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ORIGINAL ARTICLE

Estimation of fetal age at death from the basilar part of the occipital bone

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Abstract The purposes of this study are to examine documented fetal skeletal remains of Japanese, to measure the basilar part of the occipital bone, and to develop diagnostic standards for estimating fetal age at death which can be applied to poorly preserved skeletons. The sample is composed of 272 Japanese individuals of the early to middle twentieth century, whose ages were recorded in months from gestations of 5 to 11 months. The measurement items used here are the length, breadth, and index of the basilar part. The regression equations of gestational age in months for one or two variables were calculated. The results indicated that it is possible to use the regression equations to estimate the age at death of fetuses directly from the basilar part measurements. Another indicator for estimating age at death from the basilar part is the ratio of the width to the length, which was here expressed as the index of the basilar part. The width exceeded the length at 7 months and the basilar part changed with age from an anteriorly posteriorly long shape to a bilaterally wide one. It is concluded that the basilar part is a good indicator for estimating the fetal age at death.

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Introduction

Estimation of age at death of human skeletons is a fundamental tool in the fields of forensic anthropology and bioarchaeology [1–6]. The age-at-death estimation of fetuses whose teeth are not completely formed and are difficult to recognize is usually based on the diaphysis of long bones [7–12]. However, fetal skeletons from forensic and archaeological contexts are not always associated with long bones due to poor preservation.

The basilar part of the occipital bone is located in the base of the skull. The ossification center of the basilar part appears between the 11th and 12th gestational weeks [13]. Fusion of the basilar part with the lateral parts occurs at 5–7 years, and the closure of the spheno-occipital synchondrosis occurs at the end of the adolescent growth spurt [13]. Because of a thick quadrilateral plate, the basilar part is relatively resistant to decay [14–16]. Nagaoka et al. [14] examined bone preservation of non-adults from an archaeological site and found that the basilar part is one of the most well-preserved parts of skeletons. The use of well-preserved parts of skeletons for age-at-death estimation allows us to obtain information on age at death which otherwise could not be obtained from fragmentary human remains.

Redfield [15] described the developmental stage in the basilar part as an aid to estimating age in immature skeletons. Fazekas and Kósa [8] and Kósa [17] measured the length and width of the basilar part and showed diagnostic standards to estimate the age at death of fetuses. Scheuer and Mclaughlin-Black [18] measured the basilar part of 64 fetal

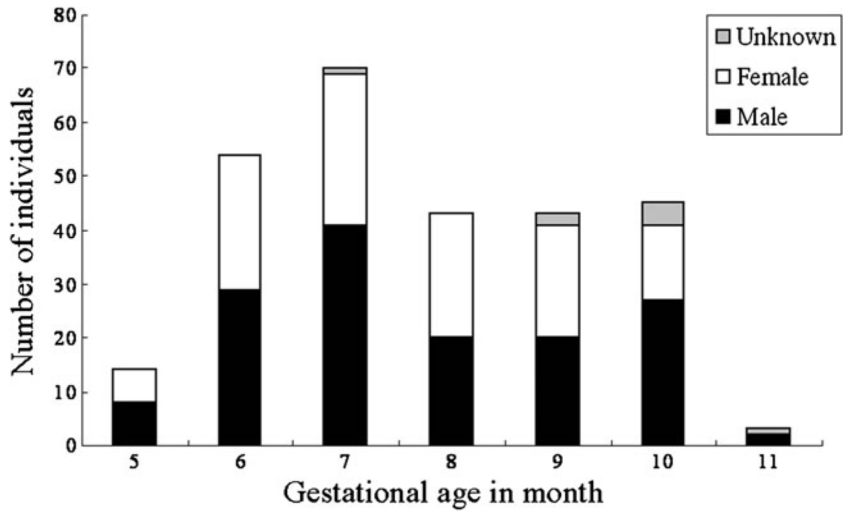

Fig. 1 Japanese fetal skeletal collections of known age, by sex

and post-natal individuals from the St. Bride and Spitalfields collections in the UK and confirmed the relationship between the dimensions in the basilar part and age at death. Tocheri and Molto [16] examined the age-related changes in the dimensions of the basilar part for 39 fetal and juvenile skeletons from Roman Period Egypt and concluded that the dimensions of the basilar part changed with gestational age and that they are useful for estimating fetal and post-natal age at death.

However, these preceding studies have three problems: (1) most of them analyzed undocumented specimens whose age at death was estimated from femoral diaphyseal length or body length; (2) these studies did not address any sufficient statistical model for estimating age at death directly from bone measurements; and (3) there is no discussion about measurement errors or population differences in their measurements. The purposes of this study are to examine documented fetal skeletal remains of Japanese, to measure the basilar part, and to develop new diagnostic standards for estimating fetal age at death which can be applied to poorly preserved skeletons.

