5129

NATIONAL LIBRARY
OTTAWA

BIBLIOTHÈQUE NATIONALE
OTTAWA

CANADA

NAME OF AUTHOR....JAIME PESCHIERA.....

TITLE OF THESIS....CHANGES IN THE CONSTITUENTS OF FOUR BOVINE MUSCLES DURING GROWTH

UNIVERSITY....OF ALBERTA.....

DEGREE....Ph.D.....YEAR GRANTED....1969.....

Permission is hereby granted to THE NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

(Signed) Jaime Peschiera

PERMANENT ADDRESS:
AV SAN GABRIEL 583
SAN ISIDRO
LIMA PERU

DATED....23 Oct....1969

NL-91

THE UNIVERSITY OF ALBERTA

CHANGES IN THE CONSTITUENTS OF FOUR BOVINE MUSCLES DURING GROWTH

BY

© JAIME ALFONSO PESCHIERA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

FALL, 1969

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Changes in the Constituents of Four Bovine Muscles During Growth", submitted by Jaime Alfonso Peschiera in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

. . . . . .

Supervisor

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

External Examiner

. . . . . .

Date . Oct. 22, 1969

ABSTRACT

This study was undertaken to investigate the growth of four bovine muscles and the pattern of change of some muscle constituents: moisture, ether extract, nitrogen, ash, potassium and four nitrogenous fractions, myofibrillar nitrogen (MYON), sarcoplasmic nitrogen (SARN), stroma nitrogen (STRN) and non-protein nitrogen (NPN).

The cattle used were sired by Shorthorn bulls and from two year old dams of diverse breeding. Three sex groups were included: 16 bulls, 16 heifers and 12 steers. The animals were slaughtered sequentially at six stages during growth from birth to 18 months. The first two groups were killed at an average weight of 40 and 80 kg, respectively; the other four at approximately 100 kg intervals. For the statistical analysis, the four youngest bulls were included with the steers, which were obtained by castration at two months of age.

Four muscles were sampled from each animal: M. longissimus dorsi (LD), M. semitendinosus (ST), M. rhomboideus (RH), and M. extensor carpi radialis (ECR). The contents of moisture, ether extract, nitrogen and ash in each muscle were determined by AO AC (1965) methods. Potassium was determined by atomic absorption spectrophotometry. Four nitrogen fractions were extracted from each muscle according to the basic method developed by Helander (1957).

Regressions of individual muscle weights on age and total carcass lean and of muscle constituents on age and individual muscle weight were computed to determine their pattern of change.

The four muscles from bulls grew significantly more rapidly relative to age than those from steers and those from steers more rapidly than those from heifers, even though the differences were not always

significant. The rates for the three groups were more similar when the regressions were based on total muscle weight, but bulls showed greater rates for the ST and RH and heifers a greater rate for the LD muscle. Moisture content increased at similar rates to those of whole muscle, but percent moisture decreased at a greater rate in heifers than in steers and at a greater rate in steers than in bulls.

The greater rate of ether extract accumulation in heifers than in steers and in steers than in bulls was very noticeable for the regressions based on muscle weight but not for those based on age. The proportion of ether extract increased more rapidly in heifers than in steers and more so in steers than in bulls regardless of whether age or muscle weight was the independent vari ble.

Regressions of ash content on age and on muscle weight were similar for the three groups, even though there were some significant differences. Percent ash remained fairly constant as age or muscle weight increased. The potassium:water ratio increased at a smaller rate in bulls and heifers than in steers, but only significantly so in bulls for the RH.

The accretion of nitrogen per day of age was more rapid in bulls than in steers and more so in steers than in heifers; it was similar for the three groups when regressions on muscle weight were compared. The regressions for percent nitrogen were similar among the sex groups when based on age, but larger in heifers, significantly so in some cases, than in steers and larger in steers than in bulls, when based on muscle weight. Nitrogen:water ratio increased in a similar way to the latter comparisons, but the rates were always significantly greater in heifers than in bulls. In steers, the increase was similar to that of bullsfor the LD and ST and similar to that of heifers for the RH and ECR.

significant. The rates for the three groups were more similar when the regressions were based on total muscle weight, but bulls showed greater rates for the ST and RH and heifers a greater rate for the LD muscle. Moisture content increased at similar rates to those of whole muscle, but percent moisture decreased at a greater rate in heifers than in steers and at a greater rate in steers than in bulls.

The greater rate of ether extract accumulation in heifers than in steers and in steers than in bulls was very noticeable for the regressions based on muscle weight but not for those based on age. The proportion of ether extract increased more rapidly in heifers than in steers and more so in steers than in bulls regardless of whether age or muscle weight was the independent variable.

Regressions of ash content on age and on muscle weight were similar for the three groups, even though there were some significant differences. Percent ash remained fairly constant as age or muscle weight increased. The potassium:water ratio increased at a smaller rate in bulls and heifers than in steers, but only significantly so in bulls for the RH.

The accretion of nitrogen per day of age was more rapid in bulls than in steers and more so in steers than in heifers; it was similar for the three groups when regressions on muscle weight were compared. The regressions for percent nitrogen were similar among the sex groups when based on age, but larger in heifers, significantly so in some cases, than in steers and larger in steers than in bulls, when based on muscle weight. Nitrogen:water ratio increased in a similar way to the latter comparisons, but the rates were always significantly greater in heifers than in bulls. In steers, the increase was similar to that of bullsfor the LD and ST and similar to that of heifers for the RH and ECR.

The proportion of MYON relative to TN was larger in steers, followed by that in bulls and finally that in heifers. There was a tendency for the MYON:TN ratio to increase, especially in the RH and ECR from steers, except for the ST muscles and the muscles from heifers. The reverse was true for the proportion of SARN and the SARN:TN ratio. The proportion of STRN and NPN was similar for the three sex groups but there was a general decrease in STRN:TN and NPN:TN ratios changed little.

ACKNOWLEDGEMENTS

I wish to thank Dr. L. W. McElroy, Chairman of the Department of Animal Science, for placing the department equipment and other facilities at my disposal for the successful completion of the work in this study. To Dr. R. T. Berg, Professor of Animal Genetics, I am especially thankful for his advice and assistance during the present study and for his suggestions and criticisms in the preparation of the text. I also want to thank Dr. L. P. Milligan for his valuable advice in the techniques and procedures for the analysis of tissue.

For his assistance in the laboratory, I am very grateful to Dr. Kiyoshi Namikawa, Post-doctorate fellow from the University of Kyoto, Japan.

To my wife, Maureen, I am especially grateful for her understanding, patience and encouragement during the many months taken to complete this study.

I also extend my thanks to Mrs. J. A. Relf, Mrs. P. MacKechnie and to Mrs. M. Wylie for the excellent typing of the text.

At the start of this study, and for the last three years, I received a National Research Council Scholarship. During my last year I also received a Dissertation Scholarship from the University of Alberta.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

To date, several, and in many ways unrelated, approaches have been used to describe the complex process of growth. Growth in animals has been explained by calculating mathematical quantities that could be used to predict the characteristic increment in weight during a period of time. An alternate path followed, especially in more recent times, has been to depict growth as a process of change in the proportion of tissues in an organism. This approach has been lately expanded to include the changes within the tissues, i.e. changes in the proportions of cell constituents, prominent among which are the more predominant macromolecules.

The importance of an accurate description of growth is two-fold. It will provide a greater and wider understanding of the organisation in living beings and eventually permit a measure of control that will improve the utilization of animal resources.

In this study, mathematical tools were used to describe the changes in some muscle constituents during growth.

REVIEW OF LITERATURE

I. Changes in the Tissue Proportions of the Carcass during Growth

The proportions of muscle, fat and bone in a beef carcass determine to a large extent its commercial value. Studies which describe relative growth in the beef carcass or the changes which occur in the proportions of these major tissues are, therefore, of considerable importance. An equally important objective of these studies is the elucidation of the growth process in large animals, which would partially satisfy the innate curiosity of scientists and enable them to eventually control the process. To measure changes in major tissue proportions, the carcass is usually separated by partial or complete dissection techniques.

Some of the earliest carcass studies were done by Haecker (1920). He slaughtered beef-bred steers at 100-lb intervals from 100 to 1500 pounds. Over this period, the rate of fat deposition was higher than that of muscle and muscle accumulated more rapidly than bone. Using muscle plus bone as the independent variable, Berg and Butterfield (1966) determined the growth coefficients of muscle ($1.05 \pm .010$), bone ($0.82 \pm .034$) and fat ($1.78 \pm .204$). These coefficients described relative growth, indicating that the proportion of bone was decreasing and that of muscle increasing whereas the proportion of fat also increased but at a very rapid rate.

The deposition of muscle, bone and fat is influenced by breed, sex and nutritional history. British beef cattle (e.g. Hereford) have higher muscle:bone ratios and fatten earlier than the European breeds (e.g. Holstein - Friesian) (Berg, 1967). Callow (1961) also found breed differences in tissue proportions of cattle. Furthermore, differences in muscle:bone ratios of five breeds of sheep have been reported (Vesely and Peters, 1966). Rollins, Julian and Carroll (1960)

reported that there was more muscle, less fat and equal ash in a double-muscled heifer compared with a normal heifer. In this case, the effect of an inherited character was very noticeable. To determine the influence of sex on growth, Berg (1967) compared carcasses from bulls, heifers and steers. The carcasses of bulls had a lower fat percentage and a higher muscle:bone ratio than those of steers or heifers. Bradley et al. (1966) also found heifers to have more fat and less lean than steers.

Individual muscles growing at different rates relative to total muscle mass or differential growth is found within the bovine musculature. Butterfield and Berg (1966a) calculated growth coefficients to describe the relative growth of individual muscles. They used the formula $\log Y = a + b \log X$, where Y represents the individual muscle, X represents total muscle weight, b is the growth coefficient and a the intersection of the ordinate. Some of the muscles were classed as monophasic because their growth pattern remained relatively constant during growth and others as diphasic because their pattern changed, usually soon after birth. For example, the extensor carpi radialis (ECR) was classified as having a monophasic growth pattern and a low growth impetus. The rhomboideus (RH), on the other hand, was classed as having a diphasic growth pattern and an average-high growth impetus. The semitendinosus (ST) and the longissimus dorsi (LD) muscles were both diphasic also, but with a high-average growth impetus. The coefficients calculated by Brungardt (1968) for the LD and ST were similar to those calculated by Butterfield and Berg (1966a).

Although nutritional stress retards the growth of farm animals, the proportions of the individual muscles, based on total muscle, change only slightly or not at all.

For example, Brungardt (1968) showed that there was a slightly greater growth coefficient for the LD and ST muscles from steers restricted in their feeding. In contrast, Butterfield and Berg (1966b) found that a low plane of nutrition retarded growth of muscles uniformly when related to total muscle weight and differentially when related to age.

II. Changes in the Composition of the Carcass during Growth

The idea of 'chemical maturity' is not new. Earlier in this century, Moulton (1923) suggested the use of the term to refer to the point at which the concentrations of water, protein and salts become comparatively constant in the fat-free cell. He found that the decrease of percent water and the increase of percent ash and nitrogen from embryo to maturity were asymptotic with age. Moulton's definition was not universally accepted. Reid, Wellington and Dunn (1955) postulated that if chemical maturity is defined as the age at which the composition of the fat-free body becomes predictable, then the bovine body is chemically mature at birth. Bailey, Kitts and Wood (1960) observed that attainment of mature fat-free body size coincided with attainment of chemical maturity and suggested the use of protein:water ratio as an index of physiological age. Another proposal explained that 'chemical maturity' can only be applied to the whole body when all its constituents have reached adult proportions (Dickerson and Widdowson, 1960). Because 'chemical maturity' could be influenced by nutritional state, species, specific muscles, physical environment and degree of activity, Gordon, Kowalski and Fritts (1966) suggested consideration of these factors before accepting a general definition.

When Haecker's (1920) results were plotted against live weight by Hedrick et al. (1967), total moisture, protein and ash increased linearly; total fat did not. When carcass weight was used as a basis to calculate percentages, the changes in percentages were different than those of total constituents. Brungardt (1968) found a decrease in protein from 18.4 to 14.4%; an increase in ether extract from 7 to 33%; and a decrease in water from 75.4 to 49.1%, in Holstein steer carcasses ranging in weight from 91 kg to 590 kg.

Changes during growth in whole bodies of crossbred pigs were determined by Spray and Widdowson (1950). They found that fat increased from 2 to 20% during aging to 250 days. Similarly, protein increased from 11 to 16% but water decreased from 85 to 63 per cent.

Linear relationships between age, as the predictor, and percent constituents of the empty body weight, of the carcass and of the edible portion were calculated by Hopper (1944). The best relationship was found between the percent water, percent ash and percent protein of the carcass with age, but the coefficients of determination ranged from 34.8 to 54.8%, suggesting high standard errors. Another kind of linear relationship was determined by Reid et al. (1968). They maintained that the regression of log lean (kg) and log protein (kg) on log body weight (kg) was independent of nutrition in animals kept on a positive energy balance.

There are large differences in the composition of carcasses of different species and thus the pattern of change may vary with the species. The average composition of 48 beef steer carcasses (average weight: 217 ± 42 kg) was: water 52.3 ± 4.5%, fat 27.9 ± 6.1%, nitrogen 2.5 ± 0.2% and ash 4.2 ± 0.4% (Garrett and Hinman, 1969); that of carcasses (average weight: 28.2 ± 4.6 kg) of New Zealand Romney ewes was: water 40.8 ± 4.2%, fat 43.8 ± 5.7%, nitrogen 1.9 ± 0.2% and

ash 3.6±0.4% (Ulyatt and Barton, 1963). The steers had a greater proportion of water, protein and ash, a smaller proportion of fat, varied less in percent water and more in percent fat than the ewes.

III. Changes in the Constituents of Growing Skeletal Muscle Tissue

The myoblast is the embryonic cell, derived from mesenchyme and myotomes, from which originate muscle cells by elongation and accumulation of unstriated fibrils. The first myofibrils to become striated are those just beneath the sarcolemma (Bailey and Zobrisky, 1968). Eventually, the cell acquires a striated appearance due to the accumulation of myofibrils; there is also a change in the position of nuclei from the centre to the periphery of the cell (Message, 1967).

During fetal life the muscle tissue grows by hyperplasia; after birth only hypertrophy occurs (Enesco and Puddy, 1964; Joubert, 1956). During pre-natal and early post-natal growth in the rat, there is an increase in DNA synthesis (Winick and Noble, 1965); this increase in DNA after birth reflects the increase in the number of nuclei in muscle cells and not in number of cells (Enesco and Puddy, 1964). During post-natal growth the protein:DNA ratio increases as a consequence of the increase in cell size (protein synthesis); eventually, growth rate decreases because a steady state between protein synthesis and destruction is attained (Winick and Noble, 1965). The increase in DNA and cell nuclei in rat muscle has been also noted by Gordon et al. (1966), during early post-natal growth.

The proportions of other tissue constituents also vary during growth and their mode of change has been described. Haecker (1920) analysed the flesh, which included the meat and fat, of cattle ranging in weight from 100 lb to 1000 pounds. He determined changes in the percentages of constituents on a

wet tissue basis. Moisture decreased from 77.0 to 52.0%, protein from 19.5 to 15.6% and ash from 1.0 to 0.8%; fat increased from 2.9 to 31.6 per cent. When the percentage of muscle constituents was calculated on a fat-free basis, there was a slight increase in percent ash, protein increased from 20.1 to 24.5% and water decreased from 78.9 to 74.4 per cent. Similar changes in percentages were found by Zinn (1967). Meat from beef carcasses weighing 20.9, 99.4 and 189.0 kg was analysed by Callow (1948). He found that fat increased from 4.5 to 9.1 to 18.0% and that moisture decreased from 79.9 to 76.2 to 67.4%, at the three carcass weights respectively. These results on wet tissue basis were in complete accord with those of Haecker (1920). As one would expect, the percent protein of carcass muscle is not homogeneous. Zinn et al. (1966) determined that protein in carcass muscle was 18.9%, with that in round muscle 20.1%, that in loin muscle 19.8% and that in flank muscle 19.5 per cent.

Several workers have determined the change in constituents in individual muscles. Their results are summarized in Table 1. Lawrie (1961a) found that water decreased from 78.2 to 74.% (wet basis) in the LD of steers and bulls from birth to 40 months of age. When percent water was calculated on a fat-free basis, the drop was only from 79.0 to 76.8% for the same muscle; the percentage remained fairly constant after 18 months. The increase in percent fat was greater in beef-type cattle (1 to 12%) when compared with dairy-type cattle (1 to 4%). Analyses of the LD of cattle by Lawrie (1961b) showed that percent water remained almost constant and that percent fat and percent nitrogen increased only slightly with age (Table 1). In pigs, the changes with age of percent fat and percent water in the LD determined by Lawrie, Pomeroy and Cuthbertson (1963) and McMeekan (1940a) were in the same direction but of greater magnitude (Table 1).

