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RESEARCH ARTICLE

Postnatal Muscle Growth and Allometry in Anatomical Regions of Russian Black-Pied Heifers and their Crosses With Hereford and Charolais Under Intensive Rearing

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Abstract: Crossbreeding dairy cattle with specialized beef breeds is an effective strategy to increase beef production, yet data on muscle growth patterns in crossbred heifers remain limited. This study aimed to evaluate the growth intensity and redistribution of muscle mass in anatomical regions of carcasses in Russian Black-Pied heifers and their crosses with Hereford and Charolais breeds. A scientific experiment was conducted on three groups of heifers (n = 15 per group) from birth to 18 months of age: Group 1 (control) – Russian Black-Pied; Group 2 – ½ Hereford × ½ Russian Black-Pied; Group 3 – ½ Charolais × ½ Russian Black-Pied. Live weight was recorded monthly. Control slaughters were performed at birth, 6, 12, and 18 months. Layer-by-layer dissection of half-carcasses was performed to determine the absolute and relative muscle mass of anatomical regions. Growth coefficients and relative growth rates were calculated. Charolais crossbred heifers surpassed their maternal breed contemporaries in live weight by 9.0–12.5% ($P<0.01–0.001$) and in absolute carcass muscle mass by 10.1–29.3%. The highest growth intensity was observed in the abdominal wall musculature, followed by the pelvic girdle and serratus ventralis muscle group (positive allometry). The lowest growth rates were recorded for the antebrachium, crus, brachium, thigh, and pectoral girdle (negative allometry). Redistribution of muscle mass was evidenced by an increase in axial musculature relative mass from 43.8% at birth to 48.9% at 18 months, with a corresponding decrease in peripheral musculature from 54.0 to 48.1%. The intensive growth of the abdominal wall musculature is attributed to constant gravitational pressure from internal organs, while the lower growth rates of locomotor muscles reflect their higher maturity at birth. These findings provide insights into muscle development patterns in crossbred heifers and support the use of Charolais genetics for beef production.

Keywords: Russian Black-Pied, Hereford, Charolais, Crossbreeding, Muscle Growth, Allometry, Carcass Composition, Heifers

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SCIENCE Publications

Introduction

Muscle tissue is the most important component of meat animal carcasses. Its specific weight in the carcasses of fattened bulls can reach 74.9–78.4% depending on genotype and rearing technology [1]. As the main source of protein, musculature determines both the nutritional value and the specific taste of beef.

In growing cattle, the intensity of muscle growth is highest during early postnatal ontogenesis and gradually declines as animals approach physiological maturity. This pattern reflects the principle that tissues and organs furthest from their definitive size exhibit the highest growth rates, a concept fundamental to understanding allometric growth in meat-producing animals. This principle of extended muscle protein anabolism has been successfully exploited in specialized beef breeds. In France and Italy, long-term targeted selection has produced breeds such as Charolais, Limousin, and Chianina, which are capable of building muscle mass for an extended period. At 18–20 months of age, animals of these breeds produce heavy carcasses with a high proportion of lean meat and limited fat deposition [2, 3].

Taking into account these biological characteristics, many countries worldwide, including Russia, have widely used Charolais, Limousin, and Hereford bulls in purebred breeding and crossbreeding programs to increase beef production and improve its quality [4-7]. When new genetic information is introduced into the gene pool of domestic dairy cattle, the constitutional type of crossbred animals changes. Crossbreds generally inherit the high potential for meat productivity of paternal breeds and are able to build muscle mass for an extended period [5]. A retrospective analysis of research results on crossing Russian Black-Pied and Simmental cows with Charolais and Limousin bulls showed that crossbred bulls significantly exceeded their maternal breed contemporaries in live weight, paired carcass weight, and carcass muscle mass yield [8, 9].

