APPENDIX A

Sex Determination by Discriminant Analysis and Evaluation of Non-metric Traits in the Dog Skeleton

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Introduction

Sex determination methods based on examination of the skeleton are important in the fields of physical anthropology and zooarchaeology. In dogs, sex can easily be determined according to the presence or absence of the penis bone if the skeleton has been excavated intact. However, excavation of undamaged, intact skeletons is very rare. Usually, only individual bones or incomplete sections of the skeleton are excavated. Therefore, sex determination is usually performed by observing skeletal fragments. This requires considerable experience. To facilitate sex determination, several statistical methods have been proposed. Pons (1955) developed a statistical method for sex determination using the human femoral and thoracic bones. In Japan, Hanihara (1958, 1959) developed a similar method that considers the human cranium and limb bones. Statistical methods require no particular expertise, because they employ objective measurements rather than subjective evaluation. Hanihara reported that sex determination using the cranium and limb bones was accurate, with a p value of approximately 0.03-0.11.

Dogs rarely migrate by themselves. It is generally thought that dogs move with humans: therefore, investigations of the migration of dogs may provide information about the migration of humans. Tanabe (1985) studied blood proteins in modern Japanese dogs, and within this context discussed the ancestry of both Japanese dogs and humans, [although he] examined only modern dogs. [Despite the importance of prehistoric dogs to issues of human migration,] few investigations of Japanese canine skeletons using excavated bones exist.

Canine skeletons are frequently excavated at archaeological sites. The oldest canine skeleton excavated in Japan was discovered at the Natsushima Shell Mound in Kanagawa prefecture (ca. 9,000 bp, early Jomon Period, Ota 1980). Many subjective studies have been conducted on ancient Japanese dogs (Hasebe 1925, 1929, 1936, 1943 and others), but few reports provide [metric] data. Hasebe (1952) classified ancient Japanese domestic dogs into five types, according to size. Hasebe's classification system was based on the system of classification for ancient European dogs, and did not incorporate sex determination. Due to the significant difference in size between male and female dogs, classifying dogs only according to size is not meaningful. A small number of studies have been conducted on sex-based structural differences in the canine skeleton, including a metric study of the coxa by Kato (1957) and a non-metric study on the morphology of the cranial base by The and Trouth (1976). Hasebe (1952) and Brothwell et al. (1979) only briefly refer to this problem.

In the present study, sex-determinant, quantitative characteristics are identified in Japanese shiba dogs. Non-metric sex-based differences are also discussed. A secondary purpose of the study is to report and evaluate parametric data pertaining to shiba dogs, because few reports have done so previously (Daigo 1956, 1957, 1961; Kato 1956; Obara 1980).

Materials and Methods

Skeletons of modern shiba dogs (n=87, 45 males and 42 females) were supplied by the Dokkyo University School of Medicine. The modern shiba breed descends directly from ancient Japanese dogs (Kaneko 1978; Saito 1964). The skeletons were measured and subjectively evaluated. The system of anatomical terminology proposed by Evans et al. (1970) was used. All measurements were performed according to the methods described by Saito (1963), Daigo (1956, 1957, 1961) and Kato (1957). The measurements used in the present study are shown in Figures 1 to 3. The indices used were previously described by Shigehara and Onodera (1984). The calculation method of each index is shown in the tables. After measurement, values were averaged, and discriminant analysis was performed., variables were determined according to the variable increase method (Okuno et al. 1981). The predominance of variables was evaluated using the F test, with a p value of 0.05. Some discriminant factors represent relationships between individually-measured values.

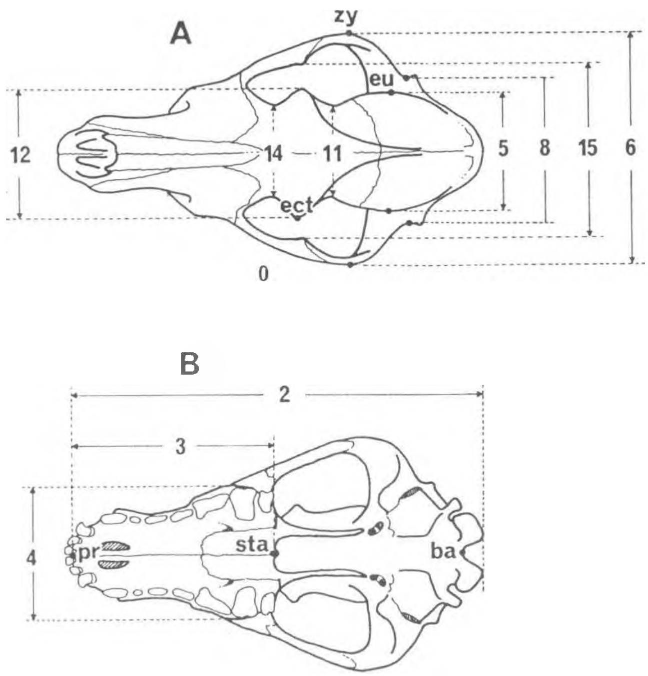

Figure 1. Cranial measurements used in this study. A dorsal aspect. B basal aspect. Numerals correspond with measurement numbers shown in Table 1.

Results and Discussion

Characteristic of modern shiba dogs

Cranium: Maximum cranial length differed by approximately 10 mm between males and females. This measurement varied from 140.7 to 169.5 mm in males, and from 131.1 to 159.7 mm in females. Thus, the range of variation was approximately 30 mm in both sexes. A similar range of variation was observed in total basal length, which is frequently used together with cranial length to determine cranial volume. The smallest range of variation was observed in cranial breadth.

The nasal curve depth (or so-called "stop"), which is the depression from the frontal region to the snout, is the most notable characteristic that distinguishes modern shiba dogs from ancient dogs (Saito 1936). The very small stop and rather straight nasal curve observed in the wolf are considered to be primitive characteristics. Thus, nasal curve depth was not correlated with other measurements or with body size in the present study. Marked variation of this trait is observed in the modern shiba dogs, as are individuals with small stops.

The minimum frontal breadth and zygomatic breadth also showed considerable variation among modern shiba dogs. The minimum frontal breadth is the right to left length of the inferior area of the lateral frontal crest. This area constitutes the lateral portion of the frontal sinus, and reflects the developmental state of the masticatory muscles.

