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Allometric Growth Pattern of Skull on Brown Bear (*Ursus arctos* Linnaeus, 1758) of the Alborz Mountain

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Abstract

This study was conducted to investigate the allometric growth pattern in the skull of both sexes of Iranian brown bear (*Ursus arctos*) in the Alborz Mountains. Allometric parameters were obtained from 2D pictures of skulls using the software ImageJ and allometric growth pattern was calculated as a power function of total length using non-transformed data. Allometric growth pattern also showed that difference between males and females during their ontogenic growth of skull. Results showed that during development of skull parts from Immature to adult in male and female, similar grow pattern will continue to a certain age, after thet sexual dimorphism appear. Growth pattern is a factor for the sexual dimorphism differences. Different charts shows more consolidate in different parts of the male skull. According to the results Males in different parts of the skull is stronger whereas have shown more length, narrower and weaker in females.

Keywords; brown bear, skull, allometric growth pattern, Alborz Mountain.

INTRODUCTION

Brown bear (*Ursus arctos*) has a widespread dispersal in North, West and North-west of Iran along Alborz (from Astara to east of the Golestan Province) and Zagros (from south of Azarbayjan to Shiraz in Fars province) Mountain range, and Caucasia region (including the Azarbayjan and Ardebil Provinces) [10; 21; 24; 40]. Sexual dimorphism is a usual phenomenon in the polygamous carnivores such as Iranian browm bear [12; 13; 26], that have male-male competition for mate [6]. Hence, the comparison of shape change and growth pattern of two genders during its ontogeny can help to better understanding of its evolutionary background and ecological aspects in their distribution area.

The allometric growth pattern is a commone phenomena in animals regarding the proportion of the various body parts during its ontogeny i.e. shows size and shape changes of structures such as skull during growth from immature to mature stage [11]. In this regard, study of the allometric growth pattern of skull can provides crucial information to understand underlying differences due to sxual dimorphism [15], because skull is influenced by genetic specialitisation and environmental pressures [4; 7; 34].

Inaddition, study of shape chang and growth pattern during ontogeny can provide an opportunity to better understanding of structures' formation priority and adaptations [14; 20]. Since there is no information about allometric growth pattern of brown bear (*U. arctos*) is available, therefore this study was conducted to investigate the allometric growth pattern of two gender of Iranian brown bear.

MATERIAL AND METHOD

This study was carried out during 2011 to 2013 by collecing and examination of 65 skulls including 29 male, 20 female and 16 immature obtained from field surveys, museums and private collections. The skulls were orinigiated from the Alborz Mountain

North area of country has the largest number of brown bear. There are lots of bushy forests in northern parts, Iranian-Tourani sights in southern part, height area to 5600 meter which has also the grasslands of Southern side of the Caspian Sea [10; 17; 24]. The most parts of the forest heights go under the snow from December to March.

The samples of these skulls categorized based on collection site, immature and gender. Recognition of mature and immature bears skull and their gender is done based on outer appearance structure like indexes of dental cover, skulls sutures, length of condyle and basal and also sagittal crest [39]. This method has a simple design, so we can separate genders after dividing matures from immatures. The reason for seperating matures from immatures is that, according to [9] and [39], recognition of genders in immature skulls based on appearance charactristics isn't possible.

Measuring the sagittal and length of condyle and basal bone done by using ImageJ ver 1.45s software [5; 31; 32]. Number of male skulls is more than females and immatures because are popular for trophy hunters and museums and more over male bears have more conflict with local peoples.

Allometric data: For allometric growth study we need to mesure the size of bear skull parameters. The 9 distances on the dorsal and ventral sides are provided by using ImageJ software (fig. 1). The sides were of the skulls were photographed using a digital camera (Fuji HS10, 14 megapixels) installed on a tripod. There is a millimeter piece of paper and ruler beside the sample in all of the pictures to get pictures scale at the time of analyzing. The adjectives of skulls measuring that have importance in allometric growth according [22] (fig. 1): Total length of skull (Tl); Bi-zygomatic length (Bzl); Distance between the ecto-orbitary apophyses (Dea); Distance between inferior post-orbitary apophyses (Dpa); Transverse diameter of nasal fossae (Tnf); Maximum length of nasal bones (Ln); Length of nasal fossa (Lnf); Bi-mastoideal width (Bmw); Distance between anterior edge of superior canine alveole and posterior edge of M2 aleveole (dental row length) (Drl).

