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A Study on Age Variation and Secondary Sexual Dimorphism in Morphometric Characters of Korean Rodents: I. An Analysis on Striped Field Mice, *Apodemus agrarius coreae* Thomas, from Cheongju

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한국산 설치류의 연령에 따른 형태적 형질의 변이와 암·수간의 제 2 차 성적 이형현상에 관한 연구 : Ⅰ. 청주산 등줄쥐 (*Apodemus agrarius coreae* Thomas)에 관한 분석

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적 요

청주에서 채집한 등줄쥐 (*Apodemus agrarius coreae* Thomas)의 4종류의 외부형태 형질과 27가지의 두골형질의 연령에 따르는 변이와 암·수간의 제 2 차 성적이형현상을 통계적으로 분석했다.

표본들은 미성체, 어린성체, 중간 연령층의 성체, 그리고 늙은 성체로 구분을 하였으며, 이들 연령군에 속하는 표본들간의 형태적 형질들의 변이는 현저하게 나타났다.

동일연령군에 속하는 암컷과 숫컷사이의 차이는 유의하지 않았다.

한국산 등줄쥐의 형태적 형질의 지리적변이를 밝히기 위한 분석에서는 동일연령군에 속하는 표본들을 이용해야 한다는 것이 밝혀졌다.

INTRODUCTION

In the concept of biological species, as defined by Mayr (1963), species are groups of actually or potentially interbreeding populations which are reproductively isolated from other groups. Reproductive isolation can not be easily examined and morphological characters have to be used to infer the acquisition of reproductive isolation between related taxa (Huxley, 1938). Furthermore, age variation, secondary sexual dimorphism, and

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geographic variation of morphometric characters should be analyzed before specific status is considered (Mayr, 1969).

Most taxonomic works on Korean rodents were based on the description of pelage colour and external measurements of type specimens (Woon, 1967). Striped field mouse, *Apodemus agrarius*, distributed from West Germany to Korea and most of subspecies were separated on the basis of slight differences in pelage colour or mean size (Corbet, 1978). Thomas (1908) designated striped field mice from the Korean peninsular and Cheju Do as *A. agrarius coreae* based on the analysis of pelage colour and external measurements. Jones and Johnson (1965) reported that four subspecies of *A. agrarius* were recognized as occuring in Korea; *A. a. manchuria* in the extreme northern part, *A. a. coreae* throughout the major portion of the peninsular, *A. a. pallescens* in the coastal lowlands of southern and southwestern Korea, and *A. a. chejuensis* on Cheju Do. They also stated that subspeciation of *A. agrarius* on the Korean mainland was not clearly defined.

The objective of this study is to determine the extent of age variation and secondary sexual dimorphism in Cheongju population of *A. agrarius* in order to establish a sound basis for a reexamination of geographic variation in this species from Korea.

MATERIALS AND METHODS

Materials

Skins and skulls of 102 specimens collected from Cheongju in 1981 and 1982 were used (all specimens examined are in the collection of the author, Dept. of Biology, College of Natural Sciences, Chungbuk University, Cheongju, Korea).

Characters

Analyses were based on four external and 27 cranial characters. External measurements were taken with a ruler to millimetre and cranial measurements with a dial caliper to 0.01 millimetre. Cranial characters are illustrated in Fig. 1 and characters are defined as follows:

1. Greatest length of the skull: length from the anterior margin of the nasal bone to the posteriorly projecting edge of the occiput (A-A′).
2. Condylobasal length: length from the anterior edge of the alveolus of the upper incisor (I^1) to the posterior margin of occipital condyles (H-H′).
3. Length between incisor and incisive foramen: length from the anterior edge of the alveolus of I^1 to the anterior margin of the incisive foramen (H-I).
4. Length of the nasal bones: length between anterior and posterior edges of the nasal bones (A-B).
5. Zygomatic width: greatest width across the zygomatic arches (L-L′).
6. Mastoid width: width between the external projection of the mastoid processses (M-M′).
7. Width of brain case: maximum width of the brain case measured between the posterior

margins of the zygomatic arches (C-C′).

