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Phenotypic Characterization of Rambouillet Sheep Expressing the *Callipyge* Gene: III. Muscle Weights and Muscle Weight Distribution¹

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ABSTRACT: Paternal half-sibling Rambouillet ram lambs (n = 18) representing two muscle phenotypes were slaughtered at 54.5 kg to evaluate the effect of the *callipyge* gene on muscle mass. Lambs were produced from a sire that was heterozygous for the *callipyge* gene. Nineteen muscles were dissected from the right side of each carcass to evaluate muscle weights relative to carcass weight. Excised muscle mass was significantly higher (42%) for lambs exhibiting a *callipyge* muscle phenotype than for half-siblings. In the pelvic limb, all excised muscles except the peronius tertius were larger in lambs expressing the *callipyge* gene ($P < .001$). In the torso, the longissimus ($P < .001$), psoas major ($P < .001$), and psoas minor ($P < .01$) were larger in lambs with the

callipyge phenotype. In the thoracic limb, the biceps brachii ($P < .001$), triceps brachii ($P < .002$), and extensor carpi radialis ($P < .01$) were larger in lambs with the *callipyge* phenotype. Total pelvic limb ($P < .001$), torso ($P < .001$), and thoracic muscle weights were higher ($P < .01$) in lambs with the *callipyge* phenotype. *Callipyge* lambs had a higher ($P < .01$) percentage of excised muscle weight in the pelvic limb and torso and a lower ($P < .01$) percentage in the thoracic limb when compared to controls. These data indicate that the magnitude of expression of the *callipyge* gene is dependent upon the location of the muscle on the body and that the increased muscle mass was concentrated in the leg and loin.

Key Words: Sheep, Carcass Composition, Muscles, *Callipyge*

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Introduction

Animal shape has been used for many years to predict the proportion of high-priced cuts (Berg and Butterfield, 1976). However, studies have shown that both Brahman (Butler, 1957) and dairy cattle (Cole et al., 1964) have the same proportions as or better proportions of high-priced cuts than British beef-type breeds. After reviewing the literature on muscle dissection and conducting their own experiments, Berg and Butterfield (1976) concluded that in cattle, relative muscle weights were constant within sex and age. Butterfield (1988) found no difference in muscle weight distribution between meat and wool breeds of sheep. In double-muscled cattle, the forelimb and hindlimb hypertrophy to a higher degree than the loin (Dumont, 1982). Phenotypically, *callipyge* sheep ap-

pear to have a different pattern of muscle distribution than normal sheep or double-muscled cattle. The data needed to confirm this observation have not been reported in the scientific literature. If *callipyge* carcasses do have a novel pattern of muscle distribution, it could positively affect their retail value. The objectives of this experiment were to determine whether the degree of muscle enlargement was similar across the entire body and to determine which areas of the body were influenced the most by the *callipyge* gene.

Materials and Methods

Paternal half-sibling Rambouillet ram lambs (n = 18) representing two muscle phenotypes ("normal" and *callipyge*) were slaughtered at 54.5 kg live weight. Nine lambs exhibited a *callipyge* muscle phenotype and were assumed to be heterozygotes. The remaining nine lambs were normal-muscled paternal half-siblings. When lambs reached a slaughter end point of 54.5 kg, they were fasted for 24 h before slaughter. Lambs were humanely slaughtered and carcasses were dissected at the Texas Tech University Meat Science Laboratory.

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Carcasses were chilled for 24 h after slaughter, weighed, and split down the midline. Carcass dissection began on all carcasses 24 h after slaughter. All carcass dissection was performed by the same two technicians. All thoracic limb muscles were dissected by one technician and the torso and pelvic limb were dissected by the other technician. Each carcass required approximately 4 h for complete dissection. Nineteen muscles were dissected from the right side of each carcass to evaluate muscle weights relative to carcass weight and excised muscle weight. Muscles selected for measurement were primarily the large muscles of the body as well as additional small muscles that could be easily removed from the carcass with a high degree of precision. Each muscle was removed by detaching the muscle from its origin and insertion. Muscles were trimmed of all fat, fascia, and connective tissue and weighed immediately after dissection from the carcass.