Table 1. Results from analyses of different muscles from cattle and pigs reported by several authors

Source	Species or Breed	Muscle[3]	Stage of Growth (age or weight)	Sex	Muscle Constituents				
					% Water		% Nitrogen		% Fat
					1	2	1	2	1
Gillet et al. (1965)	pig	ST	186-200 lb	barrows	73.1		3.14		6.03
		LD	"	"	72.0		3.44		4.76
Gillet et al. (1967)	cattle	ST	232-344 kg	steers	73.4		3.41		3.57
		LD	"	"	70.8		3.44		6.21
Kolaczyk and Kotik (1966)	pig	LD	96 kg	barrows	74.4		3.61		2.24
		LD	"	gilts	74.8		3.64		1.74
Lawrie (1961b)	cattle AxRP[a]	LD	4 mos.		78.3		3.45	3.46	0.35
		LD	8 mos.		78.1		3.41	3.44	0.69
		LD	12 mos.		78.3		3.50	3.54	1.00
		LD	14 mos.		78.0		3.50	3.56	1.67
Lawrie et al. (1963)	pig	LD	150 lb	hogs		76.7 ± .2		3.71 ±.03	2.85 ±.30
		ECR	"	"		79.3 ± .2		3.29 ±.04	1.45 ±.16
		LD	200 lb	"		76.4 ± .2		3.74 ±.04	3.24 ±.27
		ECR	"	"		79.2 ± .3		3.35 ±.03	1.32 ±.08
		LD	250 lb	"		75.9 ± .3		3.87 ±.03	3.96 ±.04

Table 1 (continued)

Source	Species or Breed	Muscle[3]	Stage of Growth (age or weight)	Sex	Muscle Constituents				
					% Water		% Nitrogen		% Fat
					1	2	1	2	1
Lawrie et al. (1963)	pig	ECR	250 lb	hogs		78.7 ± .2		3.44 ± .02	1.40 ± .06
Lawrie et al. (1964)	pig	LD	200 lb	boars				3.85	2.54
		ECR	"	"				3.48	1.16
		LD	200 lb	hogs				3.74	3.28
		ECR	"	"				3.35	1.32
		LD	260 lb	boars				3.82	2.68
		ECR	"	"				3.39	1.17
		LD	260 lb	hogs				3.87	3.96
		ECR	"	"				3.44	1.40
McMeekan (1940a)	pig	LD	birth		81.5	83.1			1.92
			4 weeks		75.8	79.2			4.32
			28 weeks		71.8	76.0			5.62
McMeekan (1940b)	pig*	LD		hogs	74.9				2.26
		LD		gilts	73.8				2.28
McMeekan (1940c)	pig**	LD		hogs	71.0				4.87
		LD		gilts	72.5				4.15

Table 1 (continued)

Source	Species or Breed	Muscle[3]	Stage of Growth (age or weight)	Sex	Muscle Constituents				
					% Water		% Nitrogen		% Fat
					1	2	1	2	1
Martin et al. (1963)	pig	Ham	200 lb	barrows	65.7		2.99		16.0
		"	"	gilts	66.9		3.04		13.0

a A-Angus; RP-Red Poll.

1 on whole tissue basis
2 on fat-free wet tissue basis
3 ST - semitendinosus
LD - longissimus dorsi
RH - rhomboideus
ECR - extensor carpi radialis
* pig on high level of nutrition
** pig on high-high level of nutrition

Lawrie, Pomeroy and Williams (1964) found that the LD of a double-muscled (doppelender) heifer had a higher percent nitrogen and a lower percent fat. This was also the case for other muscles. Other inherited differences have also been reported, especially those among breeds. Gillet, Pearson and Kirton (1965) showed that the percent protein in the muscles of Yorkshire pigs was significantly higher than that in the Hampshire breed. Gillet et al. (1967) compared three breeds of cattle and found that the muscle percent fat in Herefords was significantly higher than that in Aberdeen Angus steers, and that the percent water in Angus was significantly higher than that in Hereford steers. Callow (1962) also reported a significant effect of beef cattle breed on the fat content of muscle.

Some hormonal effects on muscle constituents of steers treated with estrogens have been reported. The lower percent fat in treated animals was the more distinct change (Bailey et al. 1966; Lawrie, 1960).

Table 1 shows that the differences in constituents of different muscles can be large. In pigs and cattle the LD was lower in percent water and higher in percent nitrogen when compared with the ST or the ECR. In pigs the LD was higher than the ECR but lower than the ST in percent fat (Gillet et al., 1965; Gillet et al., 1967; Lawrie et al., 1963; Lawrie, Pomeroy and Cuthbertson, 1964). In cattle the LD was higher than the ST in percent fat (Gillet et al., 1967). Similar results were obtained by Brungardt (1968) and Terrell, Suess and Bray (1969).

The sex of an animal could also influence the composition of muscles, especially the proportion of fat. Bailey et al. (1966) found that the percent ether extract on a dry matter basis in the LD of steers (17.3%) was higher than that in the LD of bulls (7.6%). Except for one instance in which the percent fat was similar (McMeekan, 1940b), castrates had a higher percent fat (Table 1) than boars or gilts (Kolaczyk and Kotik, 1966; Lawrie et al., 1964; McMeekan, 1940c; Martin

et al., 1963). The percent nitrogen was higher in gilts than in castrates (Kolaczyk and Kotik, 1966; Martin et al., 1963); in boars it was higher than in castrates at 200 lb but lower at 260 lb (Lawrie et al., 1964). There was also less variation in the proportion of water, protein, fat and ash in the muscles from males than in those from females (Doornenbal and Martin, 1966).

The effects of nutrition on muscle composition have been investigated in pigs. McMeekan (1940b, 1940c) established that, in general, muscles from pigs on a high plane of nutrition were higher in percent fat and lower in percent water. Martin et al. (1963) found a slight increase in percent protein and percent water and a decrease in percent ether extract in the ham of pigs on a high protein diet. In cattle, muscle protein:DNA ratio increased markedly during re-feeding after starvation (Lambourne, 1968), which suggested that the muscle cells can vary in size, depending on the level of nutrition.

IV. Developmental Changes in the Constituents of Skeletal Muscle Cells

Extensive studies have been made of the changes in the proportions of proteins and concentrations of electrolytes, in individual muscles during growth. Some of this work has been done with small animals (Dickerson, 1960; Gordon et al., 1966; Robinson, 1952). However, these changes have also been described during the growth of large farm animals (Dickerson and Widdowson, 1960; Helander, 1957; Lawrie, 1961b; Link et al., 1968).

Most workers have been concerned with the changes in the four nitrogenous fractions that constitute the total nitrogen (TN) content of muscle. Solutions of different ionic strength have been used to separate these four fractions: the non-protein nitrogen (NPN), the myofibrillar nitrogen (MYON), the sarcoplasmic nitrogen (SARN) and the stroma nitrogen (STRN); the last three include the proteins in muscle (Helander, 1957).

The myofibrillar proteins are the contractile proteins of the cell: tropomyosin, actin and myosin. These structural proteins form the myofibrils (Message, 1967). The sarcoplasmic proteins are the soluble proteins of the cell including myoglobin, myoalbumins, enzymes of the glycolytic pathway, etc. The stroma proteins are collagen, reticulin and elastin. These extracellular proteins form the endomysium, perimysium and epimysium of muscle. The NPN fraction includes amino acids, creatine, creatinine, etc. (Boyd, 1960). The turnover rate of soluble proteins is high, that of the structural proteins is low and the extracellular proteins are inert (Dreyfus, Kruh and Schapira, 1962). The rate of accumulation of protein during growth is probably influenced by these differences in metabolism.

Robinson (1952) found in chicks that g of protein per 100 g of fresh muscle weight increased rapidly after hatching. At hatching, the concentration of MYON was lower than that of SARN; these concentrations increased and were practically the same when they ceased to rise. The proportion of STRN in muscle did not change. These findings were partly supported by Dickerson (1960), but in this case the levels of MYON in chicks were at all time higher than those of SARN; the levels of STRN decreased with age (Table 2). In rats, Gordon et al. (1966) showed that MYON and SARN concentrations in muscle increased.

Changes in nitrogen fractions of muscle have also been studied in pigs and humans (Dickerson and Widdowson, 1960), as well as in cattle (Helander, 1957; Lawrie, 1960; 1961b), and are summarized in Table 2. As in chicks and rats, MYON, SARN and NPN increased and STRN decreased with age. The increments in TN, MYON and SARN were from about 50 to 100% of the value at birth (or near birth) in chicks, pigs and humans. In cattle, the

Table 2. Results reported by several authors concerning the developmental changes in the concentration of nitrogenous fractions in muscle

Source	Species	Muscle	Stage of Growth	TN[1] mg/g[2]	Nitrogen Fractions[1] MYON mg/g	SARN mg/g	STRN mg/g	NPN mg/g	K[1] mg/g	% Water
Dickerson (1960)	chick	pectoral	0 wks.	17.3	8.8	4.0	2.8	1.7	1.8	85.4
			2.5 wks.	29.5	16.9	6.6	1.6	4.2	4.9	77.1
			27 wks.	37.0	19.4	11.1	1.2	5.5	4.1	73.7
Dickerson and Widdowson (1960)	pig	thigh	0 wks.	15.4	6.5	2.2	2.3	2.6	2.8	82.3
			4-6 wks.	26.9	16.1	5.2	2.0	4.1	4.2	78.8
			adult	31.1	19.8	8.0	1.1	4.3	3.6	73.5
	human	thigh	0 mos.	20.7	10.9	3.9	3.8	2.4	2.3	80.4
			4-7 mos.	29.1	17.0	5.0	4.6	3.2	3.5	78.5
			adult	32.3	19.9	6.7	1.4	3.0	4.0	76.0
Gordon et al. (1966)	rat	quadri-ceps	immature		16.0	6.6				
			adult		17.9	8.3				
Helander (1957)	cattle	gastroc-nemius and soleus	1 wk.	29.5	14.8	7.0	5.0	2.7		77.1
			6 wks.	31.5	16.0	9.0	3.2	3.3		76.1
			8 mos.	32.9	18.2	7.9	3.4	3.4		76.2
Lawrie (1960)	cattle	longis-simus dorsi	calf	33.0	15.2	6.2	8.0	3.6		78.5
			steer	35.2	13.1	8.7	6.5	3.9		77.8

Table 2 (continued)

Source	Species	Muscle	Stage of Growth	TN[1]	Nitrogen Fractions[1]				K[1]	% Water
					MYON	SARN	STRN	NPN		
				mg/g[2]	mg/g	mg/g	mg/g	mg/g	mg/g	
Lawrie (1961b)	cattle (AxRP)[3]	longis-simus dorsi	4 mos.	34.5	16.9	9.6	4.1	3.9		78.3
			8 mos.	34.1	18.6	8.3	3.3	3.8		78.1
			12 mos.	35.0	18.1	10.0	2.8	4.1		78.3
	(Friesian)	longis-simus dorsi	18 mos.	36.3	20.2	7.5	4.0	4.6		76.8

1 TN - total nitrogen; MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen; K - potassium

2 mg of nitrogen per g of fresh muscle tissue

3 A - Angus; RP - Red Poll

increments were considerably smaller. The nitrogen content in young pigs and humans seems to be lower than that in cattle. In the older animals, the levels of nitrogen were similar in all species. This was the case for all nitrogen fractions with the exception of the high values for SARN and NPN in chicks and the low values for the same fractions in humans.

Small and large animals have been used to study the effects of hormones on muscle development. An increase of TN concentration, and especially of collagen, was detected in rat thigh muscle when growth hormone was injected (Scow, 1959; Scow and Hagan, 1965). Part of the increase in the MYON fraction could be accumulation of an 'inert' protein, because Gray and Young (1954) detected no increase in adenosine triphosphatase activity with increases in myofibrillar protein concentration. Thyroxine increased myosin deposition but had no effect on collagen and it increased the response to growth hormones in rats when both hormones were injected (Scow, 1959). Testosterone had an anabolic effect only on the levator ani and seminal vesicles of rats (Scow and Hagan, 1965). The dorso-scapular muscles in bulls had larger muscle fibres when compared with those of steers and cows (Jasienski, 1929). Lawrie (1960) reported small increases in TN and STRN and a decrease in MYON in the LD of a steer implanted with hexoestrol. The mechanism of action of some hormones influencing protein synthesis has also been studied. Korner (1962) concluded that growth hormone controls protein synthesis by acting on the ribosomes. Wilson (1962) found that testosterone enhances the peptide bonding of soluble RNA-amino acid complexes to form microsomal ribonucleoprotein. These and similar findings will permit the elucidation of the differential action of hormones on muscles and muscle proteins.

The composition of muscle in cattle showing muscular hypertrophy has been investigated. The percent SARN of TN was higher, that of MYON similar and that of STRN lower in the LD of a 'doppelender' heifer when compared with a normal sibling (Lawrie, et al., 1964).

Helander (1966) reported that exercise caused a significant increase in myofibrillar protein in guinea pigs, but no large change in any of the other fractions. He also compared immobilized calf muscles in rabbits with normal ones and found that there was a decrease only in the MYON fraction. Lawrie (1950) compared immobilized and normal pigs and found a decrease in myoglobin concentration in the LD.

The effect of starvation on muscle composition has been determined. During starvation there was a reduction in muscle fibre diameter and an increase in the proportion of connective tissue in muscle; there was quick recovery with realimentation (Yeates, 1964). Only myosin and sarcoplasmic proteins decreased in muscles of starved rats; there was no change in STRN or NPN fractions (Hagan & Scow, 1957). A high protein diet caused an increase in the TN, MYON and SARN fractions in pigs, but no change in the STRN and NPN concentrations were observed (Filer and Churella, 1963).

The symptoms of some inherited diseases are manifest in muscle. In human muscular dystrophy there is a decrease in concentration and amount of sarcoplasmic and myofibrillar protein. Muscular dystrophy in mice caused an increase in the turnover rate of these proteins (Dreyfus et al., 1962).

During muscle growth the concentration of intracellular and extracellular ions varies. Potassium is an intracellular ion and its concentration in muscle is used as an indicator of intracellular water. Dickerson and Widdowson (1960) and

Dickerson (1960) detected an increase in the concentration of potassium in the muscle of pigs, humans and chicks during growth (Table 2). These authors suggested, as did Yannet and Darrow (1938), that there was an increase in the proportion of intracellular water and a decrease in extracellular water as a result of growth of muscle fibres. Helander (1966) proposed the opposite point of view because some authors, such as Norris, Lundy and Shock (1963), found a decrease in potassium concentration during growth.

The potassium concentration in some muscles can differ. The concentration of potassium (on a wet tissue basis) in the LD of swine was significantly higher than in the ST; when the comparison was made on a fat-free dry muscle basis, the ST had a significantly higher concentration than the LD (Gillet et al., 1965). In cattle, the ST had a significantly higher concentration than the LD on a wet tissue basis and on a fat-free dry muscle basis (Gillet et al., 1967). There were also significant breed differences in swine (Gillet et al., 1965), and in cattle (Gillet et al., 1967) when the concentration was expressed as g of potassium per kg of protein.

EXPERIMENTAL

I. Objectives

The main purpose of this investigation was to describe the normal development of muscle in beef cattle. The more specific aims were to study:

1) the differences in the growth of bulls, heifers and steers,

2) the changes in the proportions of lean, fat and bone in beef carcasses,

3) the patterns of change of four muscles - M. semitendinosus, M. longissimus dorsi, M. rhomboideus and M. extensor carpi radialis -- in relation to the whole carcass, and

4) the changes in some of the constituents of these four muscles.

II. Materials and Methods

A. Experimental animals

The cattle used for this work were born and raised at the University of Alberta ranch at Kinsella. The general management of the research herd has been described elsewhere (Berg, 1962; 1966). The calves were born in April and May and weaned in October. Most of the animals were born in 1967, but the six youngest bulls and heifers and the two youngest steers were born a year later.

All the animals were sired by Shorthorn bulls. The dams were two years old and of diverse breeding; most of them were crossbreds (Appendix II, Tables 1, 2 and 3). A total of 44 animals were used: 16 bulls, 16 heifers and 12 steers. The live weights at the time of slaughter ranged from 35 to 547 kg for the bulls, from 191 to 478 kg for the steers and from 38 to 449 kg for the heifers (Appendix II, Tables 1, 2 and 3).

The slaughter plan adopted entailed killing at six stages during growth from birth to eighteen months; therefore, the six groups of bulls, steers and heifers were killed at similar live weights. Consequently, the average weights at slaughter were: 40 kg (two each of males and females); 80 kg (two males and two females); 187 kg (two bulls, two steers and two heifers); 270 kg (four each of bulls, steers and heifers); 374 kg (four each of bulls, steers and heifers); and finally, 478 kg (two bulls, two steers and two heifers).

Most of the animals were slaughtered routinely at a commercial slaughter house, but the four youngest males and four youngest females were killed in the laboratory, bled by hanging, and the carcasses were immediately dissected after taking muscle samples.

The calves were suckled by their dams from birth to six months of age, at which time they were weaned. At two months of age, castration was performed to obtain the group of steers. After weaning, the bulls, steers and heifers were housed in a feedlot until slaughter. All were self-fed a ration composed of 73% barley, 22% oats and 5% supplement (proteins, vitamins and minerals); in addition 0.9 kg of brome - alfalfa hay per head per day was supplied. Salt and water were available at all times.

