Sexual dimorphism of the Eurasian otter (Lutra lutra) in South Korea: Craniodental geometric morphometry

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ABSTRACT. Sexual dimorphism of the craniodental morphology of the Eurasian otter in South Korea was studied with geometric morphometrics. 29 adult skulls (15 males and 14 females) were used. Images of the dorsal and ventral view of the cranium and right lateral view of the mandible were taken and then digitized, and measurements were taken on the right side. Results showed that size difference between males and females was significant. Correlations between the size and shape variations have not been observed in this study. The bivariate plots with centroid size showed size dimorphism between males and females with some overlapping. Most relative warp (RW) scores were not significantly different between males and females. We observed only RW2 for dorsal and ventral view of the skull, and only RW1 for mandible was significantly different between the sexes. Shape dimorphisms were revealed at the postorbital constriction, temporal-mandibular joint, coronoid process, mandibular condyle and angular process of the skull. Based on our study, sexual dimorphism exists in Eurasian otter from the South Korean population in terms of both the size and shape. Furthermore, the degree of size dimorphism is greater than shape dimorphism.

KEYWORDS: geometric morphometrics, sexual dimorphism, skull morphology

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Eurasian otter (Lutra lutra) is one of the 13 otter species in the world, and it is the species with the widest distribution [13]. Various authors recognize 7 to 10 subspecies as a result of their different habitats across the Palaearctic from Ireland to Japan. This highly solitary and territorial species because of its endangered status was also designated in 1982 as a National Natural Monument in South Korea [12]. Their status and food habits were studied by Ando et al. [1] by using scats which revealed that the species can be found widely in the coastal region and some major river systems in South Korea [1].

The mustelid family is well known for its clear sexual size dimorphism, in which males are much bigger and heavier than the females [8, 13, 20]. Early studies by Wiig [18] compared sexual dimorphism between minks, badgers and Eurasian otters.

Lynch et al. [14] also compared the skulls of Eurasian otters from five populations based on craniometrics variation without the mandible, and they found significance in sexual dimorphisms amongst males and females. In this study, we used geometric morphometrics which is the different method from previous studies. This method is now commonly used by biologist to study the form in either two or three dimensions by using a set of landmarks [21]. As size has always been the major consideration when describing the morphological variations, this method however, enables to define the shape separated from size with mathematical implications [21]. In our study using geometric morphometrics, we identified, sexual dimorphisms among males and females of Eurasian otter in the South Korean population in terms of size or shape.

MATERIALS AND METHODS

A total of 29 with 15 male and 14 female skulls and mandibles were used for this study. 18 of the specimens are the collection in Department of Anatomy and Cell Biology, College of Veterinary Medicine, Seoul National University, and the other 11 specimens are the collection in Korean Otter Research Center. Only adult skull specimens were selected for this research to prevent the variations as a result from different stages of age. Adult features are determined by the complete suture closure of the cranium and fully erupted molar teeth.

Two-dimensional images were taken with a digital camera with a scale included. Images were taken from the dorsal and ventral view of the cranium, as well as the right lateral view of the mandible. All images taken were digitized by using tpsRelw [19]. Landmarks (Table 1) in our study were adopted from some of the landmarks used in Berdnikovs [4] to identify sexual dimorphism in mustelids by using geometric morphometrics. Relative warp analysis is a method developed by Bookstein [6, 17] used to describe the shape variation with the shape deformations among the specimens. Similar to principal component scores of principal compo-
Table 1. Overview of landmarks used

| No. | Dorsal view of cranium | No. | Ventral view of cranium | No. | Right lateral mandible |
|-----|------------------------|-----|-------------------------|-----|------------------------|
| 1   | Anterior end of the incisive | 1   | Intradental superior    | 1   | Coronoid process       |
| 2   | Nasale                  | 2   | Posterior end of palatine| 2   | Mandibular condyle     |
| 3   | Lateral end of the aperture | 3   | Basion                  | 3   | Angular process        |
| 4   | Maxillary outline at the level of nasion | 4   | Occipital condyle       | 4   | Masseteric fossa       |
| 5   | Anterior end of the orbital | 5   | Mastoid process         | 5   | Anterior of canine     |
| 6   | Mesial end of the orbital | 6   | Mandibular fossa (left) | 6   | Molar cusp (on top of hypoconid) |
| 7   | Zygomatic process of frontal | 7   | Mandibular fossa (right) | 7   | Molar cusp (on top of protoconid) |
| 8   | Frontal process of zygomatic | 8   | Molar and premolar juncture (mesiolingual, first molar) | 8   | Molar cusp (on top of paraconid) |
| 9   | Postorbital constriction | 9   | Molar and premolar juncture (buccal) |       |                        |
| 10  | Posterior zygomatic arch | 10  | Molar and premolar juncture (distolingual, fourth premolar) |       |                        |
| 11  | Maximum breadth of cranial vault | 11  | Second premolar and carnassial juncture (buccal) |       |                        |
| 12  | External occipital protuberance | 12  | Second premolar and carnassial juncture (lingual) |       |                        |
|     |                        | 13  | Upper canine (posterior) |       |                        |
|     |                        | 14  | Upper canine (anterior)  |       |                        |