Muscles from the pelvic limb included the superficial gluteal, biceps femoris, tensor fascia latae, gluteus medius, gracilis, semitendinosus, adductor, semimembranosus, rectus femoris, peronius tertius, and the three muscles of the vastus group. The vastus lateralis, vastus medialis, and the vastus intermedius were combined into the vastus group because of the difficulty encountered in separating the three parts of the muscle. The superficial gluteal and the biceps femoris were also reported as a single muscle (superficial gluteal) because accurate separation of the muscles was difficult due to overlapping of muscle fibers. Muscles dissected from the torso of the body included the longissimus, psoas major, and the psoas minor. The muscles taken from the thoracic limb included the supraspinatus, infraspinatus, biceps brachii, triceps brachii, extensor carpi radialis, and the lateral digital extensor.

Statistical Analysis. Data were analyzed as a completely randomized design using the GLM procedure of SAS (1990). Data were analyzed with a model including the effect of muscle phenotype and right side carcass weight as a covariate. Dependent variables analyzed included the weights of each excised muscle

from each region of the body and a summation of the total excised muscle weights from each body region. The muscles of the pelvic limb analyzed were the superficial gluteal, adductor, semimembranosus, gluteus medius, semitendinosus, gracilis, rectus femoris, peronius tertius, tensor fascia latae, and the muscles of the vastus group. The muscles from the torso of the body analyzed were the longissimus, psoas major, and psoas minor. The biceps brachii, triceps brachii, supraspinatus, infraspinatus, extensor carpi radialis, and lateral digital extensor were the muscles from the thoracic limb for which variables were measured.

Results

The live weights of *callipyge* lambs did not differ ($P < .41$) from the live weights of normal half-siblings. However, hot and cold, right and left side carcass weights of *callipyge* lambs were heavier than those of controls (Table 1).

All muscles excised from the pelvic limb of lambs with the *callipyge* phenotype were heavier ($P < .01$) than muscles from half-sibling controls, except for the peronius tertius (Table 2). The total weight of excised muscles from the pelvic limb of lambs expressing the *callipyge* gene was 42% higher than the weight of excised pelvic muscles from half-siblings. The muscles of the pelvic limb from *callipyge* lambs also comprised a higher ($P < .001$) percentage of total excised muscle weight (Table 3) than control lambs.

In the torso of the body, all three major muscles excised were heavier ($P < .01$) in lambs that expressed the *callipyge* phenotype (Table 4) than in controls. Total torso muscle weights were 50% heavier in lambs with the *callipyge* phenotype than in controls. The longissimus from *callipyge* lambs comprised a higher ($P < .001$) percentage of the total excised muscle weight than the longissimus of controls (Table 5).

In the thoracic limb, only the weights of the biceps brachii, triceps brachii, and the extensor carpi radialis

Table 1. Mean weights and percentages for Rambouillet ram lambs and carcasses expressing different muscle phenotypes^a

Weight, kg	Phenotype		Range within phenotype		SEM	P-value
	<i>Callipyge</i>	Normal	<i>Callipyge</i>	Normal		
Live	52.8	52.2	50.5–55.4	49.9–54.4	.49	.41
Hot carcass	30.2	28.1	28.8–31.4	26.8–30.6	.39	.001
Cold carcass	29.2	26.6	28.0–30.5	24.2–29.0	.34	.001
Right side	14.2	13.1	13.3–15.4	11.7–14.6	.27	.01
Left side	15.0	13.4	14.1–16.2	12.4–14.3	.21	.001
Hindsaddle	14.7	13.0	14.1–15.4	11.8–14.2	.20	.001
Foresaddle	14.5	13.6	13.9–15.1	12.4–14.8	.19	.001

^an = 9 carcasses of each phenotype.

Table 2. Mean pelvic muscle weights for Rambouillet ram lambs expressing different muscle phenotypes^a

Muscle, g	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Superficial gluteal	575.1	360.2	9.9	.001
Tensor fascia latae	94.1	76.9	3.4	.002
Gluteus medius	396.5	265.4	6.7	.001
Gracilis	85.7	66.5	3.6	.001
Semitendinosus	169.3	133.3	4.9	.001
Adductor	233.3	158.2	5.9	.001
Semimembranosus	526.7	323.1	9.1	.001
Rectus femoris	214.1	173.6	10.1	.01
Vastus group	385.0	321.7	12.2	.002
Peronius tertius	56.9	50.8	2.1	.06
All excised pelvic muscles	2736.7	1929.7	43.7	.001

^an = 9 carcasses of each phenotype.

differed ($P < .01$) between phenotypes (Table 6). The other muscles of the thoracic limb were not significantly different in weight between the two phenotypes. The total excised thoracic muscle weight was only 14% higher in lambs with the *callipyge* phenotype than for half-siblings. When thoracic limb muscle weights are expressed as a percentage of total excised muscle weight (Table 7), lambs with the *callipyge* phenotype actually had a lower ($P < .01$) percentage of their carcass weight in the thoracic limb than controls.

