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Comparative Functional Morphology of the Skeletal Forelimb, Pectoral Girdle, and Sternum in Japanese Native Domestic Fowls

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This study aims to understand the relationships among morphological characteristics, their functional roles, and breeder preferences in Japanese native fowls. We analyzed and compared the shapes and sizes of the skeletal forelimb, pectoral girdle, and sternum among six breeds: Chabo, Oh-Shamo, Onagadori, Shokoku, Tosajidori, and Totenko. Because skeletal forelimb, pectoral girdle, and sternum are one of the bases for composing body appearance and for movement of birds such as flapping, we treated those skeletons. All measurements of size were smaller in Chabo than those in other breeds except Tosajidori. The largest measurement values of all parameters were observed in Oh-Shamo. The largest measurement values were observed in all measurements of Oh-Shamo. Short and wide forelimb bones and a short coracoid were observed in Chabo. Oh-Shamo was equipped with a wide sternum and a widely articulated coracoid. Shokoku and Totenko possessed longer bones that constitute the thoracic cavity. We suggest that the small bone size in ornamental fowls contributes toward a cute appearance and that the large bone size of fighting fowls is correlated with their masculinity and aggressiveness. The short forelimb bones, wide articulation, and corpus of forelimb bones in Chabo create a round and soft body silhouette. The observed short coracoid prevents Chabo from dragging its body on the ground while walking. The wide sternum and articulation of the coracoid observed in Oh-Shamo are considered to contribute to the ability to pounce on an opponent by flapping during a fight. The wide sternum of Oh-Shamo is considered to affect its body outline, producing a strong, masculine physical appearance. We also suggest that the characteristics observed in Shokoku and Totenko create a space for the vocal organs, such as clavicle air sacs. We suggest that the observed morphological characteristics underlie the function and breeder preferences of each breed.

Key words: breeder preference, forelimb, functional morphology, Japanese fowl, pectoral girdle, sternum

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Introduction

The numerous breeds of domestic chickens existing presently have been created from red jungle fowl (*Gallus gallus*) (Akishinonomiya *et al*., 1996; Al-Nasser *et al*., 2007). A long history of domestication has determined their biological characteristics. Domestic fowls have acquired features favorable not only for livestock but also for companion animals (Frahm and Rehkämper, 1998; Okamoto, 2001; Ichinoe and Kuwayama, 2007; Akishinonomiya and Komiya, 2009; Sheppy, 2011). In the mid-Edo Era in Japan, variegated breeds have been developed for their admirable color variation, voice, and fighting ability (Oana, 1951; Okamoto, 2001; Ichinoe and Kuwayama, 2007; Akishinonomiya and Komiya, 2009).

Japanese fowls vary not only in external and behavioral characteristics but also in osteological characteristics. Nishida *et al*. (1985) examined whole skeletons and reported morphological differences among Japanese breeds with regard to the length of tibiotarsus, tarsometatarsus, and sternum. Using principle component analyses of the skeletal forelimb, pectoral girdle, and sternum of domestic fowls, they demonstrated that the bone sizes can be classified as small, intermediate-small, intermediate-large, and large. Shape can be categorized as thick, intermediate, and thin, with morphological differences detected in the length of sternum, ulna, radius, humerus, and coracoid carpometacarpus as well as in the breadth of the corpus scapulae and clavicle (Samejima *et al*., 1989). The abovementioned study

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confirmed differences in the size and shape of bones of Japanese fowls but did not address the relationships between these morphological characteristics and the motivation for human selection of these traits.

Skeletal morphology reflects the results of artificial selection, which has been carried out by assessing the noneconomical characters for breeder preferences, such as a long voice, strong aggression and external appearances in Japanese native fowls. It is thought that the skeletal forelimb, pectoral girdle, and sternum show the functional-morphological characteristics and breeder preferences in each breed because those skeletons not only compose the body appearance but also have important role in bird movement such as flapping. Because Japanese fowls have been selected as fighting fowls, long-crowing fowls, and ornamental fowls by Japanese poultry breeders, we would expect the morphological characteristics of the skeletal forelimb, pectoral girdle, and sternum of different breeds to reflect the relationships among their morphological differences, functions, and breeder preferences.

Materials and Methods

Specimens

We osteometrically examined the skeletal forelimb, pectoral girdle, and sternum of six breeds: Oh-Shamo, Onagadori, Shokoku, Totenko, Tosajidori, and Chabo. These breeds were each selected for specific characteristics. Oh-Shamo has a large body and a strong combative instinct, which are typical characteristics of a fighting fowl. Chabo is an ornamental fowl, characterized by its small body and colorful feathers. An attractive, long crow and tail feathers with a length of up to 1 m are favored in Totenko, which are characteristics of a long-crowing and ornamental fowl. The longest tail feather is preferred in Onagadori, which is classified as a long-tailed and ornamental fowl. Shokoku is considered to be the ancestor of Totenko and Onagadori because of its long crowing and abundant feathers. Because this breed has a strong aggressive behavior, the Japanese people once bred them as fighting fowls. With feather color and body size similar to those of the red jungle fowl, Tosajidori is one of the oldest breeds in Japan (Oana, 1951; Okamoto, 2001; Ichinoe and Kuwayama, 2007; Akishinonomiya and Komiya, 2009). Because Tosajidori resembles red jungle fowl in external characteristics, we used it as a control while comparing morphology between these breeds. We used the skeletons of the abovementioned breeds included in the collection at the University Museum of the University of Tokyo. We also used the skeletons which have been stored in The Nagoya University Museum. In specimens of unknown growth stage, we defined the growth stage by the degree of ossification of the sternum (Breugelmans *et al*., 2007). Specimens over 1 year of age or with complete sternal ossification were defined as adult. Detailed information regarding these specimens is reported in Table 1. Because the aim of this study is to detect the functional–morphological characteristics of each breed, we did not separate the sexes. Although it has been known that domestic fowls show sexual dimorphism in size, sexual differences are not larger than breed differences (Samejima *et al*., 1989). We also gauged that sexual dimorphisms cannot be accurately assessed because of the presence of very few individuals of each breed.

