3
S.D.	—	3.6	5.0	9.3	—	4.4	4.9	9.2	—	3.6	4.7	9.7
Min. age	7	6	10	20	7	6	8	20	7	6	10	11
Max. age	7	14	30	50	7	14	27	50	7	14	30	50
Correlation coefficient between ages and stages												
	0.801				0.809				0.770			
P	P<0.01				P<0.01				P<0.01			
Correlation ratio $\eta 2$												
	0.584				0.584				0.530			
P	P<0.01				P<0.01				P<0.01			

Table 4. Continued

	Th11_Root			Th12_Root			L1_Root			L2_Root		L3_Root	
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 2	Stage 3	Stage 2	Stage 3
N.	6	28	65	3	28	68	1	19	79	16	83	17	82
Means	10.8	18.1	33.7	9.0	16.6	33.4	17.0	14.6	31.3	14.8	30.5	13.8	30.9
S.D.	6.6	4.8	10.1	4.4	5.5	9.8	—	4.8	10.9	5.1	11.2	4.5	10.9
Min. age	6	10	11	6	7	17	17	6	10	6	10	6	10
Max. age	23	30	50	14	30	50	17	23	50	23	50	20	50
Correlation coefficient between ages and stages													
	0.727			0.733			0.598			0.515		0.581	
P	P<0.01			P<0.01			P<0.01			P<0.01		P<0.01	
Correlation ratio $\eta 2$													
	0.473			0.478			0.312			0.235		0.294	
P	P<0.01			P<0.01			P<0.01			P<0.01		P<0.01	

	L4_Root		L5_Root			
	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	13	86	1	1	9	88
Means	13.5	30.1	17.0	7.0	13.7	29.8
S.D.	4.8	11.2	—	—	5.2	11.3
Min. age	6	10	17	7	6	10
Max. age	19	50	17	7	19	50
Correlation coefficient between ages and stages						
	0.500		0.451			
P	P<0.01		P<0.01			
Correlation ratio $\eta 2$						
	0.224		0.192			
P	P<0.01		P<0.01			