B. Sampling methods

The four muscles selected for sampling were: M. semitendinosus (ST), M. longissimus dorsi (LD), M. rhomboideus (RH) and M. extensor carpi radialis (ECR). These were chosen because of their pattern of growth; they showed different growth impetus: ST and LD, high-average; RH, average-high and ECR, low growth impetus (Butterfield and Berg, 1966a). Other considerations were their large size in relation to the carcass (Butterfield and May, 1966) and their location

on the surface of the carcass, which made them accessible and permitted easy identification and quick sampling.

The samples were taken from the right side only, as soon as possible after death, when the hide was removed in the normal processing of carcasses. A large sample of at least 20 g was taken from the same part of the muscle in each animal. When the muscles were too small for sampling, as was the case in the calves, the whole muscle was excised.

The muscle constituents can vary in the different parts of a muscle; especially in one as large as the LD (Lawrie, 1961a; Topel et al., 1966). The sample from the LD was always taken from tissue over the last rib. The proximal part of the ST, the distal part of the ECR and the part of the RH nearest the cervical vertebrae were sampled.

All surface or excess fat and tendon was quickly separated from the muscle sample before chopping and freezing by use of solid carbon dioxide.

C. Analysis of muscle constituents

The samples were weighed frozen and the moisture content was determined by difference after drying to constant weight (AOAC, 1965). The dried sample was used for ether extract determinations and the fat-free material was then used for nitrogen and ash determinations (AOAC, 1965). Potassium analyses were made using a method described in Method 1 of Appendix I. All determinations were made in duplicate. When the differences between duplicates were greater than 5%, the analysis was repeated.

Within forty-eight hours of the collection of the samples, two buffer solutions were used to extract the myofibrillar (MYON) and sarcoplasmic (SARN) proteins. The method of extraction developed and recommended by Helander (1957)

was modified for use in the present study. Two other fractions were also separated from the tissue; alkali soluble stroma (STRN) and non-protein nitrogen (NPN). See Method 2 of Appendix I for details of the procedure of extraction. The nitrogen content of the four fractions was determined by the macro-Kjeldahl technique.

The amount of nitrogen in the SARN fraction was determined by subtracting the nitrogen in the NPN fraction from the nitrogen in the fraction extracted with the weaker buffer. Similarly, the nitrogen in the MYON fraction was obtained by subtracting the nitrogen in the fraction extracted with the weaker buffer from that in the one extracted with the stronger buffer.

D. Dissection procedure

The technique used was described by Butterfield and May (1966). The carcasses were chilled in the slaughterhouse and weighed in the laboratory prior to dissection. Only the left side was dissected into muscles, fat and bone. The weight of each individual muscle was recorded.

E. Statistical analysis

The regressions and correlations were calculated according to the methods described by Steel and Torrie (1960). The differences between regressions were tested for significance by a t-test. Only differences between bulls, steers and heifers were tested; those between muscles were not tested. All tests were done at the 5% level of significance.

For statistical analyses, the values from the four youngest bull calves were included with those of the steers; this was deemed necessary to more accurately describe growth in steers. The computations were done in an IBM 360/67 computer.

III. Results and Discussion

A. Changes in the percentage of carcass lean, fat and bone during growth

After dissection of the left side of the carcasses, the percentages of lean, fat and bone and the muscle:bone (M:B) ratio were calculated . The regressions of each of these variables against carcass weight were calculated and included, with the means, in Table 3. These regressions disclose the patterns of change in the proportions of tissues and in muscle:bone (M:B) ratio as carcass weight increases.

In all three sex groups, the percentage of lean (PCL) in the carcass and that of bone (PCB) decreased as carcass weight increased, but the percentage of fat (PCF) and M:B ratio increased. Carcasses from bulls had a higher percentage muscle and showed a smaller rate of decrease in percentage muscle than those from steers and the latter showed a similar advantage over those from heifers. The reverse was true when percentage fat was compared; carcasses from heifers had a higher proportion of fat and a more rapid increase of this measure, even though the rate of accumulation of fat was not significantly different from that in carcasses from steers. The percentage bone was higher in carcasses from steers than in those from heifers, but lower than in the ones from bulls. The rate of decrease of percentage bone was greater in carcasses from heifers than in those from bulls and, even though the carcasses from steers were intermediate, they did not differ significantly in rate from those of the other two sex groups. The average M:B ratio was similar in carcasses from bulls and heifers and slightly less in those from steers. The increase in M:B ratio was similar for the three sex groups.

These results are in agreement with trends described by Berg (1967). It is evident that if fat is an indicator of stage of maturity, heifers show earlier maturity than steers and steers earlier than bulls. The contention

Table 3. Regression coefficients (b) of Percent Carcass Lean (PCL), Percent Carcass Fat (PCF), Percent Carcass Bone (PCB) and Muscle:Bone Ratio (M:B) (Y) on Carcass Weight (X)

Dependent Variable (Y)	Group[1]	b[2] (%/kg)	Mean (Y) (%)	SD of Y (%)	SE of the Estimate (%)
PCL	B	$-.009 \pm .007^{a}$	65.11	2.61	2.53
	S	$-.038 \pm .008^{b}$	61.41	4.20	2.73
	H	$-.060 \pm .006^{c}$	60.31	5.13	1.92
PCF	B	$.046 \pm .006^{a}$	18.32	4.93	2.14
	S	$.086 \pm .010^{b}$	22.25	7.96	3.20
	H	$.112 \pm .009^{b}$	24.33	9.31	2.87
PCB	B	$-.040 \pm .005^{a}$	16.00	4.26	1.78
	S	$-.051 \pm .005^{ab}$	15.71	4.60	1.57
	H	$-.056 \pm .006^{b}$	14.91	4.74	1.82
M:B	B	$.009 \pm .001^{a}$	4.31	0.99	0.39
	S	$.010 \pm .001^{a}$	4.15	0.89	0.24
	H	$.011 \pm .001^{a}$	4.32	0.95	0.44

1 B - bulls; S - steers; H - heifers
2 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

is that, because changes in carcass composition were slower in bulls, they could be considered physiologically younger at any given age.

The relative growth of the four individual muscles for each of the three sex groups was studied by calculating the regression coefficients on age and on total muscle weight (Table 4). The former would give the rate of change of the muscle relative to time and the latter the rate of change relative to the total musculature. This is illustrated for the LD muscle in Figures 1 and 2.

The LD is a loin muscle, the ST a proximal hind limb muscle, the RH a neck muscle and the ECR a distal front limb muscle. The muscles are ranked according to size in Table 4 and it is evident that rate of growth of each muscle per day of age was related to the muscle's size; the LD was the largest and grew at the most rapid rate whereas the ECR was the smallest and slowest growing muscle.

Bulls grow more rapidly than steers and the latter more so than heifers; bulls also have a higher impetus for muscle growth than either steers or heifers. This was borne out when it was determined that individual muscles from bulls grew at significantly greater rates per day of age than those from steers or heifers. The rates for muscles from steers were higher than for the heifers, but not always significantly so.

The regressions of individual muscle weight on total muscle weight were used to compare the relative growth of the four muscles in each of the three sex groups. In the heifers, the LD showed a significantly greater increment in weight per kg of total muscle increase than in the steers or bulls. Similarly, the ST and RH increased at a significantly more rapid rate in the bulls than in the other two groups. In contrast, the rates for the ECR were similar in all three sex groups.

Table 4. Regression Coefficients (b) of Individual Muscle Weights (Y) on Age and Total Muscle Weight (X)

Muscles[1]	Groups[2]	Dependent Variable: Muscle Weight Mean (hg)	Dependent Variable: Muscle Weight SD (hg)	Independent Variables: Age b[3] (hg/day)	Age SE of Estimate (hg)	Total Muscle Weight b[3] (hg/kg)	Total Muscle Weight SE of Estimate (hg)
LD	B	30.73	19.23	$.136 \pm .011^{a}$	5.56	$.314 \pm .007^{a}$	1.64
	S	26.86	15.12	$.103 \pm .006^{b}$	3.09	$.315 \pm .008^{a}$	1.53
	H	26.77	14.30	$.092 \pm .006^{b}$	3.68	$.344 \pm .007^{b}$	1.15
ST	B	11.09	6.99	$.048 \pm .005^{a}$	2.44	$.114 \pm .002^{a}$	.45
	S	8.90	4.74	$.032 \pm .002^{b}$	1.17	$.098 \pm .003^{b}$	.59
	H	8.43	4.18	$.027 \pm .002^{b}$	1.10	$.101 \pm .002^{b}$	.37
RH	B	6.85	4.94	$.033 \pm .004^{a}$	2.14	$.080 \pm .003^{a}$	.71
	S	5.19	3.18	$.021 \pm .002^{b}$	1.04	$.066 \pm .003^{b}$	.53
	H	4.42	2.46	$.016 \pm .001^{c}$	.80	$.059 \pm .003^{b}$	.42
ECR	B	3.20	1.86	$.013 \pm .001^{a}$	.57	$.030 \pm .001^{a}$	.20
	S	2.86	1.47	$.010 \pm .001^{b}$	.27	$.031 \pm .001^{a}$	.14
	H	2.67	1.21	$.008 \pm .001^{c}$	.29	$.029 \pm .001^{a}$	.17

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

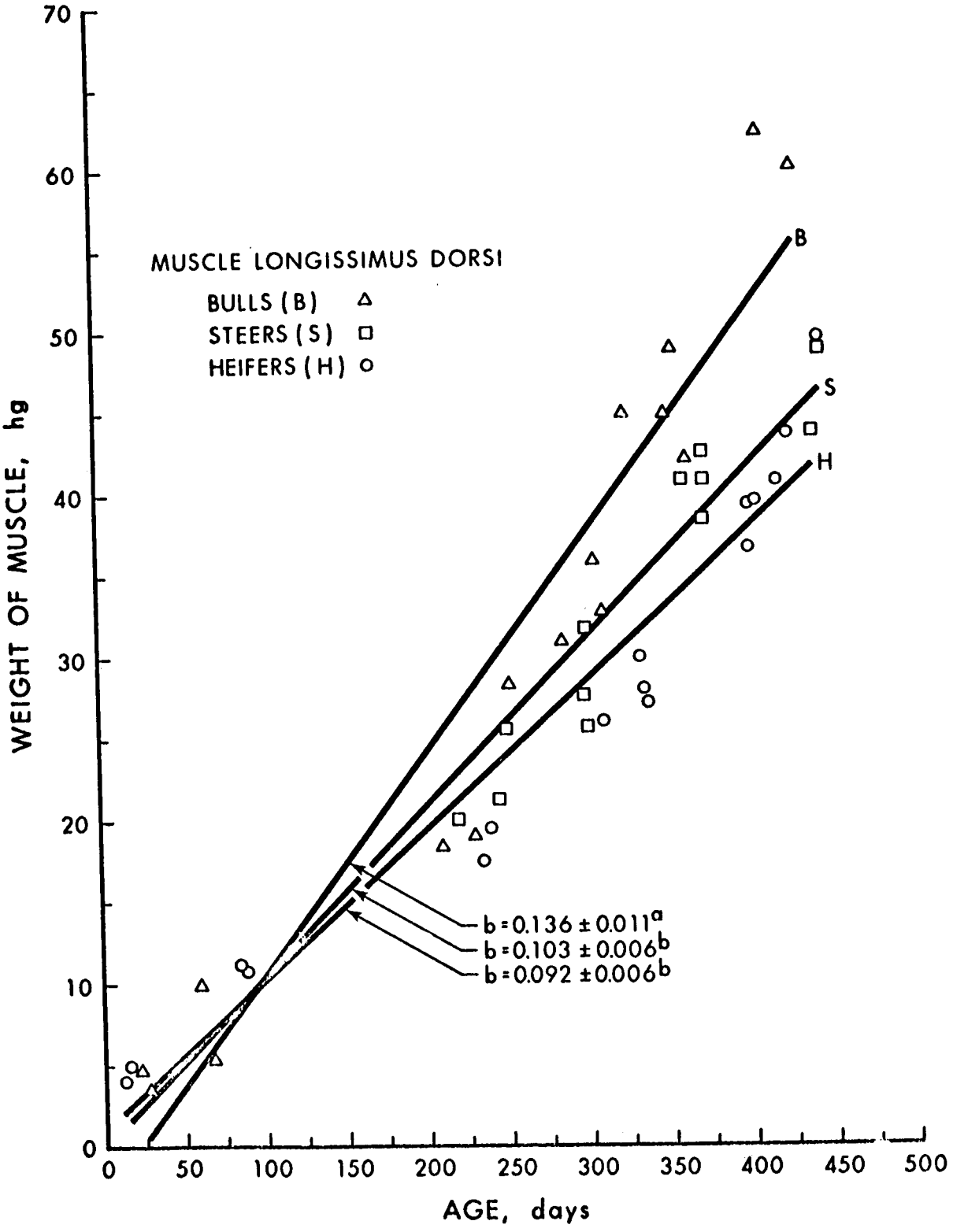


Figure 1. Regressions of Muscle Weight on Age for the Longissimus Dorsi from Bulls, Steers and Heifers

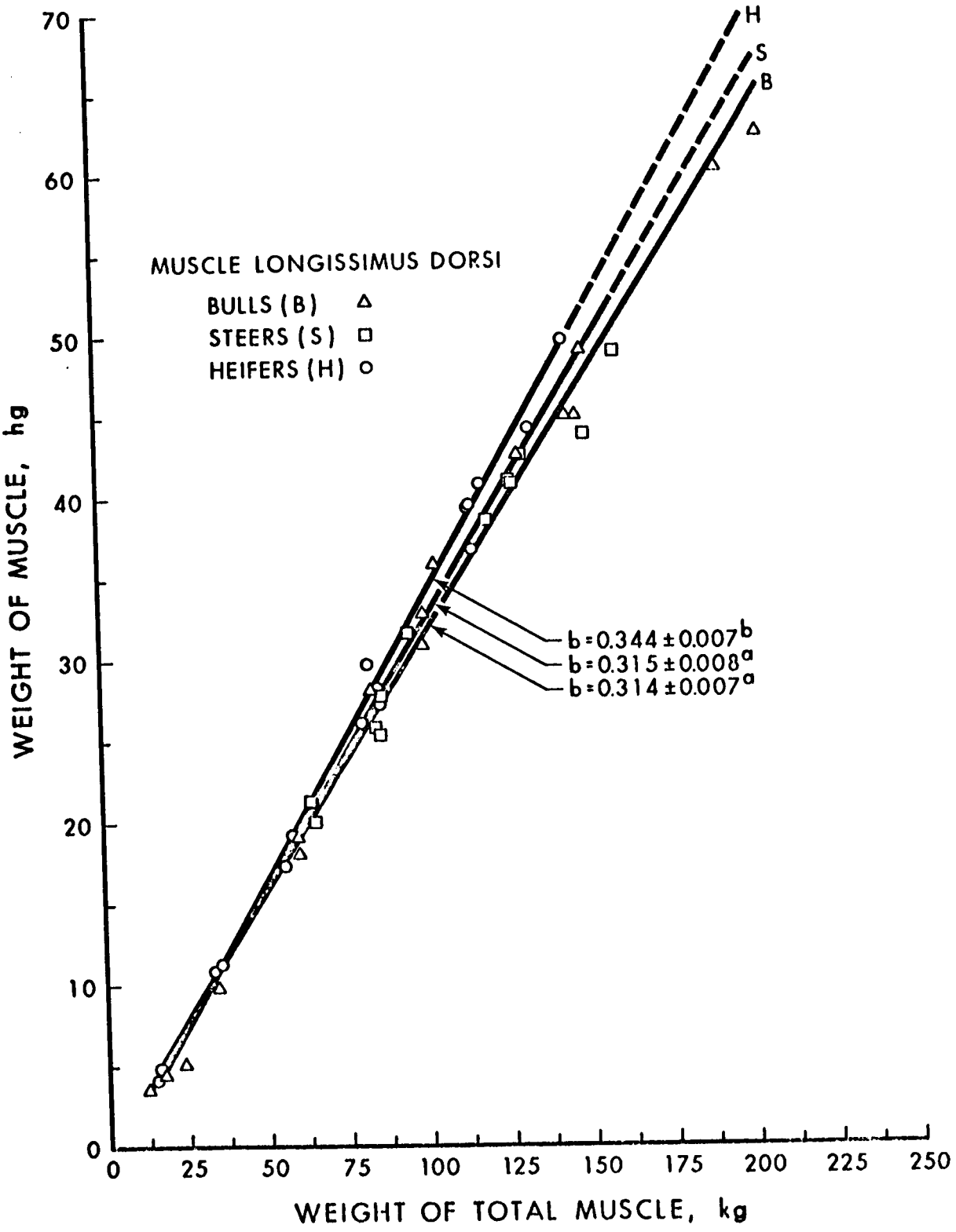


Figure 2. Regressions of Muscle Weight on Weight of Total Muscle for the Longissimus Dorsi from Bulls, Steers and Heifers

The standard errors of estimate, when total muscle was used as the predictor, were smaller than when age was the independent variable, indicating that changes in individual muscle weights were more dependent on changes in total muscle weight than on age.