The morphology of the foramen magnum also showed marked variation (Fig. 4). The primitive foramen magnum is a simple, horizontally-oriented oval (A). The primitive foramen magnum is observed in the vast majority of Jomon period dogs. In addition to the primitive foramen magnum, the modern shiba dog shows a type with a notch at the upper margin (B), a "keyhole" type (C), and a triangular type (D). In modern males, the primitive foramen magnum (A) was observed in twenty-two of the forty-five dogs, type B in

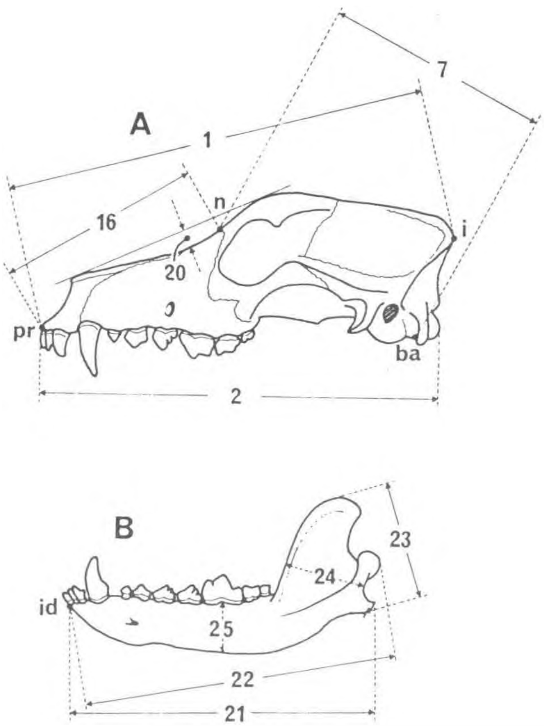

Figure 2. Cranial and mandibular measurements used in the study. A lateral aspect. B lateral aspect of the mandible. Numerals correspond with measurement numbers shown in Table 1.

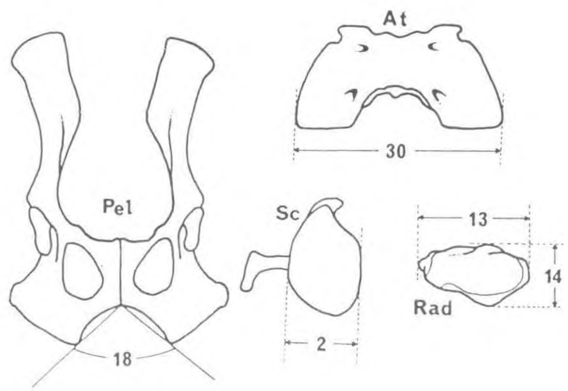

Figure 3. Trunk and extremity measurements used in this study. Pel: pelvis. At: atlas. Sc: glenoid cavity of the right scapula, Rad: distal end of right radius. Numerals correspond with measurement numbers shown in Table 4.

nine, C in eight, and D in six. Non-primitive types accounted for 51.2% of male foramen magna. In modern females, the primitive type was observed in twelve of the forty-two dogs, type B in fifteen, C in nine, and D in six. Non-primitive types accounted for 71.4% of all female foramen magna. As with all other investigated characteristics, the morphology of the foramen magnum showed more variation in females than in males.

The range of variation for each measurement was expressed using Pearson's coefficient of variance. Variation was especially great for nasal curve depth, minimum frontal breadth, frontal breadth, mandibular body thickness, and masseter fossa depth in males. In addition to these features, minimum interorbital breadth and snout height also showed great variation in females.

Dentition: The incisors showed considerable attrition and variation of size in adult modern shiba dogs The canines showed significant difference in size between males and females, as is generally observed in mammals. In males, the canines were large and strong.

Considerable size variation was observed in the first and second premolars of both the maxilla and mandible, but size variation in the third and fourth premolars was slight. Congenital absence of the two permanent medial premolars was frequently observed (Ogata et al. 1979). When present, the medial premolars have short roots and tend to fall out. Therefore, lack of these teeth is frequently observed in Jomon dogs, which used their teeth more forcefully than do modern dogs (Shigehara & Onodera 1984).

Significant variation of size was observed between the first and second molars in the maxilla, and the second molar often showed a reductive tendency. Therefore, the coefficient of variance was higher for the second molar. In the mandible, variation was greater in the distal molars.

In the maxillary dentition, the coefficient of variance was high for every tooth, especially for the medio-distal diameter of the second premolar and for the bucco-lingual diameter of the third premolar. The variation observed in the bucco-lingual diameter of the third premolar reflects the well-developed lingual cingulum often observed in modern shiba dogs.

In the mandibular dentition, the coefficient of variance was high for the medio-distal diameter of the second premolar and for both the medio-distal diameter and bucco-lingual diameter of the third molar. The third molar is a very small tooth that shows size reduction. Size variation observed in the third molar was considerable, as is observed in the human.

In modern shiba dogs, the palate is shorter and wider than in ancient domestic dogs. In addition, various types of maloccclusion have appeared in the dental arch of the modern shiba dog. Such abnormality is most frequently observed in the premolars.

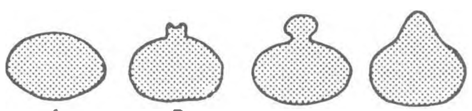

Figure 4. Variations of foramen magnum in shiba dogs. A normal oval foramen, B oval foramen with small notch, C key hole foramen, D triangular foramen.

Limb bones: In the limb bones, the coefficient of variance was high for the maximum breadth in the middle of the humerus, and for the diameter in the middle of the radius. In females, the coefficient of variation was also high for the minimum breadth in the middle of the humerus, and for the diameter of the middle of the femur. These measurements are related to the stoutness of the diaphysis, and showed a higher coefficient of variance than those related to length. Thus, the length of bones is consistent, but stoutness varies considerably in modern shiba dogs.

Analysis of difference between males and females

Non-metric observations

Although sex-based differences are widely known to exist, few reports have been published on non-metrical differences between male and female dogs. Hasebe (1952) reported sex-based differences in the swell of the inferior part of the external frontal crest and in the protuberance of the sagittal crest. The right and left temporal lines meet just behind the bregma, forming a sagittal crest in males that is generally well-developed. In females, if a sagittal crest is present, the temporal lines meet far behind the bregma (Fig. 5-1 to 5-7). The swell of the inferior part of the external frontal crest is more pronounced in males than in females. As a result, constriction of the frontal region was observed in females when viewed from a posterior perspective (Fig. 5-5, 5-6). These characteristics, especially the enlargement of the insertion part of the anterior of the temporal muscle origin, are closely associated with the masticatory muscles.

One characteristic that reflects the development of the temporal muscle is the size of the superior nuchal line in the occipital region (Fig. 5-7, 5-8). In males, the superior nuchal line is not straight. This character is also associated with the deep muscle in the back that raises the head.