However, it should be noted that virtually all published studies have focused on the meat qualities of bulls, even though practically all crossbred heifers are also raised and fattened for meat production. There is a clear lack of data on the growth intensity, muscle mass distribution, and allometric growth patterns in the anatomical regions of carcasses of crossbred heifers. Furthermore, the optimal feeding standards for the rearing and fattening of such crossbred heifers remain unclear.

We hypothesized that crossbreeding Russian Black-Pied heifers with specialized beef breeds, particularly Charolais, would significantly increase total carcass muscle mass and alter the allometric growth patterns of individual muscle groups compared with purebred contemporaries. The objective of this study was to evaluate the nature and intensity of muscle growth in the anatomical regions of carcasses in Russian Black-Pied heifers and their crosses with Hereford and Charolais under intensive rearing.

Materials and Methods

A scientific and economic experiment to study the growth, development, and meat productivity of Russian Black-Pied heifers and their crosses with Hereford and Charolais breeds was conducted at the Tula Research Institute of Agriculture, a branch of the Research Center «Nemchinovka». For the experiments, 3 groups of heifers, 15 heads in each, were selected and formed. The groups were formed using the method of pair-analogs, taking into account origin, age, and birth weight. Group 1 (control) included Russian Black-Pied heifers, while Groups 2 and 3 consisted of crossbred heifers with ½ bloodlines obtained from crossing Russian Black-Pied cows with Hereford and Charolais bulls, respectively. The experiment was conducted from birth to 18 months of age.

The feeding program was designed to support an intensive level of growth, targeting average daily gains of 800–850 g and a live weight of 450–500 kg at 18 months of age. During the pre-weaning period (0–6 months), heifers received whole milk (300 kg per calf) and milk replacer, with ad libitum access to high-quality mixed-grass hay and a starter concentrate mixture (18–20% crude protein) from the second week of life. After weaning at 6 months, the diet consisted of corn silage fed ad libitum, supplemented with 2.5–3.0 kg of a mixed concentrate (14–16% crude protein) per animal per day, provided in two equal portions. Animals had free access to water and mineral blocks throughout the experiment.

The animals were kept in stalls; group housing was used until 6 months, and tethering was used in subsequent age periods. The gain in live weight of the heifers was monitored by monthly weighing. To obtain initial data, 1 heifer from each group was slaughtered at birth on the farm. Subsequent control slaughterings were carried out at the Tula meat processing plant. At the age of 6 and 12 months, 3 heifers from each group were slaughtered, and at the end of the experimental period, 5 heifers were slaughtered. The pre-slaughter weight, weight of the fresh carcass, internal fat, and slaughter yield were determined, as well as the morphological composition of the carcasses.

To determine the patterns of age-related changes in muscle mass, layer-by-layer dissection was performed, and the weight (accurate to 1 g) of each muscle of the left half carcass was measured. Based on the absolute data on muscle mass, their average was calculated for the anatomical sections of the carcasses for each group, as well as the relative muscle mass (mass expressed as a percentage of the total mass of the studied musculature).

Axial musculature included the serratus ventralis muscle group, spinal muscles, thoracic muscles, and abdominal wall. Peripheral musculature included the thoracic limb (pectoral girdle), brachium, antebrachium, pelvic girdle, thigh, and crus.

For statistical analysis of the obtained results, methods of variational statistics using the Microsoft Excel 2010 package were used. The significance of the differences between the groups was determined using the Student's t-test. To assess the growth intensity of muscle complexes, growth coefficients were calculated as the ratio of muscle mass at specific age periods to that of newborn calves. This method, commonly used in serial slaughter studies with discrete time points, allows for the determination of allometric growth patterns (positive, negative, or isometric) without fitting continuous regression models, which would be unreliable given the limited number of slaughter age points (n = 4) in the present experimental design.