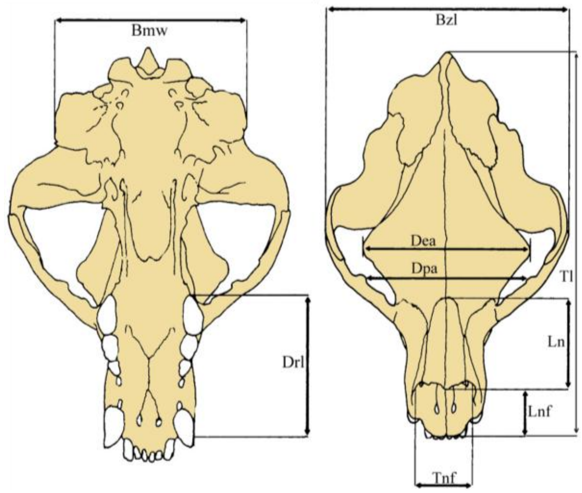

Figure 1. The adjectives of brown bear skull measuring in allometric growth pattern

Allometric growth pattern is measured by using unchangeable data like asquare function of total length of skull, in which "a" intercept and "b" is growth index. In this formula, where b=1 is Isometric growth, b>1 is positive allometric growth and b<1 is negative allometric growth. Line regression is done on logarithmic data by using the total length as an independent variant. The inflexion points of growth curves are determined according by [36] method. After choosing the growth inflexion points, the entire area growth rate was measured according by Huxley method [11]. All of the data were analyzied in 2013 excel program and minitab ver 16 software.

RESULTS AND DISCUSSIONS

According to result, the allometric growth patterns of brown bear skull were different between two sexes during its ontogeny including immature and mature stages. Bi-zygomatic length of female and male, showed different growth allometric. The female and male growth pattern have two phases with inflexion points in 254 and 364 mm, respectively. In first phase the growth pattern of female was negative (b=0.683) and in male was isometric (b=1.0893). In second phase the growth pattern of female was isometric (b_f=0.9131) and negative (b_m=-0.118) in male (Fig. 2 and 3, A graph). Comparing the bizygomatic and total length of skull regression relationship in both genders was meaningful (*P*<0.0001). It shows that at the time of maturity this part had less development growth in male. This process occurs in earlier ages in female. The growth coefficient of zygomatic arch was higher in males until old age, which could be as result of greater size and shape of temporal region i.e. the size of temporal region increase for supporting a strong zygomatic arch [16].

Distance between the ecto-orbitary apophyses in female and male gender have two phases with inflexion points in total length of skull in 263 and 338 millimeters, respectively. In first phase the growth pattern in female and male was positive allometric with (b=1.0327) and (b=1.2683). In second phase, the growth pattern in female is isometric but it was more and is positive allometric in male so the indexes are b_f=0.9453 and b_m=1.7052 (fig 2 and 3, B graph). In both genders the regression relationship is meaningful (*P*<0/0001). It shows that at the time of maturity this part had less growth in female than male and this process occurs in earlier ages in female.

