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

Kohei Kudo1,2, Naoki Tsunekawa3, Hiroshi Ogawa4 and Hideki Endo1,2

1 Graduate School of Agricultural and Life Science, The University of Tokyo, Bunkyo-ku, Tokyo 113–8657, Japan
2 The University Museum, The University of Tokyo, Bunkyo-ku, Tokyo 113–0033, Japan
3 Department of Bioscience in Daily Life, Nihon University, Fujisawa, Kanagawa 252–0880, Japan
4 Department of Human and Animal-Plant Relationships, Tokyo University of Agriculture, Atsugi, Kanagawa 243–0034, Japan

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

J. Poul. Sci., 54: 47–57, 2017

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). 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 coracid carpometacarpus as well as in the breadth of the corpus scapulae and clavicle (Samejima et al., 1989). The abovementioned study

Received: April 11, 2016, Accepted: June 9, 2016
Released Online Advance Publication: July 25, 2016
Correspondence: Dr. Kohei Kudo, The University Museum, The University of Tokyo, Bunkyo-ku, Tokyo, 113–0033, Japan.
(E-mail: kkudo.6c5a4d3g2b1e@gmail.com)

The Journal of Poultry Science is an Open Access journal distributed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. To view the details of this license, please visit (https://creativecommons.org/licenses/by-nc-sa/4.0/).
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:

\[ \text{GM} = \sqrt[3]{\frac{\text{Lms} \times \text{Hs} \times \text{SBf}}{\text{Lms} \times \text{Hs} \times \text{SBf}}} \]

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 SBl 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, GBlc, 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 4–2).
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).

**Totentko**

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, 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 1. Specimens used in this study**

| breed     | sex    | specimen No. | growth stage | donor | depository |
|-----------|--------|--------------|--------------|-------|------------|
| Chabo     | female | UMUT-15166   | adult¹       | HU    | UMUT       |
| Chabo     | female | UMUT-15167   | adult¹       | HU    | UMUT       |
| Chabo     | male   | UMUT-15168   | adult¹       | HU    | UMUT       |
| Chabo     | female | UMUT-14035   | adult²       | TUA   | UMUT       |
| Chabo     | male   | UMUT-14042   | adult²       | TUA   | UMUT       |
| Chabo     | female | UMUT-14035   | adult²       | TUA   | UMUT       |
| Chabo     | male   | UMUT-14041   | adult²       | TUA   | UMUT       |
| Chabo     | male   | UMUT-14039   | adult²       | TUA   | UMUT       |
| Chabo     | —      | UMUT-11018   | adult²       | IHA   | UMUT       |
| Oh-shamo  | male   | UMUT-15171   | adult¹       | HU    | UMUT       |
| Oh-shamo  | male   | UMUT-15172   | adult²       | HU    | UMUT       |
| Oh-shamo  | male   | UMUT-15150   | adult¹       | HU    | UMUT       |
| Oh-shamo  | male   | UMUT-15151   | adult¹       | HU    | UMUT       |
| Oh-shamo  | —      | UMUT-15152   | adult²       | HU    | UMUT       |
| Oh-shamo  | male   | UMUT-15153   | adult¹       | HU    | UMUT       |
| Oh-shamo  | female | UMUT-14018   | adult²       | TUA   | UMUT       |
| Oh-shamo  | female | UMUT-14019   | adult²       | TUA   | UMUT       |
| Oh-shamo  | —      | UMUT-15154   | adult²       | TUA   | UMUT       |
| Oh-shamo  | male   | UMUT-14021   | adult²       | TUA   | UMUT       |
| Onagadori | male   | UMUT-15155   | adult¹       | HU    | UMUT       |
| Onagadori | male   | UMUT-15156   | adult¹       | HU    | UMUT       |
| Onagadori | male   | UMUT-15157   | adult¹       | HU    | UMUT       |
| Onagadori | male   | UMUT-15158   | adult¹       | HU    | UMUT       |
| Onagadori | female | UMUT-15159   | adult¹       | HU    | UMUT       |
| Onagadori | female | UMUT-15160   | adult¹       | HU    | UMUT       |
| Onagadori | female | UMUT-15161   | adult¹       | 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. adult¹ indicates completed ossification of sternum.
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). 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