Results

Live Weight and Carcass Characteristics

The high feeding level provided by the experimental design contributed to the realization of the genetic growth potential of the animals in the compared groups. Charolais crossbred heifers inherited the capacity for intensive growth from the sire breed. At 6, 12, and 18 months of age, they reached live weights of 204.5±3.8, 386.7±6.8, and 511.1±9.5 kg, respectively, exceeding their maternal breed contemporaries by 9.0% ($P<0.01$), 11.0% ($P<0.001$), and 12.5% ($P<0.001$). The live weight of Hereford crossbred heifers at the same ages was 198.2±2.7, 367.9±5.3, and 471.5±8.4 kg, respectively.

The paired carcass weight of Charolais crossbreds at 6, 12, and 18 months of age was 108.0±2.6, 210.9±2.9, and 282.7±4.2 kg, respectively. The differences in this trait between Charolais crossbred heifers and their Russian Black-Pied contemporaries were 8.7 kg or 8.8% ($P<0.05$), 32.3 kg or 18.1% ($P<0.01$), and 40.2 kg or 16.6% ($P<0.001$), respectively, in favor of the crossbreds. Between Hereford crossbreds and their control group contemporaries at the same ages, the differences were 4.5 kg or 4.5% ($P>0.05$), 13.9 kg or 7.8% ($P<0.05$), and 14.3 kg or 5.9% ($P<0.01$).

Absolute Muscle Mass and its Anatomical Distribution

The influence of genotype on skeletal musculature was expressed in its more intensive growth in crossbred animals. With a nearly identical muscle mass in the carcasses of newborn calves, its value in Charolais crossbred heifers at 6, 12, and 18 months of age was 74.2, 143.4, and 194.5 kg, respectively, exceeding that of their maternal breed contemporaries by 10.1, 32.3, and 29.3%.

The differences in absolute carcass muscle mass between Hereford crossbred heifers and their control group contemporaries at the specified ages were 4.4 kg (6.6%), 10.9 kg (10.1%), and 9.3 kg (6.2%), respectively.

The pattern of muscle mass distribution across the anatomical regions of the carcasses of 18-month-old heifers is presented in Table 1. Charolais crossbred heifers surpassed their control group contemporaries in the muscle mass of all anatomical regions. Specifically, the differences in the mass of the serratus ventralis muscle group, spinal muscles, thigh region, and abdominal wall between Charolais crossbreds and Russian Black-Pied contemporaries at the end of the experimental period were 3.9 kg (29.3%; $P<0.01$), 3.3 kg (29.1%; $P<0.01$), 5.2 kg (29.1%; $P<0.001$), and 1.9 kg (29.3%; $P<0.001$), respectively. Hereford crossbred heifers significantly exceeded their contemporaries of the maternal breed only in the muscle mass of the thigh region, by 1.1 kg, or 6.2% ($P<0.05$).

Growth Intensity and Allometry of Muscle Groups

The pattern of age-related changes in the absolute growth rate of the carcass muscular component in heifers of the compared groups was similar (Fig. 1). Statistically significant differences ($P<0.01$) in absolute growth rate were observed between Charolais crossbreds and the Russian Black-Pied control group at the 6–12 month and 12–18-month intervals. The highest absolute growth rate of carcass musculature in Charolais crossbred heifers was observed in the age period from 6 to

12 months, while in their contemporaries of Groups 1 and 2, it was observed from birth to 6 months. At one year of age, Charolais crossbreds exceeded their contemporaries of Groups 1 and 2 in this trait by 68.8 and 45.9%, respectively, and at the end of the experimental period, by 21.3 and 26.2%.