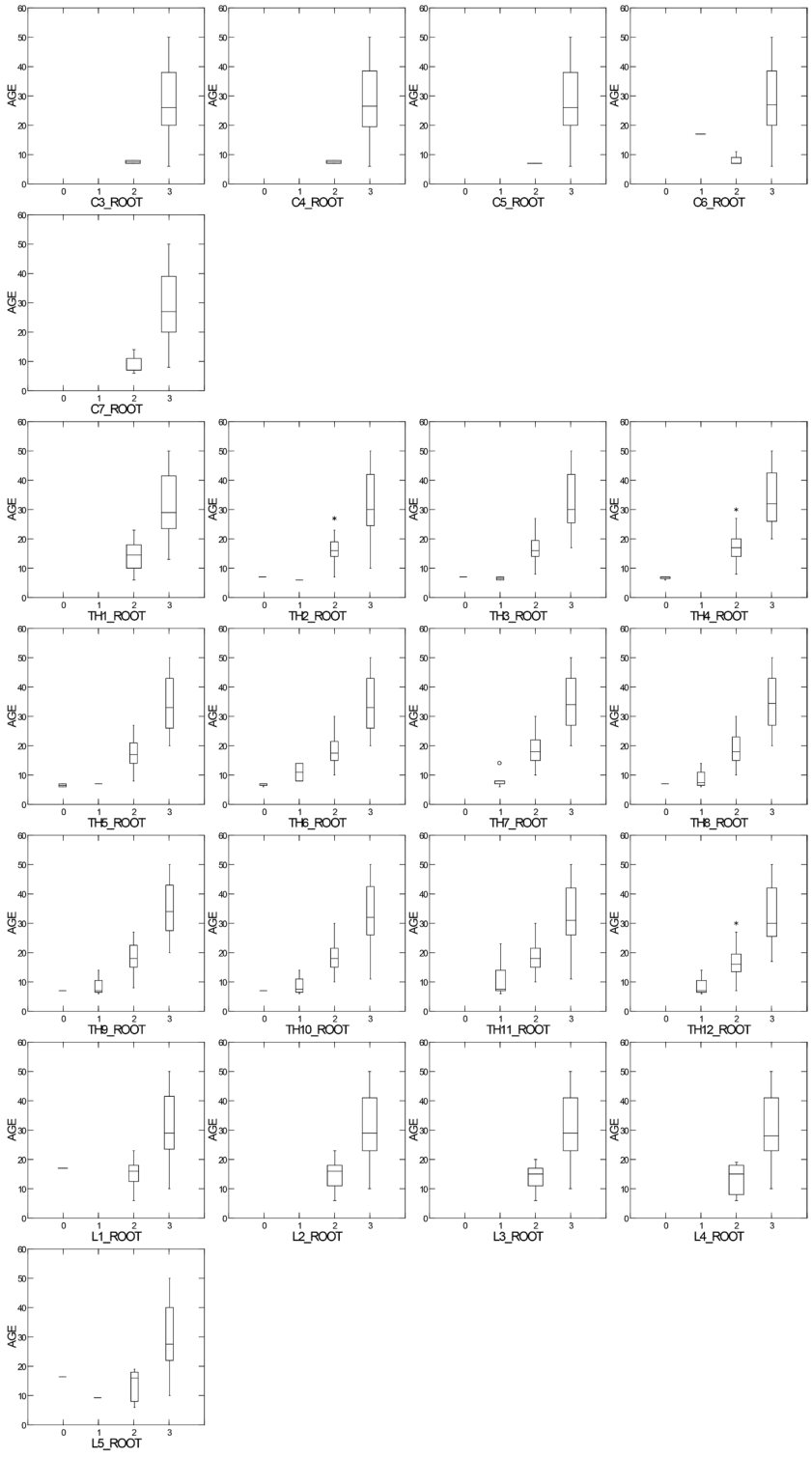

Figure 8. Box plots of each stage of the ossification of neurocentral cartilage.

Table 5. Basic statistics, Spearman rank correlation coefficients, and correlation ratios for the state of epiphyses on transverse processes of the thoracic vertebrae and mammillary processes of the lumbar vertebrae.

	Th1_trans			Th2_trans			Th3_trans			Th4_trans		
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	24	4	71	25	4	70	25	7	67	25	5	69
Means	13.6	22.3	33.1	13.8	22.0	33.3	13.8	21.0	33.9	13.8	21.6	33.5
S.D.	4.0	3.6	9.7	4.1	3.9	9.6	4.1	3.1	9.4	4.1	3.5	9.6
Min. age	6	19	18	6	18	19	6	18	20	6	18	19
Max. age	21	27	50	21	27	50	21	27	50	21	27	50
Correlation coefficient between ages and stages												
	0.756			0.768			0.802			0.779		
P	P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$												
	0.498			0.512			0.553			0.524		
P	P<0.01			P<0.01			P<0.01			P<0.01		

	Th5_trans			Th6_trans			Th7_trans			Th8_trans		
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	25	5	69	24	5	70	22	7	70	22	8	69
Means	13.8	21.4	33.5	14.0	19.4	33.3	13.5	19.6	33.3	13.7	18.9	33.5
S.D.	4.1	3.8	9.6	4.5	4.6	9.6	4.2	4.2	9.6	4.6	3.7	9.6
Min. age	6	17	19	6	15	19	6	15	19	6	15	19
Max. age	21	27	50	23	27	50	21	27	50	23	27	50
Correlation coefficient between ages and stages												
	0.778			0.763			0.767			0.773		
P	P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$												
	0.523			0.504			0.509			0.517		
P	P<0.01			P<0.01			P<0.01			P<0.01		

Table 5. Continued

	Th9_trans			Th10_trans			Th11_trans			Th12_trans			L1_mammillary			
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 1	Stage 2	Stage 3
N.	19	8	72	22	4	73	24	1	74	20	4	75	19	1	9	70
Means	12.8	19.0	32.9	13.5	19.3	32.8	14.0	15.0	32.6	13.1	16.2	32.5	13.1	20.0	18.9	33.2
S.D.	4.2	4.0	9.8	4.2	5.3	9.8	4.5	—	9.9	4.1	4.4	9.9	4.4	—	4.1	9.7
Min. age	6	15	17	6	15	17	6	15	17	6	15	17	6	20	14	17
Max. age	21	27	50	21	27	50	23	15	50	19	23	50	23	20	27	50
Correlation coefficient between ages and stages																
	0.742			0.737			0.728			0.727			0.756			
P	P<0.01			P<0.01			P<0.01			P<0.01			P<0.01			
Correlation ratio $\eta 2$																
	0.482			0.473			0.459			0.458			0.499			
P	P<0.01			P<0.01			P<0.01			P<0.01			P<0.01			