Measurements

Table 2, Figures 1–1 and 1–2 indicate the details of measurements. Size differences were determined by comparing the measurements between breeds. To measure shape, we used measurement ratios that were obtained by dividing the measurement value by the geometric mean (GM). GM is commonly used as an index of body size (Mosimann, 1970; Niemi, 1985; Simons, 2010; Simons *et al*. 2011). The GM was calculated using measurements of the Lms, Hs, and SBf as follows:

$$\mathrm{GM} = \sqrt[3]{\mathrm{Lms} \times \mathrm{Hs} \times \mathrm{SBf}}$$

We measured the skeletons using the procedure described by Driesch (1976), Samejima *et al.* (1989) and Yasuda (2002). Forty-three selected measurements were determined using a vernier caliper with an accuracy of 0.05 mm (Table 2, Figs. 1–1 and 1–2).

Analyses

The mean values and standard deviations (SD) for all measurements in each breed were calculated to compare the morphological differences between skeletons. One-way analysis of variance (ANOVA) was performed to detect differences among breeds. When ANOVA indicated significant morphological differences, the data were further analyzed using the Tukey–Kramer method for multiple comparisons. We defined significant morphological differences as $P < 0.05$. Statistical analyses were performed using the software “R” (R: A language and environment for statistical computing. URL http://www.R-project.org/).

Results

Each breed differed morphologically from the others, as determined using the size data from measurements and shape data from measurement ratios (Tables 3–1 to 4–2). All size measurements were greatest for Oh-Shamo. Onagadori, Shokoku, and Totenko showed similar values in all size measurements, except for GBs; these ranged between Oh-Shamo and Tosajidori. All measurements of size for Chabo and Tosajidori were similar, which were smaller than those for the other breeds (Tables 3–1 and 3–2). In terms of shape, Bph, GLh, Lc, Lpr, and SBc did not differ significantly between the breeds (Tables 4–1 and 4–2). The morphological differences detected in each breed are described below.

Oh-Shamo

All measurements for Oh-Shamo were significantly larger than those for the other breeds (Tables 3–1 and 3–2). With regard to shape, Bfc, GBc, SBf, and GBs for this breed were wider than those for the other breeds, with significant differences observed for Oh-Shamo, Onagadori, Shokoku, Totenko, and Tosajidori (Tables 4–1 and 4–2). Compared with the other breeds, shortest measurements of GLsc, GLst, Lcc, and Lap were obtained in Oh-Shamo (Tables 4–1 and 4-

Table 1. **Specimens used in this study**

breed	sex	specimen No.	growth stage	donor	depository	breed	sex	specimen No.	growth stage	donor	depository
Chabo	female	UMUT-15166	adult[1]	HU	UMUT	Shokoku	female	UMUT-15161	adult[1]	HU	UMUT
Chabo	female	UMUT-15167	adult[1]	HU	UMUT	Shokoku	male	UMUT-15162	adult[2]	TUA	UMUT
Chabo	male	UMUT-15168	adult[1]	HU	UMUT	Shokoku	male	NUM-ab1-1212	adult[2]	—	NUM
Chabo	female	UMUT-14035	adult[2]	TUA	UMUT	Shokoku	male	NUM-ab1-221	adult[2]	—	NUM
Chabo	male	UMUT-14042	adult[2]	TUA	UMUT	Shokoku	male	NUM-ab1-222	adult[2]	—	NUM
Chabo	female	UMUT-14035	adult[2]	TUA	UMUT	Shokoku	female	NUM-ab1-223	adult[2]	—	NUM
Chabo	male	UMUT-14041	adult[2]	TUA	UMUT	Shokoku	male	NUM-ab1-226	adult[2]	—	NUM
Chabo	male	UMUT-14039	adult[2]	TUA	UMUT	Shokoku	male	NUM-ab1-227	adult[2]	—	NUM
Chabo	—	UMUT-11018	adult[2]	IHA	UMUT	Shokoku	male	NUM-ab1-236	adult[2]	—	NUM
Oh-shamo	male	UMUT-15171	adult[1]	HU	UMUT	Shokoku	male	NUM-ab1-237	adult[2]	—	NUM
Oh-shamo	male	UMUT-15172	adult[2]	HU	UMUT	Shokoku	female	NUM-ab1-238	adult[2]	—	NUM
Oh-shamo	male	UMUT-15150	adult[1]	HU	UMUT	Shokoku	male	NUM-ab1-57	adult[2]	—	NUM
Oh-shamo	male	UMUT-15151	adult[1]	HU	UMUT	Shokoku	male	NUM-ab1-1347	adult[2]	—	NUM
Oh-shamo	—	UMUT-15152	adult[2]	HU	UMUT	Shokoku	male	NUM-ab1-224	adult[2]	—	NUM
Oh-shamo	male	UMUT-15153	adult[1]	HU	UMUT	Tosajidori	female	UMUT-15163	adult[1]	HU	UMUT
Oh-shamo	female	UMUT-14018	adult[2]	TUA	UMUT	Tosajidori	—	UMUT-15164	adult[2]	HU	UMUT
Oh-shamo	female	UMUT-14019	adult[2]	TUA	UMUT	Tosajidori	male	UMUT-14027	adult[2]	TUA	UMUT
Oh-shamo	—	UMUT-15154	adult[2]	TUA	UMUT	Tosajidori	female	NUM-ab1-1336	adult[2]	—	NUM
Oh-shamo	male	UMUT-14021	adult[2]	TUA	UMUT	Tosajidori	female	NUM-ab1-1349	adult[2]	—	NUM
Onagadori	male	UMUT-15155	adult[1]	HU	UMUT	Totenko	male	UMUT-15165	adult[2]	TUA	UMUT
Onagadori	male	UMUT-15156	adult[1]	HU	UMUT	Totenko	male	UMUT-14031	adult[2]	TUA	UMUT
Onagadori	male	UMUT-15157	adult[1]	HU	UMUT	Totenko	female	UMUT-14030	adult[2]	TUA	UMUT
Onagadori	male	UMUT-15158	adult[1]	HU	UMUT	Totenko	male	UMUT-14034	adult[2]	HU	UMUT
Onagadori	female	UMUT-15159	adult[1]	HU	UMUT	Totenko	male	UMUT-14033	adult[2]	TUA	UMUT
Onagadori	female	UMUT-15160	adult[1]	HU	UMUT	Totenko	female	UMUT-14029	adult[2]	TUA	UMUT
Onagadori	female	UMUT-14015	adult[1]	HU	UMUT						

UMUT indicates The University Museum, The University of Tokyo. NUM indicates Nagoya University Museum, Nagoya University. HU indicates Hiroshima University. TUA indicates Tokyo University of Agriculture. IHA indicates Imperial Household Agency. adult[1] indicates over one years old. adult[2] indicates completed ossification of sternum.