B. Changes in the content and percentage of moisture in the four muscles during growth

The moisture content of each muscle for each sex was regressed on the age of the animal and on the weight of each individual muscle (Table 5). The regressions of percent moisture, on fresh muscle basis, against the same independent variables were included in Table 6.

When age was used as a predictor, the regressions were probably influenced by the rate of overall growth of each of the three groups, whereas the use of individual muscle weight as the independent variable allowed comparisons of relative changes in each one of the muscles. In this and later sections the pattern followed was to regress total content (weight of water, weight of nitrogen, etc.) on age and individual muscle weight, followed by regressions of proportionate content (percent water, percent nitrogen, etc.) on the same independent variables. The former permitted quantitative comparisons related to muscle weight whereas the latter allowed comparisons of changes in the proportions of major constituents among the sex groups, independently of muscle weight.

Increase in total water content of the four muscles (Table 5) followed the same pattern as that previously described for individual muscle weight. As moisture makes up the greater proportion of muscle tissue, this was an expected result.

The regressions of total moisture on individual muscle weight permitted comparisons independent of size comparisons (Table 5). In general,

Table 5. Regression Coefficients (b) of Moisture Content (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: Moisture Content Mean (hg)	Dependent Variable: Moisture Content SD (hg)	Independent Variables: Age b^3 (hg/day)	Independent Variables: Age SE of Estimate (hg)	Independent Variables: Individual Muscle Weight b^3 (hg/kg)	Independent Variables: Individual Muscle Weight SE of Estimate (hg)
LD	B	22.93	13.96	$.099 \pm .007^a$	3.71	$7.252 \pm .071^a$	.53
	S	19.85	10.88	$.074 \pm .004^b$	2.13	$7.194 \pm .051^a$	.30
	H	19.58	10.03	$.065 \pm .004^b$	2.28	$7.011 \pm .068^b$	.37
ST	B	8.35	5.17	$.036 \pm .003^a$	1.75	$7.398 \pm .038^a$	.10
	S	6.69	3.49	$.024 \pm .002^b$	.85	$7.367 \pm .039^a$	.07
	H	6.28	3.01	$.019 \pm .001^c$	.75	$7.200 \pm .044^b$	.07
RH	B	5.22	3.67	$.025 \pm .003^a$	1.54	$7.420 \pm .045^a$	.09
	S	3.89	2.29	$.015 \pm .001^b$	.70	$7.203 \pm .058^b$	.07
	H	3.30	1.76	$.011 \pm .001^c$	.54	$7.161 \pm .063^b$	.06
ECR	B	2.49	1.42	$.010 \pm .001^a$	.42	$7.640 \pm .040^a$	.03
	S	2.21	1.11	$.008 \pm .001^b$	.20	$7.538 \pm .048^a$	.03
	H	2.07	.91	$.006 \pm .001^c$	.21	$7.559 \pm .050^a$	.02

1 LD - longissimus dorsi;ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis

2 B - bulls; S - steers; H - heifers

3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$.

Table 6. Regression Coefficients (b) of Percent Moisture (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: % Moisture Mean (%)	SD (%)	Independent Variables: Age b[3] (%/day)	Age SE of Estimate (%)	Individual Muscle Weight b[3] (%/kg)	Individual Muscle Weight SE of Estimate (%)
LD	B	75.53	1.72	-.010 ± .002[a]	1.03	- .813 ± .100[a]	.74
	S	74.85	1.85	-.012 ± .001[a]	.55	-1.183 ± .081[b]	.48
	H	74.32	2.38	-.015 ± .001[a]	.83	-1.640 ± .076[c]	.42
ST	B	75.91	1.08	-.007 ± .001[a]	.56	-1.457 ± .139[a]	.38
	S	75.69	1.16	-.008 ± .001[a]	.45	-2.277 ± .247[b]	.45
	H	75.31	1.89	-.012 ± .001[b]	.43	-4.444 ± .222[c]	.36
RH	B	77.26	1.69	-.011 ± .002[a]	.86	-3.322 ± .221[a]	.42
	S	76.20	2.35	-.016 ± .001[b]	.77	-7.198 ± .441[b]	.54
	H	75.75	2.37	-.015 ± .001[b]	.86	-9.475 ± .492[c]	.47
ECR	B	78.31	1.06	-.007 ± .001[a]	.57	-5.228 ± .592[a]	.43
	S	77.73	1.36	-.009 ± .001[a]	.50	-8.830 ± .760[b]	.43
	H	77.99	1.31	-.008 ± .001[a]	.57	-10.004 ± 1.142[b]	.53

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis

2 B - bulls; S - steers; H - heifers

3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$.

the muscles from bulls accumulated more moisture per unit increase in weight than those from steers and the ones from steers more than those from heifers, but the differences were not always significant. The regressions of moisture content on age were evidently proportional to the size of the muscle, but those on individual muscle weight were inversely related to size. Consequently, there was a tendency for a more rapid increase in moisture relative to muscle weight in the smaller muscles when compared with the larger ones.

Additional evidence for the pattern of moisture changes can be obtained from the comparison of the rates of change of the proportion of moisture listed in Table 6. There was a decrease per day of age in the percentage of moisture in all muscles, but in most comparisons there was no difference between the sex groups. The exceptions were two instances in which the differences were significant. The ST muscle from heifers showed a more rapid decrease in percent moisture and in the RH from bulls percent moisture decreased at a smaller rate than in the RH from steers or heifers (Fig. 3). However, when rates based on muscle weight were compared, the four muscles from bulls showed a consistently slower decline in percent moisture than those from steers or heifers. The decrease in percent moisture in the muscles from heifers was more rapid than that in those from steers, but the difference was not significant for the ECR muscle.

The content of moisture seemed to be characteristic of each of the four muscles; the proportion of water in muscle was probably related to size, location and activity of the muscle, even though there was a general decrease with maturity. The ECR, a small muscle which shows low growth impetus and contracts quickly, had a higher proportion of water; the opposite was true for the LD, a large muscle which shows average growth impetus and contracts more slowly. In general, the muscles from bulls had a higher proportion of water and the decrease in percent moisture was slower.

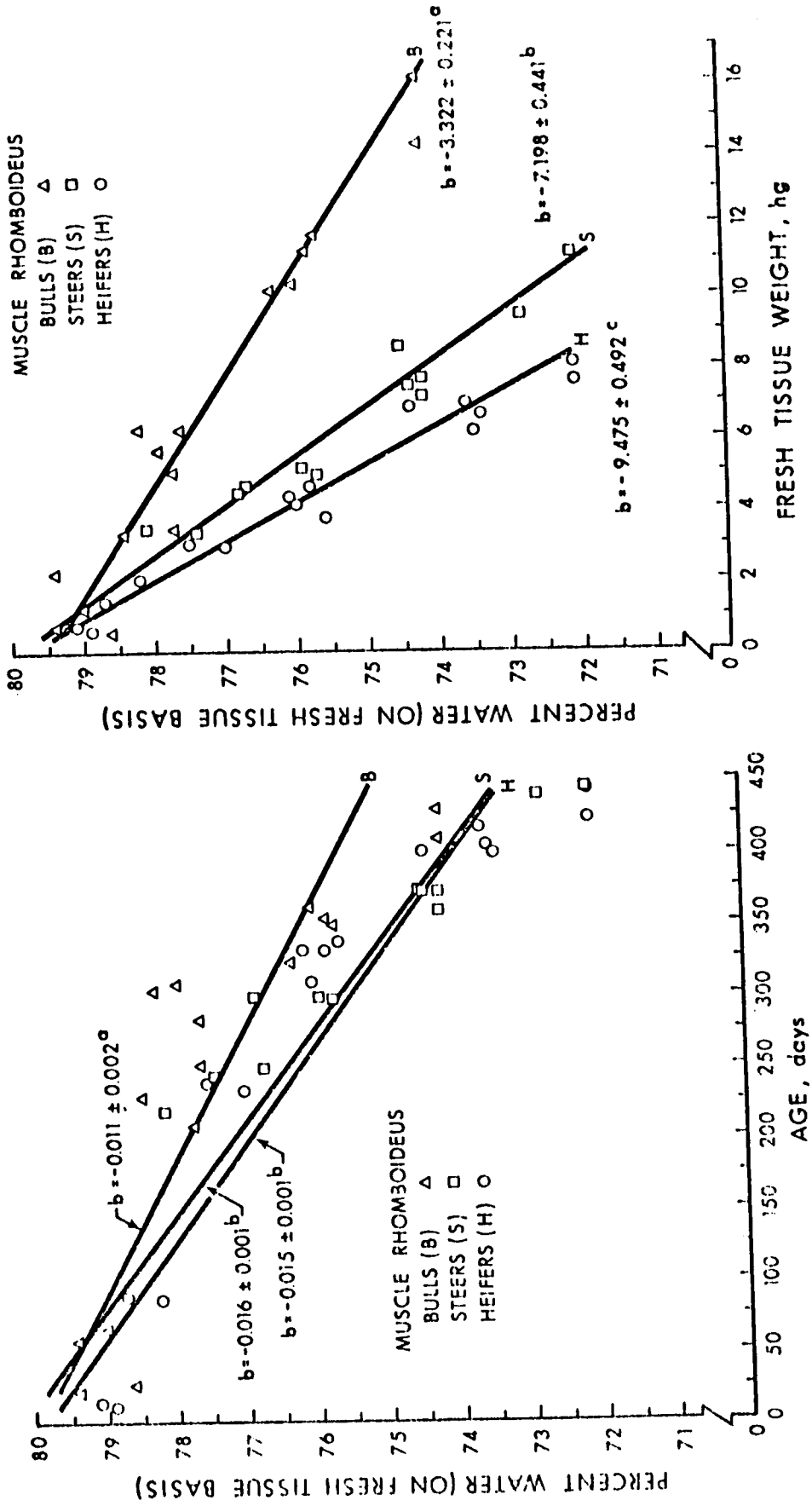


Figure 3. Regressions of Percent Water on Age and on Fresh Tissue Weight for the Rhomboideus from Bulls, Steers and Heifers

The decrease in percent water in bovine muscles has been detected by Helander (1957) and Lawrie (1960). However, the differences between the LD from calves and from steers (78.5 to 77.5%) reported by Lawrie (1960; 1961b) were smaller than those found in the present study (Appendix II, Table 8).

Differences between sexes were also established by McMeekan (1940b), who found that the LD from hogs had a higher content of moisture than from gilts. On the other hand, Martin et al. (1963) reported that the percent water in the ham from barrows was lower than that from gilts. These and the above findings agree with some of the results in this study.

C. Increases in the content and proportion of ether extract in the four muscles during growth

The rates of increase of ether extract (EE) content and of percent EE, dependent on increases in age and muscle weight, are reported in Tables 7 and 8.

The rates based on age were very similar for the three sex groups but not for the four muscles, as the larger regressions were associated with the larger muscles. A completely different pattern was observed when the regressions of EE on muscle weight were compared. In almost all cases the heifers showed a significantly greater rate of increase of EE per kg increase in muscle weight than the steers, and the steers a greater increase than the bulls. This was most noticeable when the LD and RH muscles from each group were compared.

These results indicated that the pattern of EE accumulation in any of the three sex groups was strongly dependent on the age of the animal and on the size of the muscle. The differences among sex groups were very obvious when the regressions on muscle weight were compared, especially when the larger muscles were involved (Fig. 4). The increases in EE only

Table 7. Regression Coefficients (b) of Ether Extract (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: Ether Extract Content Mean (hg)	Dependent Variable: Ether Extract Content SD (hg)	Independent Variables: Age b^3 (hg/day)	Age SE of Estimate (hg)	Individual Muscle Weight b^3 (hg/kg)	Individual Muscle Weight SE of Estimate (hg)
LD	B	.410	.363	$.0023 \pm .0003^{a}$	.183	$.180 \pm .015^{a}$	.109
	S	.538	.473	$.0030 \pm .0004^{a}$	.215	$.293 \pm .029^{b}$	.170
	H	.646	.582	$.0033 \pm .0005^{a}$	.315	$.387 \pm .034^{c}$	.187
ST	B	.108	.081	$.0005 \pm .0001^{a}$	.035	$.113 \pm .007^{a}$	.018
	S	.123	.098	$.0006 \pm .0001^{a}$	.044	$.199 \pm .015^{b}$	.027
	H	.126	.097	$.0006 \pm .0001^{a}$	.046	$.223 \pm .017^{b}$	.028
RH	B	.074	.066	$.0004 \pm .0001^{a}$	.033	$.131 \pm .006^{a}$	.012
	S	.091	.082	$.0005 \pm .0001^{a}$	.040	$.253 \pm .015^{b}$	.018
	H	.111	.095	$.0006 \pm .0001^{a}$	.048	$.376 \pm .026^{c}$	.025
ECR	B	.020	.017	$.0001 \pm .0000^{a}$	.009	$.084 \pm .009^{ab}$	.006
	S	.021	.013	$.0001 \pm .0000^{a}$	.005	$.088 \pm .006^{a}$	.004
	H	.021	.014	$.0001 \pm .0000^{a}$	.006	$.111 \pm .009^{b}$	.004

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis

2 B - bulls; S - steers; H - heifers

3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Table 8. Regression Coefficients (b) of Percent Ether Extract (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: % Ether Extract Mean (%)	SD (%)	Independent Variables: Age b[3] (%/day)	Age SE of Estimate (%)	Individual Muscle Weight b[3] (%/kg)	Individual Muscle Weight SE of Estimate (%)
LD	B	1.09	.44	$.0030 \pm .0004^{a}_{b}$	.19	$.218 \pm .055^{a}_{b}$	.15
	S	1.58	.85	$.0055 \pm .0006^{b}$	.32	$.532 \pm .048^{b}$	.28
	H	1.87	1.10	$.0067 \pm .0008^{b}$	.46	$.753 \pm .044^{c}$	.24
ST	B	.87	.23	$.0014 \pm .0002^{a}$	.13	$.257 \pm .055^{a}$	.15
	S	1.16	.47	$.0031 \pm .0003^{b}$	.17	$.959 \pm .069^{b}$	.13
	H	1.24	.56	$.0035 \pm .0004^{b}$	.21	$1.288 \pm .099^{c}$	.16
RH	B	.96	.26	$.0017 \pm .0002^{a}$	.12	$.431 \pm .077^{a}$	.15
	S	1.42	.61	$.0041 \pm .0003^{b}$	.17	$1.878 \pm .115^{b}$	.14
	H	1.98	.99	$.0062 \pm .0006^{c}$	.36	$3.914 \pm .262^{c}$	.25
ECR	B	.58	.16	$.0006 \pm .0003^{a}$	.14	$.453 \pm .192^{a}$	.14
	S	.67	.16	$.0009 \pm .0002^{ab}$	.10	$.829 \pm .188^{a}$	.11
	H	.73	.21	$.0013 \pm .0001^{b}$	.07	$1.616 \pm .156^{b}$	.07

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

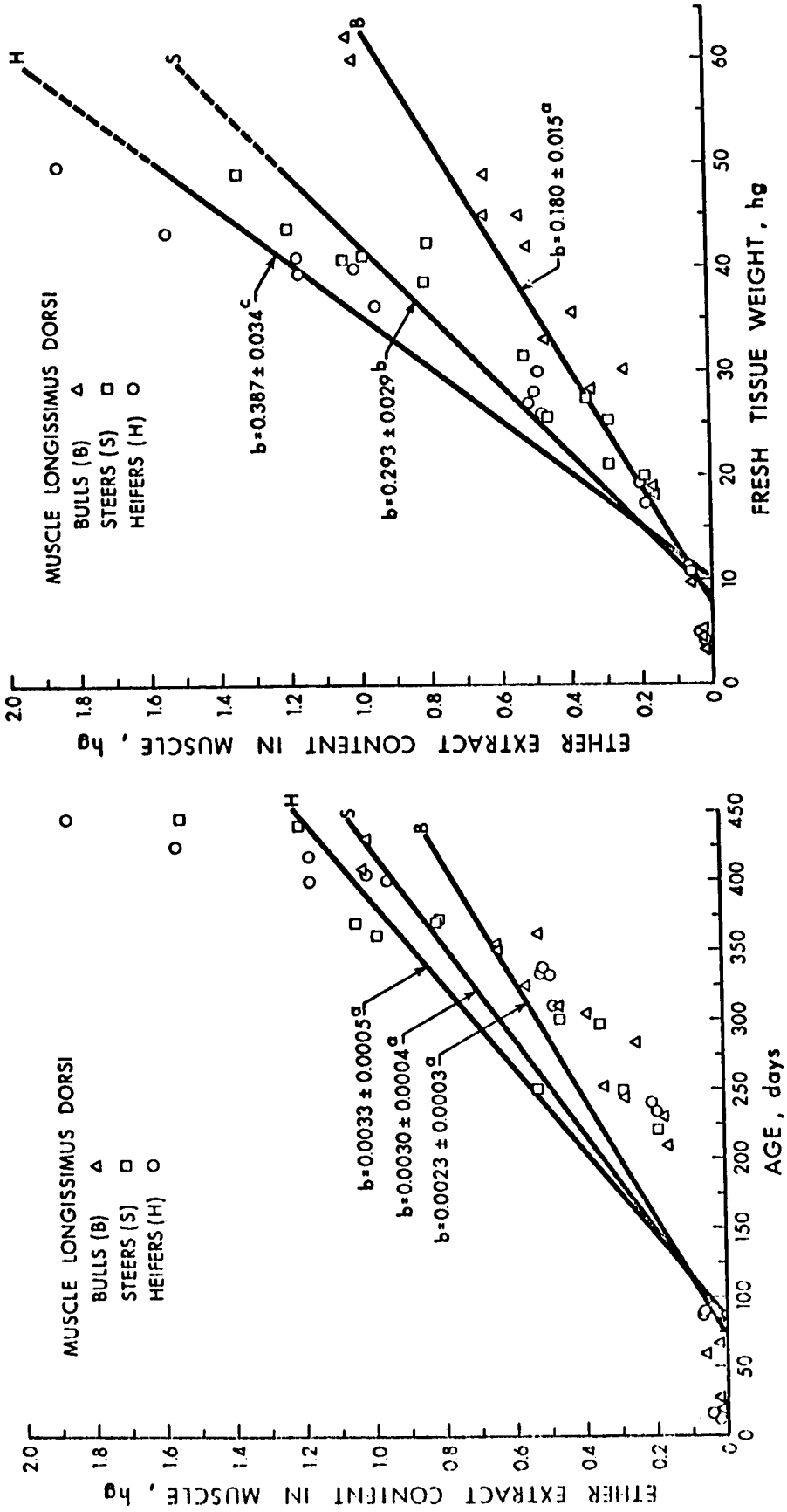


Figure 4. Regressions of Ether Extract Content on Age and Fresh Tissue Weight for the Longissimus Dorsi from Bulls, Steers and Heifers

reflected the increments in intramuscular (interstitial) fat, because any excess fat was removed when sampling. For this reason, the EE fraction did not include all the ether soluble fat normally associated with muscle tissue.