Distance between inferior post-orbitary apophyses in female and male have two phases with inflexion points in total length of skull in 279 and 331 millimeters, respectively. In first phase the growth pattern in female was nearly isometric (b=0.922) and in male was positive allometric (b=1.1116). In second phase, the growth pattern in female is negative allometric and in male is positive allometric with their indexes b_f=0.8497 and b_m=1.1784 (fig. 2 and 3, C graph). In both genders the regressing relationship is meaningful (*P*<0.0001). Comparing the growth pattern of distance between inferior post-orbitary apophyses with total length of skull, shows that there is more growth in males in mature than female. This process occurs in earlier ages in female. Positive allometric growth pattern of ecto-orbitary apophyses and inferior post-orbitary apophyses in male can be lead a remarkable strength of frontal. Similar pattern was observed in other bear species [15; 19; 37]. Strong and large frontal region makes this strong and protective structure and provides more space for a larger sinus. Presence of a large sinus in male bear is unclear (refer to 38). In male, the frontal has a positive allometric growth pattern with increasing age and this phenomena can help protecting its brain during male-male competition [28]. Similar pattern was reported in American black bear (*Ursus americanus*) and Asian black bear (*Ursus thibetanus*) [23; 30; 33]. Male-male competion is severly occured during mating season to access females [8; 29; 35].

The transverse diameter of nasal fossae in female and male have two phases with inflexion points in total length of skull in 304 and 362 millimeters, respectively. In first phase of growth in both genders is positive allometric in b=1.5859 and b=1.1514, respectively. In second phase, the growth speed in both genders decreased, and became isometric in female and negative allometric in male with indexes b_f=0.9178 and b_m=0.1858 (fig. 2 and 3, D graph). In both genders the regressing relationship is meaningful (*P*<0.0001). Comparing the growth pattern of transverse diameter of nasal fossae with total length of skull shows that decreases the growth in both genders but more in males. The results revealed similar growth pattern of the transverse diameter of nasal fossae in females and immatures that was higher compared to that of males.

Distance between maximum length of nasal bones in female and male have two phases with inflexion point in total length of skull in 263 millimeter for both genders. In first phase the growth pattern of both genders was negative allometric with same index b=0.0602. In second phase, the growth pattern in female is positive allometric and in male is negative allometric but with more growth with their