8. Height of brain case: height of brain case measured from the posterior margin of the alveolus of the upper third molar (M^3) to the suture of the frontal and parietal bones (Q-Q′).
9. Width between infraorbital canals: width between the external foramina of each infraorbital canal (F-F′).
10. Length of rostrum: length from the anterior edge of orbit to the anterior margin of the alveolus of I^1 (H-J).
11. Length of hard palate: length from posterior margin of incisive foramina to posterior edge of palate (I′-K).
12. Interorbital constriction: minimum width across the frontal bones (E-E′).
13. Width across upper third molars (M^3): distance between buccal margins of alveoli of M^3 (0-0′).
14. Incisor-upper-first-molar (M^1) length: distance from the anterior margin of alveolus of I^1 to the anterior alveolus of M^1 (H-S).
15. Width across upper first molars (M^1): distance between buccal margins of alveoli of M^1 (N-N′).
16. Length of incisive foramen: length between anterior and posterior margins of incisive foramen (I-I′).
17. Width of the interparietal bone: width across the interparietal bone between the most left and right extensions (D-D′).
18. Length of the interparietal bone: length across the interparietal bone between the anterior and posterior margins (G-G′).
19. Postpalatine length: length between posterior edge of the palatine bone and the anterior margin of foramen magnum (K-K′).
20. Height of rostrum: height of premaxilla and nasals from the postero-external margin of the alveolus of I^1 to the most dorsal projection of the nasal bones (P-P′).
21. Bullae-brain case height: height of brain case from the most ventral projection of the tympanic bullae to the most dorsal projection of the parietal (R-R′).
22. Greatest length of mandible: greatest length measured from the anterior edge of the crown of lower incisor to the posterior maigin of the condyloid process (V-V′).
23. Length of mandibular tooth row: length between the anterior margin of alveolus of the first lower molar (M^1) to the posterior margin of the alveolus of the third lower molar (X-Y).
24. Height of mandible: height measured from the most ventral surface of the mandible to the highest point of the coracoid process (W-W′).
25. Length of ramus: distance from anterior margin of posterior projection of mandible to the anterior margin of the alveolus of M_1 (X-X′).
26. Length of M^2 and M^3: distance from the anterior margin of the alveolus of M^2 and

posterior margin of the alveolus of M^3 (T-Q').

27. Length of the first upper molar (M^1): distance between anterior and posterior rims of the alveolus of M^1 (S-T).
28. Length of tail vertebrae: greatest length of tail vertebrae.
29. Length of hind foot: length of hind foot from heel to tip of claws.
30. Body length: length of head and body (total length less length of tail vertebrae).
31. Length of ear: greatest length of ear from notch.

Age classification

Each specimen was assigned to one of three age classes (juvenile, subadult, and adult) based on the eruption of M^3, degree of tooth-wear, and pelage colour. Adults were further subdivided on degree of tooth-wear as young adults (A-I), middle-aged adults (A-II), and old adults (A-III). The terminology of tooth-wear follows that of Trout (1963) developed for *Onychomys* with further definition by Hinesley (1979) as illustrated in Fig. 2. The description of pelage colour is that of Thomas (1908). The 102 specimens were classified as 25 subadults (8 males, 17 females), 34 young adults (15 males, 19 females), 35 middle-aged adults (21 males, 14 females), and 8 old adults (4 males, 4 females). Criteria for the five age classes were as follows:

1. Juvenile—M^3 not reaching the height of M^1 and M^2.
2. Subadult—specimens in greyish, subadult pelage with little or no tooth wear or with molting adult pelage with little or no tooth wear—'Canyon condition' (Fig. 2A).
3. Young adult (A-I)— specimens with adult pelage and smooth wear on cusps of upper molars—'Stream condition' (Fig. 2B).
4. Middle-aged adults (A-II)—specimens in adult pelage with much wear on cusps of upper molars—'Lake condition' (Fig. 2C).
5. Old adult (A-III)—specimens in adult pelage with heavy wear on cusps of upper molars—'Dish condition' (Fig. 2D).

Age variation

All computations were made using the University of Toronto IBM/37-/165 II computer. Gabriel's (1964) Sums of Square Simultaneous Test Procedure (SS-STP) on ranked means (Power, 1970) was applied by using UNIVAR program to test significant differences of means among the four age classes; subadults (SA), young adults (A-I), middle-aged adults (A-II), and old adults (A-III).