Materials

The sample used in this study is composed of 272 Japanese individuals of the early to middle twentieth century from Tohoku University (141 individuals), Nippon Dental University (20 individuals), and Saga Medical School (111 individuals) (Fig. 1; Table 1). The specimens housed in Saga Medical School included aborted fetal specimens [19], and they were donated with the permission of their parents (Nagasaki, personal communication). The ages were recorded in months from gestations of 5 to 11 months by obstetricians who interviewed pregnant women about the date of their last menstrual period (Nagasaki, personal communication). The age categories of 5, 6, 7, 8, 9, 10, and 11 months correspond to 17–20, 21–24, 25–28, 29–32, 33–36, 37–40, and 41-44 weeks, respectively, and the individuals aged 11 months are all neonates.

The materials were dry bones, produced by soaking in water, and decaying soft tissues (Nagasaki, personal communication). Although there are no data on the postmortem shrinkage of the occipital bone during the desiccation of the organic matrix, Huxley [20] demonstrated the shrinkage of fetal long bones from fresh to dry bone: the rate of shrinkage of the fetal long bones is 5.74 % in five lunar months but decreases to 1.28 % in newborns. The method presented below can be applied to dried bones in forensic cases, if the proportion of shrinkage of each bone is assumed to be the same in the present materials and the forensic samples.

Specimens with abnormalities and pathological changes were excluded. The comparative sample for testing the validity of the present method is the forensic data for Europeans reported by Fazekas and Kósa [8].

Table 1 Japanese fetal skeletal collections of known age, by sex

Gestational age (months)	Male	Female	Unknown	Total
5	8	6	0	14
6	29	25	0	54
7	41	28	1	70
8	20	23	0	43
9	20	21	2	43
10	27	14	4	45
11	2	0	1	3
Total	147	117	8	272

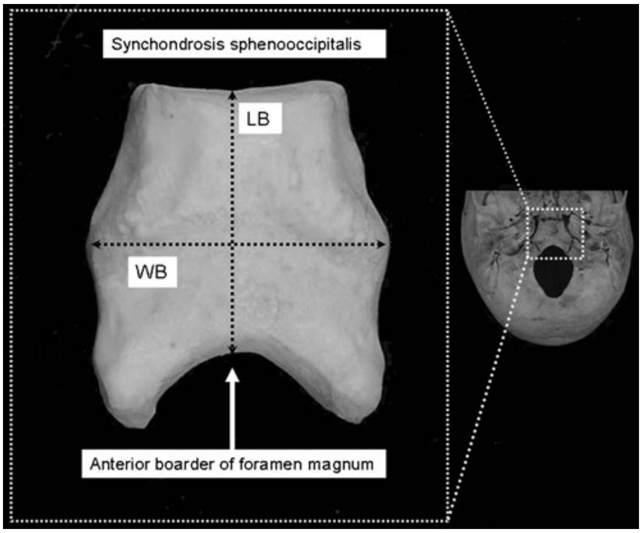

Fig. 2 Measurements of the basilar part of the occipital bone

Methods

This study measured the basilar part using a digital caliper (Mitutoyo NTD12P-15C) and obtained diagnostic standards to estimate the fetal age at death. The length and width of basilar part are defined according to Fazekas and Kósa [8] (Fig. 2), and the index of basilar part was first employed by us. The definitions of them are:

1. Length of basilar part (LB): "the distance measured in the midline between the foramen magnum and synchondrosis sphenooccipitalis" [8];
2. Width of basilar part (WB): "the greatest distance measured in the line of the lateral tubercles" [8];
3. Index of basilar part (IB): the ratio of the width to length, which is expressed as $\frac{WB}{LB} \times 100$.