The & Trouth (1976) noted a sex-based difference in the insertion of the muscles rectus capitis ventralis major and minor,muscle which correspond to the straight anterior muscle of the head and musulus longus capitis in humans (Fig. 6-1, 6-2). Sex determination using this characteristic yielded an accuracy of 87.5%. This non-metric difference has been suggested to result from behavioural differences between males and females. Brothwell et al. (1979) performed sex determination in ancient Peruvian dogs using this sex-based difference, and we applied this method for sex determination in the modern shiba dog. Of the forty-four shiba males, twenty-three were identified as males and two as females with this method; sex could not be determined in the other fifteen. Of the thirty-two shiba females, only nine were correctly judged to be females and twenty were judged to be males; sex could not be determined in the other three. In particular, accuracy of determination based on the female cranium was very poor. Our findings suggest that this characteristic differs among dog breeds and that methods successful for one breed cannot

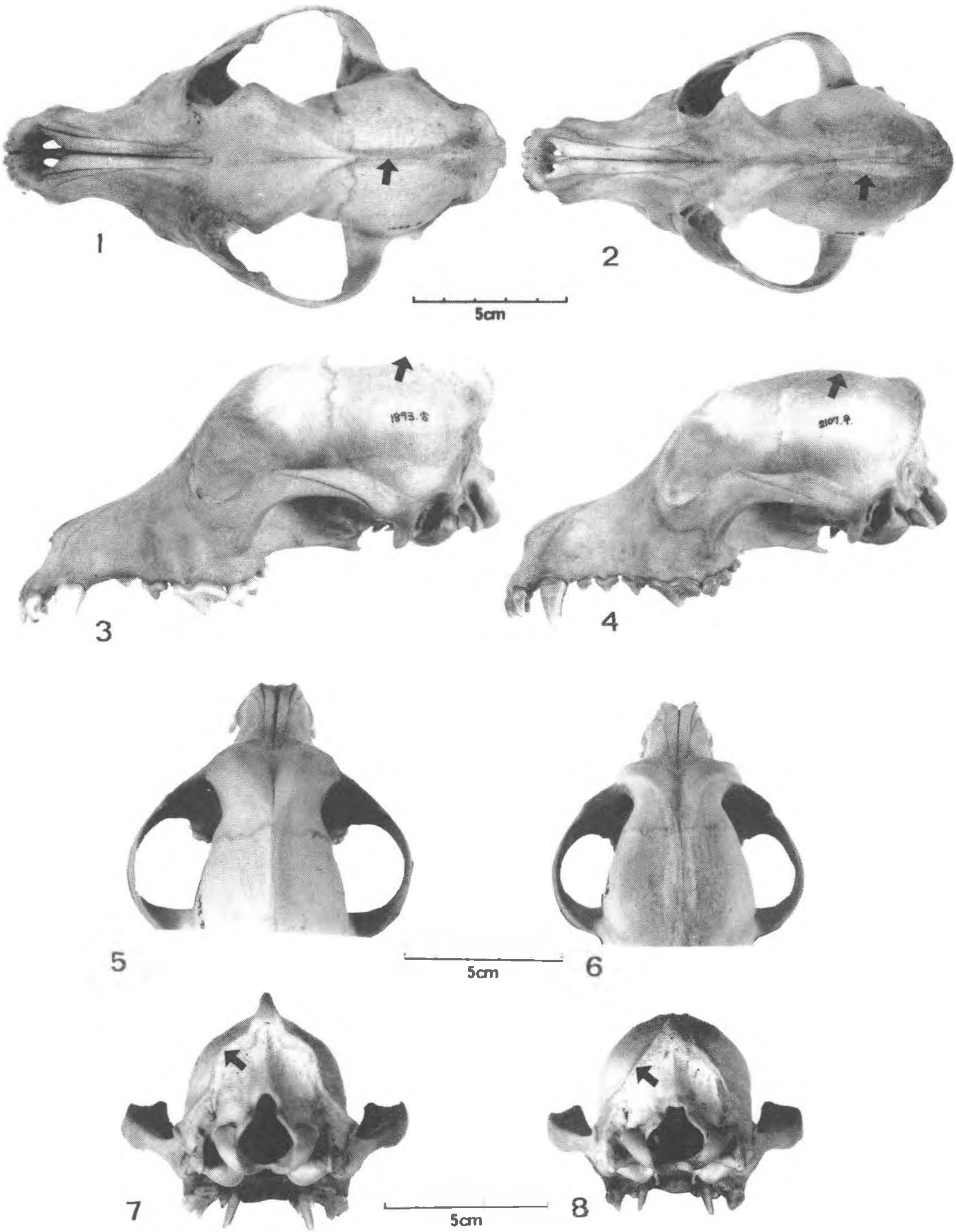

Figure 5. Sex-based differences observed in shiba dogs. Arrows indicate different features in males (left) and females (right). 1 and 2, dorsal aspect: arrows indicate temporal lines (right and left temporal lines meet just behind the bregma in males). 3 and 4, lateral aspect: arrows indicate sagittal and nuchal crests. 5 and 6, dorsal aspect, viewed from posterior: arrows indicate swells of frontal bone. 7 and 8, posterior aspect: arrows indicate nuchal crest.