Secondary sexual dimorphism

Multivariate Analysis of Variance (MANOVA) by using program MANOVA (Cooley and Lohnes, 1971) was separately performed with raw data of young adults (A-I) and middle-aged adults (A-II), which contained large numbers of both sexes. The 31 characters were separated into three sets of variables. Set A of 11 characters was selected to include those with little or no age variation; set B included 13 of 15 characters showing marked age variation; and set C included the remaining seven characters (the number of characters

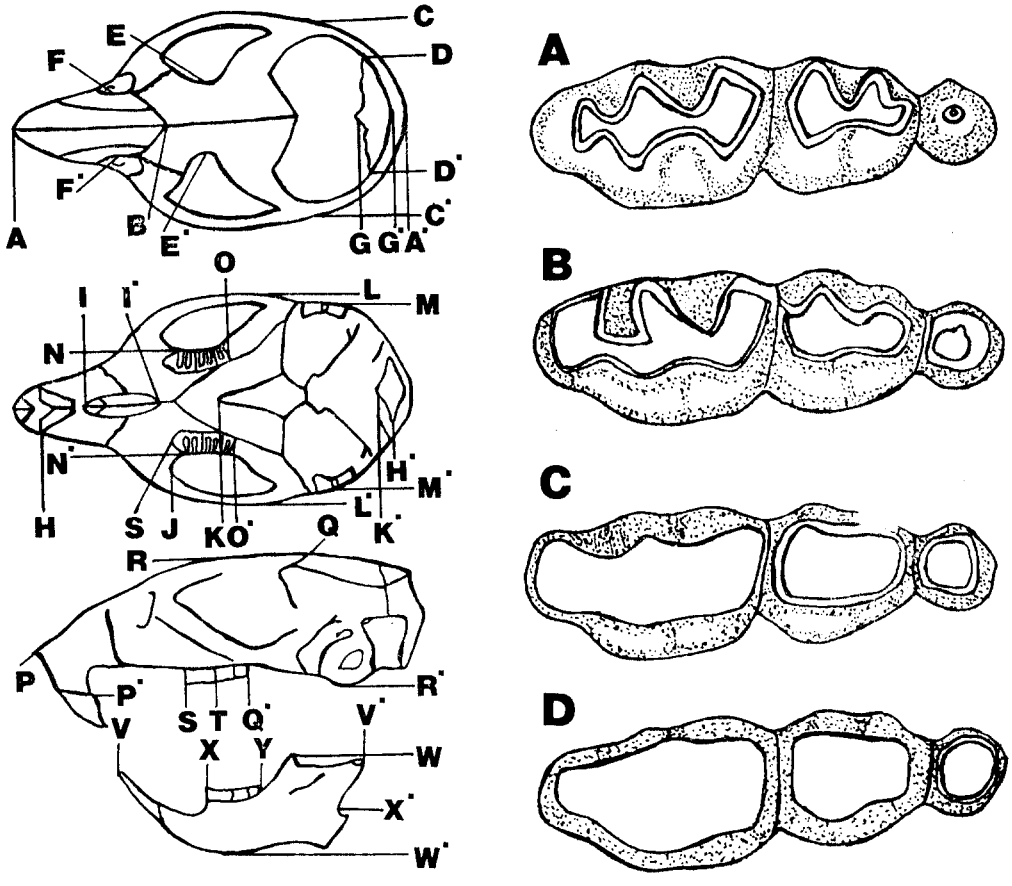

Fig. 1. Dorsal, ventral and lateral views of the skull of *Apodcmus* illustrating the characters measured. See Materials and Methods for definitions of measurements.

Fig. 2. Stages of tooth wear of the four age-classes of *Apodemus* redrawn from Hinesley (1979). Terminology is that of Trout (1963). Age classes are illustrated by wear on the right upper molars.
A. Subadult showing 'Canyon stage'.
B. Young adult (A-I) showing 'Stream stage'.
C. Middle-aged adult (A-II) showing 'Lake stage'.
D. Old adult (A-III) showing 'Dish stage'.

used must be less than the number of samples in order to use the program MANOVA).

RESULTS

Age variation

Character means of each age class by SS-STP analysis are shown in Table 1, in which the age classes showing non-significant difference are connected by straight lines. In seven

Table 1. Age variation among four age classes of *Apodemus agrarius coreae* from Cheongju based on SS-STP analysis.