Table 2. The measurements used in this study

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

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

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 distal view. (H) Radius from cranial view. (I) Carpo-metacarpus from caudal view. (J) Os carpi alulae ulnare from dorsal view. (K) Os carpi alulae radiale from dorsal view. The abbreviated forms were remarked in Table 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 3-1. Mean values and standard deviations for skeleton measurements of forelimb, pectoral girdle and sternum in various breeds

| Breed | Measurements | GLst | Lms | Le | Hs | Lap | Lar | GLco | Lpr | SBF | GBC | Bfc | SBC | Lmc | GLsc | GBs |
|-------|--------------|------|-----|----|----|-----|-----|------|-----|-----|-----|-----|-----|-----|------|-----|
| Chabo | mean standard | 80.74| 80.41| 66.78| 26.90| 36.77| 24.25| 38.13| 12.96| 21.83| 10.91| 8.66| 3.51| 38.13| 8.66| 3.51|
| Ohshamo | mean standard | 155.26| 158.46| 136.70| 54.90| 74.44| 49.04| 79.69| 27.72| 46.48| 23.15| 18.32| 6.67| 37.72| 11.97| 9.07|
| Ohshamo | mean standard | 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 standard | 118.99| 119.15| 96.44| 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|
| Shokoku | mean standard | 118.95| 117.81| 98.66| 40.40| 61.64| 52.83| 44.00| 60.03| 20.44| 31.13| 15.23| 12.42| 4.80| 57.40| 77.51| 8.00|
| Tosajidori | mean standard | 85.42| 85.27| 71.96| 29.72| 42.52| 14.07| 24.00| 11.06| 8.56| 3.65| 9.84| 14.35| 50.72| 5.46| 9.97| 1.38|
| Totenko | mean standard | 11.46| 113.90| 93.44| 42.12| 8.60| 8.69| 18.04| 33.47| 47.14| 6.73| 7.43| 3.53| 9.84| 14.35| 50.72| 5.46|

Each alphabet indicates comparing pair with significant difference; See the caption of Table 3-2.
Because the sternum is suspended from the coracoid (Yasuda, 2002), we suggest that the shortening of the coracoidelevatesthesternum. Theshortcoracoid,whichisobservedinChabo,mightbeaffectedbyitsshortleg(IchinoeandKuwayama,2007;AkishinonomiyaandKomiya,2009).WesuggestthatChaboavoidshaulingitsbodybyshorteningofthecoracoid.

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 larger ratio of Lar, Lcc, and GLco, which is the result of artificial selection for an attractive voice.

Acknowledgments

The authors thank the Japanese Society for the study of H. I. H. Akishinonomiya Collection for their encouragement. We are grateful to Dr. Masaoki Tsudzuki and Dr. Takao Oka (Animal Breeding and Genetics Laboratory, Hiroshima University) for providing specimens for this study. We also thank Dr. Michiko Niimi (Nagoya University Museum, Nagoya University) for supporting us in the use of the specimens.
Table 4-1. Mean values and standard deviations for skeleton measurement ratios of forelimb, pectoral girdle and sternum in various breeds

| Breed       | Measurements | GLst | Lms | Lc | Hs | Lap | Lar | GLco | Lpr | SBf | GBe | Bfc | SBe | Lmc | GLsc | GBs |
|-------------|--------------|------|-----|----|----|-----|-----|------|-----|-----|-----|-----|-----|-----|------|-----|
| 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| 1.07| 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| 0.02| 0.01| 0.01| 0.04| 0.05| 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| 0.03| 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| 0.04| 0.01 | 0.05| 0.02| 0.02| 0.01| 0.01| 0.05| 0.05| 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         | Measurements | Bdh | GLr | Bpr | SBr | Brd | Bpc | HcAU | WcAU | Hear | Wear | Lm  | GLcm | Dide |
|---------------|--------------|-----|-----|-----|-----|-----|-----|------|------|------|------|-----|------|------|
| 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     | 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     | 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     | 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     | 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     | 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     | 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.

### References

Aizawa M and Ohno K. *The background of kawaiiculture*. Research Reports of Shokei Gakuin College, 59: 23–34. 2010. (in Japanese)

Akishinonomiya F, Miyake T, Takada M, Shingu R, Endo T, Gojobori T, Kondo N and Ohno S. *Monophyletic origin and uniquedispersal patternsof domestic fowls*. Proceedings of the National Academy of Sciences of the United States of America, 93: 6792–6795. 1996.

Al-Nasser A, Al-Khalaifa H, Al-Saffer A, Khalil F, Al-Bahouh M, Raghb G, Al-Haddad A and Mashaly M. *Overview of chicken taxonomy and domestication*. World's Poultry Science Journal, 63: 423–430. 2007.

Altshuler DL, Bahlman JW, Dakin R, Gaede AH, Goller B, Lentink D, Segre PS and Skandalis DA. *The biophysics of bird flight: functional relationships integrate aerodynamics, morphology, kinematics, muscles, and sensors*. Canadian Journal of Zoology, 93: 961–975. 2015.