Although Redfield [15] and Fazekas and Kósa [8] employed the same definition of the basilar part width and measured the greatest distance in the line of the lateral tubercles, they referred to different definitions in the basilar part length. While Redfield [15] measured the length from the synchondrosis sphenooccipitalis to the tip of the occipital condyle, Fazekas and Kósa [8] measured the minimum length from the synchondrosis sphenooccipitalis to the foramen magnum. This study employed the definition of Fazekas and Kósa [8], because the tip of the occipital condyle is often lost in fragmentary fetal skeletons,

Table 2 Technical error of measurements and coefficient of reliability

Measurements	Number of individuals	TEM	%TEM	*r*
LB	19	0.089	0.836	0.989
WB	19	0.133	1.083	0.996
IB	19	1.320	1.154	0.990

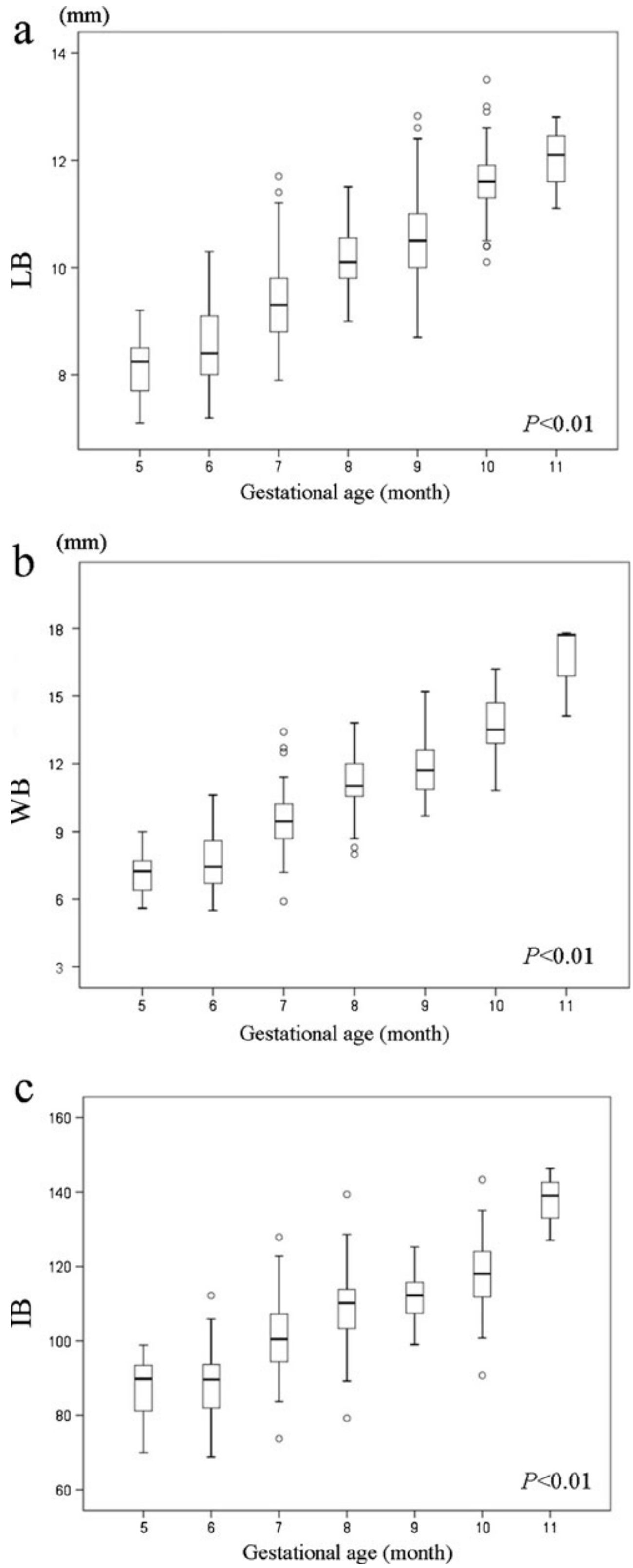

Fig. 3 Box plot showing the distribution of measurements for each gestational age of the sample. **a** LB; **b** WB; **c** IB

Table 3 Descriptive statistics for basilar part measurements

Measurements	Basic statistics	Gestational age (months)							Kolmogorov-Smirnov test	Analysis of variance	
		5	6	7	8	9	10	11	*P* value	*F* value	Probability
LB	Number of individuals	14	54	70	43	43	45	3	>0.05	95.651	<0.001
	Mean (mm)	8.1	8.6	9.4	10.1	10.6	11.6	12.0			
	Standard deviation (mm)	0.6	0.8	0.8	0.6	0.9	0.7	0.9			
WB	Number of individuals	14	54	70	43	43	45	3	>0.05	138.367	<0.001
	Mean (mm)	7.1	7.6	9.5	11.1	11.8	13.7	16.5			
	Standard deviation (mm)	1.1	1.3	1.3	1.3	1.3	1.3	2.1			
IB	Number of individuals	14	54	70	43	43	45	3	>0.05	59.993	<0.001
	Mean	87.2	88.8	100.8	109.0	111.6	118.2	137.5			
	Standard deviation	9.0	9.5	10.6	10.5	6.1	9.9	9.7			

because the comparative sample used in this study was measured according to the definition of Fazekas and Kósa [8], and because the maximum length of Redfield [15] has been commonly used in the age estimation of postpartum infants rather than fetuses in the preceding studies [15, 16, 18].