Table 1: Absolute muscle mass (kg) of anatomical sections of half-carcasses in Russian Black-Pied and crossbred heifers at 18 months of age (n = 5 in each group)

Muscle Section	Group		
	1	2	3
Serratus ventralis muscle group	13.3±0.35	14.1±0.41	17.1±0.44**
Spinal muscles	11.3±0.33	12.1±0.38	14.7±0.42**
Thoracic muscles	5.5±0.11	5.8±0.11	7.1±0.12***
Abdominal muscles	6.6±0.14	7.1±0.15	8.6±0.17***
Thoracic limb (pectoral girdle)	4.1±0.17	4.3±0.20	5.3±0.24**
Brachium	3.3±0.09	3.5±0.11	4.3±0.12**
Antebrachium	1.9±0.06	2.0±0.06	2.4±0.07**
Pelvic limb (pelvic girdle)	5.3±0.20	5.6±0.19	6.8±0.20**
Thigh	17.9±0.24	19.0±0.23*	23.2±0.27***
Crus	3.7±0.08	3.9±0.07	4.8±0.09***
Subcutaneous muscles	2.3±0.05	2.4±0.04	2.9±0.05
Total	75.2±1.54	79.9±1.60	97.2±1.78***

Note: *P<0.05; **P<0.01; ***P<0.001

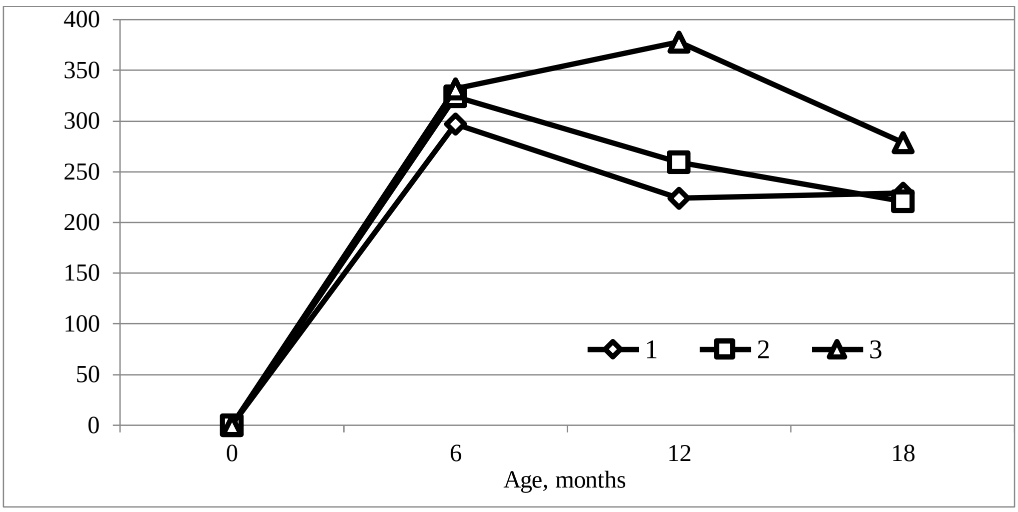

Fig. 1: Dynamics of the absolute growth rate of carcass musculature in Russian Black Pied and crossbred heifers, g. Statistically significant differences between Charolais crossbreds (Group 3) and the control group (Group 1) at 12 and 18 months are indicated in the text

The growth intensity of musculature in anatomical regions of carcasses was assessed using growth coefficients, calculated as the ratio of muscle complex mass at specific age periods to that of newborn calves. Since the growth pattern of musculature across anatomical regions was similar in the animals of all compared groups, the data for Charolais crossbred heifers, which surpassed their contemporaries in both muscle mass and growth rates, are presented in detail. For comparative analysis, the growth coefficients of the total carcass muscular component were used as a reference value; deviations from this reference indicate isometric, positive, or negative allometric growth.

The fold increase of the total carcass muscular component in Charolais crossbreds at 6, 12, and 18 months of age was 5.5, 10.6, and 14.3, respectively, whereas in their Russian Black-Pied contemporaries it was 5.2, 8.3, and 11.5. Hereford crossbreds occupied an intermediate position.

As shown in Figure 2, the most intensive growth was characteristic of the abdominal wall musculature, the fold increase of which exceeded that of the total carcass muscular component by 2.6, 6.0, and 11.6 units at 6, 12, and 18 months, respectively. In contrast, the growth coefficients of the brachium musculature were consistently lower than the reference values.