Characters	1. Greatest length of the skull				2. Condylobasal length				3. Length between incisor and incisive foramen			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	24.5	25.9	27.0	28.0	22.2	23.5	24.7	25.5	2.73	3.00	3.16	3.20
Subsets	——	——	——	——	——	——	——	——	——	——	——	
Characters	4. Length of the nasal bones				5. Zygomatic width				6. Mastoid width			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	9.18	9.78	10.4	10.8	12.1	12.7	13.0	13.3	9.45	9.57	9.74	9.70
Subsets	——	——	——		——	——	——		——	——	——	——
Characters	7. Width of brain case				8. Height of brain case				9. Width between infra-orbital canals			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	11.0	11.4	11.5	11.5	8.25	8.56	8.81	8.88	2.89	3.03	3.04	3.01
Subsets	——	——	——	——	——	——	——	——	——	——	——	——
Characters	10. Length of rostrum				11. Length of hard palate				12. Interorbital constriction			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	8.01	8.53	8.96	9.25	4.80	4.92	5.03	5.17	4.17	4.30	4.31	4.43
Subsets	——	——	——	——	——	——	——	——	——	——	——	——
Characters	13. Width across upper third molars				14. Incisor-upper-first-molar length				15. Width across upper first molar			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	4.28	4.41	4.43	4.43	7.66	8.18	8.62	9.02	4.75	4.87	4.97	5.00
Subsets	——	——	——	——	——	——	——	——	——	——	——	——
Characters	16. Length of incisive foramen				17. Width of the inter-parietal bone				18. Length of the inter-parietal bone			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	4.33	4.67	4.86	5.13	9.93	10.2	10.3	10.2	3.00	3.02	2.99	3.15
Subsets	——	——	——	——	——	——	——	——	——	——	——	——
Characters	19. Postpalatine length				20. Height of rostrum				21. Bullae-brain case height			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	8.07	8.71	9.25	9.57	3.72	3.97	4.22	4.26	9.27	9.48	9.62	9.81
Subsets	——	——	——	——	——	——	——	——	——	——	——	——
Characters	22. Greatest length of mandible				23. Length of mandibular tooth row				24. Height of mandible			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	15.0	16.4	16.9	17.5	3.86	3.86	3.84	3.96	6.29	6.65	6.99	7.38
Subsets	——	——	——	——	——	——	——	——	——	——	——	——
Characters	25. Length of ramus				26. Length of the 2nd & the 3rd upper molars				27. Length of the first upper molar			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	6.93	7.38	7.60	7.83	1.87	1.85	1.85	1.85	1.88	1.95	1.97	2.04
Subsets	——	——	——	——	——	——	——	——	——	——	——	——

Characters	28. Length of tail vertebrae				29. Length of hind foot				30. Body length			
Age classes	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III	SA	A-I	A-II	A-III
Means(mm)	77.2	85.6	91.0	94.6	20.3	20.9	21.3	21.5	73.0	86.2	91.2	95.0
Subsets	—	—	—		—	—	—		—	—	—	
Character	31. Length of ear											
Age classes	SA	A-I	A-II	A-III								
Means(mm)	12.7	12.9	13.5	14.0								
Subsets	—	—	—									

Character means of each age class are shown with non-significant subsets connected by straight lines. The four age classes are subadult (SA), young adult (A-I), middle-aged adult (A-II), and old adult (A-III). Means are given in millimetres.

Table 2. Results of MANOVA comparison of males and females in young adult(A-I) and middle-aged adult (A-II) of *A. agrarius coreae* from Cheongju.

Age	Variable set	No. of males	No. of females	Overall discrimination
A-I	A	15	19	0.92($P>0.05$) (12, 22)
	B	15	19	0.80($P>0.05$) (14, 20)
	C	15	19	0.99($P>0.05$) (8, 26)
A-II	A	21	14	1.22($P>0.05$) (12, 23)
	B	21	14	1.35($P>0.05$) (14, 21)
	C	21	14	1.30($P>0.05$) (8, 27)

Characters were separated into three sets of variables, set A of 11 characters showing little or no age variation, set B of 13 cranial characters with marked age variation, and set C of the remaining seven characters. Degree of freedom are given beside each F-ratio.

characters (6, 9, 13, 17, 18, 23, and 26) means were not significantly different among the four age classes tested. In 24 characters the order of ranked means were the same as the order of age classes from young to old, and the differences between means of successive age classes became smaller.

The means showed non-significant difference between subadult and A-I or A-II in four characters (11, 27, 29, and 31), whereas means of subadults were significantly smaller than any adult age class in 20 characters. The means were not significantly different between A-I and A-II or A-III in five characters (7, 12, 15, 21, and 22): A-I was significantly smaller than A-II and A-III in 15 characters. Means of A-II were not significantly smaller than A-III in 11 characters (3, 4, 5, 8, 10, 16, 19, 20, 25, 28, and 30), while means of A-II were significantly smaller than A-III in four characters (1, 2, 14, and 24).

