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Features of the Bone System Formation of Carcasses of Simmental and Crossbreed Steers

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Abstract

The article describes the results of the research on the formation of the bone system of the carcasses of purebred and crossbreed steers. Three groups of animals were selected for the experiment by the analog method. The first group consisted of purebred steers of Simmental breed, the second and third groups consisted of ½ blooded steers of Simmental and Charolais beef breeds, respectively. The dynamics of age changes in the skeleton were studied by determining the absolute relative weight and calculating the growth coefficient. The research showed that the absolute weight of the skeleton has increased with the development of the test steers. Thus, if the skeleton mass of newborn steers was 7.44, 7.34, and 8.30 kilos for each group, then at the age of 6 and 12 months, it had increased to 29.2, 29.8, and 30.6 in group 2, 45.8, 45.3, and 46.4 in group 3, and 53.7, 54.2, and 54.6 at the end of the experimental period at the age of 18 months.

Keywords: Live weight, Skeleton, Growth coefficient, Bone tissue, Simmental steers, Charolais crossbreed

Introduction

In biology, to analyze and describe the growth, development, and aging of organisms, the evolutionary criterion of thermodynamics of linear irreversible processes, based on the theory of I. Prigogine and J. M. Wiame (Bravetti & Padilla, 2019), the essence of which is that in the stationary state of an organism, the production of entropy (useless energy dissipating in space) is minimal and constant within an open thermodynamic system when external parameters are constant. If a living system deviates from its stationary state under the influence of various factors, it will tend to be constant until the entropy production is again minimal. It follows that under various age changes of an organism, a living system will tend towards its final standard state, which implies that it is continuously aging.

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The intensity of respiration and glycolytic processes in animals determine the level of heat production. Therefore, in living open systems, the entropy production rate with some assumption can be equated with the heat production rate (basic metabolism) (Viertel & Borisyuk, 2019).

The present work is devoted to the study of the growth and development of the skeleton and its parts of carcasses of Simmental and crossbreed steers.

Materials and Methods

The scientific and economic experiment was carried out at the State Scientific Institution Tula Research Institute of Farming of the Russian Academy of Agricultural Sciences. Three groups of 15 steers were selected and formed for the experiments. The groups were formed by the pairwise method, considering the origin, age, and birth weight. The first (control) group included bulls of Simmental breed, the second and third (experimental) groups had 1/2 bulls of Simmental (S + cb) and Charolais (S + Ch) blood by crossing cows of the Simmental breed with bulls of the said beef breeds.

Experiments were conducted with animals from birth to 18 months of age. Animals of all groups were under the same feeding and housing conditions. Calves from birth to weaning at 7 months of age were reared according to the beef cattle breeding technology. Calves were housed in stables until the second half of May. Thereafter, the cows and calves were kept on pasture until October. After weaning the young calves from their mothers, the technology provided for stall housing on a leash. The level of the feeding of experimental young animals was intensive and calculated according to the norms of the animal breeding station to get an average daily gain of 1000-1100 g and to reach a live weight of 550-600 kg at the age of 18 months. Feed intake was monitored quarterly by weighing the feed and its residues. The gain in live weight of steers was monitored by monthly weighing.

Control slaughters were carried out at the Tula meat processing plant. One steer from each group was slaughtered at birth, 3 steers at 6 and 12 months of age, and 5 and 4 steers at 15 and 18 months of age, respectively. After the controlled slaughter at the age of 15 months of the main experiment (Maslov, 2013), the fattening of the remaining 4 bulls in each group was continued. The aim was to study the age-related changes in the morphological composition of the carcasses and the growth and development of the axial and peripheral parts of the skeleton and their constituent bones (Mostafavi *et al.*, 2019; Yamany, 2019). To determine the patterns of age-related changes in the skeleton of the carcasses, the bones were weighed to the nearest 1 g after thoroughly cleaning them. The total mass of the spine and ribs was determined. Each limb bone and sternum were weighed separately. The dynamics of age-related bone changes were studied by determining the absolute and relative weight, calculating growth coefficients as the ratio of the weight of the skeleton and its parts in certain age periods to that of newborn steers.

Results and Discussion

Intensive breeding of steers during the suckling period according to beef cattle breeding technology and high level of feeding during the following age periods ensured high growth intensity of steers of all groups. The Charolais crossbreeds had increased growth energy and at 12, 15, and 18 months of age their live weight reached 431.9 ± 6.1; 523.4 ± 6.4 and 620.6 ± 12.4 kg, which was 7.8, 7.5, and 10.2% higher than their maternal counterparts, respectively. There was little difference in the value of this indicator between bulls of groups 1 and 2 at all ages.

