

BISONIANA LVIII

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### Growth Rate of Bones in the Postembryonic Development of the European Bison

[With 6 Tables]

The measurements of dimension of the arm and thigh bones were carried out in 100 European bisons, *Bison bonasus* (Linnaeus, 1758) (57 males and 43 females) in 5 age groups in order to determine the rate of bone tissue formation according to the formula of Szmalhauzen-Brodi. Four periods differing in bone growth rate were distinguished. It was found that the activity of processes of periosteum-initiated growth in most cases the bone-destruction activity. The rate of periosteum-initiated growth of the bone tissue occurs according to the rule of non-uniformly delayed movement. At the same time it was found that distal parts of the bone show a smaller growth rate. The mean rate of these processes in the arm bone is for majority of dimensions faster than in the thigh bone. Moreover, the rate of periosteal apposition of the bone tissue of shafts in the studied bones is in four distinguished periods alternatively faster either in the width or in the thickness.

#### I. INTRODUCTION

When interpreting the increase of bone dimensions most authors employ the growth coefficients of Davletova (1960), the indicates proposed by Duerst (1926), and relative increases of dimensions between particular age groups. These calculations give only limited information on the growth of bone without taking into account the rate of this process.

We have made an attempt to investigate, on selected examples, the periosteum-initiated growth of bone in the postembryonic development of the European bison.

#### II. MATERIAL AND METHOD

The material consisted of bones of stylopodial segments of extremities of 100 bisons, *Bison bonasus* Linnaeus, 1758 (57 males and 43 females) starting from fetuses just before birth and from newborns up to individuals 23 years

old. The age of the animals was established on the basis of the Pedigree Books of European bisons (Żabiński, 1947—63; Żabiński & Raczyński, 1965—69). The division of the material into five age groups (Table 1) was based on the studies of Kobryńczuk (1972). It was assumed that the mean age of representatives of group 0 and subsequent groups corresponds to the age of one individual during its postembryonic development, and that the time intervals between mean values of age in neighbouring groups correspond to four periods, their length being equal to time ( $t$ ) after which the measurements of the bones were made.

The arm and thigh bones were used for making a few basic linear measurements (Tables 2 and 3) by employing the method of Duerst (1926). Besides the mean dimensions for particular groups ( $\bar{x}$ ) also standard deviation ( $s$ ) and coefficient of variation ( $v$ ) are given.

Table 1  
Material used in the investigations.

Age group	Males			Females			Total
	n	Avg. age, year	Period	n	Avg. age, year	Period	
0	5	0.00		2	0.00		7
I	11	2.47	1	7	2.55	1	18
II	15	5.98	2	5	6.38	2	20
III	13	9.36	3	7	9.82	3	20
IV	13	15.71	4	22	17.73	4	35
Total	57			43			100

For the proper determination of the relative rate of formation of the bone tissue the formula of Szmulhauzen-Brodi (Nikitiuk, 1972) was employed:

$$C = \frac{\log V_2 - \log V_1}{t \cdot 0.4343}$$

where  $C$  corresponds to the relative rate of bone formation,  $V_1$  — bone dimension of the former group,  $V_2$  — bone dimension of the latter group,  $t$  — time interval (in years) after which the measurements were made, 0.4343 — constant coefficient.

The mean rate of bone formation processes during postembryonic development was also calculated according to the above formula taking into account the dimensions in the group 0 ( $V_1$ ) and group IV ( $V_2$ ).

### III. RESULTS

The rate of formation of the bone tissue in the arm and thigh bones in the distinguished four periods of the postembryonic development is different for particular dimensions.



1. Arm Bone, *Humerus*

The first period (Table 1) is characterized by the highest growth of the bone tissue in all investigated dimensions (Table 4). The relative rate of this process reaches here its maximum. This rate is particularly high in the increase of the width of the proximal extremity and thickness of the shaft. The smallest increase of the bone tissue in the unit of time was observed in two basic dimensions of the distal extremity. The intensity of bone formation processes in relation to the remaining examined dimensions shows intermediate values. Most of these dimensions (except the width of the proximal and distal extremity) increases in a higher rate in bison females.