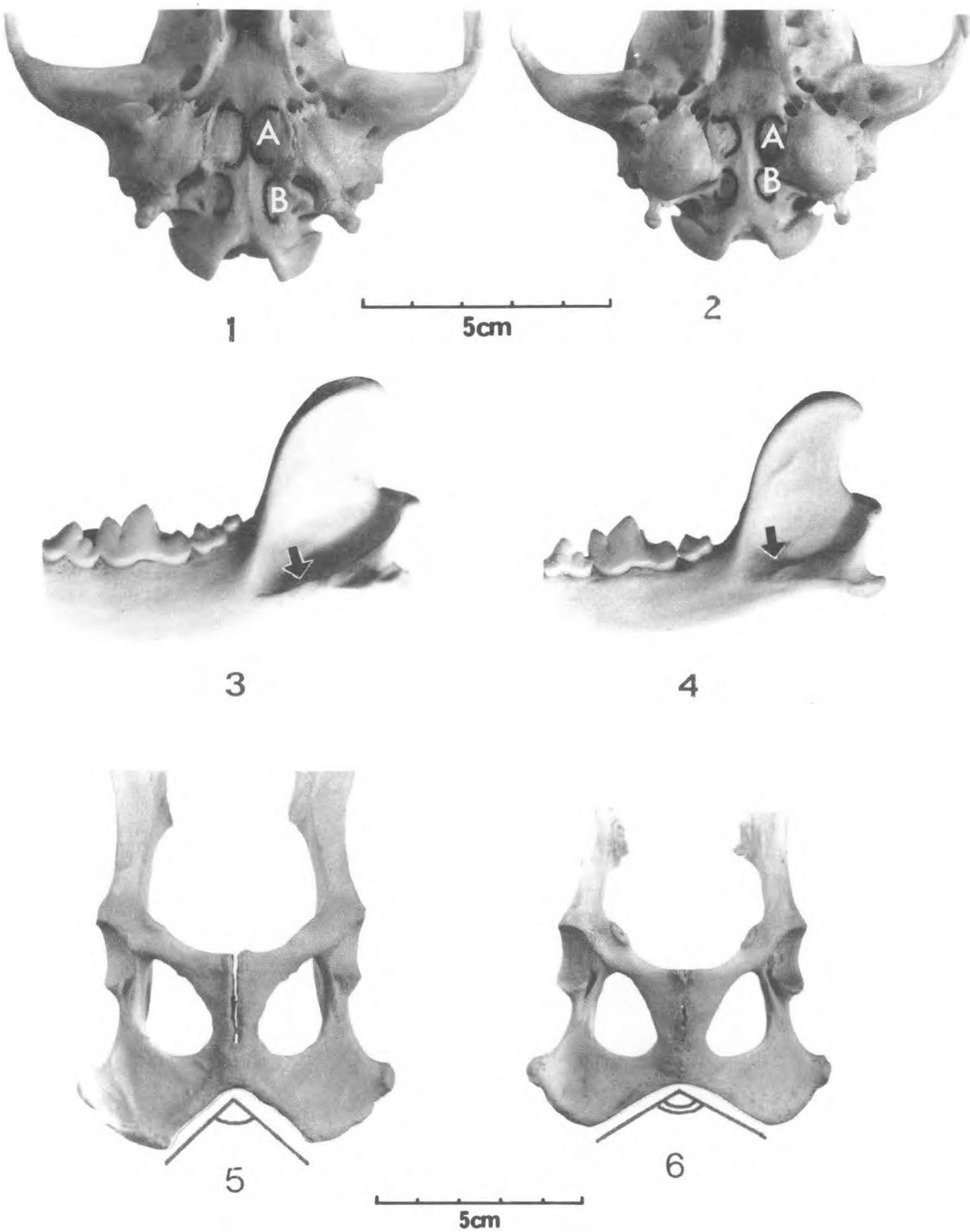

Figure 6. Sexual differences observed in shiba dogs. 1 and 2, basal aspect: showing the difference in hasicranium structure. A: attachment of muscle rectus capitis ventralis major. B: attachment of rectus capitis ventralis minor. 3 and 4, lateral aspect of left mandible; arrrows indicate condyloid crest. 5 and 6, ventral aspect of pelvis showing the difference in sub-pubic angle.

necessarily be applied to other breeds without adjustment.

The condyloid ridge, which forms the inferior margin of the masseter fossa of the mandible, also showed sex-based differences (Fig. 6-3, 6-4). This ridge marks the lower margin at which the middle layer of the masseter muscle is inserted. In males, the masseter fossa is distinguished from the inferior area by a clear condyloid ridge. In females, the masseter fossa is gently shifted downward, without any acute angle.

The subpubic angle of the pelvis also differed between males and females (Fig. 6-5, 6-6). This is commonly observed in mammals. The difference in this angle can also be metrically confirmed.

Metric observations

Differences between mean values of males and females were analyzed using a t-test (Table 1). In the cranium, significant differences were observed at $p < 0.01$ in twenty-six of the twenty-seven items, and at $p < 0.05$ for minimum frontal breadth. On the other hand, very few cranial indices showed significant sex-based differences. Sex-based differences were observed at $p < 0.01$ for the interorbital index and the length-breadth index of the mandibular body, and at $p < 0.05$ for the nasal depth index. These findings suggest that cranial proportion does not differ greatly between males and females.

Sex-based differences ($p < 0.01$) were observed in all measurements for each maxillary tooth. Those of males were consistently larger than those of females (Table 2). Similarly, the length of each tooth row (premolar, molar, and postcanine) was larger in males than in females. However, the relative size of each tooth row showed no significant sex-based difference according to the tooth row indices.

In the mandibular teeth, sex-based differences were observed at $p < 0.01$ in nineteen of the twenty-six measurements, and a $p < 0.05$ in the other six measurements. Only the medio-distal diametre of the first incisor showed no sex-based difference (Table 3). On the other hand, no index showed a significant sex-based difference.

In the limb bone (Table 4), significant sex-based differences ($p < 0.01$) were observed in every measurement (twenty-nine items, excluding penis bone length). On the other hand, only one significant sex-based difference ($p < 0.05$) was observed among the eight limb bone indices, in the cross-section index of the middle of the femur.

Evaluation of determinant factors

A discriminant function is an equation incorporating determinant factors that accurately identifies an individual as belonging to a specific group. In the present study, discriminant analysis was performed using several measurements selected from among those evaluated for effectiveness in modern shiba dogs. The following criteria, developed to be applicable to dog bones excavated from archaeological sites, were applied to the following selection of determinant factors: (1) The body part should not be susceptible to damage, (2) The correlation coefficient between the measurements should not be excessively high, (3) The variation should be small, (4) The coefficient of difference between males and females should be high (coefficient of difference = (the difference in mean value between two groups)/(sum of standard deviations of the two groups), and (5) The number of measurements required should be small.

Nine discriminant functions were derived, such that at least one of them can be used wherever a partial skeleton is excavated (Table 5). The discriminant functions were standardized, such that when the discriminant value (y) obtained after substitution of the measurement values was positive, the individual was determined to be male, and when the discriminant value was negative, the individual was determined to be female.

Discriminant analysis using cranial bones without mandible

Based on their coefficients of difference, six determinant factors were identified for cranial bones, and discriminant analysis was performed (Table 5-(1)). The bizygomatic breadth was the most accurate, followed in order by total basal length, minimum interorbital breadth, palatal breadth, auricular breadth, and nasion-basion length. However, the zygomatic arch is an area that is damaged easily.

Discriminant analysis using the mandible

In contrast to the cranial bones and teeth, very few measurements in the mandible were useful for sex determination, judging from the coefficients of difference. The masseter fossa depth and the thickness of the mandibular body, both of which are conventionally used for sex determination,

Appendix A

Table 1. Cranial and mandibular measurements and indices of Shiba dogs and male Tagara (Jomon period) dogs.