RESULTS

The results of Mann-Whitney U-test, Pearson correlation test and MANOVA of dorsal and ventral view of the skull, as well as the mandible are shown in Table 2. In Pearson correlation test, no pair was significant for the comparisons of all the specimens, as well as each sex. Figure 1 shows the bivariate plots of the centroid size with the RWs that are significantly different (U-test) between male and female of Eurasian otter. The deformation of the shapes is illustrated with thin-plate spline in Fig. 2. The centroid size was significantly different between sexes (P=0.001, U-test). In the bivariate plots (Fig. 1a, b and c), males and females were separated by the size with some overlapping occurred. RW2 of the dorsal view of the skull was significantly different between the sexes which explained 14.54% (Table 2) of the total variation. It indicates the males show narrower postorbital constriction, as well as larger temporal fenestra, in comparison with the females (Fig. 2a). Postorbital process of frontal bone, postorbital process of zygomatic bone and maxillar outline for males display broader facial cranium and snout than the females (Fig. 2a). RW2 of ventral view of the skull was also significantly different (P=0.028; U-test) (Table 2), which explained 13.65% of the total deformation whose difference was observed at the temporal mandibular joint region as well as landmarks on the palatal region (Fig. 2b). In the mandible, variation was explained mostly by RW1, accounted 28.33%, and was significantly different between sexes (P=0.021; U-test) whose difference was observed at coronoid process, mandibular condyle and angular process, respectively (Fig. 2c). However, the MANOVA results using 90% cumulative relative warps revealed that only ventral view of the skull is significantly different between sexes (P=0.013; MANOVA) (Table 2).

DISCUSSION

Wig [20] studied sexual dimorphism between minks, badgers and Eurasian otters using skull measurements and found sexual size dimorphism in all three species. In another study with the linear measurement by Lynch et al. [14] with five populations of Eurasian otter also found out that most measurements for males were bigger than females, except for postorbital constriction. These findings are consistent with our result where from our centroid size comparison, male skull specimens were larger than females in general (Fig. 1). Both of the previous studies with linear measurement had supported that sexual dimorphism exists in Eurasian otter [14, 20]. In the study by Lynch et al. [14], shape dimorphism was greater than the size dimorphism. In their study, the first principal component is considered as the size factor, while the rest of the principal component as the shape factor [14]. They performed subsequent canonical variate analyses on all principal components (size-in) and those other than the first component (size-out) and found that the
Sexual dimorphism in Korean Eurasian otter well-discriminates sexual dimorphism [14]. However, our study shows that size dimorphism appeared to be greater than shape dimorphism, which is shown in our bivariate plots where males and females were separated by the centroid size (Fig. 1a, b and c) with minimum overlapping. Another evidence that shape dimorphism is low in Korean Eurasian otter from our study is that most relative warps and MANOVA results were insignificant (Table 2). The different results between our study and Lynch et al. [14] could be caused by the difference in the methodology. An example of these different results can be seen in the sexual dimorphism study by Natori et al. [16] and shape variation study by Asahara [2, 3] on Japanese raccoon dog skulls. The former study by using linear measurement found sexual dimorphism [16], while the latter with geometric morphometrics did not find that in shape [2, 3]. Among the geographical comparisons in Natori et al. [16], two of the populations exhibited low degree of sexual dimorphism, but male Japanese raccoon dogs had a longer cranium than the female individuals. However, Asahara [2, 3] did not find any sexual dimorphism, using geometric morphometrics, in shape between populations of Japanese raccoon dogs.