Arkoff A and Weaver HB. *Body image and body dissatisfaction in Japanese-Americans*. The Journal of Social Psychology, 68: 323–330. 1966.

Baek S, Hwang M, Chung H and Kim P. *Kansei factor space classified by information for kansei image modeling*. Applied Mathematics and Computation, 205: 874–882. 2008.

Beaufre H. A review of biomechanic and aerodynamic considerations of the avian thoracic limb. Journal of Avian Medicine and Surgery, 23: 173–185. 2009.

Beckers GJL, Suthers RA and Cate CT. *Pure-tone birdsong by resonance filtering of harmonic overtones*. Proceedings of the National Academy of Sciences of the United States of America, 100: 7372–7376. 2003.

Beverland MB, Farrelly F and Lim EAC. *Exploring the dark side of pet ownership: Status- and control-based pet consumption*. Journal of Business Research, 61: 490–496. 2008.

Biewener AA. *Muscle function in vivo: a comparison of muscles used for elastic energy savings versus muscles used to generate mechanical power*. American Zoologist, 38: 703–717. 1998.

Breitburg DL. *Interspecific competition and the abundance of nest sites: Factors affecting sexual selection*. Ecology, 68: 1844–1855. 1987.

Breugelmans S, Muylle S, Cornillie P, Saunders J and Simoens P. *Agedetermination of poultry: a challenge for customs*. Vlaams Diergeneeskundig Tijdschrift, 76: 423–430. 2007.

Coy AE, Green JD and Price ME. *Why is low waist-to-chest ratio attractive in males? The mediating roles of perceived dominance, fitness, and protection ability*. Body Image, 11: 282–289. 2014.

Dial KP, Goslow GE and Jenkins FA. *The functional anatomy of the shoulder in the European starling (Sturnus vulgaris)*. Journal of Morphology, 207: 327–344. 1991.

Driesch A von den. *A Guide to The Measurement of Animal Bones*...
from Archaeological Sites. Peabody Museum of Harvard University, Cambridge. 1976.

Dundes A. The Cockfight. University of Wisconsin Press, Madison. 1994.

Frahm HD and Rehkämper G. Allometric comparison of the brain and brain structures in the white crested polish chicken with uncrested domestic chicken breeds. Brain, Behavior and Evolution, 52: 292–307. 1998.

Glocker ML, Langleben DD, Ruparel K, Loughead JW, Gur RC and Sacher N. Baby schema in infant faces induces cuteness perception and motivation for caretaking in adults. Ethology, 115: 257–263. 2009.

Horvath T. Physical attractiveness: The influence of selected torso parameters. Archives of Sexual Behavior, 10: 21–24. 1981.

Hospitalche CA and Carlo UD. The coracoids in functional and morphological studies of penguins (aves, spheniscidae) of the Eocene of Antarctic. Rivista Italiana di Paleontologia e Stratigrafia, 116: 23–34. 2010.

Ichinoe K and Kuwayama T. Kakín. Soubun, Tokyo. 2007. (in Japanese)

Ishida K. On the character and history of Japanese kawaii culture, and a proposal of its way of international communication. The Faculty journal of Komazawa Women's University, 19: 57–68. 2012. (in Japanese)

Jonart LM, Hill GE and Badyaev AV. Fighting ability and motivation: Determinants of dominance and contest strategies in female of a passerine bird. Animal Behaviour, 1675–1681. 2007.

Jones MR and Witt CC. Migrate small, sound big: Functional constraints on body size promote tracheal elongation in cranes. Journal of Evolutionary Biology, 27: 1256–1264. 2014.

Jourard SM and Secord PF. Body size and body-catexhis. Journal of Consulting Psychology, 18: 184. 1954.

Jourard SM and Secord PF. Body-catexhis and the ideal female figure. The Journal of Abnormal and Social Psychology, 50: 243–246. 1955.

Kruger DJ. Non-mammalian infants requiring parental care elicit greater human caregiving reactions than superpreocial infants do. Ethology, 121: 769–774. 2015.

Ksepka DT. Phylogeny, Histolog and Functional Morphology of Fossil Penguins (sphenisciformes). Columbia University, Chicago. 2007.

Kuwayama T, Ogawa H, Munechika I, Kono T and Ichinoe K. Crowing characteristics of jungle fowl, Japanese native breeds and white leghorn breed of chicken. Japanese Journal of Poultry Science, 33: 89–95. 1996.