−2). Significant differences in GLsc and Lar were observed among Oh-Shamo, Onagadori, Shokoku, and Totenko, and those in GLst were observed among Chabo, Onagadori, and Shokoku (Tables 4−1 and 4−2).

Shokoku

Measurement of sizes for Shokoku ranged between that for Oh-Shamo and Tosajidori (Tables 3−1 and 3−2). While all measurement values, except GBs, were similar to those obtained for Onagadori and Totenko, GBs of this breed was significantly larger than that associated with Onagadori (Table 3−1). In terms of shape, we observed that Didc, Didu, and SBh were narrower than those of Totenko, and that GBs was wider than that of Onagadori. Lms was significantly shorter than that of Onagadori (Tables 4−1 and 4−2).

Onagadori

We found no significant difference among Onagadori, Shokoku, and Totenko except with regard to GBs (Tables 3−1 and 3−2). GBs of this breed was smaller than that of Shokoku (Table 3−1). With regard to shape, compared with the other breeds, the ratios of Ba, Bfc, Dic, and GBs were lowest (Tables 4−1 and 4−2). Ba was shorter than that of Chabo, Oh-Shamo, Tosajidori, and Totenko (Table 4−1). The highest ratios compared with those for other breeds were of GLst, Lm, Lms, Lpr, and Lsa (Tables 4−1 and 4−2). A significant difference in Lms was observed among Onagadori, Oh-Shamo, and Shokoku (Table 4−2).

Totenko

Significant differences in size were detected among Totenko and Oh-Shamo, Chabo, and Tosajidori (Tables 3−1 and 3−2). Measurement values for Totenko were smaller than those for Oh-Shamo and larger than those for Chabo (Tables 3−1 and 3−2). All measurements obtained for this breed were similar to those for Shokoku and Onagadori (Tables 3−1 and 3−2). Compared with other breeds, the highest ratios of GLco, GLh, GLr, GLsc, Lar, and Lcc were obtained (Tables 4−1 and 4−2). For Totenko, GLco and GLr were longer than those of Chabo; GLsc and Lcc ratios were longer than those of Oh-Shamo, and Lar was longer than that of Chabo and Oh-Shamo, all with significant differences (Tables 4−1 and 4−2).

Tosajidori

All measurements of Tosajidori were similar to those of Chabo, with smaller values in each measurement compared with the other breeds (Tables 3−1 and 3−2). Significant differences in all measurements, except those for Ba, Bc, Bdh, Bfc, GBs, Lpr, SBc, SBf, SBh, SBr, SBs, and SBu, were found between breeds, except Chabo (Tables 3−1 and 3−2). In terms of shape, we detected that Bpc was wider than

Table 2. **The measurements used in this study**

Abbreviation of measurements	Details	Abbreviation of measurements	Details
Ba	Breadth of the acromion[c]	Hcau	Heighth of the os carpi alulae ulnare[c]
Bc	Breadth between the facies articularis clavicularis[c]	Hs	Heighth of the sternum; from the apex sterni to the facies articularis costalis[b,c]
Bdh	Breadth of the distal end of the humerus[a,b]	Lap	Length between the apex sterni to the edge of the processus costalis[c]
Bdr	Breadth of the distal end of the radius[a,b]	Lar	Length between the apex sterni to the ventral edge of the rostrum sterni[c]
Bfc	Breadth of the facies articularis basalis of the coracoid (= basal articular surface)[a,b]	Lc	Length of the crista sterni; from the apex cristae sterni to the caudal border (or point) of the metasternum in the median plane[a,b]
Bpc	Breadth of the proximal extremity of the carpometacarpus[a,b]	Lcc	Length of the corpus claviculae; from the median point of the synostosis interclavicularis to the edge of the facies articularis acrocoracoidae[c]
Bph	Breadth of the proximal end from the tuberculum laterale or dorsale to the tuberculum mediale or ventrale, without the crista lateralis[a,b]	Lm	Length of the metacarpus II, from articular surface to articular surface without the processus distalis[a,b]
Bpr	Breadth of the proximal end of the radius[c]	Lmc	Medial length of the coracoid[a,b]
Bpu	Breadth of the proximal end from the facies articularis medialis or ventralis to the facies articularis lateralis or dorsalis[a,b]	Lms	Length from the manubrium sterni; from the cranial point of the manubrium sterni (or the median point of the line joining the cranial points of the manubrium sterni) to the caudal border (or point) of the metasternum in the median plane[a,b]
Dic	Cranial diagonal of the scapula[a,b]	Lpr	Length between the edge of the processus costalis to the median point of the rostrum sterni[c]
Didc	Diagonal of the distal end of the carpometacarpus[a,b]	Lsa	Length between the synostosis interclavicularis to the apophysis bifurculae claviculae[c]
Didu	diagonal of the distal end of the ulna[a,b]	SBc	Smallest breadth of the coracoid[b]
Dip	Diagonal of the proximal end from the caudal border of the olecranon to the cranial border of the facies articularis lateralis or dorsalis[a,b]	SBf	Smallest breadthe between the facets for the costosternal articulations, measured at the narrowest part[a]
GBc	Greatest basal breadth of the coracoid[a,b]	SBh	Smallest breadth of the humerus[a,b]
GBs	Greatest breadth of the scapula[b]	SBr	Smallest breadth of the radius[a,b]
GLcl	Greatest length of the clavicula[c]	SBs	Smallest breadth of the scapula[b]
GLcm	Greatest length of the carpometacarpus[a,b]	SBu	Smallest breadth of the ulna[a,b]
GLco	Greatest length of the coracoid; measured generally to the distal point of the basal articular surface, exceptionally to the distal point of the processus lateralis[a,b]	Wcar	Width of the os carpi alulae radiale[c]
GLh	Greatest length of the humerus[a,b]	Wcau	Width of the os carpi alulae ulnare[c]
GLr	Greatest length of the radius[a,b]		
GLsc	Greatest length of the scapula[a,b]		
GLst	Greatest length of the sternum; from the processus carinatus sterni to the cranial edge of the processus costalis[c]		
GLu	Greatest length of the ulna[a,b]		
Hcar	Heighth of the os carpi alulae radiale[c]		