	Male				Female						Tagara (Jomon) Male	
	No.	$\bar{x}$	s	CV	No.	$\bar{x}$	s	CV	t-test	CD	$\bar{x}$	Coefficient
1 : max. cranial length	45	155.48	6.79	4.37	42	145.27	6.81	4.69	◎	0.75	163.01	0.95
2 : basal length	45	147.90	6.05	4.09	42	137.88	6.34	4.59	◎	0.81	152.44	0.97
3 : palatal length	45	74.86	3.65	4.87	42	70.26	3.64	5.18	◎	0.63	78.45	0.95
4 : max. palatal breadth	45	59.17	2.45	4.14	42	55.17	2.63	4.76	◎	0.79	57.41	1.03
5 : cranial breadth (eu-eu)	45	50.06	1.47	2.94	42	48.27	1.71	3.54	◎	0.56	52.35	0.96
6 : zygomatic breadth	45	94.79	3.77	3.98	42	88.14	3.81	4.33	◎	0.88	88.30	1.07
7 : nasion-basion length	45	84.13	3.31	3.93	42	79.05	3.41	4.32	◎	0.76	84.20	1.00
8 : auricular breadth	45	54.16	2.24	4.13	42	50.67	2.15	4.24	◎	0.80	59.39	0.91
9 : brain case length	45	86.10	4.12	4.79	42	80.81	4.20	5.19	◎	0.64	87.16	0.99
10 : cranial height	45	48.53	2.88	5.94	42	45.24	2.50	5.52	◎	0.61	49.00	0.99
11 : min. frontal breadth	45	29.51	2.67	9.03	42	28.15	2.65	9.41	○	0.26	31.70	0.93
12 : frontal breadth	45	43.52	3.77	8.67	42	39.25	3.80	9.68	◎	0.56	42.83	1.02
13 : occipital height	45	41.61	1.90	4.58	42	39.49	2.07	5.24	◎	0.53	42.23	0.99
14 : min. interorbital breadth	45	28.66	2.14	7.45	42	25.43	2.18	8.56	◎	0.75	28.69	1.00
15 : biorbital breadth	45	72.12	2.27	3.14	42	67.88	2.77	4.09	◎	0.84	67.94	1.06
16 : facial length	45	74.60	4.02	5.39	42	69.40	4.12	5.94	◎	0.64	79.39	0.94
17 : snout length	45	64.95	3.35	5.16	42	60.14	3.61	6.00	◎	0.69	68.34	0.95
18 : snout breadth	45	31.48	1.54	4.89	42	28.94	1.86	6.43	◎	0.75	34.52	0.91
19 : snout height	45	34.24	2.04	5.94	42	31.82	2.85	8.95	◎	0.50	39.14	0.87
20 : nasal curve depth	45	6.39	0.79	12.41	42	5.50	0.69	12.60	◎	0.60	5.03	1.27
21 : mand. length (1) (id-goc)	45	114.06	4.89	4.29	42	106.96	4.95	4.62	◎	0.72	118.48	0.96
22 : mand. length (2) (id-c.mid)	45	114.19	5.11	4.48	42	106.96	4.82	4.51	◎	0.73	117.41	0.97
23 : mand. ramus height	45	44.58	2.60	5.84	42	41.27	2.30	5.58	◎	0.67	44.30	1.01
24 : mand. ramus breadth	45	27.66	1.73	6.24	42	25.48	1.44	5.66	◎	0.69	29.28	0.94
25 : mand. body height (M1)	45	18.91	1.29	6.82	42	17.23	1.45	8.41	◎	0.61	22.37	0.85
26 : mand. body thickness (M1)	45	9.13	0.74	8.07	42	8.19	0.65	7.90	◎	0.68	10.86	0.84
27 : masseter fossa depth	45	5.76	0.77	13.32	42	5.25	0.57	10.85	◎	0.38	7.13	0.81
cranial index (6/1)	45	61.01	2.22	3.64	42	60.72	2.26	3.72	×	0.06	55.05	
length-height index (10/1)	45	31.23	1.53	4.89	42	31.17	1.62	5.20	×	0.02	30.03	
breadth-height index (10/6)	45	51.22	2.68	5.24	42	51.35	2.39	4.65	×	0.03	52.46	
postorbital index (11/5)	45	58.95	4.93	8.36	42	58.25	4.21	7.23	×	0.08	60.16	
interorb. index (14/15)	45	39.73	2.46	6.18	42	37.42	2.29	6.13	◎	0.49	42.51	
facial index (16/6)	45	78.75	3.88	4.93	42	78.79	4.36	5.53	×	0.00	90.28	
snout index (18/1)	45	41.76	0.78	1.87	42	41.39	1.10	2.66	×	0.20	41.97	
nasal depth index (20/19)	45	18.70	2.35	12.57	42	17.40	2.56	14.73	○	0.26	12.66	
palatal index (4/3)	45	79.15	3.80	4.80	42	78.64	4.16	5.29	×	0.06	71.13	
mand..th.-length index (26/22)	45	8.00	0.57	7.15	42	7.66	0.54	6.99	◎	0.31	9.24	

CV : coefficient of variance, CD : coefficient of difference, $\bar{x}$: average, s : standard deviation, ◎ : significant difference ($P<0.01$), ○ : significant difference ($P<0.05$), × : no significant difference.

Table 2. Measurements and indices of the upper dentition of Shiba dogs and male Tagara (Jomon period) dogs.