	L2_mammillary			L3_mammillary			L4_mammillary			L5_mammillary		
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	20	10	69	15	11	73	16	9	74	15	9	75
Means	13.3	19.1	33.5	11.6	18.3	32.7	12.3	17.6	32.6	11.5	16.9	32.5
S.D.	4.5	3.6	9.6	3.5	3.8	9.8	4.3	2.6	9.9	3.5	1.6	9.8
Min. age	6	14	19	6	14	17	6	14	14	6	14	17
Max. age	23	27	50	16	27	50	21	23	50	16	19	50
Correlation coefficient between ages and stages												
	0.769			0.738			0.727			0.744		
P	P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$												
	0.515			0.480			0.462			0.480		
P	P<0.01			P<0.01			P<0.01			P<0.01		

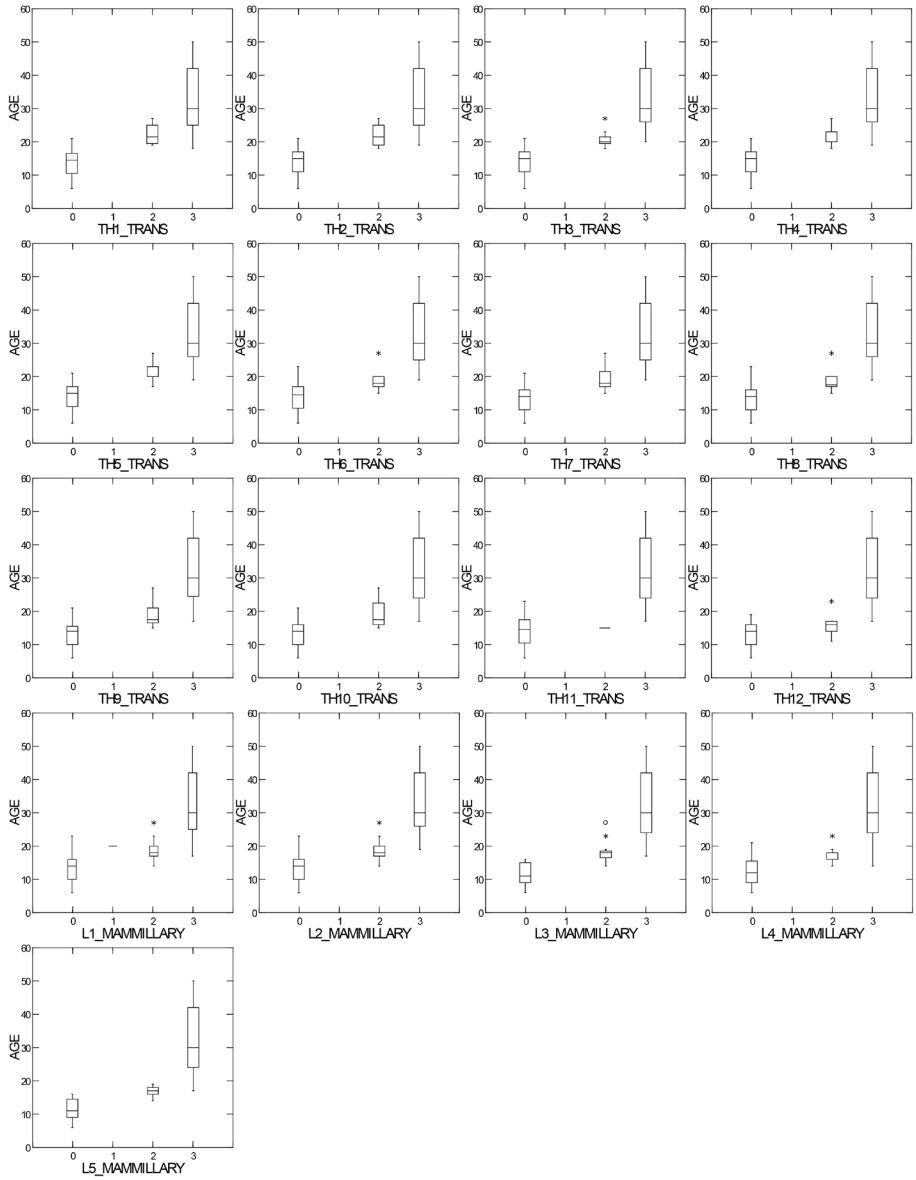

Figure 9. Box plots of each stage of epiphyses on transverse processes of thoracic vertebrae and mammillary processes of lumbar vertebrae.