Each abbreviation follows alphabetical order. [a] Driesch (1976). [b] Samejima *et al*. (1989). [c] Yasuda (2002).

that of each breed except Chabo; moreover, Lap was shorter than that of Shokoku, and Lsa was shorter than that of Onagadori, Shokoku, and Totenko. SBr was longer than that of Onagadori, and Wcar was wider than that of Shokoku (Tables 4–1 and 4–2).

Chabo

All measurements for Chabo were smaller than those for all breeds, except Tosajidori (Tables 3–1 and 3–2). Measurements, except for Ba, Bc, Bdh, GBs, and SBs, were significantly smaller than those of each breed without Tosajidori (Tables 3–1 and 3–2). Chabo had the highest ratios for Bdh, Bdr, Bpc, Bph, Bpr, Bpu, Dic, Didc, Didu, Dip, Hcau, Lc, SBc, SBh, SBs, SBu, Wcar, and Wcau (Tables 4–1 and 4–2). The values for Bc, GLcl, GLcm, GLco, GLr, GLu, Lap, Lar, Lm, Lmc, and Lsa were lower than those associated with all other breeds (Tables 4–1 and 4–2). Significant differences between Chabo and all breeds, except Tosajidori, were observed for Bpc, Hcau, Lsa, SBh, Wcar, and Wcau (Tables 4–1 and 4–2).

Discussion

Morphological Characteristics of Oh-Shamo as Fighting Fowl

All measurements indicated that Oh-Shamo had the largest body (Tables 3–1 and 3–2). Body size is considered to indicate strength, and a larger body size is one of the indices of fighting ability (Breitburg, 1987; Renison *et al*., 2002; Jonart *et al*., 2007). The bloody contest or game as seen in the cock fighting is considered as manly entertainment or gamble (McCaghy and Neal, 1974). One of the characteristics symbolizing masculinity is large size (Jourard and Secord, 1954, 1955; Nash, 1958). The large measurements of Oh-Shamo

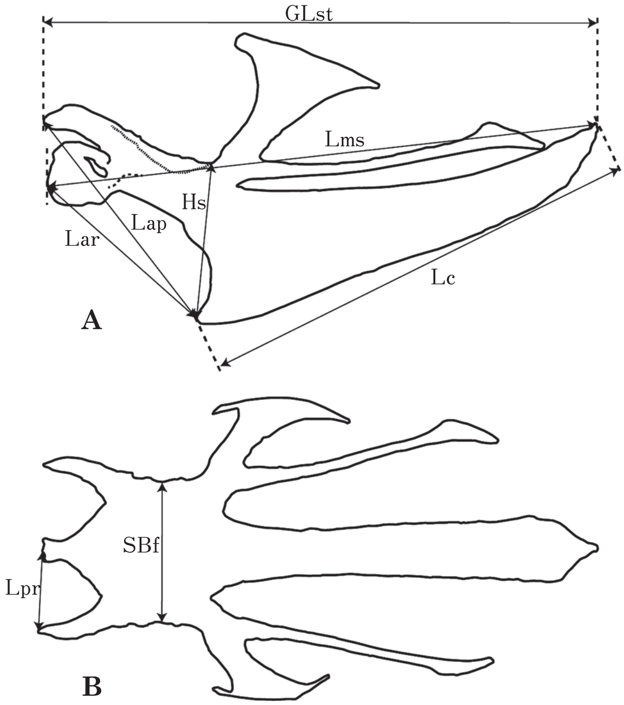

Fig. 1-1. **The measurements in sternum.** (A) Sternum of lateral view from left side. (B) Sternum from dorsal view. The abbreviated forms were remarked in Table 2.

indicate that strength and masculinity, which are essential characteristics of a fighting fowl, are reflected by its size.

The structure of the sternum is important in flying birds. The sternal surface provides the attachment area for the M. pectoralis and supracoracoideus, the muscles that function in wing flapping (Yasuda, 2002; Beaufrère, 2009; Altshuler *et al*., 2015). In the downstroke, the M. pectoralis generates and controls stroke velocity, upward force, and power for flight (Biewener, 1998). The robustly backward rotation of the humerus that is generated by the M. supracoracoideus produces a quick upstroke of the wing (Tobalske and Biewener, 2008). Both muscles also contribute to controlling rapid wing oscillation, observed in flapping (Poore *et al*., 1997; Tobalske and Biewener, 2008). Because fighting fowl pounce on their opponents with flapping (Dundes, 1994), we hypothesize that their M. supracoracoideus is more developed than other breeds. This hypothesis is confirmed by the significant differences in SBf width among Oh-Shamo, Onagadori, Shokoku, Totenko, and Tosajidori (Table 4-1). We suggest that the wide sternum of Oh-Shamo increases the adhesion area for M. supracoracoideus. This characteristic of the sternum likely helps to lift the large body of Oh-Shamo along with flapping to pounce on an opponent while fighting. This suggestion does not contradict the small ratio of GLst in Oh-Shamo (Table 4-1). Because the sternum appears elliptical in shape from a lateral view and because we performed linear measurements, our data could not show the curvature of the sternum, particularly the outline of the keel. Estimation of the elliptical shape using another method, such as Elliptic Fourier analysis, is warranted in future studies.

A wide sternum would also produce an attractive appearance for a fighting cock. Wide chest and shoulders are considered to be masculine characteristics (Arkoff and Weaver, 1966; Horvath, 1981). Coy *et al*. (2014) reported that these characteristics evoke an image of good physical strength and health. The anterior region of the sternum is articulated to the coracoid, which acts as a base for the shoulder (Yasuda, 2002). We suggest that the broad sternum of Oh-Shamo creates its shoulder and chest width, and that this characteristic contributes to its physical appearance of masculinity and strength, essential for a fighting fowl.