When studying the characteristics of meat productivity formation in fattening animals, it is important to determine at which stage of ontogenesis the muscle complexes of anatomical regions of carcasses grow most intensively. For this purpose, we determined age-related changes in the growth intensity coefficients (relative growth rates) of musculature in anatomical regions of carcasses of the experimental heifers. To calculate the growth intensity coefficients (relative growth rates), we used age-related changes in the mass of muscle complexes of Charolais crossbred heifers. The calculated coefficients are presented in Table 2.

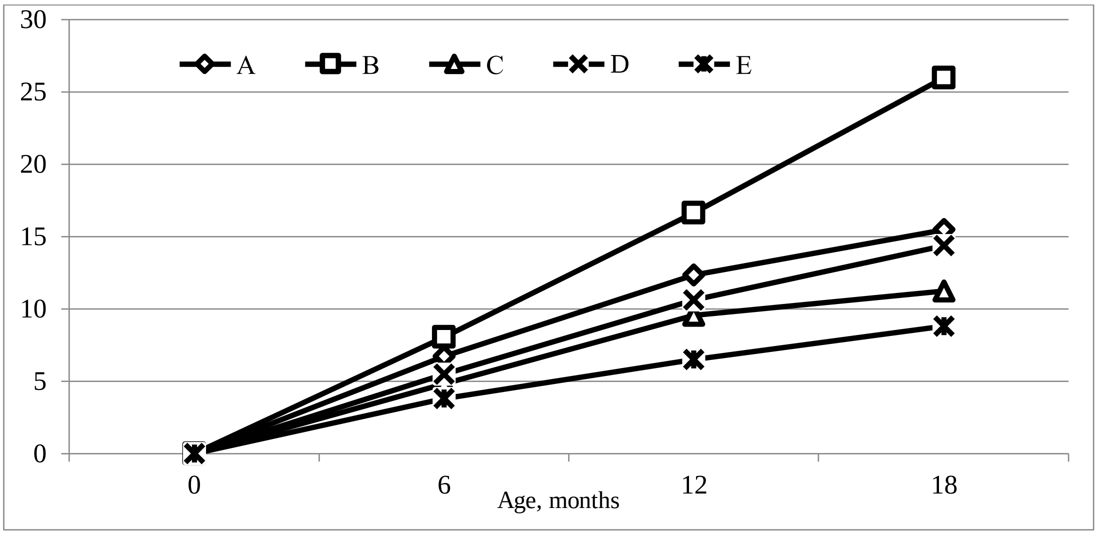

Fig. 2: Growth coefficients of musculature in anatomical regions of carcasses of Charolais crossbred heifers (A – pelvic girdle, B – abdominal wall, C – brachium, D – total muscle mass, E – antebrachium)

Table 2: Age-related dynamics of relative growth rates of musculature in anatomical regions of carcasses of Charolais crossbred heifers, %

Muscle Section	Age, months		
	6	12	18
Serratus ventralis muscle group	138.8	49.4	38.0
Spinal muscles	138.8	46.6	33.2
Thoracic muscles	143.7	86.2	32.2
Abdominal wall	158.0	55.7	42.6
Thoracic limb (pectoral girdle)	137.9	50.4	24.7
Brachium	132.7	52.3	23.5
Antebrachium	112.0	38.2	19.0
Pelvic girdle	145.2	44.9	24.9
Thigh	143.2	40.5	22.5
Crus	125.9	39.5	20.8
Total muscle mass	140.5	49.7	29.0

The highest growth intensity was recorded for the abdominal wall musculature throughout the experimental period (Table 2). The growth intensity coefficients in all anatomical regions were highest in the first 6 months of life and gradually declined thereafter, reaching minimum values by 18 months. However, the rate of this decline depended on the function and location of the muscle groups. Specifically, the growth intensity coefficients of the pelvic girdle, thoracic limb (pectoral girdle), and thigh, which are involved in locomotion, declined sharply from 145.2, 137.9, and 143.2% at 6 months to 24.9, 24.7, and 22.5%, respectively. In contrast, the relative growth rates of the axial musculature – the serratus ventralis muscle group and spinal muscles – decreased more gradually, from 138.8 and 138.8% at 6 months to 38.0 and 33.2% at 18 months. The muscle groups of the crus and antebrachium consistently exhibited the lowest growth intensity across all age periods.