The increase in percent EE was more rapid in the heifers than in the steers and more so in the steers than in the bulls, both when the regressions were based on age and on muscle weight (Table 8). When age was the independent variable, the only muscle from bulls and steers that was not significantly different in rate was the ECR. In contrast, the only significant difference in rate between the steers and heifers was found in the RH muscle. However, when the regressions based on muscle weight were compared, all the differences among the sex groups were significant, except for the ECR from bulls and steers. These differences in the rate of increase of percent EE were probably a consequence of the size and rapid growth in the muscles from bulls in relation to those from steers and heifers. The same would apply to some comparisons between steers and heifers, but in most cases, the similarities between the two suggested that there was a parallelism in the rate of fat accumulation in their muscles.

There was also some evidence of hormonal influence (mainly androgenic) on fat deposition, especially in the RH muscle, apparent from the very large differences observed among the sex groups for this and other muscles.

It was interesting to note that the ranking of the four muscles according to their percent EE was not the exact reverse of the order observed for percent water. In almost all cases, the higher percent EE was found in the LD, followed by the RH, then the ST and finally the ECR; for percent water the order was: ECR, RH, ST and LD, from higher to lower percentages.

The influence of sex on the fat content of muscles has been determined by Bailey et al.(1966), who found that the LD from steers had a higher proportion of fat than that from bulls. Similarly, for swine muscles, Kolaczyk

and Kotik (1966) established that the LD from barrows had more fat than from gilts. Lawrie et al.(1964) found that the fat content in the LD and ECR from hogs was higher than that in those from boars. The present findings and the above information demonstrate the tendency in the pattern of fat deposition in castrates to resemble that of heifers rather than that of entire animals.

D. Variation in the amount and proportion of ash during growth

The regressions of ash content on age showed that the muscles from bulls usually accumulated ash at a significantly greater rate than those from steers or heifers, with the exception of the ECR (Table 9). This was probably a consequence of the larger muscles in bulls, as the rates based on muscle weight were very similar. However, the comparison of regressions on weight of muscles showed that the increase of ash occurred at a significantly slower rate in the LD muscle from steers compared to heifers and in the RH from steers compared to bulls; the regressions for the other muscles were similar for the three groups.

The rate of change for percent ash was not significantly different for any of the comparisons made (Table 10). Nevertheless, it was interesting to establish that the proportion of ash tended to decrease in the ST and in most muscles from the steers, except the ECR. However, because there was only a small variation in percent ash, these regressions were not too reliable.

E. Changes in the accretion and proportion of nitrogen during development

Because the proportion of non-protein nitrogen is usually very small in healthy muscle during post-natal growth, the content of nitrogen in muscle is a direct reflection of the amount of protein present. Unfortunately, the factor used to convert nitrogen measurements to protein values can vary according to the concentration of nitrogen in specific proteins. For this reason, only

Table 9. Regression Coefficients (b) of Ash Content (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: Ash Content Mean (hg)	Ash Content SD (hg)	Independent Variables: Age b^3 (hg/day)	Age SE of Estimate (hg)	Individual Muscle Weight b^3 (hg/kg)	Individual Muscle Weight SE of Estimate (hg)
LD	B	.278	.177	$.0012 \pm .0001^{a}$	.061	$.089 \pm .006^{a}$	.045
	S	.221	.114	$.0008 \pm .0001^{b}$	.036	$.073 \pm .005^{a}$	.031
	H	.241	.132	$.0008 \pm .0001^{b}$	.055	$.087 \pm .008^{a}$	.044
ST	B	.102	.062	$.0004 \pm .0000^{a}$	.024	$.081 \pm .009^{ab}$	.025
	S	.076	.036	$.0002 \pm .0000^{b}$	.014	$.070 \pm .008^{a}$	.015
	H	.083	.041	$.0003 \pm .0000^{a}$	.011	$.096 \pm .005^{b}$	.009
RH	B	.056	.042	$.0003 \pm .0000^{a}$	.020	$.084 \pm .004^{a}$	.008
	S	.040	.023	$.0002 \pm .0000^{b}$	.006	$.069 \pm .005^{b}$	.006
	H	.038	.021	$.0001 \pm .0000^{c}$	.008	$.083 \pm .006^{ab}$	.006
ECR	B	.028	.016	$.0001 \pm .0000^{a}$	.005	$.083 \pm .006^{a}$	.004
	S	.024	.013	$.0001 \pm .0000^{a}$	.005	$.084 \pm .006^{a}$	.005
	H	.023	.011	$.0001 \pm .0000^{a}$	.004	$.083 \pm .008^{a}$	.004

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Table 10. Regression Coefficients (b) of Percent Ash (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: % Ash Mean (%)	% Ash SD (%)	Independent Variables: Age b[3] (%/day)	Age SE of Estimate (%)	Individual Muscle Weight b[3] (%/kg)	Individual Muscle Weight SE of Estimate (%)
LD	B	.91	.11	-.00007 ± .00021[a]	.11	-.009 ± .015[a]	.11
	S	.86	.10	-.00045 ± .00014[a]	.08	-.044 ± .013[a]	.08
	H	.91	.14	-.00003 ± .00024[a]	.14	-.006 ± .025[a]	.14
ST	B	.93	.13	.00007 ± .00025[a]	.13	-.024 ± .048[a]	.13
	S	.88	.12	-.00024 ± .00022[a]	.12	-.104 ± .064[a]	.12
	H	.98	.10	.00015 ± .00018[a]	.10	.030 ± .065[a]	.11
RH	B	.82	.06	.00002 ± .00012[a]	.06	-.006 ± .033[a]	.06
	S	.81	.09	-.00020 ± .00016[a]	.09	-.149 ± .065[a]	.08
	H	.84	.11	.00010 ± .00019[a]	.11	.038 ± .117[a]	.11
ECR	B	.84	.11	.00013 ± .00021[a]	.11	.083 ± .151[a]	.11
	S	.85	.07	.00010 ± .00013[a]	.07	.090 ± .129[a]	.07
	H	.85	.10	.00006 ± .00017[a]	.10	.025 ± .217[a]	.10

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

nitrogen measurements are reported in this study.

The regressions of the amount of muscle nitrogen on age and on muscle weight are included in Table 11. The general pattern observed for the former was that nitrogen increased most rapidly per day of age in the bulls and more rapidly in the steers than in the heifers, but the differences were not always significant. The rates were significantly greater in the bulls than in the steers, except for the RH muscle, but were only significantly greater in steers than in heifers for the RH and ECR muscles. As was the case for other constituents, the rates for the larger muscles were more rapid.

The increases in nitrogen per kg of muscle weight were similar among sex groups with two exceptions. The rate of increase was significantly smaller in the steers than in the heifers for the ST and greater in steers than in the bulls for the RH. These findings suggest that in most cases the accretion of nitrogen was more dependent on the increase in muscle weight than on age. The few noticeable differences observed, especially in the ST and RH muscles, were probably evidence of specific hormonal influence on protein synthesis.

Further evidence of hormonal control of protein deposition was obtained when the rates of increase of percent nitrogen, listed in Table 12, were compared. As above, when the regressions on muscle weight were compared, the increases in the proportion of nitrogen per day of age were similar among the sex groups except for two instances: the rate was significantly greater in heifers than in bulls or steers for the ST, as well as significantly greater in steers than in heifers for the RH muscle. Because the regressions of percent nitrogen, based on muscle weight, were similar in heifers and steers, except for the ST, the contention that increases in nitrogen concentration were basically dependent on increases in the weight of the muscle becomes stronger.

Table 11. Regression Coefficients (b) of Nitrogen Content (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: Nitrogen Content Mean (hg)	Dependent Variable: Nitrogen Content SD (hg)	Independent Variables: Age b[3] (hg/day)	Independent Variables: Age SE of Estimate (hg)	Independent Variables: Individual Muscle Weight b[3] (hg/kg)	Independent Variables: Individual Muscle Weight SE of Estimate (hg)
LD	B	1.060	.715	$.0049 \pm .0005^{a}$	.252	$.370 \pm .009^{a}$	.065
	S	.935	.556	$.0038 \pm .0002^{b}$	.128	$.367 \pm .005^{a}$	.031
	H	.931	.530	$.0034 \pm .0003^{b}$	.157	$.370 \pm .005^{a}$	.027
ST	B	.376	.249	$.0017 \pm .0002^{a}$	.096	$.356 \pm .006^{ab}$	.015
	S	.302	.168	$.0011 \pm .0001^{b}$	.044	$.354 \pm .005^{a}$	.009
	H	.290	.155	$.0010 \pm .0001^{b}$	.045	$.370 \pm .005^{b}$	.008
RH	B	.222	.174	$.0011 \pm .0002^{a}$	.084	$.351 \pm .006^{a}$	.012
	S	.175	.119	$.0008 \pm .0001^{b}$	.045	$.374 \pm .008^{b}$	.010
	H	.145	.087	$.0005 \pm .0001^{b}$	.032	$.354 \pm .005^{ab}$	.005
ECR	B	.101	.062	$.0004 \pm .0000^{a}$	.021	$.333 \pm .005^{a}$	.004
	S	.092	.051	$.0003 \pm .0000^{b}$	.011	$.348 \pm .008^{a}$	.005
	H	.083	.040	$.0002 \pm .0000^{c}$	.011	$.334 \pm .006^{a}$	.003

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Table 12. Regression Coefficients (b) of Percent Nitrogen (Y) on Age and Individual Muscle Weights (X)

Muscles[1]	Groups[2]	Dependent Variable: % Nitrogen Mean (%)	SD (%)	Independent Variables: Age b[3] (%/day)	Age SE of Estimate (%)	Individual Muscle Weight b[3] (%/kg)	Individual Muscle Weight SE of Estimate (%)
LD	B	3.343	.208	$.0012 \pm .0003^{a}$	.140	$.093 \pm .015^{a}$	.110
	S	3.389	.183	$.0012 \pm .0001^{a}$	.076	$.113 \pm .012^{a}$	.068
	H	3.385	.189	$.0012 \pm .0001^{a}$	.054	$.130 \pm .007^{a}$	.039
ST	B	3.319	.138	$.0008 \pm .0002^{a}$	.094	$.171 \pm .027^{a}$	.072
	S	3.334	.127	$.0008 \pm .0001^{a}$	.066	$.226 \pm .038^{a}$	.070
	H	3.350	.208	$.0014 \pm .0001^{b}$	.043	$.485 \pm .029^{b}$	.047
RH	B	3.087	.234	$.0014 \pm .0003^{ab}$	.147	$.443 \pm .045^{a}$	.085
	S	3.205	.289	$.0019 \pm .0002^{b}$	.115	$.877 \pm .065^{b}$	.079
	H	3.163	.216	$.0014 \pm .0001^{a}$	.073	$.869 \pm .037^{b}$	.035
ECR	B	3.063	.157	$.0009 \pm .0002^{a}$	.100	$.736 \pm .112^{a}$	.080
	S	3.138	.195	$.0012 \pm .0002^{a}$	.089	$1.215 \pm .143^{b}$	.081
	H	3.054	.165	$.0010 \pm .0001^{a}$	.066	$1.267 \pm .136^{b}$	.064

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis

2 B - bulls; S - steers; H - heifers

3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Whereas in this study the muscles from steers showed similar percent nitrogen to those from heifers, in pigs percent nitrogen was reported to be higher in gilts than in castrates (Kolaczyk and Kotik, 1966; Martin et al.1963).

To measure changes in nitrogen concentration independently of other constituents, especially fat, regressions of nitrogen:water ($N:H_2O$) ratios on fat-free fresh muscle weight were computed (Table 13). Another important reason for the inclusion of $N:H_2O$ ratios was the suggestion made by Bailey et al.(1960) that $N:H_2O$ ratios could be used as an index of physiological development.

The results show that the rates of increase of the $N:H_2O$ ratio were greater in the heifers than in the steers and greater in the steers than in the bulls, but the differences were not always significant (Figs. 5 and 6). The differences between bulls and heifers were significant in every case. However, the rates in steers were similar to those in bulls only for the LD and ST muscles, but were significantly different from those in heifers. In contrast, the steers were similar to heifers in their rates for the RH and ECR, but significantly different from bulls. It seemed as if the pattern of change of nitrogen concentration in the smaller muscles was affected to a greater extent by castration. This effect was noticeable probably because variation inherent in fat content was excluded by these calculations.

F. Changes in the concentration of potassium during muscle growth

The increase in potassium concentration as muscle weight increases (Appendix II, Tables 4 to 15) has been reported previously in work with muscle from chicks, pigs and humans (Dickerson, 1960; Dickerson and Widdowson, 1960).