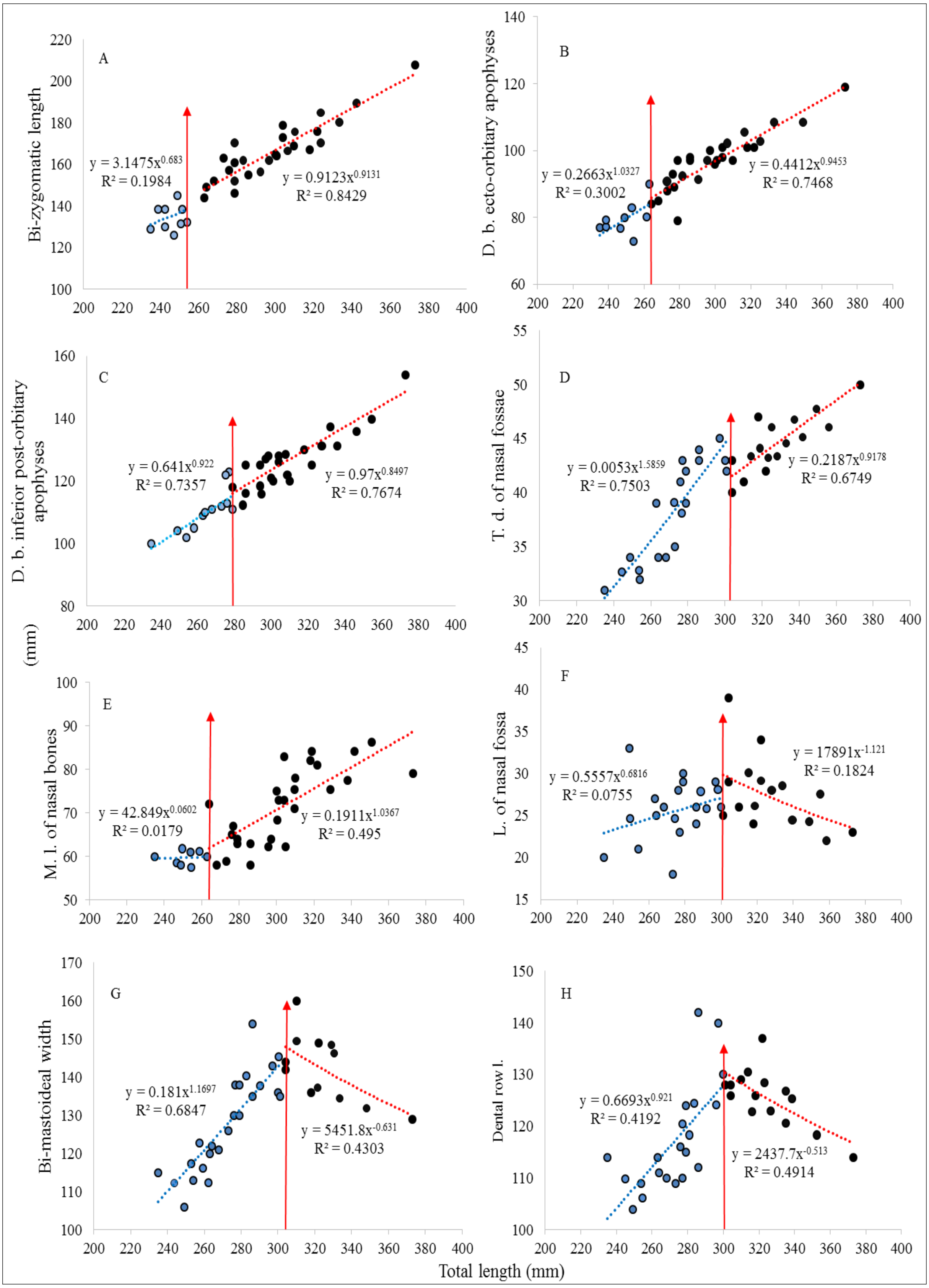

Figure 2. Allometric growth pattern in female skull. Vertical lines shows inflexion points of each characteristics in growth process. All of the samples were analyzed without two groups of mature and immature separated, until the gender growth pattern represented during the test.