To avoid inter-observer errors, the first author alone measured all specimens. In order to test intra-observer errors in the measurement items, measurements were taken twice for 19 individuals of the reference sample (Table 1) after an interval of 6 months by the first author. The technical error of measurement (TEM), the percentage expression of errors (%TEM), and the coefficient of reliability (*r*) were calculated following Ulijaszek and Lourie [21] and Goto and Mascie-Taylor [22]. The reliability of the measurement is expressed as the degree of *r* which ranges from 0 (poor reliability) to 1 (high reliability).

In order to test the validity of the regression equations, we applied them to the comparative sample of Fazekas and Kósa [8] and calculated inaccuracy and bias. Inaccuracy is an averaged absolute error calculated as $\frac{\sum |\text{estimated age} - \text{real age}|}{n}$ and bias is an averaged error expressed as $\frac{\sum (\text{estimated age} - \text{real age})}{n}$, where n is the number of comparative specimens. The statistical analyses were performed using SPSS for Windows 16.0J and Microsoft Excel 2003.

Table 4 Spearman's correlation coefficient with age for each measurement

Measurements	Spearman's correlation coefficient	Probability
LB	0.83	<0.001
WB	0.87	<0.001
IB	0.76	<0.001

Results

LB, WB, and IB show an intra-observer coefficient of reliability greater than 0.99 (Table 2). In the calculations of LB, WB, and IB, the null hypothesis for distributional normality was not rejected at the 5 % level by the Kolmogorov–Smirnov test. Since there is no significant sexual difference in these measurement items in each age group from 5 to 10 months (*t* test, $P>0.05$) with an exception of 5 months in LB (*t* test, $P<0.05$), both sexes of the sample were pooled.

Descriptive statistics of the measurements of the sample are shown in Fig. 3 and Table 3. All measurement items positively correlated with the gestational age ($P<0.01$) (Table 4). The regression equations of gestational age in months for one or two variables were calculated:

$$\text{Gestational age(month)} = 0.953 * \text{LB} - 1.693 \qquad (1;)$$

Table 5 Regression analysis of basilar part measurements in mm

Equation		Number of individuals	Correlation coefficient (*R*)	Determination coefficient (R^2)	Standard error of estimate
Equation 1	0.953*LB−1.693	272	0.822	0.676	0.876
Equation 2	0.519*WB+2.323	272	0.862	0.742	0.781
Equation 3	0.278*LB+0.389*WB+0.934	272	0.868	0.753	0.767

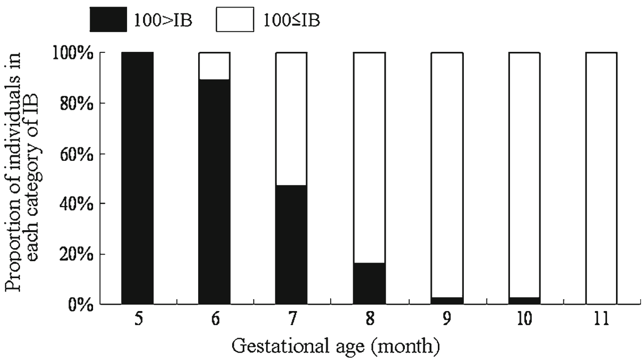

Fig. 4 Proportion of individuals in each category of IB

Table 6 Proportion of individuals in each category of IB

IB		Gestational age (months)						
		5	6	7	8	9	10	11
100>	Number of individuals	14	48	33	7	1	1	0
	Percentage expression	100.0	88.9	47.1	16.3	2.3	2.2	0.0
100≤	Number of individuals	0	6	37	36	42	44	3
	Percentage expression	0.0	11.1	52.9	83.7	97.7	97.8	100
Total		14	54	70	43	43	45	3

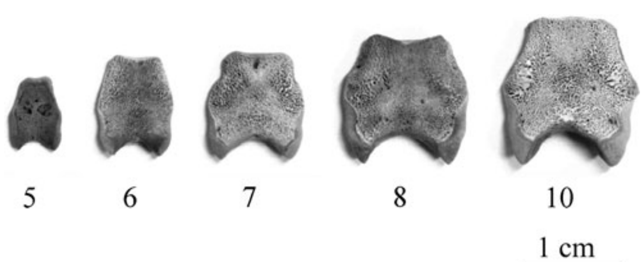

Fig. 5 Age-related changes of the basilar part. *5–8* and *10* gestational age in months

$$\text{Gestational age(month)} = 0.519 * \text{WB} + 2.323 \qquad (2;)$$

$$\text{Gestational age(month)} = 0.278 * \text{LB} + 0.389 * \text{WB} + 0.934 \qquad (3.)$$

In terms of the determination of the coefficient (R^2), the first equation (R^2=0.676) was less reliable than the second (R^2=0.742) and the third (R^2=0.753) (Table 5).