The ratio of Bfc to GBc indicates that the articulation between the coracoid and sternum is wide in Oh-Shamo (Table 4-1). Since Oh-Shamo possessed large body (Tables 3-1 and 3-2), we suppose that it needs powerful-flapping when pounce on an opponent in game. It is also predicted that the powerful-flapping causes large burden. The functional morphological study of the bone of penguins, which swim with powerful flapping in water, is useful for understanding the wide articulation of the coracoid in Oh-Shamo. Hospitaleche and Carlo (2010) reported that the wide sternocoracoidal articulation contributes to enduring transmitted forces from wing movement when flapping in water with high density. Because powerful flapping generates a large burden on the articulation of the coracoid, we suggest that the broad joint between the coracoid and sternum helps the coracoid to resist the force exerted by Oh-Shamo upon flapping during fighting.

Oh-Shamo and Shokoku possessed relatively wider scapulae than did the other breeds (Table 4-1). This region is the attachment area for the M. scapulohumeralis caudalis (Yasuda, 2002). This muscle acts during the downstroke in a flapping bird (Dial *et al*., 1991). In penguins, the wide scapula is considered to be the functional characteristic that generates this powerful downstroke (Ksepka, 2007). Because Oh-Shamo has a large body, it needs a powerful downstroke for flapping. We suggest that the wide scapula of Oh-Shamo increases the attachment area for the M. scapulohumeralis caudalis, enhancing its ability to pounce on an opponent.

Characteristics Related to Attractiveness of an Ornamental Fowl

While size differences between Chabo and Tosajidori were not significant, Chabo was evidently smaller than Tosajidori (Table 3-1). An association between cuteness and small size has been recognized since the Heian period. Both traditional and the currently popular culture in Japan reflect the emotion that is generated on observing small objects (Yomota, 2006; Nittono, 2009; Aizawa and Ohno, 2010; Ishida, 2012). Smallness is known to be a characteristic of an attractive companion animal, and that the smallness induces the motivation for caregiving and related behaviors (Morreall, 1991; Beverland *et al*., 2008; Nittono *et al*., 2012; Weiss *et al*., 2012; Lehmann *et al*., 2013; Ujigawara, 2016). We consider that the demand for cuteness is represented in the

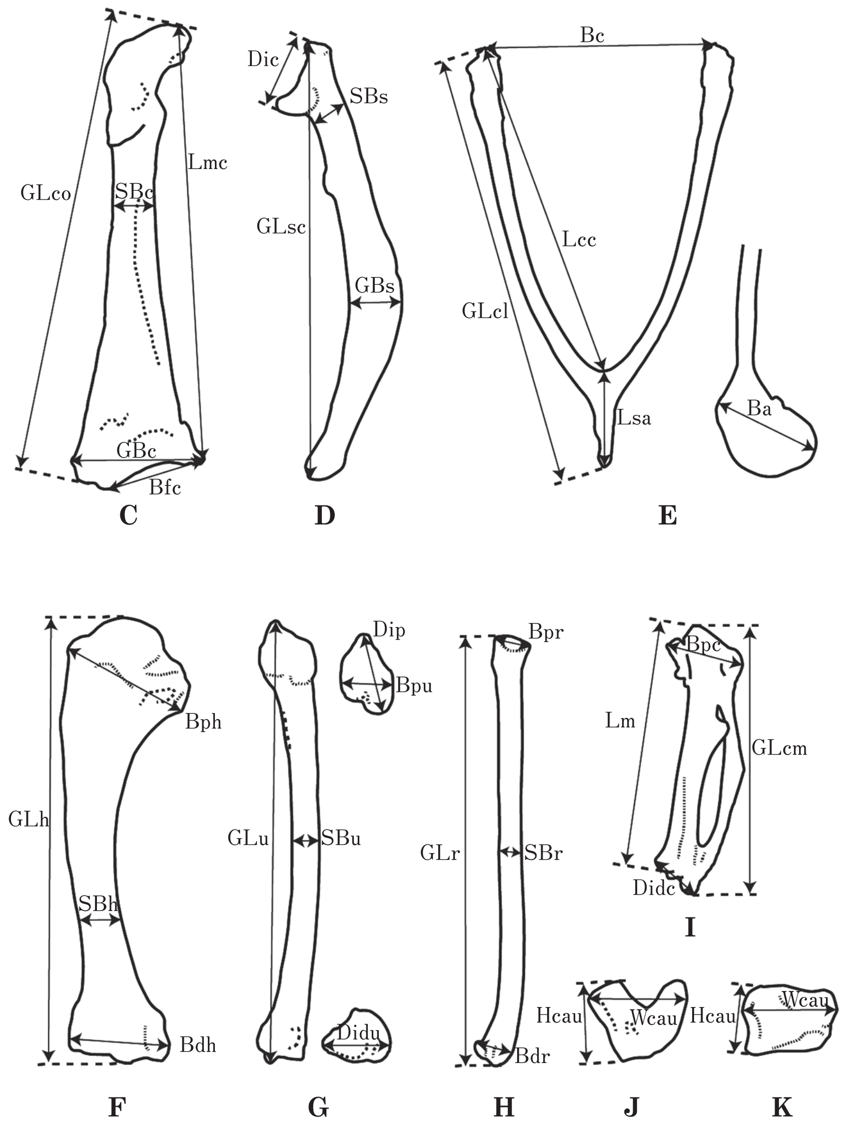

Fig. 1-2. **The measurements in skeleton of forelimb, pectoral girdle.** (C) Coracoid from dorsal view. (D) Scapula from ventromedial view. (E) Clavicula from cranial view and Acromion of clavicula from lateral view. (F) Humerus from medial or ventral view. (G) Ulna from cranial, proximal and disral view. (H) Radius from cranial view. (I) Carpometacarpus from caudal view. (J) Os carpi alulae ulnare from dorsal view. (K) Os carpi alulae radiale from dorsal veiw. The abbreviated forms were remarked in Table 2.

small size of Chabo as an ornamental fowl.