The relationship between sexual size dimorphism of feeding habits and breeding system of the Eurasian otter was discussed by Moors [15]. He hypothesized that intersexual competition for food is present and that small size females are related with less daily maintenance energy required making them more efficient for breeding [15]. Rensch’s rule about the relation of sexual size dimorphism with body size was also discussed by Hood [10] with geometric morphometrics, and noted that larger body size tends to yield greater sexual size dimorphism. As in general, the body size and mass differences between the sexes with regional variation are observed in Eurasian otter which matched the findings and discussion in both Moors [15] and Hood [10]. Therefore, although the behavioral and feeding ecology are not documented for South Korean population, the above hypotheses from previous studies might be related to our finding of greater size dimorphism than shape dimorphism. However, Wiig [20] claimed that the theories by Moors [15] are insufficient to explain the sexual dimorphism observed among the moderately dimorphic species in mustelid family. Correlation between size and shape is not directly related with sexual dimorphism. The shape variations indicate that males have narrower postorbital constriction, as well as larger temporal fenestra, in comparison with females. Wiig [20] also pointed out the same finding. However, Hysing-Dahl [11] did not find any difference in the postorbital constriction between the sexes. Narrow postorbital constriction in comparison with the skull size is related to the distribution of temporalis muscle, which furtherly affects the biting force [20]. Males had a narrower postorbital constriction in our study. Therefore, males may have greater biting force compared to the females. Furthermore, from the ventral view of the skull, as well as the mandible of Eurasian otter in our study, temporal mandibular joint, coronoid process, mandibular condyle and angular process were dimorphic [Fig. 2c]. All these features are correlated with the mechanism

| Relative warps (RW) | Singular values (%) | Result of U-test (P=) | Linear r/P value (RWs/centroid size) | Linear r/P value (Sex/centroid size) | MANOVA (90% cumulative RWs) |
|---------------------|---------------------|-----------------------|-------------------------------------|-------------------------------------|----------------------------|
| Dorsal view of skull | RW1 32.96 0.948 0.411/0.027 F: 0.520/0.057 M: 0.465/0.080 Wilks’ lambda: 0.751 | |
|                     | RW2 14.54 0.047 0.431/0.020 F: –0.126/0.668 M: 0.399/0.141 | |
|                     | RW3 11.47 0.913 0.342/0.069 F: 0.540/0.046 M: 0.270/0.331 | |
|                     | RW4 9.09 0.132 0.206/0.284 F: –0.142/0.628 M: –0.101/0.721 | |
| Ventral view of skull | RW1 19.51 0.647 0.211/0.272 F: –0.011/0.970 M: 0.303/0.273 Wilks’ lambda: 0.317 | |
|                     | RW2 13.65 0.028 0.317/0.094 F: –0.015/0.960 M: 0.153/0.587 | |
|                     | RW3 13.17 0.326 0.243/0.203 F: –0.019/0.949 M: 0.304/0.271 | |
|                     | RW4 9.2 0.055 0.089/0.645 F: 0.253/0.383 M: –0.547/0.035 | |
| Right lateral of mandible | RW1 28.33 0.021 0.429/0.023 F: –0.086/0.780 M: 0.416/0.123 Wilks’ lambda: 0.638 | |
|                     | RW2 25.92 0.174 0.315/0.102 F: 0.057/0.853 M: 0.230/0.410 | |
|                     | RW3 11.54 0.963 0.305/0.115 F: 0.538/0.058 M: 0.270/0.331 | |
|                     | RW4 10.44 0.818 0.099/0.615 F: 0.268/0.376 | |
of jaw closing and biting force that have been discussed by Biknevicius and Valkenburgh [5], as well as by Ewer [8]. Their studies mentioned that mustelids have well-developed temporalis muscle, as well as well-developed temporal mandibular joint that contributes to the greater biting force during prey hunting [5]. Christiansen et al. [7] revealed that differences in biting force could be closely related to the adaptations to the ecology and then contributed to the evolutions in order of Carnivora. Body mass and dietary factors were included in biting force estimation in their study, and they found a positive relation between prey sizes with the biting force [7]. Lynch et al. [14] mentioned that the morphological differences in the skull allowed for the separation of diets. Thus, our findings showed that dietary difference either due to the adaptation or in conjunction with different body mass and size for the prey selection probably exists among both sexes.

In summary, sexual dimorphism exists in the South Korean Eurasian otter population with size dimorphism being greater than shape dimorphism. Shape dimorphisms in the skulls were observed to a lesser degree and may be related to their feeding habits.

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Fig. 2. Thin-plate spline showing shape deformation for (a) dorsal view with RW1, (b) ventral view with RW2 of the skull and (c) right lateral mandible with RW1 on deformation grid with (i) from 0.00 to 0.10 and (ii) from 0.00 to −0.10. Landmark description as in Table 1.