At the controlled slaughter, it was established that the weight of paired carcasses of Charolais crossbreeds at the age of 12, 15, and 18 months was 240.0, 303.6, and 355.4 kg, which was 24.9 kg, 39.2, and 50.8 kg more than that of their mother breeds ($P < 0.01$ — $P < 0.001$). The crossbred steers of the 2nd group were intermediate in terms of paired carcass weight.

With the growth and development of the test steers, the absolute weight of the carcass skeleton increased. Thus, the mass of skeleton of newborn steers was 7.44, 7.34, and 8.30 kg, but at the age of 6 and 12 months, it increased to 29.2 ± 0.4; 29.8 ± 0.3; 30.6 ± 0.5 and 45.8 ± 0.7; 45.3 ± 0.6; 46.4 ± 0.8 kg, and to 53.7 ± 0.9; 54.2 ± 1.0; 54.6 ± 0.9 kg, respectively. Inter-group differences in absolute bone mass at all ages were insignificant.

The nature and intensity of growth of the fetal skeleton during the prenatal period of ontogenesis can be judged from the exterior and morphological composition of the carcasses of newborn steers. Thus, if the height at withers of newborn Charolais crossbreeds was 60.8% of the value of the mentioned dimension in 18-months bulls, then the width of a chest and the width in hips are 33.4 and 37.0% of those of the definitive animals, respectively.

In studying the age-related changes in the relative weight of the carcass bones, we found that the value of this indicator was greatest in newborn steers (31.9-32.3%). With the growth and development of the animals, the value of that indicator naturally decreased and at the age of 6 and 12 months averaged 21.9 to 23.4 and 18.8 to 21.5%, and at the end of the experimental period — 16.2 to 18.6%.

In determining the relative weight of the individual bones of the skeleton of newborn steers, it has been established that the greatest value of this indicator is characteristic of the distal parts of the limbs. The specific weight of forearm and tibia was 8.30 and 9.80%, respectively, of humerus and femur 8.9 and 13.65, of scapula and pelvis 4.08 and 6.23%.

It follows from the above-mentioned data that steers at birth have relatively narrow breasts and pelvis but well-developed limbs. From a biological point of view, this is appropriate as the developed limbs allow calves to follow their mother immediately after birth, to assume a stable position when suckling milk, and with a narrow chest and pelvis, calving occurs easily.

The relatively high specific weight of the bones of the limbs, especially their distal parts, in the carcasses of newborn steers indirectly indicates their more intensive growth during the prenatal period of ontogenesis and the degree of maturity and ability to perform their characteristic function immediately after birth.

This raises the question: what is the mechanism responsible for the uneven growth and development of different carcass skeletal bones during the uterine period of ontogenesis?

Bone tissue is a dynamic living tissue with high sensitivity to internal and external factors that regulate growth processes in it. As known from the literature, the intensity of skeletal growth in postnatal ontogenesis is influenced by a genetic program of general development (Prokhorov, 2013; Fink, 2015; Shadskaja *et al.*, 2015), energy and plastic substrate supply (Bolanowski *et al.*, 2006; Ueland *et al.*, 2006; Wassenaar *et al.*, 2011; Yuen *et al.*, 2017; Kwong *et al.*, 2020), level and ratio of hormones (Mrak *et al.*, 2007; Giustina *et al.*, 2008; Velloso, 2008; Melmed *et al.*, 2009; Kamilov *et al.*, 2014; Fink, 2015), mechanical stress on bone system (van der Meulen & Huiskes, 2002; Maslov, 2013; Kamilov *et al.*, 2014; Mattei *et al.*, 2017; Slozhenkina *et al.*, 2020), etc.

Before considering the influence of the aforesaid factors on the growth of the fetal skeleton, it should be reminded that in biological systems, there are time reporting mechanisms, or biological clocks, whose basic principle is that biochemical processes in the body occur non-simultaneously and at different rates. However, they are coordinated with each other in time and create a rhythm of change in the intensity of biochemical processes. Almost all rhythms of biological systems are coordinated with the circadian rhythm. There are also internal rhythms due to fluctuations of biochemical processes in each cell, in tissues, and in living open systems. This is shown by the fact that in prenatal ontogenesis, cells of different tissues are sensitive to inductive influences only at certain time intervals. Therefore, in the process of cell differentiation, the clock mechanism of the organism determines the sequence of gene repression and induction and the orderliness of the organism's development (Skovorodin *et al.*, 2018; Chernenko *et al.*, 2020).