Regarding shape, we confirmed that compared with the other breeds, Chabo is medio-laterally wider and proximo-distally shorter in the forelimb bones and cranio-caudally longer in the sternum (Table 4-1 and 4-2). "Baby schema," such as short limbs, is the attractive characteristic that contributes to positive emotions, endearment, caregiving behavior, and protection from aggression (Lorenz, 1943; Sternglanz *et al*., 1977; Alley, 1981; Glocker *et al*., 2009; Kruger, 2015). Medio-laterally wide and proximo-distally short forelimb bones contribute toward the formation of a thick and short wing. We believe that the morphological characteristics of the forelimb bones and sternum affect its physical appearance, with the thick wing contributing to the round outline of the body when viewing from the cranio-caudal and dorso-ventral aspect. The exposed surface area of the neck and chest is relatively larger because of the short wing and long sternum. The surface of the chest and trunk is

Table 3-1. **Mean values and standard deviations for skeleton measurements of forelimb, pectoral girdle and sternum in various breeds**

breed	measurements	GLst	Lms	Lc	Hs	Lap	Lar	GLco	Lpr	SBf	GBc	Bfc	SBc	Lmc	GLsc	GBs
comparing pair with significant difference		ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKM	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIM	ABCEFGHIMO	ABCEFGHIKMO	ABCEFGHIKMO	ACEFGHIJM
Chabo	mean	80.74	80.41	66.78	26.90	36.77	24.25	38.13	12.96	21.83	10.91	8.66	3.51	35.48	50.10	5.63
	standard deviation	4.15	3.99	6.49	2.04	2.18	1.86	2.83	1.08	1.88	0.77	0.56	0.36	2.68	1.91	0.53
Ohshamo	mean	155.26	158.46	136.70	54.90	74.44	49.04	79.69	27.72	46.48	23.15	18.32	6.67	74.76	99.07	11.97
	standard deviation	14.44	14.23	14.07	4.92	6.64	5.13	7.40	4.40	5.98	2.85	2.40	0.89	6.54	9.97	1.38
Onagadori	mean	118.99	119.15	96.44	40.73	58.84	41.04	59.25	19.82	30.76	15.03	11.31	4.51	56.86	76.46	6.56
	standard deviation	7.81	7.82	7.16	3.54	4.29	4.16	3.63	1.08	1.23	1.37	1.04	0.42	3.53	3.96	0.61
Shokoku	mean	118.95	117.81	98.66	44.00	61.64	42.58	60.03	20.44	31.13	15.23	12.42	4.80	57.40	77.51	8.00
	standard deviation	8.99	9.54	9.36	3.98	5.96	5.02	4.83	2.08	2.55	1.56	1.49	0.63	4.46	5.13	0.92
Tosajidori	mean	85.42	85.27	71.96	29.72	40.98	29.15	42.52	14.07	24.00	11.06	8.95	3.65	40.30	55.69	5.58
	standard deviation	4.46	5.14	5.89	1.41	0.97	1.40	1.29	0.91	2.44	0.71	0.71	0.58	1.07	1.30	0.59
Totenko	mean	114.60	113.90	93.44	41.22	58.38	42.33	58.56	17.73	30.49	14.57	11.41	4.85	55.68	76.03	7.11
	standard deviation	13.29	14.12	11.16	4.31	6.29	4.77	6.61	1.89	3.81	1.75	1.49	0.54	6.74	8.19	0.66

breed	measurements	SBs	Dic	GLcl	Ba	Lsa	Bc	Lcc	GLu	Bpu	Didu	SBu	Dip	Bph	GLh	SBh
comparing pair with significant difference		ACEFGHIMO	ABCEFGHIKMO	ABCEFGHIKMO	ACEFGHI	ABCEFGHIKMO	ABCEFGHI	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO	ABCEFGHIKMO
Chabo	mean	3.82	9.13	42.19	8.60	8.69	18.04	33.47	47.14	6.73	7.43	3.53	9.84	14.35	50.72	5.46
	standard deviation	0.26	0.63	2.52	0.64	1.22	2.31	1.67	3.33	0.39	0.48	0.22	0.73	3.60	3.30	0.37
Ohshamo	mean	7.92	18.17	86.28	15.22	22.35	45.31	65.86	102.14	12.56	13.87	6.26	19.50	29.41	102.39	9.79
	standard deviation	1.00	1.88	6.66	2.18	3.09	7.27	5.08	10.20	1.45	1.78	0.71	2.01	3.59	9.93	1.10
Onagadori	mean	4.60	12.30	67.62	8.83	17.77	27.72	50.39	75.82	9.04	9.45	4.44	12.94	20.76	76.74	6.87
	standard deviation	0.29	0.89	3.70	1.50	1.53	7.47	2.88	3.04	0.73	0.70	0.35	1.23	1.60	3.52	0.51
Shokoku	mean	5.09	12.76	68.31	10.86	17.69	27.00	51.83	76.29	9.51	9.55	4.49	12.43	20.84	78.82	6.82
	standard deviation	0.53	1.24	5.76	1.69	1.85	4.44	4.61	6.33	0.86	1.03	0.53	1.39	1.88	6.30	0.77
Tosajidori	mean	3.66	9.51	48.10	9.32	10.39	20.34	38.14	52.52	6.95	7.17	3.58	9.91	15.36	54.96	5.41
	standard deviation	0.37	0.49	1.67	0.65	0.63	3.35	0.64	2.71	0.33	0.37	0.30	0.82	0.70	2.39	0.29
Totenko	mean	5.20	12.44	66.86	11.50	16.19	27.45	51.69	74.50	9.18	10.21	4.73	13.08	20.75	76.19	7.13
	standard deviation	0.55	1.21	7.41	2.22	1.15	3.23	6.30	9.73	0.90	1.19	0.63	1.46	2.02	8.57	0.59

Each alphabet indicates comparing pair with significant difference; See the caption of Table 3-2.

covered with soft feathers. This larger surface area of the neck and chest produces a soft or fuzzy surface. Lorenz (1943) also noted that a soft body surface and a round body are baby schemas. Cognitive psychological reports confirm that a soft or fuzzy surface evokes the image of cuteness (Baek *et al*., 2008; Ohkura *et al*., 2013; Ohkura, 2015; Ujigawara, 2016). We propose that the proximo-distally short and medio-laterally wide forelimb bones and the cranio-caudally long sternum of Chabo contribute to baby schema characteristics that are perceived as cute and evoke caregiving in ornamental-type fowl.