Another indicator for estimating age at death from the basilar part is the ratio of the width to the length, which is here abbreviated as IB. The proportion of individuals classified into two categories according to the IB values (<100 and 100≤) is shown in Fig. 4 and Table 6. The percentage of the <100 individuals in IB which accounted for 100 % at 5 months decreased with age, and was exceeded by that of the 100≤individuals at 7 months (Fig. 4; Table 6). The width exceeded the length at 7 months and the basilar part changed with age from an anteriorly-posteriorly long shape to a bilaterally wide one (Fig. 5).

Discussion

Measurement errors

In Table 2, LB, WB, and IB show an intra-observer coefficient of reliability greater than 0.99. If an acceptable level of reliability can be assumed to be 0.90 or more [21], they are judged not to be affected by intra-observer errors. This implies that the measurement items used in this study can be easily employed by researchers.

Population difference in measurements

Scheuer and Black [13] emphasized socioeconomic conditions as potential factors for population differences in

Table 7 Comparison of basilar part measurements between the present and Fazekas and Kósa's data

Gestational age (months)	LB (mm)			WB (mm)			IB		
	This study	Fazekas and Kósa	*t* test (*P* value)	This study	Fazekas and Kósa	*t* test (*P* value)	This study	Fazekas and Kósa	*t* test (*P* value)
5	8.1	8.1	>0.05	7.1	6.4	<0.05	87.2	78.6	<0.01
6	8.6	8.6	<0.05	7.6	8.2	<0.05	88.8	92.0	>0.05
7	9.4	9.4	<0.01	9.5	9.5	>0.05	100.8	96.1	<0.05
8	10.1	10.1	<0.01	11.1	11.4	>0.05	109.0	106.7	>0.05
9	10.6	10.6	<0.01	11.8	12.9	<0.01	111.6	106.7	<0.01
10	11.6	11.6	<0.01	13.7	15.2	<0.01	118.2	116.9	>0.05
11	12.0			16.5			137.5		