The second period is characterized by a conspicuous decline of the relative rate of bone formation (Table 4). The highest growth rate in both

Table 4

Relative rate of formation of the bone tissue of the arm bone.

Period	Years	Max. length	Prox. extremity		Shaft		Distal extremity	
			Thickn.	Width	Thickn.	Width	Thickn.	Width
Males								
1	0.00— 2.47	0.262	0.270	0.399	0.286	0.236	0.224	0.237
2	2.48— 5.98	0.044	0.029	0.061	0.069	0.070	0.010	0.025
3	5.99— 9.36	0.011	0.003	0.007	0.015	0.014	0.008	0.005
4	9.37—15.71	-0.003	0.004	0.005	0.001	0.004	0.001	-0.001
Females								
1	0.00— 2.55	0.275	0.280	0.345	0.297	0.253	0.253	0.227
2	2.56— 6.38	0.018	0.011	0.034	0.029	0.030	0.007	0.024
3	6.39— 9.82	0.007	0.001	0.002	0.028	0.016	0.008	-0.013
4	9.83—17.73	-0.001	0.004	0.005	0.002	0.004	0.000	-0.001

sexes was observed for the width of the shaft, its thickness, and also for the width of the proximal extremity. The lowest growth rate was observed, similarly to the previous period, for the increase in both dimensions of the distal extremity, and moreover in females in the length and thickness of the proximal extremity. In this period all dimensions of the bone increase at a faster rate in males.

In the third period still a small growth is observed, except one case (the width of the distal extremity in females; Table 4). The rate of this growth is here also the highest in the case of both dimensions of the shaft and the lowest for the distal extremity. Except two dimensions of the shaft the growth rate of the bone tissue is higher in males.

The fourth period is characterized in most cases by positive, although small growth of the bone tissue (Table 4).

The highest rate of increase of the arm bone dimensions was observed in both sexes for the width of the proximal extremity and shaft thickness. The lowest rate was observed in both dimensions for the distal extremity (Table 6).

## 2. Tigh Bone, *Femur*

The first period. Similarly to the arm bone the highest rate of the periosteal bone formation was observed in the thickness of the proximal extremity, and the lowest for the distal extremity (Table 5). The growth rate in all dimensions of the tigh bone was higher in males. In this period the increase in all parameters of the tigh bone in females and half of these dimensions in males is smaller in this period in comparison with the arm bone.

Table 5  
Relative rate of formation of the bone tissue in the tigh bone.

Period	Years	Maxi- mum length	Thickness proximal extremity	Shaft		Distal extremity	
				Thickn.	Width	Thickn.	Width
Males							
1	0.00— 2.47	0.285	0.322	0.284	0.245	0.264	0.191
2	2.48— 5.98	0.041	0.040	0.046	0.059	0.022	0.031
3	5.99— 9.36	0.009	0.004	0.028	0.017	0.002	0.006
4	9.37—15.71	-0.001	0.003	0.001	-0.002	0.000	0.005
Females							
1	0.00— 2.55	0.270	0.295	0.284	0.244	0.197	0.188
2	2.56— 6.38	0.025	0.027	0.030	0.038	0.022	0.017
3	6.39— 9.82	0.007	0.004	0.022	0.016	0.011	0.004
4	9.83—17.73	0.000	0.001	0.001	0.001	0.002	0.004

The second period. The highest growth rate was observed in two dimensions of the shaft, and the lowest in the dimensions of the distal extremity (Table 5). Similarly to the previous period the growth rate is higher in males. In most cases the dimensions of the tigh bone in males, and also in some females, increase at a slower rate than corresponding dimensions of the arm bone.

The third period. In both sexes the highest rate of bone formation was found for the shaft (Table 5), and the lowest either for the thickness of the distal extremity (males) or its width (females). The growth of the studied dimensions (except thickness of the distal extremity) is faster in males. The rate of increase of these dimensions of the tigh bone is in some cases higher and in some cases lower in comparison with the corresponding dimensions of the arm bone.