In this regard, in living open systems with the interaction of many internal and external factors, there are constant fluctuations of biochemical processes. For example, in the individual development of the organism, along with the mechanism aimed at maintaining its homeostasis, at a certain time interval, a mechanism is triggered that provides a programmed disturbance of stability and equilibrium of the internal environment. Such programmed deviation of homeostasis is a prerequisite for the development of the organism. For example, cows undergo a significant shift in their hormonal status and metabolic profile during the period of pregnancy. In particular, with increasing periods of pregnancy, the content of estrogens and progesterone in the blood of cows significantly increases, the concentration of total lipids, cholesterol, and glucose increases (Edelhoff *et al.*, 2020; Kaurivi *et al.*, 2020; Pascottini *et al.*, 2020).

The genetic apparatus of the fetus strictly programs the shape and size of each bone and determines its degree of maturity by the end of the prenatal period. At the same time, the development and functioning of bone tissue are under dynamic neuroendocrine control throughout the ontogenetic period. The pituitary, thyroid, adrenal, and sex hormones are involved in the regulation of bone tissue metabolism, but the growth hormone plays the leading role in bone tissue formation. At a certain stage of fetal development following the biological clock, a significant shift in the hormonal profile occurs.

For example, in the medical literature (Fink, 2015), it is shown that in the human fetus the somatotropin concentration in the blood rises sharply from 12 to 16 weeks and stays at a high level until the 32nd week. The concentration of the hormone in the blood during this period of ontogenesis exceeds its level in the blood of an adult by almost 40 times. In this regard, it should be mentioned that the growth hormone has a special role in the systemic control of the growth processes of the bone tissue because, in a growing organism, the cartilage tissue is located in the epiphysis of the tubular bones is the most sensitive to the somatotropin impact. The growth hormone stimulates the intensity of bone growth through the development of hypertrophy and hyperplasia of cartilage tissue. Besides, growth hormone has a powerful fat mobilizing effect. The energy released by triglyceride oxidation is used by the body to support the growth processes of bone and muscle tissue. It follows that this hormone not only activates synthetic processes in muscular and bone tissues but also contributes to the energy supply of growth processes in them.

A high level of growth hormone during the embryonic period of ontogenesis coincides with the most intense growth of the fetus. According to a number of the researchers (Gurina *et al.*, 2019), the fetal weight of 4-month-old cattle was 1.0 kg, and at 6, 8, and 9 months, it was 6.5; 15.0, and 40.0 kg, respectively. It follows that the fetal weight increases 40-fold from 4 months of age to birth. For comparison, here are the results of the study of age-related changes in live weight of Charolais crossbreed steers distinguished by the most intensive growth during the postnatal period. Their live weight at birth was 41.8 kg, and at 18 months, it was 620.6 kg. The increase in the live weight of steers at the age of 18 months compared to that of newborn calves was 14.8 times.

The increase of growth hormone in animals increases the concentration of lipids which, by the principle of negative feedback, affecting the somatotropic function of the pituitary gland, contributes to the decrease of somatotropin in the blood. However, during the pregnancy period of cows, the mechanism of maintaining the internal environment constancy does not work, because a significant amount of somatotropin is secreted in the placenta, which is not part of the self-regulating neuroendocrine system of the body, and, therefore, the homeostatic mechanism limiting the growth hormone secretion does not work on the placenta.

The growth hormone stimulates the synthesis of insulin-like growth factor-1 (IGF-1) in the liver, which, like insulin, promotes the penetration of amino acids and glucose through the cell membrane. Under the influence of somatotropin and IGF-1, cartilage cell division, synthesis of DNA, RNA, protein, and collagen are increased, and the linear growth of the epiphyseal plate is stimulated. Only free IGF-1 is active in the body, but its half-life is short. The growth hormone is essential for insulin-like factors as it promotes the formation of the IGFBP-3 protein, which binds IGF-1 and prolongs its half-life.

We remind that the intensity of growth processes in bone tissue depends not only on the somatotropin level but also on its reactivity to the growth hormone and insulin-like growth factor-1. Since chondrocytes and osteoblasts express receptors for the growth hormone under the influence of the neuroendocrine system, it can affect these cells directly and indirectly through IGF-1.

The general growth pattern of the skeleton and its compartments can be represented as follows: The somatotropin and IGF-1 are supplied in the blood to all parts of the skeleton, but not all bones are sensitive to their effect and, therefore, their cartilage tissues cannot increase the proliferative processes and synthesis of some structural proteins (in particular, collagen) and mucopolysaccharides. During the interaction of the growth hormone, IGF-1, and the corresponding receptors, the specific ligand complexes are formed that enhance the bone tissue sensitivity to somatotropin and IGF-1 and promote their effect in the cells.