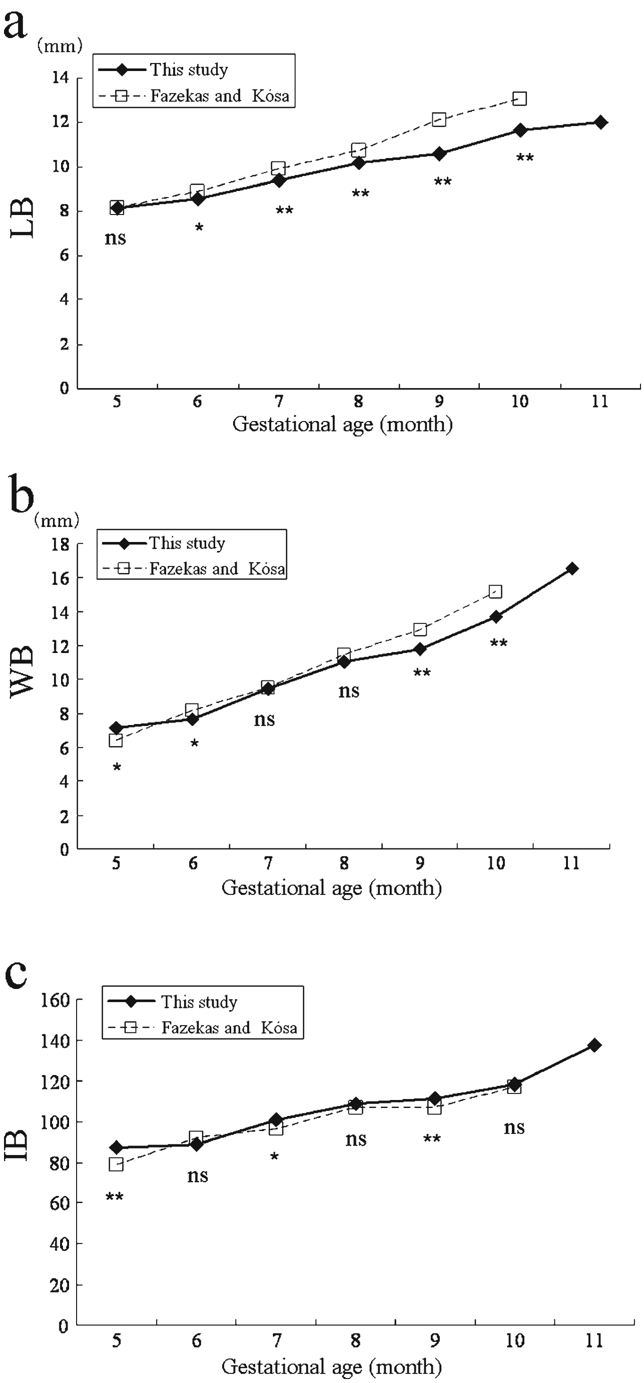

Fig. 6 Comparison of measurements between the present and Fazekas and Kósa's [8] data. **a** LB; **b** WB; **c** IB. *ns* not significant. *$P<0.05$; **$P<0.01$

body size. They cited the example of Russia and the Netherlands during World War II [23, 24] and stated that starvation conditions led to a decline in birth weight. Maternal malnutrition had a considerable effect on growth not only in infancy and childhood but also before birth [13]. The study of Garn et al. [25], who found a clear relationship between children's crown diameters and the mother's health during pregnancy, supported this view.

In this study, there are population differences in age-related changes in the basilar part measurements. Table 7 and Fig. 6 show the results of a comparison between the present and Fazekas and Kósa's [8] data. The Japanese fetuses showed significantly smaller measurements in LB and WB than the Fazekas and Kósa [8] and the difference between the two populations increased with gestational age (Fig. 6). On the other hand, the population difference in IB is not remarkable, because the differences seen in both LB and WB appeared with gestational age in the same manner. Further comparison with St. Bride and Spitalfields collections [18] or a Roman-period Egyptian skeletal population sample [16] suggested that the mean measurements of the archaeological remains were approximately within one standard deviation of the Japanese sample, but this comparison also implied that the data of Scheuer and Mclaughlin-Black [18] had longer LB and smaller IB than the Japanese at 10 and 11 months (Fig. 7). The results of this study demonstrated that population differences in the basilar part measurements had already appeared before birth. The materials used in this study belonged to the early to middle twentieth century during a period of continuous wars and were easily subject to malnutrition during pregnancy. It is reasonable to assume that maternal malnutrition caused the decline of birth weight and made the measurements in the Japanese fetuses smaller than those in the comparative sample.

Fetal age-at-death estimation using the basilar part

This study examined the age-related changes in the basilar part measurements and found that both the length and width of the basilar part were positively correlated with gestational ages. This strengthens previous findings by Scheuer and Black [13], Scheuer and Mclaughlin-Black [18], and Tocheri and Molto [16], who implied that the basilar part dimensions changed with gestational age and are likely a useful indicator for fetal age-at-death estimation.

The preceding studies have dealt with the fetal age-at-death estimation using the basilar part measurements from two approaches. The first is the ratio of the width to length of the basilar part [8, 15, 16, 18]. In the pioneering study of Redfield [15], who employed the maximum length from synchondrosis sphenooccipitalis to the tip of the occipital condyle, "infants younger than four months of age postpartum had a basilar part longer than wide, whereas infants over six months had the reverse." Based on the measurements of LB and WB, Fazekas and Kósa [8] suggested, "the