Lambs expressing the *callipyge* gene had more ($P < .01$) weight in pelvic limb, thoracic limb, and torso muscles than half-sibling controls (Table 8). Lambs with the *callipyge* phenotype also had more ($P < .001$) total excised muscle weight than half-sibling controls (Table 8). *Callipyge* lambs had a higher ($P < .01$) percentage of excised muscle weight in the pelvic limb and torso and a lower ($P < .01$) percentage in the thoracic limb when compared to controls.

Discussion

Dissection of individual muscles from the carcass yielded data that supported the hypothesis that muscles from lambs expressing the *callipyge* gene enlarged to differing degrees. These data indicate that the muscles of the pelvic limb and the torso were influenced the most by the *callipyge* gene. Visually, sheep that express the *callipyge* gene appear to be more muscular in the hind legs and also appear to be wider and deeper through the rack and loin. These data support this visual perception. Similar muscle dissection studies conducted on both wool and meat breeds reported no difference in muscle weight distribution between breed types (Butterfield, 1988). In this study, the excised muscles of the pelvic limb from lambs expressing the *callipyge* phenotype were 42% heavier than the same muscles excised from the half-sibling controls even though they were all slaughtered at the same weight. Of the 10 muscles dissected from

Table 3. Mean percentages of pelvic muscle weights relative to total excised muscle weight for Rambouillet ram lambs expressing different muscle phenotypes^a

Muscle, % of excised muscle	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Superficial gluteal	12.3	10.7	.16	.001
Tensor fascia latae	2.0	2.2	.07	.01
Gluteus medius	8.5	7.8	.15	.007
Gracilis	1.8	1.9	.09	.36
Semitendinosus	3.6	3.9	.11	.07
Adductor	5.0	4.7	.15	.15
Semimembranosus	11.2	9.5	.16	.001
Rectus femoris	4.6	5.1	.19	.05
Vastus group	8.2	9.5	.27	.003
Peronius tertius	1.2	1.5	.05	.001
All excised pelvic muscles	58.4	56.8	.91	.001

^an = 9 carcasses of each phenotype.

Table 4. Mean torso muscle weights for Rambouillet ram lambs expressing different muscle phenotypes^a

Muscle, g	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Longissimus muscle	1004.1	664.8	17.3	.001
Psoas major	140.9	96.1	4.9	.001
Psoas minor	45.9	32.6	3.5	.01
All excised torso muscles	1190.9	793.5	20.7	.001

^an = 9 carcasses of each phenotype.

Table 5. Mean torso muscle weight percentages as a percent of total excised muscle weight for Rambouillet ram lambs expressing different muscle phenotypes^a

Muscle, % of excised muscle	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Longissimus muscle	21.5	19.6	.41	.006
Psoas major	2.9	2.8	.11	.43
Psoas minor	1.0	.9	.09	.80
All excised torso muscles	25.4	23.3	.43	.01

^an = 9 carcasses of each phenotype.

the pelvic limb, the peronius tertius was the only muscle that was not significantly larger in lambs expressing the *callipyge* gene. The least difference among all muscle weights was in the tensor fascia latae (22.3%). The other muscles of the pelvic limb were between 23 and 63% larger in lambs with the *callipyge* phenotype. The muscles most affected by the *callipyge* gene were the semimembranosus, superficial gluteal, and adductor. The semimembranosus (which makes up most of the inside leg) was 63% larger in lambs expressing the *callipyge* gene than in controls. The superficial gluteal (60%) or “jump muscle” and the adductor (47%) were larger in lambs with the *callipyge* phenotype than in controls. Muscle hypertrophy has also been reported in Charolais and Maine Anjou bulls (Dumont et al., 1982). However, in these bulls the percentage increase in pelvic limb muscle

weights was consistently 17 to 34 percentage units lower than the increases shown in these data. In a review of papers on double-musced cattle, Dumont (1982) reported increases from 9 to 35% for excised muscle weights from the pelvic limb.