As mentioned above, the relatively high specific weight of the limb bones, especially their distal parts, in the carcasses of newborn steers indirectly indicates their more intensive growth in the prenatal period of ontogenesis. On this basis, it can be assumed that the more intensive growth of bones in the distal parts of the limbs is due to DNA expression and a higher concentration of receptors in them than in the proximal parts of the skeleton. Besides, the fetal neuroendocrine system, following the genetic program of overall development, by selective dilation of the blood vessels, directs large amounts of somatotropin and IGF-1, as well as plastic and energy substrates that come with the maternal blood to those bones and their complexes that should have priority growth and development in this period of ontogenesis. It can be assumed that this vectorial transfer of hormones regulating growth processes in bone tissue and plastic and energy resources of the body contribute to the formation of bone systems to such an extent that by the time of birth they can perform their proper functions. Consequently, the neuroendocrine system at a certain stage of ontogenesis is a peculiar instrument of reprogramming the influx of plastic and energy substrates into certain bone systems and, as a consequence, a factor determining the intensity of their growth.

Considering the aforesaid, it can be assumed that the growth of the skeleton and its parts is provided not by the global growth of all bones, but by the selective expression of genes and increased reactivity to the growth hormone and IGF-1 specifically to the bones and their complexes where the growth and development at a certain stage of ontogenesis should be a priority.

It was stated above that the intensity of bone tissue growth is significantly affected by mechanical stress. It is known from the medical literature that weightlessness and hypodynamy in spaceflight conditions cause significant losses of bone tissue mass and volume and a decrease in the rate of skeletal mineralization. This is the consequence of accelerated bone degradation and simultaneous suppression of new bone tissue formation as a result of a cessation of gravitation.

In this regard, the deficit of physical impact on fetal bone tissue due to space limitation and hypodynamy can, with some assumptions, be compared with that of humans in weightlessness. At the same time, the intensity of fetal skeletal growth is significant, as evidenced by the highest relative bone mass of newborn steers. The arising contradiction seems to be related to the fact that the fetal bone system is in the process of formation and for its growth, with excessive content of growth hormone and IGF-1 in blood, the hydraulic pressure created by the selective expansion of the blood vessels of the bone tissue and those minor movements made by the fetus are sufficient. Besides, fetal bone growth is influenced by the gravitational field.

It was noted that the relatively high specific weight of the bones of limbs, especially their distal parts, in carcasses of newborn steers indirectly indicates a more intensive growth in the uterine period of ontogenesis and their degree of maturity and ability to perform their peculiar function immediately after birth. In this regard, it is of particular interest to study the intensity of growth of bones with different relative weights in newborn steers in postnatal ontogenesis.

According to the thermodynamic theory, the mass of an animal organism, as a biological constant of any living open system, always tends to the final stationary state during the growth and development, which implies a continuous decrease in the intensity of basic metabolism and, consequently, a decrease in the growth rate of active tissues and an increase in fat deposition. At the same time, the further the mass of the organism and its constituent tissues are from the final stationary state in time and degree of maturity, the more intensive is their growth. This suggests that the intensity of growth of individual bones and their complexes underdeveloped in newborn steers in subsequent age periods will be higher than that of bone tissue with a higher growth rate in the embryonic period of ontogenesis.

The analysis of the character and growth rates of the bones of various parts of the skeleton showed that the growth rate of individual bones and their complexes underdeveloped in newborn steers was higher in subsequent age periods than that of the bone tissue with a higher growth rate in the embryonic period of ontogenesis. To establish this position, the mass difference of individual bones and bone complexes of the carcasses of newborn steers was determined concerning those of the definitive animals. The degree of difference of bones and their complexes of the carcasses of newborn steers was determined by calculating their mass relative to that of 18-month old steers. For example, the mass of ribs, scapula, spine, humerus, and forearm of newborn calves was 9.88; 12.12; 13.30; 17.76; 20.85% of similar bones in carcasses of 18-month old steers. The smaller the relative mass of bones of newborn bulls is, the greater their distance from those of defining animals is.

Below in brackets are data (in percent) showing the mass of separate bones and their complexes in carcasses of newborn calves relative to those of 18-month old steers and the degree of difference of these bones from the definitive animals. Bones and their complexes of newborn steers' carcasses were distributed according to their development in the following decreasing order: tibia (23.45), forearm (20.85), femur (17.92), humerus (17.76), spine (13.30), breastbone (12.51), scapula (12.12), pelvis (11.28), and ribs (9.88).