these epiphyses are in the process of fusing is short in the Japanese population, and epiphyseal lines only remain for a short period.

At the average age of the thoracic vertebrae for each stage, stage 0 was between the ages of 12.8 and 14.0, and stage 2 was between 15.0 and 22.3. Stage 3 was observed in 32.5 and 33.9. At the average age of the lumbar vertebrae for each stage, stage 0 was between the ages of 11.5 and 13.3, stage 2 was between 16.9 and 19.1, and stage 3 was between 32.5 and 33.5. There was no overlap between the average ages of the stages. This can also be observed in the box plots in Figure 9. For the thoracic vertebrae, the maximum age for stage 0 was 23 years, the range of the minimum and maximum ages for stage 2 was 15–27 years old, and the minimum age for stage 3 was 17 years. For the lumbar vertebrae, the maximum age for stage 0 was 23 years, the range of minimum and maximum ages for

stage 2 was 14–27 years old, and the minimum age for stage 3 was 14 years. There were overlaps in the age range between the stages of both the thoracic and lumbar vertebrae.

Therefore, it can be said that the epiphyses on the transverse and mammillary processes are not as appropriate for age estimation as the epiphyseal rings. However, it also can be said that "individuals with an epiphyseal line of transverse and mammillary processes are those who are in their late teens to 20s."

Epiphyses on the spinous process

Table 6 shows the basic statistics, the Spearman rank correlation coefficients for age and each stage, and correlation ratios for the state of the epiphyses on the spinous processes of the cervical, thoracic, and lumbar vertebrae, and Figure 10 shows the box plot.

The correlation coefficients for all vertebrae with age and stage were statistically significant at the 1% level. The coefficient for the seventh cervical vertebra was 0.763, the average correlation coefficient for the thoracic vertebrae was 0.773, and the average correlation coefficient for the lumbar vertebrae was 0.772. All correlation ratios were significant at the 1% level, with those for the cervical vertebra being 0.503, those for the thoracic vertebrae being 0.491–0.554 (average 0.517), and those for the lumbar vertebrae being 0.498–0.530 (average 0.518); all values were high. Therefore, it can be said that the morphological changes in epiphyses on spinous processes are significantly related to age. The number of individuals in stages 1 and 2 was small, with only one individual in stage 1 at the first lumbar vertebra and fewer than 13 individuals in stage 2. The tendency for high correlation coefficient values over 0.700, high correlation ratios around 0.500, and the number of individuals in the process of fusion to be small was similar to the trend observed in epiphyses in the transverse and mammillary processes.

At the average ages of the thoracic vertebrae for each stage, stage 0 is between the ages of 13.8 and 15.2, and stage 2 is between 18.5 and 24.0. Stage 3 was observed in 33.2 and 34.3. At the average age of the lumbar vertebrae for each stage, stage 0 was between the ages of 13.1 and 14.8, stage 2 was between 18.8 and 21.3, and stage 3 was between 33.3 and 33.8. It appears that there is no overlap between the average ages of the stages, as shown in the box plots in Figure 10. For the thoracic vertebrae, the maximum age for stage 0 was 27 years, the range of the minimum and maximum ages for stage 2 was 19–27 years old, and the minimum age for stage 3 was 18 years. For the lumbar vertebrae, the maximum age for stage 0 was 27 years, the range of the minimum and maximum ages for stage 2 was 14–27 years old, and that for stage 3 was 17 years. This outlier of 27 years of age in stage 0 of the thoracic and lumbar vertebrae was the same individual as that seen in stage 0 of the clavicle and epiphyseal rings, as mentioned above, and the next highest age for this individual was 23 years. There were overlaps in the age range between the stages in both the thoracic and lumbar vertebrae.