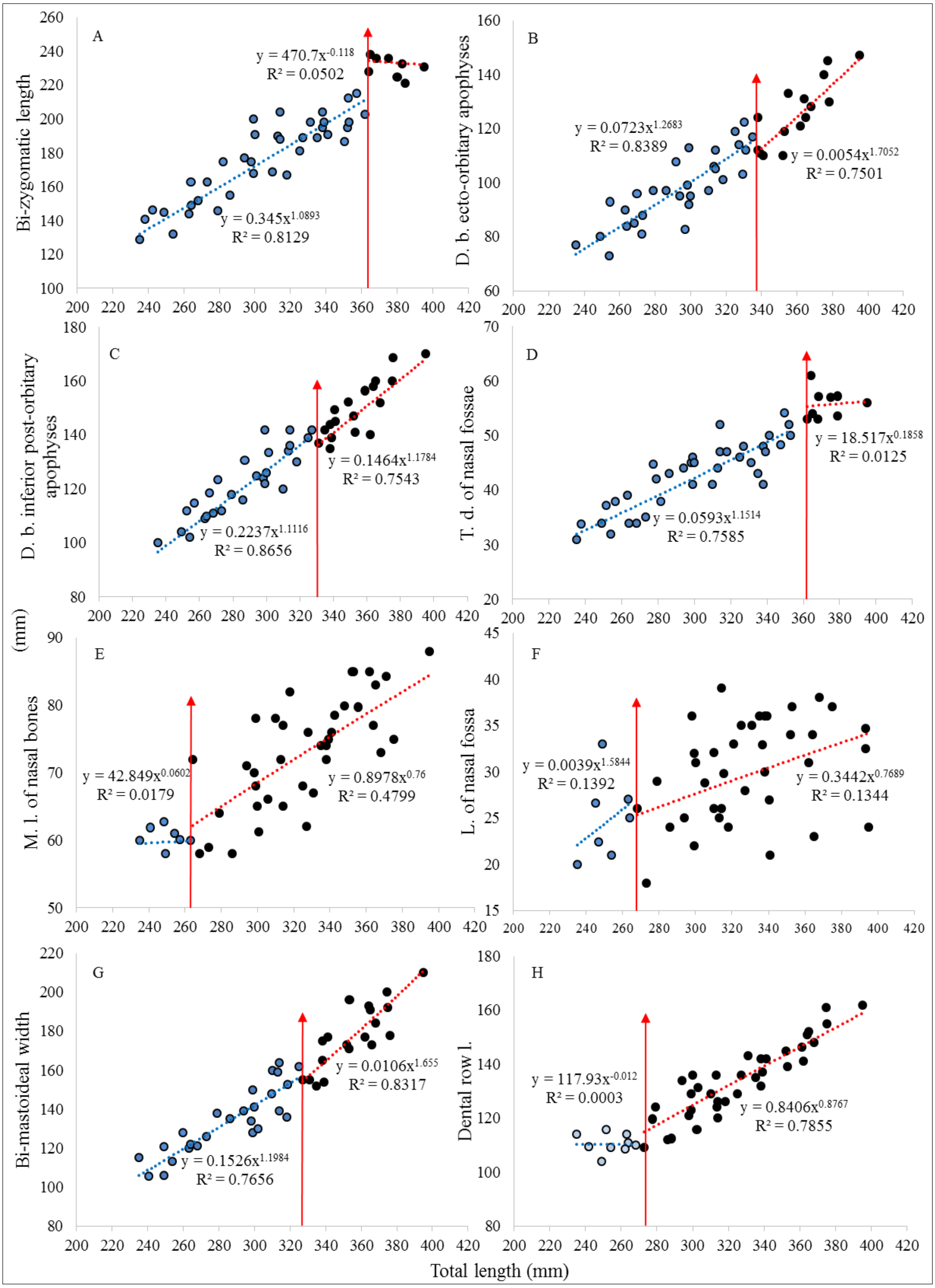

Figure 3. Allometric growth pattern in male skull. Vertical lines shows inflexion points of each characteristics in growth process. All of the samples were analyzed without two groups of mature and immature separated, until the gender growth pattern represented during the test.

indexes b_f=1.0367 and b_m=0.76 (fig. 2 and 3, E graph). In both genders the regressing relationship is meaningful (P<0.0001). Comparing the growth pattern of maximum length of nasal bones with total length of skull, shows that there is growth but less in males so more in female, in second phase. This process occurs in earlier ages in both genders. Increasing the length of nasal bone provides more space for olfactory organ resulting an efficient smelling sence, which can help for finding food, protecting cubs and avoid enemies in brown bear. Power smelling sence is vital for species whereas have week eyesight. According to [25] in breeding season, females prevent male infanticide by choosing the safest habitat which is called female core area. In female core area, female depends on smelling sense, because they have a weak eyesight.

Distance in length of nasal fossa in female and male have two phases with inflexion points in total length of skull in 268 and 301 millimeters, respectively. In first phase the growth pattern in female was negative allometric (b=0.6816) and in male was positive allometric (b=1.5844). In second phase, the growth pattern in both gender is is negative allometric with their indexes b_f=-1.121 and b_m=0.7689 (fig. 2 and 3, F graph). The regression relationship in male is meaningful (P<0.0001) but in female is not meaningful (P>0.001). Comparing the length growth pattern of distance between nasal fossa with total length of skull, shows that the male have less growth and female have more growth. The growth and development pattern of this organ of body in different people are so asymmetric and they have polymorphism.

Distance between bi-mastoideal width in female and male have two phases with inflexion points in total length of skull in 304 and 327 millimeter, respectively. In the first phase the growth pattern was positive allometric with indexes b=1.1697 and b=1.1984 in female and male, respectively. In second phase, the growth pattern in females is negative allometric and in males is positive allometric with their indexes b_f=-0.631 and b_m=1.655 (fig. 2 and 3, G graphs). In both genders the regressing relationship is meaningful (P<0.001). Comparing the growth pattern of distance between with bi-mastoideal width, shows that there is more growth in males than females. Increasing the bi-mastoideal width has more importance for male gender. This growth pattern of mastoideal can be due to increase in size of parietal, sagittal and temporal.