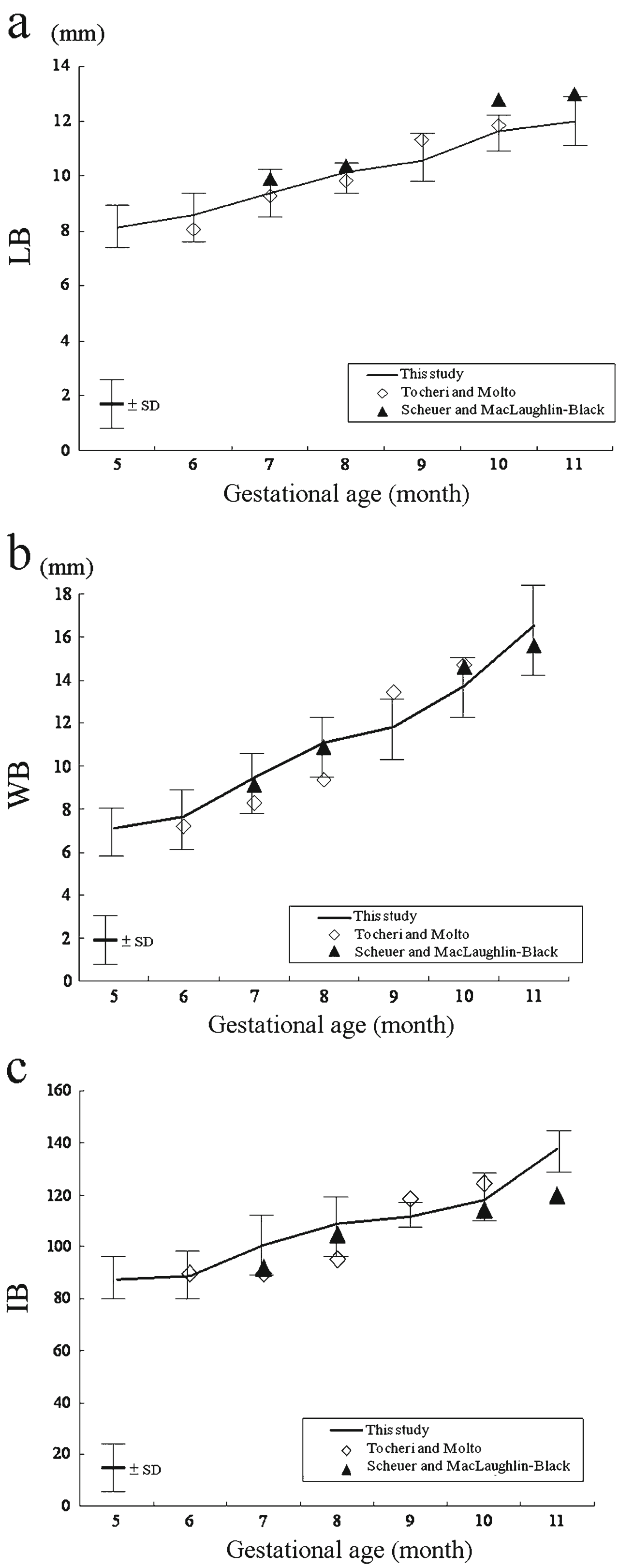

Fig. 7 Comparison of measurements between the present data and the archaeological data of Scheuer and Mclaughlin-Black [18] and Tocheri and Molto [16]. **a** LB; **b** WB; **c** IB

width of the basilar part measured in this plane at the age of $7\text{–}7\frac{1}{2}$ months exceeds its sagittal length." Scheuer and Mclaughlin-Black [18] measured 64 fetal and post-natal individuals from the St. Bride and Spitalfields collections and concluded, "(i) if the [WB] is less than the [LB] then the individual is likely to be less than 28 weeks in utero, and (ii) if the [WB] is greater than the maximum length then the individual is likely to be in excess of five months of age postpartum." Tocheri and Molto [16] further examined 39 fetal and juvenile skeletons from Roman Period Egypt and stated, "If [the LB] equals or exceeds [the WB], the individual is likely to be younger than 32 fetal weeks or eight lunar months." The preceding studies commonly concluded that the basilar part changed with age from an anteriorly-posteriorly long shape to a bilaterally wide one. This study employed the definition of Fazekas and Kósa [8] of the basilar part length and found that the percentage of the <100 individuals in the IB was exceeded by that of the 100≤individuals at 7 months. Figure 8 and Table 8 compared the proportion of individuals in two categories of IB (IB<100 and 100≤IB) between the present and Fazekas and Kósa's [8] data and found no significant difference between the two populations. The results of this study support the previous finding that LB is greater than WB before 7 months, whereas after 7 months WB exceeds LB and imply that the ratio of WB to LB is an indicator which can be universally applied to temporally and geographically different populations.

Another method used in the preceding studies is a two-step estimation from the basilar part measurements. Fetal body length was calculated from the regression analysis of basilar part measurements; and the estimated body length was then used to estimate fetal age at death [8]. This method, however, has been criticized by Sherwood et al. [12]. "Because any