It can also be said that the epiphyses of spinous processes are inappropriate for age estimation. However, it also can be said that "individuals with an epiphyseal line of spinous processes are those who are in their late teens to 20s."

The results of this preliminary study showed that in the Japanese population, the fusion status of the epiphyseal rings, ossification of the neurocentral cartilage, fusion status of the epiphyses on the transverse processes, and epiphyses on the spinous process of the vertebrae are correlated with age. In particular, the epiphyseal rings show a similar trend to the fusion status of the sternal end of the clavicle; therefore, they can be used for age estimation. In addition, ossification of the neurocentral cartilage in the thoracic vertebrae can be used for age estimation, and ossification of the cervical and lumbar vertebrae may be more useful in younger age groups. The fusion status of the transverse and spinous processes can be used for age estimation to a limited extent; however, it cannot be used for a wide range of age groups, such as epiphyseal rings.

It is not easy to compare this study with previous studies. For example, the stage classification was the same as that used by Albert *et al.* (2010); however, the sample sizes and distributions were different. This score classification differs from that of Cardoso and Rios (2010), as does the sample size and distribution. Table 12 shows the minimum and maximum ages of each epiphyseal ring stage in each study. The maxi-

Table 6. Basic statistics, Spearman rank correlation coefficients, and correlation ratios for the state of epiphyses on spinous processes of the cervical, thoracic, and lumbar vertebrae.

	C7_spinous			Th1_spinous			Th2_spinous			Th3_spinous		
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	26	6	65	25	7	67	25	2	70	27	2	70
Means	15.4	23.5	34.0	13.8	21.9	33.9	14.1	22.5	33.4	14.5	22.5	33.3
S.D.	4.2	3.0	9.7	4.0	2.7	9.5	4.4	0.7	9.6	4.7	0.7	9.7
Min. age	7	19	14	6	19	19	6	22	18	6	22	18
Max. age	23	27	50	21	27	50	21	23	50	27	23	50
Correlation coefficient between ages and stages												
	0.762			0.795			0.760			0.756		
P	P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$												
	0.503			0.545			0.504			0.496		
P	P<0.01			P<0.01			P<0.01			P<0.01		

	Th4_spinous			Th5_spinous			Th6_spinous			Th7_spinous		
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	26	3	70	27	4	68	27	2	70	29	3	67
Means	14.0	24.0	33.3	14.3	23.5	33.6	14.6	22.5	33.2	14.9	22.3	33.8
S.D.	4.1	2.6	9.7	4.4	2.4	9.6	4.9	0.7	9.7	4.9	0.6	9.5
Min. age	6	22	18	6	22	18	6	22	19	6	22	19
Max. age	20	27	50	23	27	50	27	23	50	27	23	50
Correlation coefficient between ages and stages												
	0.763			0.773			0.751			0.780		
P	P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$												
	0.507			0.518			0.491			0.525		
P	P<0.01			P<0.01			P<0.01			P<0.01		

Table 6. Continued

	Th8_spinous			Th9_spinous			Th10_spinous			Th11_spinous			Th12_spinous		
	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	29	3	67	30	4	65	28	3	68	27	3	69	29	3	67
Means	14.9	23.3	33.8	15.0	21.8	34.3	14.6	22.3	33.6	14.7	19.0	33.5	15.2	18.5	33.8
S.D.	4.9	1.5	9.6	4.8	1.3	9.3	4.7	0.6	9.6	4.9	3.6	9.6	5.0	5.7	9.5
Min. age	6	22	19	6	20	20	6	22	18	6	15	19	6	14	19
Max. age	27	25	50	27	23	50	27	23	50	27	22	50	27	22	50
Correlation coefficient between ages and stages															
	0.774			0.803			0.776			0.766			0.773		
P	P<0.01			P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$															
	0.520			0.554			0.519			0.507			0.517		
P	P<0.01			P<0.01			P<0.01			P<0.01			P<0.01		