Regressions of potassium:water on fat-free fresh muscle weight were calculated to determine the differences in rate of increase among the sex groups (Table 13). Although there was a general increase in potassium:water ratio as the muscles grew, the regression coefficients had relatively large standard

Table 13. Regression Coefficients (b) of Nitrogen:Water and Potassium:Water Ratios (Y) on the Weight of Fat-Free Wet Muscle (X)

Muscles[1]	Groups[2]	Nitrogen:Water[3] b[4] (ratio/kg)	Mean	SD	SE of Estimate	Potassium:Water[3] b[4] (ratio/kg)	Mean	SD	SE of Estimate
LD	B	.177 ± .026[a]	4.435	.382	.193	.099 ± .050[a]	5.531	.400	.366
	S	.228 ± .020[a]	4.536	.353	.116	.236 ± .070[a]	5.512	.516	.396
	H	.286 ± .014[b]	4.566	.401	.076	.124 ± .075[a]	5.134	.424	.401
ST	B	.314 ± .042[a]	4.376	.243	.113	.453 ± .121[a]	5.627	.441	.322
	S	.441 ± .065[a]	4.409	.234	.117	.876 ± .241[a]	5.651	.583	.432
	H	.919 ± .049[b]	4.457	.384	.078	.422 ± .249[a]	5.416	.419	.400
RH	B	.765 ± .070[a]	4.004	.395	.132	.260 ± .147[a]	4.581	.297	.278
	S	1.603 ± .111[b]	4.221	.513	.133	1.286 ± .329[b]	4.816	.551	.394
	H	1.745 ± .081[b]	4.188	.417	.074	1.352 ± .375[b]	4.549	.459	.342
ECR	B	1.210 ± .170[a]	3.914	.253	.122	1.247 ± .559[a]	4.667	.451	.401
	S	2.041 ± .234[b]	4.043	.323	.132	1.969 ± .765[a]	4.827	.505	.431
	H	2.144 ± .234[b]	3.920	.277	.108	1.400 ± .527[a]	4.366	.289	.244

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Nitrogen:Water ratios were multiplied by 100; Potassium:Water ratios by 1000
4 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

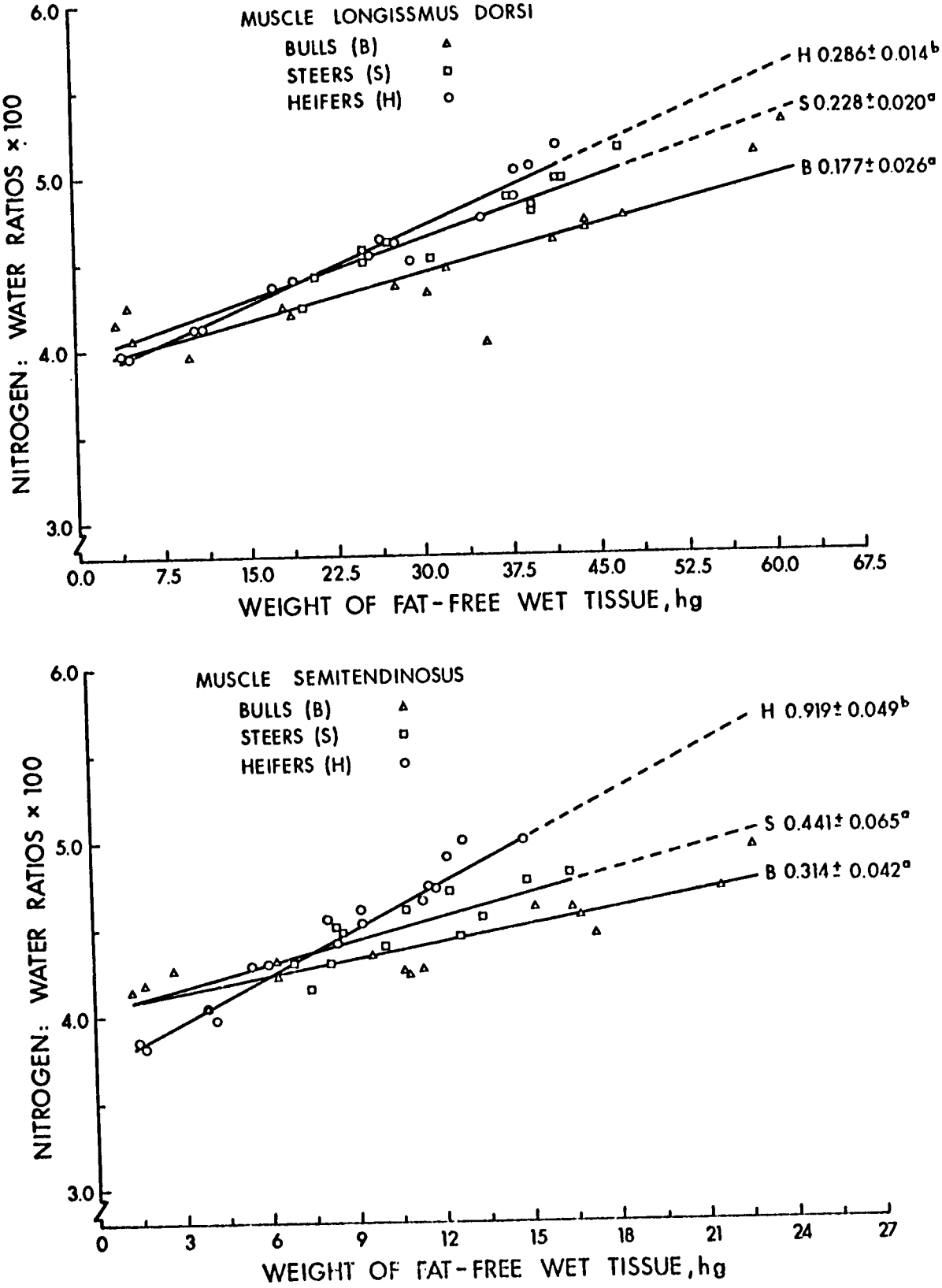
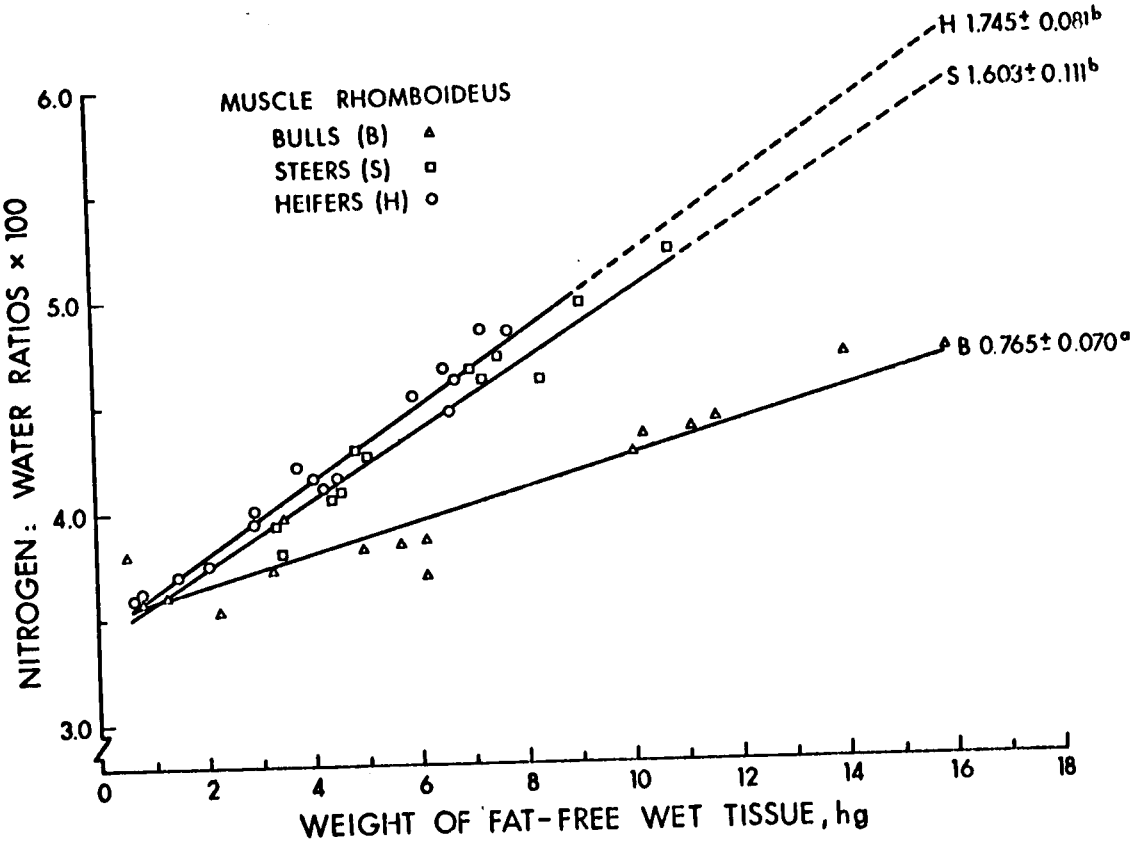


Figure 5. Regressions of Nitrogen:Water Ratios on Weight of Fat-Free Wet Tissue for the Longissimus Dorsi and Semitendinosus from Bulls, Steers and Heifers



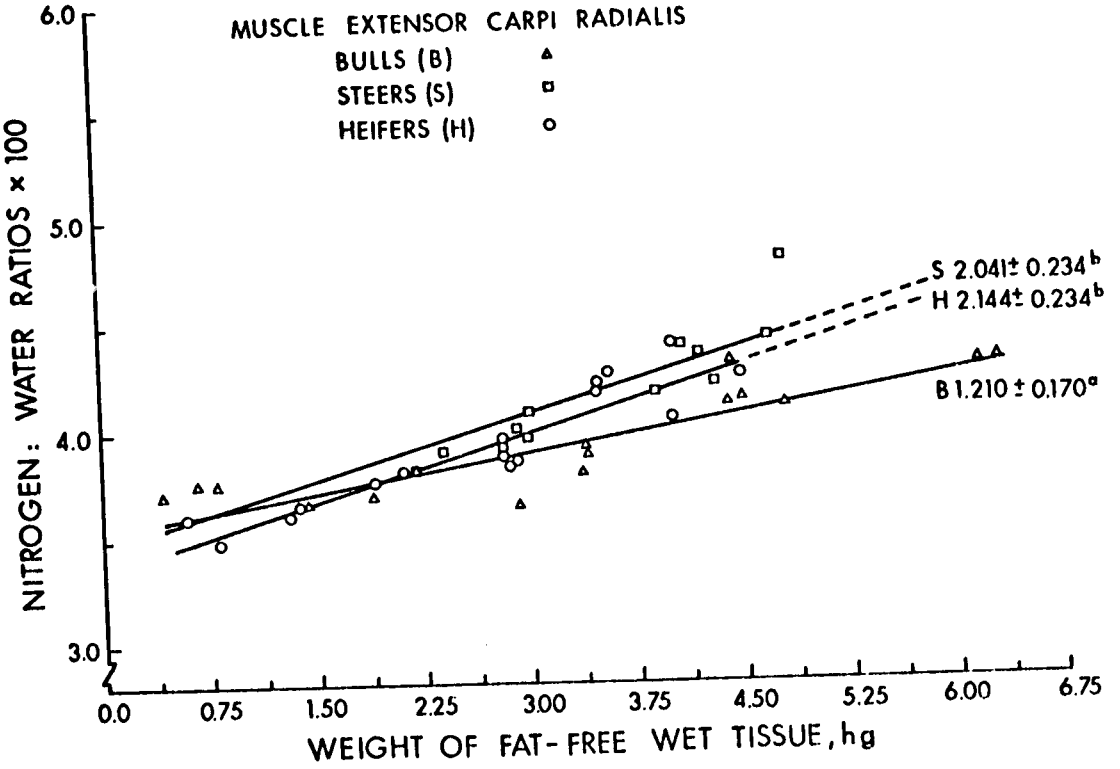


Figure 6. Regressions of Nitrogen:Water Ratios on Weight of Fat-Free Wet Tissue for the Rhomboideus and Extensor Carpi Radialis from Bulls, Steers and Heifers

errors associated and significant differences among sex groups occurred in only one case. The rate of increase of the potassium:water ratio was significantly smaller only in the RH from bulls. Bull muscles tended to increase in potassium: water ratio at a slower rate than steers or heifers which may be a reflection of changes in percent water reported in an earlier section. The rates were also inversely related to the size of the muscles which suggests that the greater rates in the smaller muscles were associated with the more rapid decrease in percent moisture. The average ratio was larger in the ST than in the LD and larger in the latter than in either of the two smaller muscles. This agreed with Gillet et al. (1967), who found a larger concentration of potassium (on a wet tissue basis) in the ST than in the LD muscle of cattle.

The general increase in potassium concentration was evidence for an increase in the proportion of intracellular water, most likely as a result of hypertrophy. This interpretation was suggested by Dickerson and Widdowson (1960) to explain their results.

G. Developmental changes in the amount and proportion of four nitrogenous fractions

The results of the analyses of individual muscles from bulls, steers and heifers demonstrated that in every animal, regardless of age or weight, myofibrillar nitrogen (MYON) made up the greater proportion of the total nitrogen (TN) content in muscle. The second largest fraction was sarcoplasmic nitrogen (SARN), followed by stroma nitrogen (STRN) and, finally non-protein nitrogen (NPN) (Appendix II, Tables 4 to 15).

The relative changes of the four fractions were determined by calculating regressions of each one of the fractions on total nitrogen content (Tables 14 and 16). To detect any changes in the proportion of these fractions, i.e. changes in the ratios MYON:TN, SARN:TN, STRN:TN and NPN:TN,

regressions of each one of these ratios on fat-free muscle weight were computed (Tables 15 and 17). Other workers have reported the nitrogenous fractions on the basis of mg/g of wet muscle tissue. These proportions would be very markedly influenced by the decrease in water which occurs as muscles mature. The purpose of looking at the nitrogen fractions relative to TN was to remove the bias which moisture content would cause and to look at the changes of the nitrogen fractions relative to each other and to the change in TN.

In general, the rates of increase of MYON based on TN were greater in the steers than in the bulls and greater in the bulls than in the heifers (Table 14). Not all the differences between two of the groups were significant. The rates for the bulls and steers were significantly different only in the case of the ST and ECR muscles; those for the bulls and heifers were only significantly different in the comparisons of the LD and ST muscles. The rates in the steers were significantly greater than those in the heifers for all muscles, except for the ST. There seemed to be a characteristic rate of increase of MYON for every muscle, dependent to some degree on the sex of the animal and on the size of the muscle. The accumulation of SARN was, as expected, inversely related to the deposition of MYON (these two fractions make up the bulk of the nitrogen in muscle). In this instance, the heifers usually showed a significantly greater rate of increase of SARN relative to TN than did steers, except for the LD. The rates in the bulls were smaller than those in the steers for the LD and ST muscles but larger for the RH and ECR muscles.

When the rates of change of the MYON:TN and SARN:TN fractions were compared, the complete picture emerges (Table 15). In general, changes in the proportion of MYON and in SARN were not consistent among sex groups or for different muscles. There was little change in proportions of either fraction in the LD from bulls and steers, but the LD from heifers accumulated

Table 14. Regression Coefficients (b) of Myofibrillar (MYON) and Sarcoplasmic (SARN) Nitrogen Fractions (Y) on Total Nitrogen (TN) Content (X)

		MYON				SARN			
Muscles[1]	Groups[2]	b[3] (hg/hg)	Mean (hg)	SD (hg)	SE of Estimate (hg)	b[3] (hg/hg)	Mean (hg)	SD (hg)	SE of Estimate (hg)
LD	B	$.519 \pm .007^{a}$	.542	.372	.020	$.341 \pm .006^{a}$	.366	.244	.016
	S	$.521 \pm .008^{a}$	.478	.290	.017	$.363 \pm .007^{b}$	.337	.202	.015
	H	$.467 \pm .010^{b}$	.449	.248	.020	$.419 \pm .008^{c}$	.365	.222	.016
ST	B	$.506 \pm .004^{a}$	.190	.126	.004	$.341 \pm .006^{a}$	.127	.085	.006
	S	$.490 \pm .006^{b}$	.149	.082	.004	$.372 \pm .006^{b}$	.107	.063	.004
	H	$.480 \pm .007^{b}$	.142	.074	.004	$.387 \pm .006^{b}$	.106	.060	.004
RH	B	$.539 \pm .007^{ab}$	.118	.094	.005	$.300 \pm .008^{ab}$	.068	.052	.005
	S	$.554 \pm .007^{a}$	.094	.066	.003	$.279 \pm .010^{a}$	.052	.034	.004
	H	$.533 \pm .006^{b}$	.076	.046	.002	$.317 \pm .005^{b}$	.045	.028	.002
ECR	B	$.522 \pm .006^{a}$	.052	.032	.001	$.320 \pm .006^{a}$	.031	.020	.002
	S	$.552 \pm .007^{b}$	.049	.028	.001	$.281 \pm .010^{b}$	.028	.015	.002
	H	$.515 \pm .006^{a}$	.043	.021	.001	$.333 \pm .006^{a}$	.027	.013	.001

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis

2 B - Bulls; S - steers; H - heifers

3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Table 15. Regression Coefficients (b) of MYON:TN[1] and SARN:TN[1] Ratios (Y) on the Weight of Fat-Free Wet Muscle (X)

Muscles[2]	Groups[3]	(MYON:TN) x 100 b[4] (%/kg)	Mean (%)	SD (%)	SE of Estimate (%)	(SARN:TN) x 100 b[4] (%/kg)	Mean (%)	SD (%)	SE of Estimate (%)
LD	B	.189 ± .261[a]	50.94	1.88	1.91	- .056 ± .224[a]	34.66	1.58	1.64
	S	.113 ± .256[a]	51.02	1.42	1.46	.543 ± .269[a]	35.64	1.68	1.53
	H	-1.273 ± .403[b]	49.17	2.71	2.14	2.039 ± .296[b]	37.69	3.19	1.57
ST	B	-1.126 ± .584[a]	51.01	1.69	1.56	1.362 ± .596[a]	33.19	1.80	1.59
	S	-2.978 ± .915[a]	50.29	2.11	1.64	4.340 ± .810[b]	34.33	2.46	1.45
	H	-2.163 ± .908[a]	49.27	1.65	1.44	5.043 ± .724[b]	35.31	2.34	1.15
RH	B	3.316 ± 1.119[ab]	52.01	2.61	2.12	-1.923 ± .990[a]	31.26	2.04	1.87
	S	7.156 ± 1.855[a]	52.26	3.09	2.22	-4.738 ± 1.580[a]	30.66	2.34	1.89
	H	- .562 ± 1.466[b]	52.77	1.30	1.34	4.627 ± 1.680[b]	30.74	1.84	1.53
ECR	B	1.435 ± 2.268[a]	51.86	1.59	1.63	3.512 ± 1.558[a]	30.59	1.26	1.12
	S	9.311 ± 2.149[b]	52.85	1.79	1.21	-3.531 ± 3.125[b]	30.09	1.78	1.76
	H	- .774 ± 2.195[a]	51.75	.99	1.02	5.554 ± 2.408[a]	32.11	1.27	1.12

1 MYON:TN -myofibrillar nitrogen:total nitrogen; SARN:TN - sarcoplasmic nitrogen:total nitrogen
2 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
3 B - bulls; S - steers; H - heifers
4 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

SARN at a greater rate (conversely MYON percentage decreased). The RH and ECR from bulls and steers showed an increase in proportion of MYON and the RH from steers decreased in SARN percentage. The RH and ECR from heifers changed little in the percentage of MYON but did increase in the proportion of SARN. If the three sex groups are compared to establish some similarities, the relationships would be: the LD and RH from bulls and steers showed similar patterns; the ST from steers and heifers were not different in changes of nitrogen distribution; the bulls and heifers were very different except for the ECR; and the RH and ECR from steers showed large increases in MYON and decreases in SARN. From another point of view, generalizing, it could be said that the proportion of SARN increased in the muscles from heifers, that of MYON increased in the muscles from steers and that the muscles from bulls were intermediate in these parameters. The rates of increase of STRN and NPN based on TN were similar for all three sex groups; the rates were similar for all muscles, although they were slightly greater in the ECR and slightly smaller in the LD (Table 16). Total nitrogen increase seemed to determine in all cases the accumulation of STRN and NPN, even though there was a significantly smaller rate of STRN increase for the ST from heifers.