The intensity of growth of individual bones and their complexes was judged by the deviation of their growth coefficients up or down compared to those of the carcass skeleton. The skeleton growth coefficients of Charolais crossbreeds at the ages of 6, 12, and 18 months were 3.69; 5.59, and 6.58, respectively. The bone growth coefficients of the different parts of the carcass skeleton are shown in **Figure 1**.

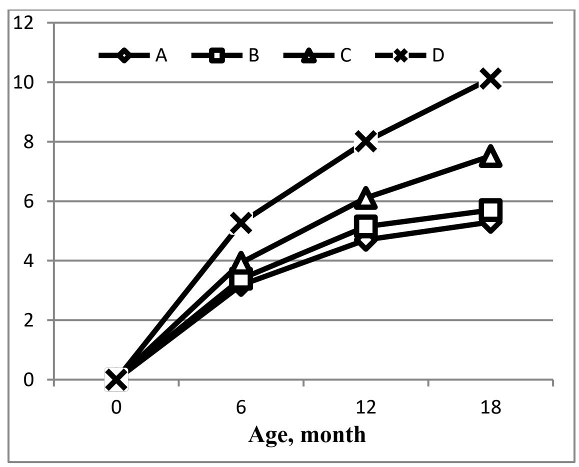

Figure 1. Bone Growth Coefficients of Pelvic Limb (A), Thoracic Limb (B), Spine (C), and Ribs (D) of Charolais Crossbreed Carcasses

The analysis of the growth rate of the carcass skeleton and the bones of its components showed that the highest intensity is typical for the ribs, and the lowest — for the bones of the limbs. Thus, while the growth rates of rib mass in steers at 6, 12, and 18 months of age were 5.27, 8.01, and 10.12, respectively, those of the spine were 3.93, 6.11, and 7.52; the bones of the thoracic limbs were 3.39, 5.15, and 5.70, and those of the pelvic limbs were 3.18, 4.70, and 5.30. Moreover, the intensity of bone growth was significantly influenced by the anatomical arrangement of the thoracic and pelvic limb bones **(Figure 2)**.

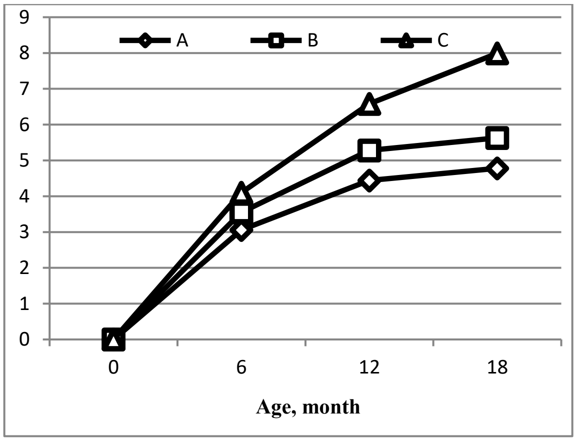

Figure 2. Growth Coefficients of Thoracic Limb Bones: Forearm (A), Humerus (B), and Scapula (C) of Charolais Crossbreed Carcasses

The data show that the growth rate of the bones located distally is significantly lower than the growth rate of the proximal bones.

In determining the growth rate of individual bones and their complexes by calculating growth coefficients, it was found that in terms of growth intensity in postnatal ontogeny, they were distributed in the following descending order: ribs, pelvis, scapula, sternum, spine, humerus, femur, forearm, and tibia.

Conclusion

1. The weight of tibia, forearm, femur, humerus, backbone, breastbone, scapula, pelvis, and ribs of carcasses of newborn Charolais crossbreed steers were 23.45; 20.85; 17.92; 17.76; 13.30; 12.51; 12.12; 11.28, and 9.88%, respectively.
2. The smaller the mass of the skeleton bones of the carcasses of newborn steers relative to those of the definitive animals is, the greater their remoteness from the final mass is. The greater the distance of the bones from the final mass is, the greater their intensity of growth is.
3. The bones and their complexes of the carcasses of newborn steers are in the following descending order from those of 18-month old steers: tibia, forearm, femur, humerus, backbone, sternum, scapula, pelvis, and ribs.
4. The bones of the limbs, especially the distal parts of the limbs, of the fetus outgrow the other parts of the skeleton in the intensity of growth and degree of maturity.
5. In determining the intensity of bone growth in the postnatal period, they were distributed in the following descending order: ribs, pelvis, scapula, sternum, spine, humerus, femur, forearm, and tibia.

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