		Male				Female						Tagara (Jomon) Male	
		No.	$\bar{x}$	s	CV	No.	$\bar{x}$	s	CV	t-test	CD	$\bar{x}$	Coefficient
1 : I 1	(m-d)	42	4.31	0.23	5.37	37	4.04	0.30	7.44	◎	0.62	4.3	1.00
2 :	(b -l)	42	4.67	0.28	5.94	39	4.27	0.27	6.26	◎	0.88	4.1	1.14
3 : I 2	(m-d)	44	5.05	0.35	6.87	38	4.78	0.31	6.45	◎	0.49	5.0	1.01
4 :	(b -l)	44	5.22	0.26	5.04	40	4.77	0.27	5.68	◎	1.07	4.6	1.13
5 : I 3	(m-d)	43	5.18	0.30	5.88	37	4.68	0.33	7.15	◎	0.87	4.5	1.15
6 :	(b -l)	43	6.20	0.28	4.49	38	5.55	0.47	8.43	◎	0.99	6.0	1.03
7 : C	(m-d)	45	9.14	0.64	6.98	42	8.27	0.61	7.40	◎	0.71	9.3	0.98
8 :	(b -l)	45	5.33	0.37	6.94	42	4.69	0.43	9.13	◎	0.96	5.3	1.01
9 : P 1	(m-d)	41	5.32	0.33	6.25	39	4.99	0.39	7.81	◎	0.46	5.0	1.06
10 :	(b -l)	41	3.73	0.15	4.16	39	3.41	0.22	6.49	◎	0.87	3.5	1.06
11 : P 2	(m-d)	37	8.22	0.86	10.43	33	7.42	0.67	9.04	◎	0.49	8.2	1.00
12 :	(b -l)	37	3.97	0.24	6.03	33	3.55	0.26	7.38	◎	0.90	3.5	1.13
13 : P 3	(m-d)	45	10.78	0.55	5.09	42	9.79	0.48	4.93	◎	0.85	10.5	1.03
14 :	(b -l)	42	4.90	0.41	8.41	41	4.52	0.40	8.76	◎	0.46	4.3	1.14
15 : P 4	max (m-d)	45	17.55	0.78	4.43	42	16.26	0.75	4.63	◎	0.80	17.6	1.00
16 :	lat (m-d)	45	16.80	0.58	3.46	42	15.71	0.66	4.18	◎	0.79	17.4	0.97
17 :	(b -l)	44	9.45	0.42	4.49	42	8.59	0.49	5.69	◎	0.91	9.0	1.05
18 : M 1	(m-d)	45	11.12	0.55	4.94	42	10.44	0.56	5.35	◎	0.72	11.1	1.00
19 :	max (b -l)	45	14.94	0.72	4.83	42	14.06	0.76	5.37	◎	0.60	15.3	0.98
20 : M 2	(m-d)	44	6.13	0.41	6.73	42	5.70	0.39	6.88	◎	0.49	6.0	1.02
21 :	(b -l)	44	8.90	0.63	7.04	42	8.38	0.52	6.19	◎	0.44	9.5	0.94
22 : tooth row length (I1-M2)		44	79.40	3.37	4.25	42	74.33	3.67	4.94	◎	0.56	—	—
23 : premolar row length (P1-P4)		43	41.63	2.73	6.55	39	38.76	2.13	5.49	◎	0.47	—	—
24 : molar row length (M1-M2)		44	14.95	0.81	5.39	42	13.85	1.13	8.16	◎	0.58	—	—
25 : cheek teeth length (P1-M2)		42	53.40	2.64	4.95	39	49.99	2.47	4.94	◎	0.56	—	—
(M1+M2)×100/P4		44	102.75	5.14	5.01	42	102.74	4.07	3.96	×	0.03	—	—
(23/22)×100		42	52.40	1.94	3.69	39	52.00	1.58	3.04	×	0.06	—	—
(24/22)×100		44	18.85	1.18	6.26	42	18.66	1.56	8.34	×	0.16	—	—
(23/25)×100		42	77.84	2.05	2.64	39	77.52	1.64	2.11	×	0.03	—	—
(8/7)×100		45	58.46	3.09	5.29	42	56.71	3.62	6.38	◎	0.39	—	—

m-d : medio-distal diameter, b-l : bucco-lingual diameter. Abbreviations : see Table 1.

Table 3. Measurements and indices of the lower dentition of Shiba dogs and male Tagara (Jomon period) dogs.

		Male				Female						Tagara (Jomon) Male	
		No.	$\bar{x}$	s	CV	No.	$\bar{x}$	s	CV	t-test	CD	$\bar{x}$	Coefficient
1 : I 1	(m-d)	38	2.62	0.19	7.33	38	2.56	0.16	6.39	×	0.23	2.5	1.05
2 :	(b-l)	39	3.41	0.22	6.46	40	3.11	0.19	6.06	◎	0.68	3.3	1.03
3 : I 2	(m-d)	40	3.77	0.27	7.12	33	3.63	0.24	6.62	○	0.39	4.0	0.94
4 :	(b-l)	41	4.35	0.26	6.04	35	4.03	0.25	6.21	◎	0.60	4.4	0.99
5 : I 3	(m-d)	42	4.98	0.30	6.04	38	4.64	0.39	8.47	○	0.45	5.0	1.00
6 :	(b-l)	43	4.63	0.32	6.82	40	4.14	0.34	8.27	◎	0.60	4.3	1.08
7 : C	(m-d)	45	9.85	0.76	7.71	42	8.79	0.82	9.38	◎	0.78	9.2	1.07
8 :	(b-l)	45	5.81	0.35	5.94	42	5.05	0.42	8.27	◎	0.91	5.4	1.08
9 : P 1	(m-d)	41	4.05	0.29	7.14	41	3.87	0.21	5.46	○	0.37	—	—
10 :	(b-l)	41	3.10	0.19	6.15	41	2.86	0.20	7.16	◎	0.63	—	—
11 : P 2	(m-d)	24	7.25	0.67	9.18	25	6.60	0.79	11.96	○	0.39	7.0	1.04
12 :	(b-l)	24	4.07	0.26	6.50	25	3.64	0.49	13.40	◎	0.56	3.6	1.13
13 : P 3	(m-d)	44	9.29	0.44	4.77	41	8.50	0.46	5.44	◎	0.74	8.7	1.07
14 :	(b-l)	44	4.77	0.23	4.85	41	4.30	0.29	6.81	◎	0.76	4.1	1.16
15 : P 4	(m-d)	42	10.81	0.54	5.00	38	9.89	0.70	7.13	◎	0.61	10.2	1.06
16 :	(b-l)	42	5.85	0.36	6.20	38	5.29	0.32	6.11	◎	0.83	5.3	1.10
17 : M 1	max (m-d)	45	18.58	0.65	3.51	42	17.38	0.89	5.10	◎	0.61	19.5	0.95
18 :	med (b-l)	45	7.69	0.36	4.65	42	7.06	0.40	5.66	◎	0.67	7.9	0.97
19 : M 2	(m-d)	45	7.44	0.42	5.70	42	6.90	0.47	6.78	○	0.42	7.8	0.95
20 :	(b-l)	45	5.89	0.36	6.19	42	5.46	0.37	6.85	◎	0.57	6.2	0.95
21 : M 3	(m-d)	39	3.82	0.47	12.32	32	3.57	0.44	12.32	◎	0.48	3.8	1.01
22 :	(b-l)	39	3.49	0.38	10.78	32	3.23	0.35	10.91	◎	0.46	3.5	1.00
23 : tooth row length (I1-M3)		40	80.31	3.29	4.10	34	76.38	2.73	3.58	◎	0.67	—	
24 : premolar row length (P1-P4)		41	32.81	2.28	6.94	37	31.21	1.83	5.86	○	0.40	—	
25 : molar row length (M1-M3)		40	28.89	1.16	4.01	34	27.30	1.40	5.12	◎	0.71	—	
26 : cheek teeth length (P1-M3)		39	60.65	2.93	4.82	33	57.97	2.22	3.83	◎	0.58	—	
(24/23) × 100		37	40.80	1.59	3.90	32	41.06	1.50	3.65	×	0.01	—	
(25/23) × 100		40	35.99	1.25	3.48	34	35.76	1.62	4.54	×	0.06	—	
(24/26) × 100		37	53.97	1.75	3.23	32	54.14	1.72	3.18	×	0.02	—	
(8/7) × 100		45	59.20	3.35	5.65	42	57.64	3.96	6.86	×	0.02	—	

Abbreviations: see Tables 1 and 2.