	L1_spinous				L2_spinous			L3_spinous			L4_spinous			L5_spinous		
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3	Stage 0	Stage 2	Stage 3
N.	25	1	5	68	26	6	67	24	7	68	19	13	67	22	8	69
Means	14.5	20.0	20.2	33.6	14.8	18.8	33.8	13.7	21.3	33.6	13.1	19.8	33.7	13.5	20.9	33.3
S.D.	4.9	—	2.4	9.6	5.1	3.7	9.5	4.1	3.6	9.6	4.4	3.6	9.7	4.5	3.6	9.8
Min. age	6	20	17	19	6	14	19	6	17	19	6	14	17	6	16	17
Max. age	27	20	23	50	27	23	50	20	27	50	21	27	50	25	27	50
Correlation coefficient between ages and stages																
	0.773				0.776			0.783			0.773			0.753		
P	P<0.01				P<0.01			P<0.01			P<0.01			P<0.01		
Correlation ratio $\eta 2$																
	0.517				0.522			0.530			0.521			0.498		
P	P<0.01				P<0.01			P<0.01			P<0.01			P<0.01		

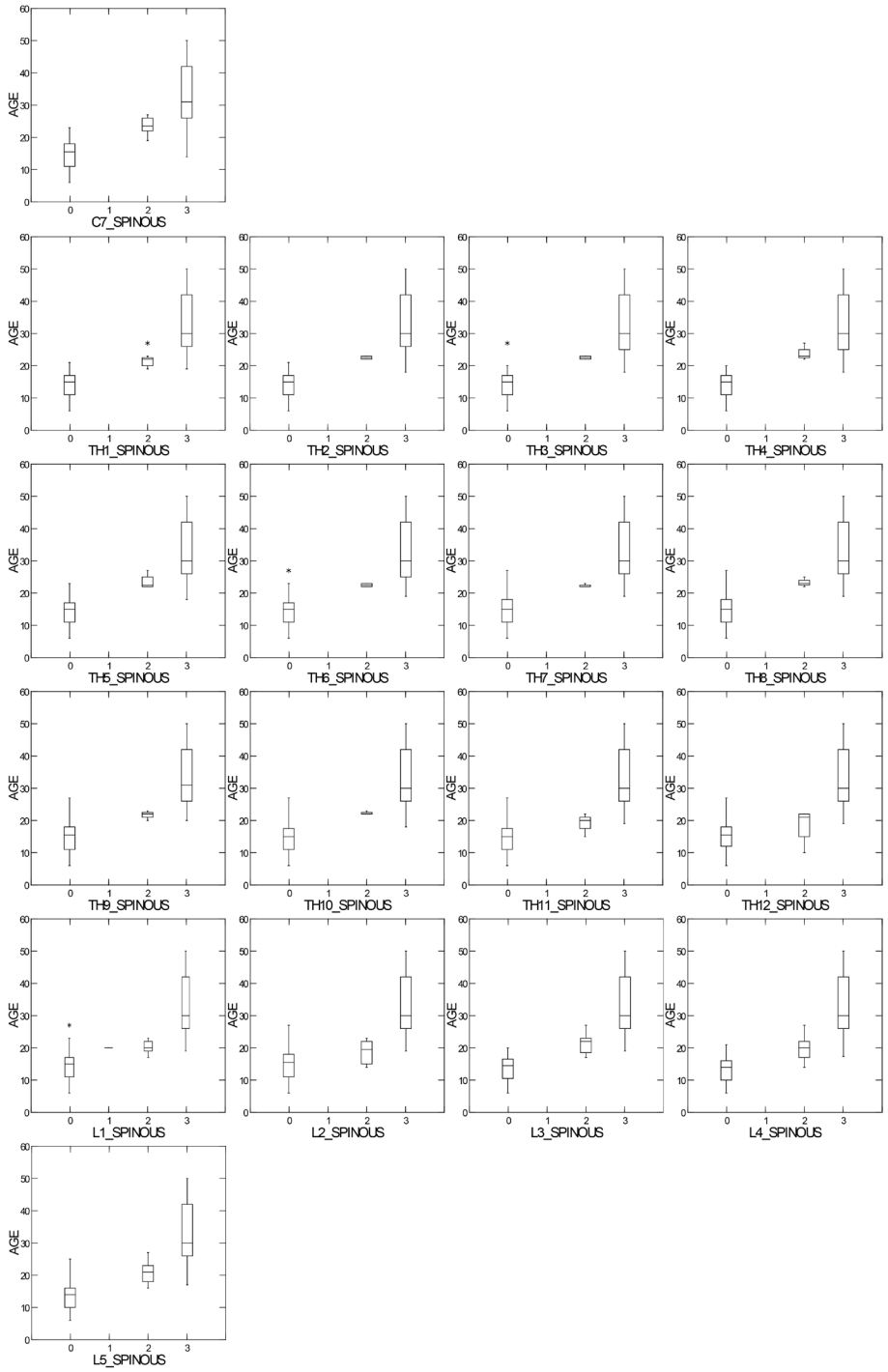

Figure 10. Box plots of each stage of epiphyses on spinous processes.