Distance between anterior edge of superior canine alveole and posterior edge of M2 aleveloe in female and male have two phases with inflexion points in total length of skull 301 and 274 millimeters, respectively. In first phase, the growth pattern in female was about isometric (b=0.921) and in male was negative allometric (b=0.012). In second phase, the growth pattern in both genders is negative allometric with their indexes b_m=0.8676 and b_f=-0.513 (fig. 2 and 3, H graphs). In both genders the regression relationship is meaningful (P<0.001). Comparing the growth pattern of dental row length (distance between anterior edge of superior canine alveole and posterior edge of M2 aleveole) with total length of skull, shows that there is in male happens in earlier ages than female and have development. The allometric growth pattern of dental row length in both gender were found negative and this may be related to the mechanical advantages of jaws. Bsed on the mechanical advantages, the gnawing muscles can provide more powerful bitting for molars and premolar positioned posteriorly. Hence, the posterior M2 aleveole that is positioned close to jaw joint, is larger than incisor. [18] reprted similar attern in Sea Otter (*Enhydra lutris*).

Table 2. Growth indexes based on grade percentage (*b*) Intercept (*a*) variables amount (r^2)

graph	immature			Female				Male			
	a	±*b*	r^2	*a*	±*b*	r^2	*p*	*a*	±*b*	r^2	*p*
Bi-zygomatic length	1.2676	0.8512	0.7652	2.4538	0.7454	0.7284	***	0.8267	0.9439	0.653	***
Distance between the ecto-orbitary apophyses	0.2683	1.0329	0.7631	0.353	0.9841	0.7314	***	0.0852	1.2391	0.7812	***
Distance between inferior post-orbitary apophyses	1.111	0.8227	0.9256	0.8772	0.8683	0.778	***	0.8481	0.8803	0.7633	***
Transverse diameter of nasal fossae	0.0226	1.3208	0.7579	1.9741	0.5392	0.4951	***	0.1428	0.835	0.586	***
Maximum length of nasal bones	0.234	1.0014	0.504	0.5638	0.8477	0.4897	***	1.166	0.7144	0.3962	***
Length of nasal fossa	8.1711	0.1959	0.0105	64.531	0.146	0.0062	NS	6.4338	0.2693	0.0135	**
Bi-mastoideal width	0.2767	1.0919	0.735	201.93	-0.066	0.0094	**	0.0447	1.4112	0.8422	***
Dental row length	4.8887	0.5627	0.5451	107.07	0.0279	0.0007	**	1.3371	0.7976	0.724	***

NS: Meaning less (P<0.05) P<0.01 *** P<0.001 ***

According to the result, inflextion point in two genders is different. The growth pattern showed befor and after of inflexion points, as it is shown growth pattern in immature and mature (table 2). According to (table 2) nasal fossae and nasal bone growth happens in immature age. Skull have growth in ecto-orbitary apophyses and bi-mastoideal width in immature and male bears. It seems that all changes of mentioned, are compatible from immature to mature in species. The skull growth pattern showed a sexual dimorphism after their inflexion points i.e. there were no differences perior to this points. The skull shape pattern in female was found almost similar to that of immature, whereas the male's skull growth pattern showed some differences in the zygomatic arch, frontal bone, nasal bone, and dental row length. [28] pointed out that occurrence of sexual dimorphism at a certain age, possibly coincide with their mature age that is about 4 years for females and later in males. In second phase of growth patterns i.e. in mature age, the skull's shape continues to changes in brown bear particularly in males. In most of mammals, growth of skull is stopped coincide with completing maturity and stopping the growth of other parts of body [1; 2; 3; 27] that our results did not show similar phenomena in brown bear.

In conclusion, differences in growth pattern between males and female were observed during second phase showing that the skull of male become bigger and stronger than that of female for intraspecific comptition. In addition, positive growth patterns of the zygomatic arch, occipital bone and sagital crest in both gender can provide more space for inserting muscles. Female's skull often tend to be homogeneous, thin and longer similar to immature one. Based on the results, the parietal region of skull changes from circle-shaped in immature to cube-shaped in matures.

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