In summary, seven characters (6, mastoid width; 9, width betwnen infraorbital canals; 13, width across upper third molars; 17, width of the interparietal bone; 18, length of the interparietal bone; 23, length of mandibular tooth row; and 26, length of M^2 and M^3) apparently reach full growth by the subadult stage, whereas most other characters

show full size by the middle adult stage (A-II). Some characters (1, greatest length of the skull; 2, condylobasal length; 14, incisor-upper-first-molar length; and 24, height of mandible), however, apparently continue to grow well into old adult stage (A-III).

Secondary sexual dimorphism

Measurements of young adults (A-I) and middle-aged adults (A-II) were subjected to MANOVA analyses (see Table 2). Variable set A was selected to include 11 characters (6, 9, 11, 13, 17, 18, 23, 26, 27, 29, and 31) with little or no age variation; set B included 13 cranial characters (1, 2, 3, 4, 5, 8, 10, 14, 16, 19, 20, 24, and 25) showing marked age variation; and set C included the remaining seven characters (7, 12, 15, 21, 22, 28, and 30) as shown in Table 1.

Males and females were not significantly different.

DISCUSSION

Secondary sexual dimorphism is believed to be caused by sexual selection, either through female choice or male competition (Maynard Smith, 1976). The degree of secondary sexual dimorphism in rodents is small to moderate, and males are larger in most species showing secondary sexual dimorphism (Ralls, 1977). Significant dimorphism was reported in *Dipodomys* sp. (Best, 1978) and *Glaucomys* sp. (Madden, 1974). On the other hand, adult males do not differ significantly from adult females in *Peromyscus leucopus* (Cockrum, 1954), *P. boylii* (Schmidly, 1973), and *Apodemus agrarius* (Table 1).

The basic difficulty in using wild-caught specimens with a random assortment of ages for phenetic analyses is that character means are strongly influenced by age, and consequently specimens must be sorted. Cockrum (1954) stated that "The age groups are real and represent groups of individuals of comparable age. Furthermore, by utilizing such age groups, I suggest that series of wild-taken animals can be used for statistical comparisons. Without such groupings, however, age variations between samples may be great enough to obscure differences resulting from other causes."

As shown in Table 1, the ranked means of four age classes in most characters were in the same order as relative age (subadult, A-I, A-II, and A-III), although differences of means between succesive age classes became less with age. The four characters (1, greatest length of the skull; 2, condylobasal length; 14, incisor-upper-first-molar length; and 24, height of mandible), however, appeared to continue to grow well into old adult stage (A-III). Marked age variation was also found in *Peromyscus leucopus* (Cockrum, 1954), *P. boylii* (Schmidly, 1973), and *Onychomys torridus* (Hinesley, 1979).

In *Apodemus agrarius coreae*, Thomas (1906) and Kuroda (1934) noted that there was no difference in external morpholgy between the specimens from Cheju Do and those from the Korean peninsular. Johnson and Jones (1955) recognized two more subspecies within *A. agrarius coreae* (*A. a. pallescens* from coastal areas of southwestern Korea and *A. a. chejuensis* from Cheju Do) based on the measurements of external and cranial characters

without the consideration of age variation and sexual dimorphism. Jones and Johnson (1965) noted that they would expect future specimens of *A. agrarius* from Korea to illustrate a rather gradual change in size from north to south.

In this study evident age variation in morphometric characters of *A. agrarius coreae* was revealed (see Table 1), and the univariate and multivariate phenetic analyses using specimens of the same age class are necessary in further studies to determine geographic variation of morphometric characters in *A. agrarius* from Korea.

SUMMARY

Age variation and secondary sexual dimorphism in four external and 27 cranial characters of 102 specimens of striped field mice, *Apodemus agrarius coreae* Thomas, from Cheongju, Korea, were analyzed statistically.

Specimens were classified as subadults, young adults, middle-aged adults, and old adults, and variation of morphometric characters among the four age classes was evident.

Significant secondary sexual dimorphism among sexes of the same age class was not revealed.

The specimens of the same age class have to be used in further analyses to clarify geographic variation of morphometric characters in *Apodemus agrarius* from Korea.

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