The fourth period is characterized by very low or even negative values of the bone tissue formation (Table 5).

The highest mean growth rate of the tigh bone in the postembryonic development of the European bison was found in both sexes for the thickness of the proximal extremity, and in the second place for the shaft thickness (Table 6). The lowest rate of increase was observed in respect of both dimensions of the distal extremity.

#### IV. DISCUSSION

The growth of long bones in their principal dimensions is the result of two opposite trends of osteogenesis — bone formation and bone destruction. This is accompanied by continuous reconstruction of the microscopic structure of the bone (Lasota & Kossakowski, 1972), and by quantitative change depending on either increase or decrease of the total mass of the bone. All these changes are reflected in the shape

Table 6

Mean relative rate of bone tissue formation in the arm and tigh bones.

Sex	Max. length	Proximal extremity		Shaft		Distal extremity	
		Thickn.	Width	Thickn.	Width	Thickn.	Width
Arm bone							
Males	0.053	0.051	0.080	0.064	0.058	0.039	0.044
Females	0.045	0.046	0.059	0.054	0.047	0.040	0.036
Tigh bone							
Males	0.055	0.062		0.061	0.054	0.044	0.041
Females	0.046	0.053		0.054	0.047	0.036	0.039

or proportion of the bone. In most cases the activity of the periosteum-initiated bone growth in the postembryonic development of the bison exceeds bone destruction, this manifesting as a constant increase in the bone volume (Kobryńczuk & Kobryń, 1973) and its linear dimensions (Bojanus, 1827; Koch, 1932; Janicki, 1938; Juśko, 1953; Empel, 1962; Roskosz, 1962; 1972; 1973; Empel & Roskosz, 1963; Kobryńczuk, 1972; Radomski, 1972; Sokolov, 1972; Kobryń, 1973). A full insight into the bone formation processes requires also studies on changes in the size of medullary cavity. But such studies were not carried out.

A decrease in the mass of bone tissue, observed in some old bisons, constitutes an exceptional phenomenon.

When the way, time and speed of centrifugal migration of points lying

on the surface of the bone are observed during the post-embryonic development of the bison it appears that the migration may be described as a not uniformly or variably delayed movement, characterized by a constantly decreasing rate. Perhaps the absolute acceleration of this movement is related by some factor to the value of gravity ( $981 \text{ cm/sec}^2$ ). Such presumption is supported by the values obtained in our experiments on the relative rate of increase of principal dimensions of the arm and thigh bones. It is likely that investigations carried out on larger material will confirm the above supposition.

The rate of enlargement of particular parts of the long bone results from the increase in both thickness and width. The value of the resultant is proportionally smaller for distal parts of the bone. This is not in full agreement with the results of Nikitiuk (1968, 1972) according to which the rate of bone formation for arm and thigh bones, as well as bones of the foot in man, is the highest not in proximal but in distal parts of these bones. This author supposes that increased mechanical load of the skeleton in distal parts is responsible for stimulation of the bone growth. The method of Nikitiuk (*l.c.*) depending on the measurements of bones with a trammel on X-ray plates is not sufficiently precise according to our opinion. The sharpness of the bone contour without taking tomographic photographs may be accidental and hence there is a considerable chance of making relative error, especially during studies of small objects, such as for example phalanges.

Undoubtedly the osteogenesis is subordinated to the general body biomechanics, but it is unlikely that the relationship of size within the skeleton are solely dictated by the mechanical load, independently of the fact whether they concern the man with its vertical posture, or other mammals. This is supported by the fact that for example *os carpi accessorium*, *patella* or *corpus calcanei*, although are not mechanically loaded they show particularly impressive development in comparison with other bones (Empel & Roskosz, 1963; Kobryńczuk & Kobryń, 1973).