Redistribution of Muscle Mass During Postnatal Ontogenesis

Although the absolute muscle mass differed considerably between genotypes, the pattern of age-related redistribution of relative muscle mass was similar across all three groups. For brevity, data for the Charolais crossbred group, which exhibited the most pronounced changes, are presented in Table 3; the corresponding values for the Russian Black-Pied and Hereford crossbred groups are available on request. The uneven growth of musculature in different anatomical regions during postnatal ontogenesis led to a redistribution of muscle mass in the carcasses (Table 3). For example, the intensive growth of the abdominal muscle complex in heifers resulted in an increase in its relative mass from 4.9% in newborn calves to 7.2, 7.7, and 8.8% at 6, 12, and 18 months of age, respectively. By the end of the experimental period, a significant decrease in the relative mass of musculature was observed in the thigh (from 28.3% at 6 months to 23.8% at 18 months), brachium, crus, and antebrachium regions.

Table 3: Dynamics of relative muscle mass in anatomical regions of carcasses of Charolais crossbred heifers, %

Muscle Section	Age, months			
	0 (n = 1)	6 (n = 3)	12 (n = 3)	18 (n = 5)
Serratus ventralis muscle group	16.8	16.1	16.1	17.6
Spinal muscles	15.0	14.9	14.5	15.0
Thoracic muscles	7.2	4.7	7.1	7.3
Abdominal wall	4.9	7.2	7.7	8.8
Thoracic limb (pectoral girdle)	5.9	5.6	5.7	5.4
Brachium	5.7	5.0	5.1	5.4
Antebrachium	4.1	2.8	2.5	2.5
Pelvic girdle	6.5	8.0	7.6	7.0
Thigh	25.0	28.3	25.7	23.8
Crus	6.8	5.4	5.0	4.9

Note: the sum of percentages does not reach 100% due to the exclusion of minor muscle groups

The redistribution of muscle mass is evidenced by an increase in the relative mass of axial musculature of carcasses from 43.8% in newborn calves to 45.3 and 48.9% at one year of age and at the end of the experimental period, respectively, while the specific mass of peripheral musculature during the same age periods decreased from 54.0% to 51.6 and 48.1%.

Discussion

The higher live weights and carcass weights of Charolais crossbred heifers observed in this study are consistent with the well-documented growth potential of late-maturing, large-framed beef breeds. At 18 months, Charolais crosses attained 511.1 kg live weight compared to 471.5 kg for Hereford crosses and 454.5 kg for purebred Russian Black-Pied heifers, reflecting the additive genetic effects of specialized beef sires on growth rate. However, total live weight gain provides an incomplete picture of productive performance. The key question addressed in this study is how this enhanced growth was partitioned among different anatomical muscle groups, and whether the patterns of muscle development differed qualitatively between genotypes or merely reflected differences in overall size. Our results demonstrate that the superior muscle mass in Charolais crossbreds was not uniformly distributed across all anatomical regions, indicating differential allometric responses to genetic selection.

The data obtained in this study indicate a significantly higher growth intensity of the abdominal wall musculature in Charolais crossbred heifers compared to other muscle groups (Table 2; Fig. 2). The abdominal wall muscle complex comprises primarily the m. obliquus externus abdominis, m. obliquus internus abdominis, m. transversus abdominis, and m. rectus abdominis, which function collectively to support the abdominal viscera against gravitational pressure and maintain the structural integrity of the ventral body wall. Since the abdominal wall muscles are not involved in locomotion, the question arises as to the factors driving their intensive growth.