As expected, because the proportion of one of the larger fractions always increased, the proportions of STRN and NPN usually decreased (Table 17), but in some cases NPN:TN ratio remained fairly constant (LD and ST from steers and bulls). The decrease in STRN:TN ratio was significantly more rapid in the ST from heifers, but significantly less rapid in the ECR from heifers. Similarly, the rate of decline of the NPN:TN ratio in the RH from heifers was significantly greater than in the steers. These differences did not seem to be related except for the fact that they could be characteristic of heifers. The most important fact in these last two tables was the

Table 16. Regression Coefficients (b) of Stroma (STRN) and Non-Protein (NPN) Nitrogen Fractions (Y) on the Total Nitrogen (TN) Content (X)

Muscles[1]	Groups[2]	STRN				NPN			
		b[3] (hg/hg)	Mean (hg)	SD (hg)	SE of Estimate (hg)	b[3] (hg/hg)	Mean (hg)	SD (hg)	SE of Estimate (hg)
LD	B	$.096 \pm .004^{a}$	.104	.069	.011	$.011 \pm .002^{a}$	.013	.009	.004
	S	$.091 \pm .005^{a}$	.092	.052	.011	$.012 \pm .002^{a}$	.012	.008	.004
	H	$.087 \pm .005^{a}$	.086	.047	.010	$.010 \pm .001^{a}$	.011	.006	.003
ST	B	$.114 \pm .004^{a}$	.044	.029	.004	$.015 \pm .002^{a}$	.005	.004	.002
	S	$.114 \pm .004^{a}$	.036	.019	.002	$.015 \pm .002^{a}$	.004	.003	.001
	H	$.095 \pm .004^{b}$	.031	.015	.002	$.012 \pm .003^{a}$	.004	.002	.002
RH	B	$.112 \pm .005^{a}$	.026	.020	.003	$.011 \pm .002^{a}$	.003	.002	.001
	S	$.114 \pm .003^{a}$	.021	.014	.002	$.015 \pm .002^{a}$	.002	.002	.001
	H	$.104 \pm .004^{a}$	.017	.009	.002	$.010 \pm .002^{a}$	.002	.001	.001
ECR	B	$.122 \pm .005^{a}$	.013	.008	.001	$.015 \pm .003^{a}$	.001	.001	.001
	S	$.117 \pm .005^{a}$	.012	.006	.001	$.013 \pm .003^{a}$	.001	.001	.001
	H	$.126 \pm .004^{a}$	.010	.005	.001	$.011 \pm .003^{a}$	.001	.001	.001

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Table 16. Regression Coefficients (b) of Stroma (STRN) and Non-Protein (NPN) Nitrogen Fractions (Y) on the Total Nitrogen (TN) Content (X)

Muscles[1]	Groups[2]	STRN				NPN			
		b[3] (hg/hg)	Mean (hg)	SD (hg)	SE of Estimate (hg)	b[3] (hg/hg)	Mean (hg)	SD (hg)	SE of Estimate (hg)
LD	B	$.096 \pm .004^{a}$	.104	.069	.011	$.011 \pm .002^{a}$	.013	.009	.004
	S	$.091 \pm .005^{a}$	.092	.052	.011	$.012 \pm .002^{a}$	.012	.008	.004
	H	$.087 \pm .005^{a}$	.086	.047	.010	$.010 \pm .001^{a}$	.011	.006	.003
ST	B	$.114 \pm .004^{a}$	.044	.029	.004	$.015 \pm .002^{a}$	.005	.004	.002
	S	$.114 \pm .004^{a}$	.036	.019	.002	$.015 \pm .002^{a}$	.004	.003	.001
	H	$.095 \pm .004^{b}$	.031	.015	.002	$.012 \pm .003^{a}$	.004	.002	.002
RH	B	$.112 \pm .005^{a}$	.026	.020	.003	$.011 \pm .002^{a}$	.003	.002	.001
	S	$.114 \pm .003^{a}$	.021	.014	.002	$.015 \pm .002^{a}$	.002	.002	.001
	H	$.104 \pm .004^{a}$	.017	.009	.002	$.010 \pm .002^{a}$	.002	.001	.001
ECR	B	$.122 \pm .005^{a}$	.013	.008	.001	$.015 \pm .003^{a}$	.001	.001	.001
	S	$.117 \pm .005^{a}$	.012	.006	.001	$.013 \pm .003^{a}$	.001	.001	.001
	H	$.126 \pm .004^{a}$	.010	.005	.001	$.011 \pm .003^{a}$	.001	.001	.001

1 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
2 B - bulls; S - steers; H - heifers
3 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

Table 17. Regression Coefficients (b) of STRN:TN[1] and NPN:TN[1] Ratios (Y) on the Weight of Fat-Free Wet Muscle (X)

Muscles[2]	Groups[3]	(STRN:TN) x 100				(NPN:TN) x 100			
		b[4] (%/kg)	Mean (%)	SD (%)	SE of Estimate (%)	b[4] (%/kg)	Mean (%)	SD (%)	SE of Estimate (%)
LD	B	- .235 ± .148[a]	10.07	1.14	1.08	.004 ± .041[a]	1.24	.29	.30
	S	- .411 ± .195[a]	10.18	1.23	1.11	.008 ± .059[a]	1.26	.32	.34
	H	- .532 ± .188[a]	9.61	1.21	1.00	- .181 ± .050[b]	1.34	.36	.27
ST	B	- .040 ± .383[a]	11.77	.99	1.02	.048 ± .163[a]	1.34	.42	.44
	S	- .179 ± .503[a]	11.83	.88	.90	.048 ± .227[a]	1.26	.39	.41
	H	-2.006 ± .390[b]	11.15	1.02	.62	- .438 ± .267[a]	1.32	.45	.42
RH	B	-2.087 ± .879[a]	12.56	1.90	1.66	- .099 ± .177[ab]	1.24	.33	.33
	S	-3.491 ± .895[a]	12.83	1.50	1.07	- .005 ± .251[a]	1.18	.29	.30
	H	-4.807 ± 1.051[a]	11.95	1.46	.96	- .781 ± .348[b]	1.36	.36	.32
ECR	B	-6.445 ± 2.029[ab]	13.77	1.84	1.46	- .007 ± .662[a]	1.39	.46	.47
	S	-9.768 ± 2.269[a]	13.52	1.88	1.28	- .245 ± .687[a]	1.34	.38	.39
	H	-1.554 ± 1.369[b]	12.58	.64	.63	-1.402 ± .827[a]	1.39	.41	.38

1 STRN:TN - stroma nitrogen:total nitrogen; NPN:TN - non-protein nitrogen:total nitrogen
2 LD - longissimus dorsi; ST - semitendinosus; RH - rhomboideus; ECR - extensor carpi radialis
3 B - bulls; S - steers; H - heifers
4 Regression coefficients labelled with the same superscript were not significantly different at $P<0.05$

uniformity of decline in the proportion of STRN and NPN. The general decrease in the proportion of STRN is further evidence of the decrease in extracellular space as indicated by the rise in potassium concentration.

The general increase in percent protein has been previously reported by several workers (Table 2). The range of the present results (Appendix II, Tables 4 to 15) was smaller than that found for chicks (Dickerson, 1960), but similar to that for pigs, humans and cattle (Dickerson and Widdowson, 1960; Helander, 1957; Lawrie, 1961b). The increase in concentration of the MYON fraction in this work (Appendix II, Tables 4 to 15) was similar to that determined by the above workers (Table 2); on the other hand, the concentration of SARN was higher and that of STRN and NPN lower in the present work. This was probably due to the different methods and conditions of extraction of the four fractions.

The changes in proportions of the four nitrogen fractions have been calculated from previous reports and are reported in Table 18. The same general trends discussed previously were detected. The proportion of MYON and SARN increased;that of STRN decreased and NPN changed only slightly. But the patterns of change are somewhat erratic. There are some reports in which the proportion of MYON or SARN first increased, to decrease later and similarly for the other two fractions.

More muscles and more animals need to be studied to compare patterns of development under different conditions and under the influence of different factors, to be able to accurately describe this phase of growth in large animals.

Many of the findings in this study only show trends, and at that, many could be artifacts of the method of computation as in some instances a linear regression was not the best fit but only the easiest to interpret in terms of the muscle constituents studied.

Table 18. Changes in the proportions and concentrations of the four nitrogenous fractions reported by several workers

Source	Species or Breed	Muscle	Stage of Growth	Distribution of Four Nitrogenous Fractions[1]				
				MYON:TN	SARN:TN	STRN:TN	NPN:TN	TN:H_2O
Dickerson (1960)	chick	pectoral	0 wks	50.9	23.2	16.2	9.8	2.02
			2.5 wks	57.4	22.4	5.4	14.3	3.83
			27 wks	52.4	30.0	3.2	14.9	5.02
Dickerson and Widdowson (1960)	pig	thigh	0 wks	47.8	16.2	16.9	19.2	1.87
			4-6 wks	59.0	19.0	7.3	15.0	3.42
			adult	60.3	24.3	3.3	12.9	4.25
	human	thigh	0 mos	52.1	18.6	18.2	11.5	2.58
			4-7 mos	57.6	17.0	15.6	11.0	3.71
			adult	65.6	22.0	4.6	9.7	4.25
Helander (1957)	cattle	gastrocnemius and soleus	1 wk	50.2	23.7	17.0	9.2	3.83
			6 wks	50.8	28.6	10.2	10.5	4.14
			18 mos	55.4	24.0	10.4	10.4	4.32
Lawrie (1960)	cattle	longissimus dorsi	calf	46.0	18.9	24.2	10.9	4.20
			steer	45.6	24.7	18.5	11.1	4.52
Lawrie (1961b)	cattle (AxRP)[2]	longissimus dorsi	4 mos	49.0	27.8	11.9	11.3	4.41
			8 mos	54.6	24.4	9.7	11.2	4.36
			12 mos	51.7	28.6	8.0	11.7	4.47

Table 18 (continued)

Source	Species or Breed	Muscle	Stage of Growth	Distribution of Four Nitrogenous Fractions[1]				
				MYON:TN	SARN:TN	STRN:TN	NPN:TN	TN:H_2O
Lawrie (1961b)	Friesian	longis-simus dorsi	18 mos	55.6	20.6	11.0	12.7	4.73
Link et al.(1968)	cattle	longis-simus dorsi	12 mos	54.6	36.7			
			16 mos	46.7	43.1			
			22 mos	53.3	37.7			

1 TN - total nitrogen; MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen. The ratios with TN and those with water were multiplied by 100.

2 A - Angus; RP - Red Poll

SUMMARY AND CONCLUSIONS

As in some other studies, many differences were detected in the growth of bulls, steers and heifers.

The dissection of carcasses showed that fat accumulated more rapidly in heifers than in steers and more rapidly in steers than in bulls, relative to carcass weight. Mainly because of this, the proportions of lean and bone decreased at a greater rate in heifers than in steers and at a greater rate in steers than in bulls. On the other hand, muscle:bone ratio increased at similar rates in all three groups. Therefore, heifers fattened at lighter weights than steers or bulls.

The faster growth in bulls was reflected in the growth of the individual muscles. The four muscles sampled, longissimus dorsi (LD), semitendinosus (ST), rhomboideus (RH) and extensor carpi radialis (ECR), grew at a greater rate in bulls than in steers and at a greater rate in steers than in heifers. Because moisture and nitrogen compounds make up the greater proportion of muscle, the pattern of increase per day of age for the content of these constituents was similar to that of muscle weight. However, the regressions of individual muscle weight on total lean and of moisture and nitrogen content on individual muscle weight were similar for the three sex groups, even though there were some significant differences, especially for the RH muscle. The use of fat-free fresh muscle weight instead of individual fresh muscle weight did not reduce the standard errors of estimate.

The three sex groups were similar in the way percent moisture and percent nitrogen changed per day of age, but the rate of decrease of the former based on muscle weight was greater in heifers than in steers and greater in steers than in bulls. Similarly, percent nitrogen increased at a greater rate, based on muscle weight, in heifers than in steers and at a greater rate in steers

than in bulls. The differences were again especially noticeable for the RH muscle. The nitrogen:water ratios increased at greater rates in heifers than in bulls for every muscle. However, in steers, the ratio increased at a similar rate to that in bulls for the LD and ST, but at similar rate to that of heifers for the RH and ECR. The change in nitrogen concentration in the two largest muscles(LD and ST) seemed to be less influenced by castration. Part of this difference between large and small muscles could be a result of the smaller rates of decrease in percent moisture in the two larger muscles.

A different pattern of change was observed for ether extract content. Regressions based on age were similar for all three groups, but larger in heifers than in steers and larger in steers than in bulls for those based on muscle weight. As expected, percent ether extract increased most rapidly in heifers than in steers and more rapidly in steers than in bulls for comparisons based on either age or muscle weight. These results indicate that the rate of accumulation of ether extract was determined by the aging of the animal to a greater extent than by muscle weight.

Although the proportion of ash remained fairly constant, the potassium:water ratio increased in all muscles tested. This increase was similar for the three sex groups, except for the RH from bulls, in which it was much lower than in steers or heifers. This is evidence of a decrease in the proportion of extracellular water in muscles, because potassium is an intracellular ion.

The hormonal influence on the pattern of change of constituents was, as expected, more noticeable for some muscles from bulls, particularly for the RH muscle which is involved in the expression of secondary sexual characteristics in bulls.

The rate of increase of myofibrillar nitrogen (MYON) relative to total nitrogen (TN) was usually greater in steers than in bulls and greater in bulls than in heifers. These differences were more marked when the rate of change of MYON:TN ratio were compared. The ratio increased in bulls and steers, except for the ST muscle. However, in heifers the ratio changed little or decreased. These differences were reflected in the comparisons of the rates of change for sarcoplasmic nitrogen (SARN) and for SARN:TN ratio. The accumulation of SARN was more rapid in heifers and the ratio SARN:TN increased at a greater rate in this group. Also, the SARN:TN ratio increased in the ST from the three groups, but decreased in the RH from steers. In general, the accretion of stroma nitrogen (STRN) and of non-protein nitrogen (NPN) was similar for the three sex groups. There were practically no differences in the rate of decrease of STRN:TN ratio. The NPN:TN ratios changed little. There were also some similarities in the pattern of nitrogen accretion; the LD and RH from bulls and steers and the ST from steers and heifers were alike.

There was a definite effect of castration on the accretion of nitrogen, especially on the change in the proportions of the main nitrogen fractions, MYON and SARN. The changes of the nitrogen fractions in the muscles from heifers seem to be characteristic of that sex. The increase in the proportion of SARN in heifers is somewhat surprising because of the large decrease in the proportion of moisture in muscles from heifers.

Although a description has been given of some of the changes occuring in muscle constituents during growth, the control mechanisms hormonal or otherwise have still to be elucidated.

BIBLIOGRAPHY

Association of Official Agricultural Chemists. 1965. Official Methods of Analysis. 10th Ed., Washington, D.C.

Bailey, C.B., W.D. Kitts and A.J. Wood. 1960. Changes in the gross chemical composition of the mouse during growth in relation to the assessment of physiological age. Can. J. Animal Sci. 40:143-155.

Bailey, C.M., C.L. Probert, Paula Richardson, V.R. Bohman and Julianne Chancerelle. 1966. Quality factors of the longissimus dorsi of young bulls and steers. J. Animal Sci. 25:504-508.

Bailey, Milton E. and S.E. Zobrisky. 1968. Changes in proteins during growth and development of animals, p. 87-125. In Body composition in animals and man. Publ. 1598. National Academy of Sciences, Washington, D.C.

Berg, R.T. 1962. The University of Alberta beef breeding project. 41st Annual Feeders' Day Report, p. 24. Dept. of Animal Science, University of Alberta.

Berg, R.T. 1966. University beef breeding project. Report No. 4. 45th Annual Feeders Day Report, p. 28. Dept. of Animal Science, University of Alberta.

Berg, R.T. 1967. Genetic and environmental influences on growth in beef cattle, p. 429-450. In G.A. Lodge and G.E. Lamming (Ed.) Growth and development of mamals. Butterworths, London.