Apart from the pressure exerted on the bones of bison extremities by the body weight, the bones are deformed and stimulated to growth in different planes by forces acting mainly obliquely in relation to the long bone axis as the effect of appropriate muscles. The action of muscles is one of the reasons for which the extremities of long bones, as the main points of muscle attachment, are thicker than their shafts. For the spongy substance, prepared for the action of non-polarized forces, while shafts are prepared for the action of more organized forces and are built mainly of the compact substance.

The mean growth rate of the bone tissue in the extremities of the arm



bone is always higher in relation to its width than thickness (Table 6). This rule should be explained by lateral localization of muscle attachments (Świeżyński, 1962), or ligament attachments (Radomski, 1972), on the extremities of this bone. A faster growth rate of proximal than distal extremities can be explained by the fact that they correspond to places of insertion of appropriate muscles, while the distal extremities correspond to the origin of muscles. It is known that the main effect of muscle action is usually related to its insertion.

The rate of periosteal apposition of the bone tissue in the shafts of the arm and thigh bones during the postembryonic development of the European bison is in the four distinguished periods alternatively higher either in thickness or in width (Tables 4 and 5). The shaft of the thigh bone in the fourth period constitutes the only exception from this rule. This fact confirms the results of microscopic observations of the tibia (Lasota & Kossakowski, 1972). These authors found that most of the investigated bone features are subjected to considerable changes with age, and moreover, that the diameter of Haversian canals changes in a cyclical manner. According to these observations two cycle of changes are observed in European bisons until the age of 20 years. Each of the cycles consists of the phase of increase and then decrease of the canal diameter. The phase of diameter increase is associated with the period of intense reconstruction of the bone, and the phase of decrease — with the period of stabilization in the process of bone reconstruction. Hence it may be supposed that when in the dimension of thickness the growth phase is observed, in the dimension of width the phase of stabilization occurs. It can be concluded that the dimension increase of the shaft width is delayed by half of the cycle in relation to thickness.

The mean rate of the arm bone formation is in most cases faster than the thigh bone. This may be caused by the fact that the arm bone (apart from muscles serving solely for the extremity), contains also insertions, hence more active attachments, of strong muscles joining the trunk and extremities (*m. brachiocephalicus*, *m. latissimus dorsi*, *mm. pectorales*). The forces acting through these muscles affect the faster growth rate of the arm bone in comparison with the thigh bone.

In distinction to observations of Nikitiuk (1972) in man it was not found that the relative rate of bone tissue formation was increased in old individuals.

Finally it should be added that the mean rate of formation of the bone tissue in both investigated bones is higher in males than in females (Table 6). Only in the case of thickness of the distal extremity of the arm bone this rate is slightly lower in males.



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#### WZROST KOŚCI W ROZWOJU POZAPŁODOWYM ŻUBRA

##### Streszczenie

Przeprowadzono pomiary kości ramiennej i udowej u 100 żubrów (57 samców i 43 samice) w pięciu grupach wiekowych (Tabela 1) i określono szybkość tworzenia tkanki kostnej wg wzoru Szmahlauzena-Brodi. Wyróżniono cztery okresy szybkości wytwarzania tkanki kostnej. Stwierdzono, że aktywność procesów odokostnowego wzrostu kości u żubra w życiu pozapłodowym, w przeważającej ilości przypadków, przeważa nad działalnością kościogubną. Szybkość odokostnowego wzrostu tkanki kostnej odbywa się według prawideł ruchu niejednostajnie opóźnionego; obowiązuje przy tym zasada, że im dana część kości dłuższej leży bardziej obwodowo, tym szybkość ta jest mniejsza. Średnia szybkość tych procesów w kości ramiennej (Tabela 2, 4) jest dla przeważającej ilości wymiarów większa niż w kości udowej (Tabela 3, 5). Ponadto tempo, w jakim następuje odokostnowe nawarstwienie tkanki kostnej trzonów badanych kości jest w wyróżnionych czterech okresach naprzemiennie raz większe w przypadku szerokości a raz grubości (Tabela 6).