Throughout biological evolution, animal organisms have been constantly influenced by gravitational forces, leading to structural adaptations in various systems, including muscle tissue [10-12]. The response to increased gravitational load is an increase in muscle mass and power. During the first 6 months of life, heifers undergo the establishment of rumen digestion, accompanied by a substantial increase in stomach volume and mass. In the present study, the empty stomach mass in newborn calves was 0.45 kg, and by 6, 12, and 18 months, it had increased by 14.7, 26.0, and 31.4 times, respectively. The early postnatal period in cattle is characterized by dramatic structural and metabolic changes in the digestive tract as the animal transitions from milk to solid feed [13]. When considering stomach contents, changes in intestinal mass, and the accumulation of omental and mesenteric fat, the mechanical load on the abdominal wall muscles increases substantially. Unlike locomotor muscles, which experience load only during movement, the abdominal muscle complex is under constant gravitational pressure from the expanding viscera, which accounts for its disproportionately intensive growth.

Whether the disproportionate growth of the abdominal wall musculature in late-maturing genotypes represents an advantage or a liability in terms of overall nutrient utilization efficiency remains an open question. On one hand, the increased mass of this muscle group imposes an additional maintenance energy cost; on the other, it is a necessary anatomical adaptation to accommodate the greater gastrointestinal capacity associated with high feed intake. Dedicated studies measuring individual feed intake and partitioning of metabolizable energy among carcass and non-carcass components are needed to resolve this question.

It is well established that mechanical load is a primary driver of skeletal muscle hypertrophy [14, 15]. However, in our study, muscle groups subjected to high load during locomotion (thigh, brachium, crus, antebrachium) exhibited lower growth rates compared with the muscle complexes of the vertebral column, thoracic muscles, abdominal wall, and serratus ventralis muscle group. This apparent contradiction can be explained by the concept of functional maturity at birth. For newborn calves to survive, the musculature involved in locomotion must be sufficiently developed at birth to enable standing, suckling, and movement. In cattle, primary muscle fiber development occurs mainly during the first trimester of gestation, and by six months of gestation the structural organization of muscle fibers into bundles is already well established [16]. Consequently, organs and tissues that undergo intensive growth during the prenatal period and thus reach a higher degree of maturity at birth exhibit relatively lower growth rates during postnatal ontogenesis. The degree of maturity of muscle groups can be assessed by their mass at birth relative to that of definitive animals. In our study, the muscle mass of the crus, thoracic limb, and thoracic muscles in newborn calves, expressed as a percentage of that in 18-month-old heifers, was 10.5, 13.3, and 14.7%, respectively. The higher this percentage, the more mature the muscle group, and consequently, the lower its postnatal growth coefficient. Muscles that achieve greater maturity at birth, having fulfilled their early functional demands, thus exhibit lower growth rates during the postnatal period.

Based on growth intensity, the muscle complexes of anatomical regions at the end of the experimental period were ranked in the following descending order: abdominal wall (26.0), pelvic girdle (15.5), serratus ventralis muscle group (15.1), thoracic muscles (14.7), spinal muscles (14.5), thigh (13.7), thoracic limb (pectoral girdle) (13.3), brachium (11.2), crus (10.5), antebrachium (8.8). The fold increase of the total carcass muscular component was 14.3. Based on these data, the musculature of the abdominal wall, pelvic girdle, and serratus ventralis muscle group exhibit positive allometry; the musculature of the antebrachium, crus, thigh, brachium, and thoracic limb (pectoral girdle) exhibit negative allometry; and the muscle complexes of the spinal muscles and thoracic muscles grow isometrically.

These findings are consistent with the results of other researchers, who have noted the high growth potential of crossbred young stock when crossed with beef breeds [17-19]. The redistribution of muscle mass from peripheral to axial regions during postnatal ontogenesis, observed in our study, corresponds to the general patterns of growth in cattle [20, 21].