In the torso of the body a similar increase in muscle size was evident. The longissimus, which is the largest muscle in the body, was 51% larger in lambs with the *callipyge* phenotype. The psoas major (47%) and psoas minor (41%) were also larger in lambs with the *callipyge* phenotype. The longissimus was only 19% heavier in double-musced Charolais bulls than in normal-musced controls (Dumont, 1982).

In the thoracic limb, the differences in muscle weights between the two phenotypes were much smaller than those in the pelvic limb and torso. The only muscles that were larger in the thoracic limbs of

Table 6. Mean thoracic limb muscle weights for Rambouillet ram lambs expressing different muscle phenotypes^a

Muscle, g	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Supraspinatus	136.3	128.0	4.3	.19
Infraspinatus	183.6	172.9	8.3	.37
Biceps brachii	49.4	41.3	1.2	.001
Triceps brachii	298.2	244.7	7.3	.001
Extensor carpi radialis	55.2	47.5	2.0	.01
Lateral digital extensor	29.0	25.9	1.5	.17
All excised thoracic limb muscles	751.7	660.3	19.4	.01

^an = 9 carcasses of each phenotype.

Table 8. Mean excised muscle weights (by muscle group) for ram lambs expressing different muscle phenotypes^a

Muscle group, g	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Pelvic limb	2736.7	1929.7	43.7	.001
Torso	1190.9	793.5	20.7	.001
Thoracic limb	751.7	660.3	19.4	.01
Total excised muscle	4679.3	3383.5	61.2	.001

^an = 9 carcasses of each phenotype.

Table 7. Mean thoracic limb muscle weight percentages as a percent of total excised muscle weight for Rambouillet ram lambs expressing different muscle phenotypes^a

Muscle, % of excised muscle weight	Phenotype		SEM	P-value
	<i>Callipyge</i>	Normal		
Supraspinatus	2.91	3.78	.09	.001
Infraspinatus	3.94	5.10	.17	.001
Biceps brachii	1.06	1.22	.03	.001
Triceps brachii	6.39	7.22	.18	.005
Extensor carpi radialis	1.19	1.42	.05	.004
Lateral digital extensor	.63	.76	.04	.02
All excised thoracic limb muscles	16.1	19.5	.34	.01

^an = 9 carcasses of each phenotype.

callipyge lambs were the biceps brachii (20%), triceps brachii (22%), and the extensor carpi radialis (16%). The other three excised muscles of the thoracic limb were not significantly different between the two phenotypes. The thoracic limb muscles of lambs with the *callipyge* phenotype were not enlarged to the same degree as muscles from other parts of the body. These data are much different from data on cattle with the double-musled trait. In cattle, the muscles of the front limb are enlarged at least as much, and many times more, than the muscles of the hind limb (Dumont, 1982). It is clear that there are differences in the degree of muscle enlargement between sheep with the *callipyge* gene and double-musled cattle.

Most double-musled cattle are born expressing the double-musled condition. Sheep, however, express the *callipyge* condition at approximately 4 to 6 wk of age if they are on a high level of nutrition. The increases in muscle mass between the two species are not consistent from muscle to muscle or even limb to limb, suggesting that the mechanism of muscle enlargement is different for the two species. In cattle, it is fairly clear that muscle enlargement is due to a combination of muscle hypertrophy and muscle hyperplasia (Swatland and Kieffer, 1974). In sheep, the mechanism responsible for the increase in muscle size and weight has not been clearly identified. It has been speculated that hypertrophy is the most likely explanation for muscle enlargement (Rice and Carpenter, 1994).

Implications

Approximately 58% of the value of a USDA yield 2.0 lamb carcass is in the leg and loin of the carcass (Botkin et al., 1988). More than 78% of the value of the carcass is in the leg, loin, and rack. These data suggest that 54.5-kg ram lambs expressing the *callipyge* gene have a higher percentage of leg and loin muscle in their carcasses than their normal-musled half-siblings. The use of lambs with the *callipyge* gene in the U. S. sheep industry may significantly improve the value of lamb carcasses.

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