Lehmann V, Haus EM and Vingerhoets AJ. The human and animal baby schema effect: Correlates of individual differences. Behavioural Processes, 94: 99–108. 2013.

Lorenz K. Die angeborenen Formen möglicher Erfahrung. Zeitschrift für Tierpsychologie, 5: 235–409. 1943.

Mackelprang R and Goller F. Ventilation patterns of the songbird lung/air sac system during different behaviors. The Journal of Experimental Biology, 216: 3611–3619. 2013.

McCagh CH and Neal AG. The fraternity of cockfighters: Ethical embellishments of an illegal sport. Journal of Popular Culture, 8: 557–569. 1974.

Morreall J. Cuteness. British Journal of Aesthetics, 31: 39–47. 1991.

Mosimann JE. Size allometry: Size and shape variables with characterization of the lognormal and generalized gamma distributions. Journal of the American Statistical Association, 65: 930–945. 1970.

Nash H. Assignment of gender to body regions. The Journal of Genetic Psychology, 92: 113–115. 1958.

Niemi GJ. Patterns of morphological evolution in bird genera of new world and old world petatlans. Ecology, 66: 1215–1228. 1985.

Nishida T, Hayashi Y, Fujisaka T, Tsugiyama I and Mochizuki K. Osteometrical studies on the phylogenetic relationships of Japanese native fowls. The Japanese Journal of Veterinary Science, 47: 25–37. 1986.

Nitto H. A behavioral science approach to “kawai”. Bulletin of the Graduate School of Integrated Arts and Science, Hiroshima University, I, Studies in Human Science, 4: 19–35. 2009. (in Japanese)

Nitto H, Fukushima M, Yano A and Moriya H. The power of kawaii: Viewing cute images promotes a careful behavior and narrows attentional focus. PloS One, 7: e46362. 2012.

Oana H. History of Japanese Domestic Fowl. Nihon-kei Kenkyusha Press, Tokyo. 1951. (in Japanese)

Ohkura M, Osawa S and Komatsu T. Kawaii feeling in tactile material perception. Proceedings of The 5th International Congress of International Association of Societies of Design Research, Tokyo. 2013.

Ohkura M. “Kawaii” as an affective value. Oukan : Journal of Transdisciplinary Federation of Science and Technology, 9: 14–19. 2015. (in Japanese)

Okamoto S. Zoology of Domestic Fowl. University of Tokyo Press, Tokyo. 2001. (in Japanese)

Poore SA, Aschoft A, Sánchez-Haiman A and Goslow GE. The contractile properties of the M. supracoracoideus in the pigeon and starling: a case for long-axis rotation of the humerus. The Journal of Experimental Biology, 200: 2987–3002. 1997.

Renison D, Boersma D and Martella MB. Winning and losing: causes for variability in outcome of fights in male Magellanic penguins (Spheniscus magellanicus). Behavioral Ecology, 13: 462–466. 2002.

Samejima M, Ito S and Fujioka T. Principal component analysis of measurements in the skeleton of red jungle fowl and 12 breeds of domestic fowls: II. Sternum and ossa membri thoracici. Japanese Journal of Poultry Science, 26: 157–171. 1989. (in Japanese)

Sheppy A. The colour of domestication and the designer chicken. Optics and Laser Technology, 43: 295–301. 2011.

Simons ELR. Forelimb skeletal morphology and flight mode evolution in penguiniform birds. Zoology, 113: 39–46. 2010.

Simons ELR, Hieronymus TL and O'Connor PM. Cross sectional geometry of the forelimb skeleton and flight mode in penguiniform birds. Journal of Morphology, 272: 958–971. 2011.

Sternglanz SH, Gray JL and Murakami M. Adult preferences for infantile facial features: An ethological approach. Animal Behaviour, 25: 108–115. 1977.

Tobalske BW and Biewener AA. Contractile properties of the pigeon supracoracoideus during different modes of flight. The Journal of Experimental Biology, 211: 170–179. 2008.

Ujigawara M. Classifying the cause and effect system of “kawaii” - To typify the psychological phenomenon of “kawaii” -. Japan Society of Kansai Engineering, 15: 39–46. 2016. (in Japanese)

Weiss E, Miller K, Mohan-Gibbons H and Vela C. Why did you choose this pet?: Adopters and pet selection preferences in five animal shelters in the United States. Animals, 2: 144–159. 2012.

Yasuda M. The Anatomical Atlas of Gallus. University of Tokyo Press, Tokyo. 2002. (in Japanese)

Yomota I. “Kawaii” Ron. Chikuma Shinso, Tokyo. 2006. (in Japanese)