The superior muscle growth performance of Charolais crossbred heifers, particularly their prolonged phase of intensive muscle accretion between 6 and 12 months of age, is consistent with the biological type of the Charolais breed. As a late-maturing, large-framed continental breed, Charolais has been selected for sustained muscle protein synthesis and delayed fat deposition, whereas earlier-maturing British breeds such as Hereford are characterized by earlier fattening at lower live weights [22]. The Russian Black-Pied, as a dairy breed selected primarily for milk production, lacks the genetic potential for extended muscle growth characteristic of specialized beef breeds. These fundamental differences in maturity type explain not only the absolute differences in muscle mass but also the distinct temporal patterns of muscle accretion observed across the three groups.

The potential influence of sex and reproductive maturity on the observed muscle growth patterns warrants consideration. In the present study, only heifers were evaluated, and no records of age at puberty were collected. It is plausible that the onset of ovarian activity and the associated increase in circulating estrogen levels could alter nutrient partitioning, favoring adipose tissue deposition over muscle protein accretion and potentially modulating the growth trajectories of specific muscle groups. Comparative studies involving steers and intact bulls, with concurrent monitoring of reproductive hormone profiles, would be necessary to determine whether the allometric growth patterns described here are consistent across sexes or are modulated by reproductive status.

Study limitations and Future Directions

Several limitations of the present study should be acknowledged. First, the number of animals slaughtered at birth was limited to one heifer per group due to both ethical considerations and economic constraints inherent in this type of research. Consequently, the data obtained at this earliest time point should be interpreted as indicative trends rather than as a basis for definitive statistical comparisons between groups. Future studies with larger sample sizes at early age points would strengthen the statistical robustness of the neonatal findings. Second, the experimental design with four discrete slaughter age points precluded the application of continuous non-linear regression models for growth curve analysis; the use of growth coefficients and relative growth rates, while appropriate for determining allometric patterns, does not fully capture the continuous dynamics of growth.

Furthermore, the present study focused exclusively on skeletal muscle growth and did not include a detailed analysis of adipose tissue deposition (subcutaneous, intermuscular, and intramuscular fat), which is an important determinant of beef quality and a potential indicator of physiological maturity. The relationship between abdominal muscle hypertrophy and overall nutrient utilization efficiency also warrants dedicated investigation with individual feed intake measurements. Finally, the observed muscle growth patterns are specific to the genotypes studied (Russian Black-Pied and its crosses with Charolais and Hereford). Whether similar patterns would be observed with other breed combinations (e.g., Jersey crosses, Limousin crosses) or in steers and bulls remains to be determined. Future research addressing sex-related differences, the influence of reproductive maturity on muscle growth dynamics, and a wider range of breed combinations would be valuable for a more comprehensive understanding of muscle development in crossbred cattle.

Conclusion

Crossbreeding Russian Black-Pied heifers with Charolais sires increased absolute skeletal muscle mass by 29.3% at 18 months. The relative mass of axial musculature increased from 43.8% at birth to 48.9% at 18 months, while peripheral musculature declined correspondingly. The abdominal wall, pelvic girdle, and serratus ventralis muscle groups exhibited positive allometry; the antebrachium, crus, brachium, and thigh exhibited negative allometry; and the spinal and thoracic muscles grew isometrically.

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Author’s Contributions

Ivan Petrovich Prokhorov: Conceptualization, methodology, writing review and edited.
Grigorii Sergeyevich Shekhovtsev: Conceptualization, methodology, investigation, data curation, writing original draft preparation.
Yulia Vasilevna Shoshina: Writing review and editing, project administration.

Ethics

This article is original and has never been published before. The author also confirmed with all authors involved in the study that they had read and agreed to the contents of the article and that there were no ethical issues involved.

Conflict of Interest

All authors declare that they have no conflicts of interest.

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