Table 4. Measurements and indices of the trunk and the extremities of Shiba dogs and Tagara (Jomon period) dogs

	Male				Female						Tagara (Jomon) Male	
	No.	$\bar{x}$	s	CV	No.	$\bar{x}$	s	CV	t-test	CD	$\bar{x}$	Coefficient
1 : Scapula length	41	108.59	5.59	5.15	37	100.64	4.68	4.65	◎	0.84	—	—
2 : glenoid cavity breadth	41	14.85	0.88	5.93	38	13.58	0.75	5.56	◎	0.84	15.0	0.99
3 : glenoid cavity length	41	20.17	0.99	4.91	38	18.43	1.06	5.76	◎	0.91	20.9	0.96
4 : min. neck breadth	41	20.02	1.28	6.38	38	18.51	1.18	6.37	◎	0.71	21.5	0.93
5 : Humerus length	41	122.99	7.29	5.92	38	114.46	6.13	5.35	◎	0.73	131.3	0.94
6 : max. prox. breadth	41	21.80	1.11	5.09	38	20.08	1.14	5.67	◎	0.85	22.7	0.96
7 : min. breadth in the middle	41	9.39	0.71	7.57	38	8.69	0.72	8.29	◎	0.45	11.2	0.84
8 : max. breadth in the middle	41	11.89	1.04	8.74	38	11.05	0.92	8.32	◎	0.44	15.0	0.79
9 : max. distal breadth	41	26.10	1.30	4.97	38	24.29	1.51	6.22	◎	0.68	28.4	0.92
10 : Radius length	41	118.52	7.19	6.07	38	109.70	6.08	5.54	◎	0.80	125.7	0.94
11 : breadth in the middle	41	9.87	0.70	7.08	38	8.94	0.61	6.84	◎	0.74	10.7	0.92
12 : diameter in the middle	41	5.75	0.49	8.44	38	5.25	0.49	9.41	◎	0.52	7.1	0.81
13 : max. dist. breadth	41	18.69	0.96	5.13	38	17.17	0.91	5.31	◎	0.92	20.6	0.91
14 : max. dist. diameter	41	10.52	0.57	5.40	37	9.55	0.61	6.39	◎	0.94	12.5	0.84
15 : Ulna length.	41	141.52	8.00	5.66	38	130.89	7.10	5.42	◎	0.82	148.5	0.95
16 : Pelvis length	41	119.05	6.29	5.28	37	111.59	5.44	4.87	◎	0.80	117.6	1.01
17 : max. acetabulum length	41	17.02	0.97	5.68	38	16.07	0.97	6.04	◎	0.49	18.5	0.92
18 : sub-pubic angle	39	101.28	7.32	7.22	36	109.75	5.68	5.18	◎	0.71	—	—
19 : Femur length	41	133.81	7.95	5.94	38	124.12	6.61	5.32	◎	0.79	134.8	0.99
20 : breadth in the middle	41	10.56	0.63	5.95	38	9.74	0.66	6.83	◎	0.66	12.0	0.88
21 : diameter in the middle	41	9.61	0.77	7.96	38	9.16	0.74	8.04	◎	0.36	11.6	0.83
22 : max. dist. breadth	41	24.53	1.15	4.68	38	22.84	1.55	6.80	◎	0.65	27.5	0.89
23 : Tibia length	41	135.12	8.16	6.04	38	125.19	6.81	5.44	◎	0.80	141.8	0.95
24 : max. prox. breadth	41	26.82	1.35	5.04	38	25.17	1.54	6.14	◎	0.62	29.2	0.92
25 : breadth in the middle	41	10.01	0.65	6.50	38	9.26	0.69	7.49	◎	0.55	10.9	0.92
26 : diameter in the middle	41	9.75	0.70	7.20	38	9.09	0.63	6.95	◎	0.47	10.6	0.92
27 : max. dist. breadth	41	17.93	0.97	5.41	38	16.75	1.04	6.21	◎	0.61	20.1	0.89
28 : Calcaneus length	41	34.28	1.84	5.38	38	32.01	1.73	5.40	◎	0.69	37.6	0.91
29 : Penis bone length	41	71.59	5.67	7.91	—	—	—	—	—	—	—	—
30 Atlas max. breadth	41	70.58	19.85	28.13	38	61.69	3.02	4.90	◎	0.82	68.0	1.04
(7/8)×100	41	79.21	4.67	5.90	38	78.74	4.85	6.15	×	0.03	—	—
(12/11)×100	41	58.37	4.36	7.47	38	58.78	4.11	6.99	×	0.03	—	—
(20/21)×100	41	110.17	6.35	5.76	38	106.54	5.86	5.50	○	0.24	—	—
(20/19)×100	41	7.90	0.41	5.20	38	7.85	0.47	6.02	×	0.05	—	—
(25/26)×100	41	102.92	5.99	5.82	38	102.12	6.84	6.69	×	0.07	—	—
brachial index	41	96.38	1.91	1.98	38	95.87	2.48	2.59	×	0.12	95.74	—
crural index	41	101.00	2.22	2.20	38	100.87	1.97	1.95	×	0.02	102.44	—
intermembral index	41	89.81	1.21	1.35	38	89.92	0.96	1.06	×	0.04	91.60	—

Abbreviations: see Table 1.

Table 5. Various discriminant functions of modern shiba dogs and

	Discriminant	Error prob.	$x1$
(1) Cranium	$y=x1+0.447\ x2-154.26$	17.2%	zygomatic B.
(2) Mandible	$y=x1+3.413\ x2+0.130\ x3-69.22$	21.1%	mand. ramus B.
(3) Upper dentition	$y=x1+2.051\ x2+1.289\ x3-20.29$	10.6%	upper Canine b-l
(4) Lower dentition	$y=x1+0.95\ x2-9.76$	13.5%	lower Canine b-l
(5) Up. & Lo. Dent.	$y=x1-0.229\ x2-4.28$	15.7%	upper Canine b-l
(6) Cran. & Dent.	$y=x1+0.119\ x2-11.69$	12.7%	lower Canine b-l
(7) Trunk & Extrem.	$y=x1-0.16\ x2+0.296\ x3-17.10$	16.5%	Scapula gl. cav. B.
(8) Total	$y=x1-0.0423\ x2+0.0767\ x3-5.89$	7.0%	lower Canine b-l
	$y=x1-0.0365\ x2+0.0239\ x3-0.45$	7.0%	lower Canine b-l

B : breadth, L: length, Th : thickness, b-l : bucco-lingual diameter. Because of no Sub-pubic in both groups.

were not as accurate as expected. However, since the mandible is frequently excavated alone, determinant factors in the mandible should be identified.