Chabo is equipped with a short coracoid (Table 4-1).

Table 3-2. **Mean values and standard deviations for skeleton measurements of forelimb, pectoral girdle and sternum in various breeds**

breed	measure-ments	Bdh	GLr	Bpr	SBr	Bdr	Bpc	Hcau	Wcau	Hcar	Wcar	Lm	GLcm	Didc	GM
comparing pair with significant difference		ABCEF GHIKM	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIM	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O	ABCEF GHIKM O
Chabo	mean	12.37	42.07	4.19	2.56	5.42	10.11	5.62	6.51	4.31	6.30	24.45	26.74	5.90	36.12
	standard deviation	0.86	2.85	0.30	0.22	0.44	0.64	0.44	0.41	0.25	0.39	1.63	1.65	0.39	2.11
Ohshamo	mean	23.46	91.31	8.17	4.83	10.23	17.62	10.29	12.06	8.47	11.56	51.89	56.16	10.62	73.85
	standard deviation	2.57	9.36	1.06	0.61	1.38	1.63	0.91	1.27	1.02	1.35	5.37	5.61	1.35	6.55
Onagadori	mean	15.74	68.65	5.35	3.21	7.06	12.49	7.55	8.76	5.75	8.14	39.93	42.63	7.72	53.02
	standard deviation	1.41	2.61	0.68	0.29	0.78	1.17	0.70	0.78	0.65	0.86	1.75	2.03	0.40	3.15
Shokoku	mean	15.93	69.23	5.72	3.41	6.79	12.73	7.27	8.47	5.86	8.09	39.52	42.26	7.24	54.42
	standard deviation	1.55	5.75	0.77	0.27	0.78	1.08	0.76	0.89	0.58	0.72	3.32	3.45	0.71	4.32
Tosajidori	mean	11.87	47.23	3.97	2.76	5.39	10.41	5.57	6.46	4.52	6.35	28.01	30.17	5.68	39.31
	standard deviation	0.71	2.25	0.27	0.29	0.51	0.69	0.30	0.50	0.41	0.46	1.23	1.32	0.31	2.60
Totenko	mean	15.71	67.43	5.50	3.27	7.08	12.69	7.33	8.73	5.76	8.14	38.18	41.24	8.03	52.29
	standard deviation	1.33	8.85	0.56	0.23	0.69	1.01	0.69	0.91	0.67	0.80	5.02	5.26	0.71	5.96

Each alphabet indicates comparing pair with significant difference as follows; [A] Oh-Shamo - Chabo, [B] Onagadori - Chabo, [C] Shokoku - Chabo, [D] Tosajidori - Chabo, [E] Totenko - Chabo, [F] Onagadori - Oh-Shamo, [G] Shokoku - Oh-Shamo, [H] Tosajidori - Oh-Shamo, [I] Totenko - Oh-Shamo, [J] Shokoku - Onagadori, [K] Tosajidori - Onagadori, [L] Totenko - Onagadori, [M] Tosajidori - Shokoku, [N] Totenko - Shokoku and [O] Totenko - Tosajidrori.

Because the sternum is suspended from the coracoid (Yasuda, 2002), we suggest that the shortening of the coracoid elevates the sternum. The short coracoid, which is observed in Chabo, might be affected by its short leg (Ichinoe and Kuwayama, 2007; Akishinonomiya and Komiya, 2009). We suggest that Chabo avoids hauling its body by shortening of the coracoid.

Large ratios of Lar, Lcc, and GLco were detected in Totenko (Table 4−1). The clavicle and anterior part of the sternum, which include these measurements, constitute the thoracic cavity. This cavity provides space for the ingluvies, trachea, and clavicular air sac (Yasuda, 2002). The clavicular air sac is one of the structures needed to phonate (Beckers *et al*. 2003; Mackelprang and Goller, 2013). Beckers *et al*. (2003) reported that the interclavicle air sacs serve as resonator that contribute to the production of pure tones in songbirds. Mackelprang and Goller (2013) report that vibrations of the labia and membranes, which affect gating of airflow and acoustic parameters such as frequency, are generated by the pressure of interclavicle air sacs. Jones and Witt (2014) reported that the length of trachea, which generates the sound in crowing, is limited by the sternum in cranes. These birds possess a trachea coil into the sternum. While the trachea of domestic fowl is not inserted into the sternum, it is considered that the thoracic bones such as clavicle, coracoid, and anterior part of the sternum restrict the space for vocal organs. Totenko is valued for its long, low crowing (Kuwayama *et al*., 1996; Akishinonomiya and Komiya, 2009). To generate this attractive sound, Totenko has a large anterior air sac and long trachea. Although the air sac volume and trachea length were not compared in this study, we suggest that the physiological demand for increasing the thoracic space is reflected in the large ratio of Lar, Lcc, and GLco, which is the result of artificial selection for an attractive voice.

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Table 4-1. **Mean values and standard deviations for skeleton measurement ratios of forelimb, pectoral girdle and sternum in various breeds**