mum age for "no union (stage 0)" in this study is almost the same as those in Albert *et al.* (2010) and Albert and Maier (2013) and is higher than that reported by Cardoso and Rios (2010). The minimum age for "partial union (stage 1 and stage 2)" was 14 years for all cases except for the lumbar vertebrae in

Table 7. The minimum and maximum ages for each stage of the epiphyseal rings in this study and previous studies.

	Stage 0		Stage 1		Stage 2		Stage 3	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Epiphyseal ring of cervical v.	6	27 (23)	14	27	19	46	15	50
Epiphyseal ring of thoracic v.	6	27 (23)	14	30	19	45	20	50
Epiphyseal ring of lumbar v.	6	27 (23)	17	23	19	34	21	50
Albert et al(2010 & 2013)								
Epiphyseal ring of cervical v.	14	22	14	22	14	26	14	27
Epiphyseal ring of thoracic and lumbar v.	17	22	14	24	14	26	19	27
Cardoso and Rios (2010)								
Epiphyseal ring of cervical v.	9	18	14			21	15	30
Epiphyseal ring of thoracic v.	9	21	14			27	18	30
Epiphyseal ring of lumbar v.	9	17	14			23	17	30

The number in parentheses indicates the next highest age after "27 years old".
The results for Albert *et al.* (2010) and Albert and Maier (2013) are shown for both sexes combined.

this study, but the maximum age tended to be higher in the results of this study. The minimum ages for "complete union (stage 3)" were close to each other in all studies. The results of this study and those of Albert *et al.* (2010) and Albert and Maier (2013) differ in the maximum ages for stage 1, minimum ages for stage 2, and maximum ages for stage 2. The fact that the maximum ages of "partial union" in this study differ from previous studies may be due to the upper age limit of the sample used in this study. In previous studies, the upper limit of the sample was 27 and 30 years of age; therefore, it is possible that individuals in whom fusion continued until older ages were omitted. However, the fact that the minimum ages for Stage 2 are higher than those reported by Albert *et al.* (2010) and Albert and Maier (2013) cannot be explained. It is possible that there were differences between the groups or in the definitions of the stages. In Albert *et al.* (2010) and Albert and Maier (2013), the Pearson's correlation coefficient between age and stage of the epiphyseal ring was 0.655 for males and 0.682 for females in the cervical vertebrae, and 0.71 for males and 0.87 for females in the thoracic and lumbar vertebrae. As previously discussed, this study tends to show a slightly higher coefficient. Considering the above, the results of the epiphyseal rings in this study showed a similar trend to those of previous studies, but it is impossible to deny the possibility that group differences may have an effect.

Other morphological features of the vertebrae that those in this study, osteophyte formation is used to estimate the age of people in their middle years or older (Stewart, 1958; Watanabe and Terazawa 2006). Among the samples in this study, the youngest individual with osteophyte formation was 34 years old, and there were no individuals aged >40 years without osteophytes. In addition, as shown in the case of ossification of the neurocentral cartilage, if younger individuals are included in the analysis, it may be possible to estimate their age at death. Therefore, by considering a wider age range than that in this study and adding more morphological features to the analysis, it may be possible to estimate the age of individuals from young to old using vertebrae. As shown in Figure 1, very few females were included in the study. It is also necessary to analyze data from more female individuals in future studies. Furthermore, as Cardoso and Rios (2010) pointed out, preservation conditions are important for evaluating the morphology of epiphyses, which is a problem in this study. While collecting the samples in this study, many individuals could not be analyzed because only one epiphysis was damaged. Regarding the results of this study, it was necessary to select variables to increase the sample size. In addition, this study did not consider interobserver errors. Although previous studies have indicated little error, it is necessary to consider this issue in the Japanese population.

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