Six determinant factors were identified after excluding total mandibular length (1) (Table 5-(2)). The mandibular ramus breadth was the most useful, followed in order by mandibular body thickness, total mandibular length (2), mandibular ramus height, masseter fossa depth, and mandibular body height (M1).

The probability of error using discriminant functions in the mandible was 21.1%. This was considerably higher than the percentage of error using discriminant functions for other elements.

Discriminant analysis using teeth

Discriminant analysis was performed using determinant factors that showed low percentages of error. The bucco-lingual diameters of the mandibular and maxillary canines were the most accurate determinant factors.

Discriminant analysis was performed on maxillary teeth using fourteen determinant factors selected according to ease of tooth identification and accuracy of measurement (Table 5-(3)). Among the maxillary teeth, the bucco-lingual diameter of the canine was the most accurate determinant factor, followed by that of the second premolar and that of the third incisor.

From the twenty-six measurements of the mandibular teeth, six determinant factors were selected, based on their coefficients of difference, ease of identification and accuracy of measurement (Table 5-(4)). The bucco-lingual diameter of the canine was the most accurate determinant factor, followed in order by that of the third premolar, the medio-distal diameter of the third premolar, the bucco-lingual diameter of the fourth premolar, the medio-distal diameter of the canine, and the length of the molar tooth row.

Discriminant analysis using the maxillary and mandibular teeth

Discriminant analysis was performed using the bucco-lingual diametre of the maxillary canine and that of the mandibular canine, which yielded the most accurate sex determination in each jaw (Table 5-(5)). The probability of error using these teeth was 15.7%. Thus, the accuracy using this factor was higher than that of using the mandible

Discriminant analysis using the cranium and teeth

Discriminant analysis was performed using the interorbital breadth instead of the easily-damaged zygomatic arch, as well as six other factors that showed high coefficients of difference and are well preserved (Table 5-(6)). The bucco-lingual diameter of the mandibular canine was the most accurate determinant factor, followed in order by the auricular breadth, total basal length, bucco-lingual diametre of the maxillary canine, and palatal breadth.

Discriminant analysis using bones of the trunk and extremities

From the measurements of the limb bones, nine revised discriminant functions for Jomon dogs.

$x2$	$x3$	Revised discriminant
Cranium basal L.		$y=x1+0.405\ x2-144.17$
Mand. body Th. (M1)	Mandibular L. (2)	$y=x1+3.05\ x2+0.134\ x3-73.64$
upper P2 b-l	upper I3 b-l	$y=x1+2.29\ x2+1.315\ x3-20.09$
lower P3 b-l		$y=x1+1.02\ x2-9.04$
lower Canine b-l		$y=x1-0.24\ x2-4.23$
Auricular B.		$y=x1+0.1\ x2-10.82$
Sub-pubic angle	Atlas max. B.	$y=x1-0.162\ x2+0.311\ x3-17.27$
Sub-pubic angle	Atlas max. B.	$y=x1-0.039\ x2+0.074\ x3-5.45$
Sub-pubic angle	Cranium basal L.	$y=x1-0.0338\ x2+0.0215\ x3-0.42$

angle data in Jomon dogs, this angle is tentatively assumed to be equal

determinant factors with high coefficients of difference were selected, and the discriminant functions were derived (Table 5-(7)). The scapular glenoid breadth was the most accurate factor, followed in order by the subpubic angle, the maximum breadth of the atlas, and the sagittal diameter of the distal end of the radius.

Discriminant analysis using the entire skeleton

From the measurements in the cranium, limb bones, trunk bones, maxillary teeth, and mandibular teeth, thirteen determinant factors showing high coefficients of difference were selected, and discriminant analysis was performed (Table 5-(8)). Several of these items were combined into the following discriminant function:

$y = (x1) - 0.0423(x2) + 0.0767(x3) - 5.89$
x1 = bucco-lingual diameter of the mandibular canine
x2 = subpubic angle
x3 = atlas maximum breadth

The probability of error using this function was 7.0%, which was the lowest for any discriminant function. If the cranium is not damaged, the total basal length can be used instead of the maximum breadth of the atlas. The discriminant function using total basal length is as follows:

$y = (x1) - 0.0365(X2) + 0.0239(x3) - 0.45$
x1 = bucco-lingual diameter of the mandibular canine
x2 = subpubic angle
x3 = total basal length of the cranium

The probability of error using this function was also 7%.

Adjustments for application to Jomon period dogs

To apply these discriminant functions to dogs of the Jomon period (9000-2300 bp), adjustments must be made that reflect the morphological differences between Jomon dogs and modern shiba dogs. For example, the relative breadth of the zygomatic arch is greater in modern shiba dogs. Therefore, before applying the corresponding discriminant function to Jomon dogs, zygomatic breadth measurements were proportionally converted. Measurements obtained from modern shiba dogs were divided by the corresponding measurements obtained from standard Jomon dogs (Tables 1 through 4). Using the obtained value, the coefficient of each discriminant function was multiplied. This converted value was used as the coefficient of the discriminant function in Jomon dogs (Table 5). In breeds or species of dogs with different characteristic sizes of measurement items, differences in the proportion can be overcome using a similar method.

In this study, the Tagara Shell Mound data reported by Shigehara and Onodera (1984) were used to obtain standard values for Jomon dogs. Morphological changes were similar in males and females. Therefore, measurements in males were used as representative values. Since the number of Jomon dogs in which sex was definitely determined is small, the validity of the revision method is questionable. However, when the dogs with known sexes from the Tagara Shell Mound were evaluated, sex was accurately determined. The revised discriminant functions are shown at the end of Table 5.

Summary

In non-metric sex determination of dogs, the probability of error is high, depending on the feature used for determination. However, the error rate was low (about 7%) using a metric determinant function applied to the entire skeleton, including the teeth. This discriminant function may prove useful. The accuracy may be increased further by combining metric results with non-metric evaluation.

Acknowledgments

The authors are indebted to Mr. Hideo Sakurai of Dokkyo University School of Medicine, for their assistance in collecting and preparing dog skeletons. The authors are also grateful to Mrs. Yoshiko Arai for handling the data, and to Prof. Masao Serisawa for his permission to conduct this study.

This paper was translated into English by Dr. N. Shigehara from the following original paper "Onodera, S., N. Shigehara and M. Eto (1987). Discriminant analysis of the sexual differences of the skeletons in shiba dogs (Canis familiaris). Acta Anatomica Nipponica 62 (1):19-32." (In Japanese with English summary). The contents have been slightly changed from the original paper with the kind permission of the two co-authors (Dr. S. Onodera & Dr. M. Eto).

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