breed	measure-ments	GLst	Lms	Lc	Hs	Lap	Lar	GLco	Lpr	SBf	GBc	Bfc	SBc	Lmc	GLsc	GBs
comparing pair with significant difference		afg	afj	—	cgm	bcefgim	bcefgi	be	—	fgi	cfghi	befgi	—	bce	fgi	bfgij
Chabo	mean	2.24	2.23	1.85	0.74	1.02	0.67	1.06	0.36	0.60	0.30	0.24	0.10	0.98	1.39	0.16
	standard deviation	0.08	0.07	0.11	0.03	0.04	0.05	0.04	0.03	0.03	0.01	0.01	0.01	0.04	0.06	0.01
Ohshamo	mean	2.10	2.15	1.85	0.74	1.01	0.67	1.08	0.38	0.63	0.31	0.25	0.09	1.01	1.34	0.16
	standard deviation	0.06	0.05	0.08	0.04	0.05	0.06	0.04	0.05	0.04	0.02	0.02	0.01	0.04	0.05	0.02
Onagadori	mean	2.24	2.25	1.82	0.77	1.11	0.77	1.12	0.37	0.58	0.28	0.21	0.08	1.07	1.44	0.12
	standard deviation	0.04	0.04	0.05	0.03	0.04	0.06	0.03	0.01	0.02	0.01	0.01	0.01	0.03	0.07	0.01
Shokoku	mean	2.19	2.16	1.81	0.81	1.13	0.78	1.10	0.38	0.57	0.28	0.23	0.09	1.06	1.43	0.15
	standard deviation	0.04	0.04	0.04	0.02	0.06	0.06	0.05	0.02	0.02	0.02	0.01	0.01	0.04	0.05	0.01
Tosajidori	mean	2.18	2.17	1.83	0.76	1.05	0.74	1.08	0.36	0.61	0.28	0.23	0.09	1.03	1.42	0.14
	standard deviation	0.08	0.05	0.06	0.03	0.07	0.06	0.04	0.02	0.02	0.02	0.01	0.01	0.04	0.06	0.01
Totenko	mean	2.19	2.18	1.79	0.79	1.12	0.81	1.12	0.34	0.58	0.28	0.22	0.09	1.06	1.46	0.14
	standard deviation	0.07	0.06	0.08	0.02	0.04	0.01	0.05	0.02	0.02	0.01	0.01	0.01	0.05	0.05	0.01

breed	measure-ments	SBs	Dic	GLcl	Ba	Lsa	Bc	Lcc	GLu	Bpu	Didu	SBu	Dip	Bph	GLh	SBh
comparing pair with significant difference		bcfg	bcfg	bcefgi	bcfkl	abcekmo	g	i	bce	ab	abcdgln	abc	bcg	—	—	abcemn
Chabo	mean	0.11	0.25	1.17	0.24	0.24	0.50	0.93	1.31	0.19	0.21	0.10	0.27	0.40	1.40	0.15
	standard deviation	0.01	0.01	0.03	0.02	0.03	0.08	0.04	0.05	0.01	0.01	0.00	0.02	0.10	0.05	0.01
Ohshamo	mean	0.11	0.25	1.17	0.21	0.30	0.62	0.89	1.38	0.17	0.19	0.08	0.26	0.40	1.39	0.13
	standard deviation	0.01	0.01	0.07	0.02	0.03	0.10	0.06	0.07	0.01	0.01	0.01	0.01	0.02	0.05	0.01
Onagadori	mean	0.09	0.23	1.28	0.17	0.34	0.52	0.95	1.43	0.17	0.18	0.08	0.24	0.39	1.45	0.13
	standard deviation	0.00	0.01	0.06	0.03	0.03	0.14	0.05	0.06	0.01	0.01	0.00	0.01	0.01	0.04	0.01
Shokoku	mean	0.09	0.23	1.26	0.20	0.33	0.50	0.95	1.40	0.17	0.18	0.08	0.23	0.38	1.45	0.13
	standard deviation	0.01	0.01	0.07	0.03	0.03	0.08	0.05	0.05	0.01	0.01	0.01	0.02	0.01	0.05	0.01
Tosajidori	mean	0.09	0.24	1.23	0.24	0.26	0.52	0.97	1.34	0.18	0.18	0.09	0.25	0.39	1.40	0.14
	standard deviation	0.00	0.01	0.05	0.03	0.01	0.06	0.05	0.04	0.01	0.01	0.01	0.00	0.02	0.04	0.01
Totenko	mean	0.10	0.24	1.28	0.22	0.31	0.53	0.99	1.42	0.18	0.20	0.09	0.25	0.40	1.46	0.14
	standard deviation	0.00	0.01	0.06	0.03	0.02	0.03	0.05	0.09	0.01	0.01	0.01	0.02	0.01	0.06	0.01

Each alphabet indicates comparing pair with significant difference; See the caption of Table 4–2.

Table 4-2. **Mean values and standard deviations for skeleton measurement ratios of forelimb, pectoral girdle and sternum in various breeds**

breed	measure-ments	Bdh	GLr	Bpr	SBr	Bdr	Bpc	Hcau	Wcau	Hcar	Wcar	Lm	GLcm	Didc
comparing pair with significant difference		abcde fg	bce	b	bcek	bcg	abceh kmo	abce	abcde	bc	abcem	bcef	b	abcdn
Chabo	mean	0.34	1.17	0.12	0.07	0.15	0.28	0.16	0.18	0.12	0.17	0.68	0.74	0.16
	standard deviation	0.02	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.01
Ohshamo	mean	0.32	1.24	0.11	0.07	0.14	0.24	0.14	0.16	0.11	0.16	0.70	0.76	0.14
	standard deviation	0.02	0.08	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.01
Onagadori	mean	0.30	1.30	0.10	0.06	0.13	0.24	0.14	0.16	0.11	0.15	0.75	0.80	0.15
	standard deviation	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.01
Shokoku	mean	0.29	1.27	0.10	0.06	0.12	0.23	0.13	0.16	0.11	0.15	0.73	0.78	0.13
	standard deviation	0.01	0.05	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.03	0.03	0.01
Tosajidori	mean	0.30	1.20	0.10	0.07	0.14	0.26	0.14	0.16	0.11	0.16	0.71	0.77	0.14
	standard deviation	0.01	0.04	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.01
Totenko	mean	0.30	1.29	0.11	0.06	0.14	0.24	0.14	0.17	0.11	0.16	0.73	0.79	0.15
	standard deviation	0.02	0.09	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.04	0.04	0.01

Each alphabet indicates comparing pair with significant difference as follows; [a] Oh-Shamo - Chabo, [b] Onagadori - Chabo, [c] Shokoku - Chabo, [d] Tosajidori - Chabo, [e] Totenko - Chabo, [f] Onagadori - Oh-Shamo, [g] Shokoku - Oh-Shamo, [h] Tosajidori - Oh-Shamo, [i] Totenko - Oh-Shamo, [j] Shokoku - Onagadori, [k] Tosajidori - Onagadori, [l] Totenko - Onagadori, [m] Tosajidori - Shokoku, [n] Totenko - Shokoku and [o] Totenko - Tosajidori.
- signified that every pair shows no significant difference.

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