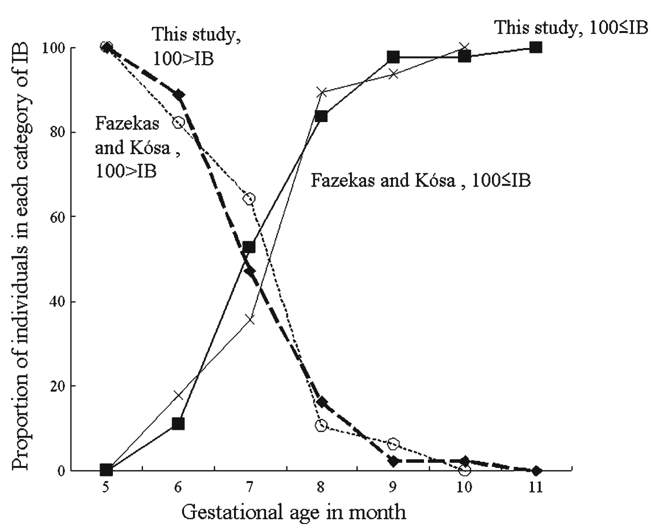

Fig. 8 Comparison of the percentage of individuals in two categories of IB between the present and Fazekas and Kósa's [8] data

Table 8 Comparison of the proportion of individuals in each category of IB between the present and Fazekas and Kósa's data

Gestational age (month)	This study				Fazekas and Kósa				Fisher's exact test between two populations (*P* value)
	100>IB		100≤IB		100>IB		100≤IB		
	Number of individuals	Percentage expression	Number of individuals	Percentage expression	Number of individuals	Percentage expression	Number of individuals	Percentage expression	
5	14	100.0	0	0.0	28	100.0	0	0.0	>0.05
6	48	88.9	6	11.1	23	82.1	5	17.9	>0.05
7	33	47.1	37	52.9	18	64.3	10	35.7	>0.05
8	7	16.3	36	83.7	2	10.5	17	89.5	>0.05
9	1	2.3	42	97.7	1	6.3	15	93.8	>0.05
10	1	2.2	45	97.8	0	0.0	12	100.0	>0.05
11	0	0.0	3	100.0					

predicted value resulting from a regression model is associated with an uncertainty, successive applications of the product of one regression as input into subsequent models will magnify the overall error of the final prediction" [12]. This study calculated the regression equations of gestational age in months directly from bone measurements. In terms of the determination of the coefficient, LB yielded a less reliable regression equation than WB or the combination of the two variables. When these equations were applied to the comparative sample, both the inaccuracy and bias of the first equation were greater than those of the second and third ones (Table 9). The bias produced by the first equation is the positive value and indicates an overestimation of fetal ages in the comparative sample. The bias produced by the second and third equations, on the other hand, exhibits negative values in seven to ten gestational months, which indicates an underestimation of fetal ages. The application of the present methods to different populations might lead to some misclassification of fetal age at death, but in total the errors were within 1 month (Table 8). Hence, the fetal age at death can be satisfactorily estimated per month, even when the regression equations are applied to different populations.

Conclusions

This study examined documented fetal skeletal remains of Japanese individuals and developed diagnostic standards for estimating age at death. One indicator for estimating age at death from the basilar part is the ratio of WB to LB. LB is greater than WB before 7 months, whereas WB exceeds LB after 7 months. The basilar part changed with age from an anteriorly posteriorly long shape to a bilaterally wide one. Another method is regression equations calculated using one or two variables of the basilar part. The results indicated that it is possible to use regression equations to estimate age at death directly from measurements. As there are population differences in bone measurements, the regression equations derived here are population specific and are the most appropriate for the age-at-death estimation of Japanese fetuses. Fortunately, the application of the present methods to different populations led to a fetal age-at-death estimation with an error of less than 1 month.

These methods employed here are useful, because the basilar part is resistant to decay, especially when compared with other parts of skeletons. As human skeletons from

Table 9 Inaccuracy and bias of estimated age at death when applying the regression equations to the comparative sample of Fazekas and Kósa

Gestational age (month)	Equation 1	Equation 2	Equation 3
5			
Inaccuracy	0.43	0.18	0.21
Bias	0.43	0.18	0.21
6			
Inaccuracy	0.36	0.07	0.11
Bias	0.21	0.00	0.04
7			
Inaccuracy	0.36	0.54	0.21
Bias	0.07	−0.25	−0.07
8			
Inaccuracy	0.22	0.17	0.22
Bias	−0.11	−0.17	−0.22
9			
Inaccuracy	0.31	0.44	0.19
Bias	0.31	−0.44	−0.19
10			
Inaccuracy	0.33	0.33	0.17
Bias	0.17	−0.17	0.00
Total			
Inaccuracy	0.34	0.27	0.18
Bias	0.19	−0.11	−0.02

forensic and archaeological contexts are not complete, it is necessary to have a fetal age estimation methodology which can be applied to various parts of skeletons. This study provides new standards for estimating fetal age at death from the basilar part measurements.

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Ethical standards The authors complied with the current laws of Japan and the ethical guideline of Saga Medical School.

Conflict of interest There is no conflict of interest with regard to this manuscript.

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