Berg, R.T. and R.M. Butterfield. 1966. Muscle:bone ratio and fat percentage as measures of beef carcass composition. Animal Prod. 8:1-11.

Boyd, J.D. 1960. Development of striated muscle, p. 63-85. In G.H. Bourne (Ed.) The structure and function of muscle. Volume 1, Structure. Academic Press, New York.

Bradley, N.W., L.V. Cundiff, J.D. Kemp and T.R. Greathouse. 1966. Effects of sex and sire on performance and carcass traits of Hereford and Hereford-Red Poll calves. J. Animal Sci. 25:783-788.

Brungardt, V.H. 1968. Changes in composition during maturation of Holstein steers. Proc. 21st Annual Rec. Meat Conf., p. 115-133. National Live Stock and Meat Board, Chicago, Ill.

Butterfield, R.M. and R.T. Berg. 1966a. A classification of bovine muscles based on their relative growth patterns. Res. Vet. Sci. 7:326-332.

Butterfield, R.M. and R.T. Berg, 1966b. A nutritional effect on relative growth of muscles. Proc. Austral. Soc. Animal Prod. 6:298-304.

Butterfield, R.M. and N.D.S. May. 1966. Muscles of the ox. Univ. of Queensland Press, Brisbane, Australia.

Callow, E.H. 1948. Comparative studies of meat, II. The changes in the carcass during growth and fattening and their relation to the chemical composition of the fatty and the muscular tissues. J. Agric. Sci. 38:174-199.

Callow, E.H. 1961. Comparative studies of meat, VII. A comparison between Hereford, Dairy Shorthorn and Friesian steers on four levels of nutrition. J. Agric. Sci. 56:265-282.

Callow, E.H. 1962. Comparative studies of meat, VIII. The percentage of fat in the fatty and muscular tissues of steers and the iodine number of the extracted fat, as affected by breed and level of nutrition. J. Agric. Sci. 58:295-307.

Dickerson, J.W.T. 1960. The effect of growth on the composition of avian muscle. Biochem. J. 75:33-37.

Dickerson, J.W.T. and E.M. Widdowson. 1960. Chemical changes in skeletal muscle during development. Biochem. J. 74:247-257.

Doornenbal, H. and A.H. Martin. 1966. The association between commercial cut-out yield and gross chemical composition in market pigs. Animal Prod. 8:445-455.

Dreyfus, J.-C., J. Kruh and G. Schapira. 1962. Muscular protein metabolism in normal and diseased states, p. 326-349. In F. Gross (Ed.) Protein Metabolism. Springer-Verlag, Berlin.

Enesco, M. and Della Puddy. 1964. Increase in the number of nuclei and weight in skeletal muscle of rats of various ages. Amer. J. Anatomy. 114:235-244.

Filer, Lloyd J.,Jr. and Helen Churella. 1963. Relationship of body composition, chemical maturation, homeostasis, and diet in the newborn mammal. Ann. N.Y. Acad. Sci. 110:380-394.

Garret, W.N. and N. Hinman. 1969. Re-evaluation of the relationship between carcass density and body composition. J. Animal Sci. 28:1-5.

Gillet, T.A., A.M. Pearson and A.H. Kirton. 1965. Variation in potassium and sodium in muscles of the pig. J. Animal Sci. 24:177-181.

Gillet, T.A., A.M. Pearson, D.M. Allen and R.A. Merkel. 1967. Variation in potassium and sodium content of bovine muscles. J. Animal Sci. 26:46-49.

Gordon, Edward E., Kazimierz Kowalsky and Martha Fritts. 1966. Muscle proteins and DNA in rat quadriceps during growth. Amer. J. Physiol. 210:1033-1040.

Gray, B.J. and F.G. Young. 1954. The influence of growth hormone on the protein composition of rat muscle. J. Endocrinology. 10:179-183.

Haecker, T.L. 1920. Investigations in beef production. Univ. of Minnesota Agricultural Experiment Station Bull. 193.

Hagan, Susie N. and Robert O. Scow. 1957. Effect of fasting on muscle proteins and fat in young rats of different ages. Amer. J. Physiol. 188:91-94.

Hedrick, H.B., D.W. Zinn, S.E. Zobrisky and M.E. Bailey. 1967. Quantitative relationships of meat animal composition during growth and development. Proc. 20th Annual Rec. Meat Conf., p. 55-87. National Live Stock and Meat Board, Chicago, Ill.

Helander, Einar. 1957. On quantitative muscle protein determination. Acta Physiol. Scand. Volume 41. Supp. 141.

Helander, E. 1966. General consideration of muscle development, p. 19-29. In E.J. Briskey, R.G. Cassens and J.C. Trautman (Ed.) The physiology and biochemistry of muscle as a food. University of Wisconsin Press, Madison, Wis.

Hopper, T.H. 1944. Methods of estimating the physical and chemical composition of cattle. J. Agric. Res. 68:239-268.

Jasienski, J. 1929. Comp. Rend. Soc. Biol. (Fr.) 101:533. Cited in: J.A. Szirmai. 1962. Histological aspects of the action of androgens and oestrogens, p. 45-74. In F. Gross (Ed.) Protein Metabolism. Springer-Verlag, Berlin.

Joubert, D.M. 1956. An analysis of factors influencing post-natal growth and development of the muscle fibre. J. Agric. Sci. 47:59-102.

Kolaczyk, S. and T. Kotik. 1966. A note on sex differences in muscle properties of pigs with special emphasis on colour. Animal Prod. 8:153-154.

Korner, A. 1962. The effect of growth hormone on protein synthesis, p. 8-25. In F. Gross (Ed.) Protein Metabolism. Springer-Verlag, Berlin.

Lambourne, J.L. 1968. Muscular depletion in animals utilizing arid ranges. J. Animal Sci. 27:1123 (Abstr.)

Lawrie, R.A. 1950. Some observations on factors affecting myoglobin concentrations in muscle. J. Agric. Sci. 40:356-366.

Lawrie, R.A. 1960. Analysis of longissimus dorsi muscles from cattle implanted with hexoestrol. Brit. J. Nutrition. 14:255-258.

Lawrie, R.A. 1961a. Studies on the muscles of meat animals. I. Differences in composition of beef longissimus dorsi muscles determined by age and anatomical location. J. Agric. Sci. 56:249-259.

Lawrie, R.A. 1961b. Systematic analytical differences between psoas major and longissimus dorsi muscles of cattle. Brit. J. Nutrition. 15:453-456.

Lawrie, R.A., R.W. Pomeroy and A. Cuthbertson. 1963. Studies on the muscles of meat animals. III. Comparative composition of various muscles in pigs of three weight groups. J. Agric. Sci. 60:195-209.

Lawrie, R.A., R.W. Pomeroy and A. Cuthbertson. 1964. Studies on the muscles of meat animals. VI. Comparative composition of various muscles in boars of two weight groups in relation to hogs. J. Agric. Sci. 63:385-386.

Lawrie, R.A., R.W. Pomeroy and D.R. Williams. 1964. Studies on the muscles of meat animals. IV. Comparative composition of muscles from 'doppelender' and normal sibling heifers. J. Agric. Sci. 62:89-92.

Link, B.A., R.W. Bray, R.G. Cassens and R.G. Kauffman. 1968. Bovine muscle protein solubility during growth. J. Animal Sci. 27:1143 (Abstr.)

Martin, T.G., V.A. Garwood, W.V. Kessler, J.E. Christian and F.N. Andrews. 1963. The influence of ration on body composition of growing farm animals. Ann. N.Y. Acad. Sci. 110:374-379.

Message, Michael A. 1967. Some problems associated with the development of the mammalian skeletal muscle fibre, p. 26-50. In G.A. Lodge and G.E. Lamming (Ed.) Growth and development of mammals. Butterworths, London.

McMeekan, C.P. 1940a. Growth and development in the pig, with special reference to carcass quality characters. I. J. Agric. Sci. 30:276-343.

McMeekan, C.P. 1940b. Growth and development in the pig, with special reference to carcass quality characters. Part II. The influence of plane of nutrition on growth and development. J. Agric. Sci. 30:387-436.

McMeekan, C.P. 1940c. Growth and development in the pig, with special reference to carcass quality characters. Part III. Effect of the plane of nutrition on the form and composition of the bacon pig. J. Agric. Sci. 30:511-569.

Moulton, C.R. 1923. Age and chemical development in mammals. J. Biol. Chem. 57:79-97.

Norris, A.H., T. Lundy and N.W. Shock. 1963. Trends in selected indices of body composition in man between the ages of 30 and 80 years. Ann. N.Y. Acad. Sci. 110:623-639.

Reid. J.T., A. Bensadoun, L.S. Bull, J.H. Burton, P.A. Gleeson, I.K. Han, Y.D. Joo, D.E. Johnson, W.R. McManus, O.L. Paladines, J.W. Stroud, H.F. Tyrrell, B.D.H. Van Niekerk, G.H. Wellington and J.D. Wood. 1968. Present status of various methods of estimating body composition. Proc. 21st Annual Rec. Meat Conf., p. 82-114, National Live Stock and Meat Board, Chicago, Ill.

Reid, J.T., G.H. Wellington and H.O. Dunn. 1955. Some relationships among the major chemical components of the bovine body and their application to nutritional investigations. J. Dairy Sci. 38:1344-1359.

Robinson, D.S. 1952. Changes in protein composition of chick muscles during development. Biochem. J. 52:621-628.

Rollins, W.C., L.M. Julian and F.D. Carroll. 1969. A note on the body composition of a double-muscled female and a normal female from a linebred Aberdeen Angus herd. Animal Prod. 11:111-114.

Scow, Robert O. 1959. Effect of growth hormone and thyroxine on growth and chemical composition of muscle, bone and other tissues in thyroidectomized-hypophysectomized rats. Amer. J. Physiol. 196:859-865.

Scow, R.O. and S.N. Hagan. 1965. Effect of testosterone propionate and growth hormone on growth and chemical composition of muscle and other tissues in hypophysectomized male rats. Endocrinology. 77:852-858.

Spray, Christine M. and Elsie M. Widdowson. 1950. The effect of growth and development on the composition of mammals. Brit. J. Nutrition. 4:332-353.

Steel, Robert G.D. and James H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York.

Terrell, R.N., G.G. Suess and R.W. Bray. 1969. Influence of sex, live weight and anatomical location on bovine lipids. II. Lipid components and subjective scores of six muscles. J. Animal Sci. 28:454-458.

Topel, D.G., R.A. Merkel, D.L. Mackintosh and J.L. Hall. 1966. Variation of some physical and biochemical properties within and among selected porcine muscles. J. Animal Sci. 25:277-282.

Ulyatt, M.J. and R.A. Barton. 1963. A comparison of the chemical and dissectible carcass composition of New Zealand Romney ewes. J. Agric. Sci. 60:285-289.

Vesely, J.A. and H.F. Peters. 1966. Muscle, bone and fat in five breeds of lamb. J. Animal Sci. 25:887 (Abstr.)

Wilson, J.D. 1962. Regulation of protein synthesis by androgens and estrogens, p. 26-40. In F. Gross (Ed.) Protein Metabolism. Springer-Verlag, Berlin.

Winick, M. and A. Noble. 1965. Quantitative changes in DNA, RNA and protein during pre-natal and post-natal growth in the rat. Developmental Biol. 12:451-466.

Yannet, Herman and Danield C. Darrow. 1938. The effect of growth on the distribution of water and electrolytes in brain, liver and muscle. J. Biol. Chem. 123:295-305.

Yeates, N.T.M. 1964. Starvation changes and subsequent recovery of adult beef muscle. J. Agric. Sci. 62:267-272.

Zinn, D.W. 1967. Quantitative and qualitative beef carcass characteristics as influenced by time on feed. Ph.D. Dissertation. Univ. of Missouri, Columbus, Mo. Cited in: H.B. Hedrick, D.W. Zinn, S.E. Zobrisky and M.E. Bailey, 1967. Quantitative relationships of meat animal composition during growth and development. Proc. 20th Annual Rec. Meat Conf., p. 55-87. National Live Stock and Meat Board. Chicago, Illinois.

Zinn, D.W., R.C. Albin, S.E. Curl and C.T. Gaskins. 1966. Growth and fattening of the bovine. I. Postweaning composition - crude protein and gross energy. J. Animal Sci. 25:587. (Abstr.)

APPENDIX I

Method 1

Determination of Potassium in Muscle Tissue by Atomic Absorption Spectrophotometry

The samples were first weighed accurately; then, 20 ml of a mixture of 17 parts by volume concentrated HNO_3 and 3 parts 70% $HClO_4$ were added to approximately 0.5 g of sample.

The samples were placed on heaters and digested for 40 minutes. They were then cooled and 15-20 ml deionized water were added after re-heating, they were finally removed from the heaters when white fumes were observed.

The digestion flasks were washed thoroughly to collect all of the digested samples, which were then taken to a constant volume in a 100 ml volumetric flask.

A constant small volume (10 ml) of a sodium solution of 10,000 ppm was always added to the sample. This minimized variation in readings due to sodium contamination.

All the absorbance readings were made with an atomic absorption spectrophotometer[1] using a potassium hollow cathode lamp[2] at a slit width of 300 μ.

The results obtained were then compared with several standards to determine the concentration of potassium in the samples. The relationship between absorbance and concentration was linear over the range covered.

1 Techtron Pty. Ltd. Type AA4

2 Atomic Spectral Lamps Pty. Ltd. AEO 34

Method 2

Extraction of Proteins from Muscle (Helander, 1957)

The frozen samples of muscle were cut into very small pieces with a scalpel and, while frozen, weighed on a torsion balance (error $\pm$ 0.2 mg). To prevent thawing and adherence of carbon dioxide snow, small 0.5 g samples were used for most extractions; however, 1 g samples were weighed for the first few extractions.

The small pieces were immediately transferred to a homogenizing tube[1] and buffer was then mixed with the small particles. The samples and buffers were kept on ice at approximately 0 C. A teflon pestle on a steel shaft was used to homogenize the sample. The liquid was poured out and more buffer was added to homogenize the tissue left in the tube. This was done several times with each sample until only very thin pieces of tissue were left. The tube was then rinsed with buffer and all the homogenate was collected in a 50 ml volumetric flask.

The two buffers used were those recommended by Helander (1957). Sarcoplasmic proteins (SARN) and non-protein nitrogen (NPN) were extracted for approximately one hour in the 50 ml flasks, using 0.03 M potassium phosphate solution at pH 7.4. The samples were then pipetted into plastic centrifuge tubes and spun at 39,000 xg for fifteen minutes. The protein solution was poured into storage bottles. The centrifuge tubes were filled with buffer and centrifuged again. This rinse was also poured into the same storage bottles. This solution was frozen and stored. Later, it was thawed, taken to a constant volume and aliquots were pipetted to determine the nitrogen concentration.

1. Kontes

Different aliquots were used to determine NPN; equal volumes of protein solution and 50% cold trichloroacetic acid were mixed and, after centrifugation, the nitrogen in the supernatant was taken to be NPN.

The second buffer, 1.1 M KI + 0.1 M potassium phosphate at pH 7.4 was used to extract myofibrillar proteins (MYON), SARN and NPN. The extraction time in the 50 ml volumetric flasks was approximately three hours. For the next steps, the procedure was the same as described above except that before the second centrifugation, the proteins were re-extracted for 10 to 15 minutes. No NPN determinations were made with this solution.

The tissue residue in the centrifuge tubes left after extraction with the second buffer was mixed with 10 ml of 0.1 M sodium hydroxide and placed in a boiling water bath for 30 to 60 minutes.

After centrifugation, the supernatant was saved. The nitrogen concentration was determined and used to calculate the amount of alkali soluble stroma (STRN) in the tissue consisting of the extracellular proteins which would be mainly collagen.

A factor of 6.45 should be used to convert nitrogen values to protein percentages. The factor of 6.25, which is commonly used, is based on an average content of 16% nitrogen in proteins. Helander (1957) determined that the content of nitrogen in muscle proteins was 15.5%.

APPENDIX II

Tables containing data for individual animals and the results of the analyses made for each muscle from the 44 animals from which samples were taken.

Table 1. Birth weights, slaughter weights and ages at slaughter for the 16 bulls from which samples were taken

Identification[1] (Tag no.)	Breed of[2] dam	Weight at birth (kg)	Age at slaughter (days)	Live weight at slaughter (kg)	Weight of carcass (kg)	% lean of carcass	% fat of carcass	% bone of carcass
265-8	HY	21	27	35	20	60.2	16.1	23.8
266-8	HE	30	22	45	26	65.3	13.0	21.7
371-8	HY	25	67	64	35	67.6	8.8	23.6
375-8	HY	30	59	85	51	67.7	12.0	20.3
228-8	HE	26	231	170	87	68.5	13.6	17.8
259-8	HY	26	210	191	92	65.7	17.6	16.6
259-7	HE	33	252	256	130	64.1	18.4	16.5
231-7	HY	39	284	274	145	68.3	17.2	13.5
211-7	HY	31	305	282	153	67.3	18.0	13.8
243-7	HY	34	310	292	158	63.0	21.9	13.8
232-7	HE	37	362	361	205	64.0	21.4	13.7
265-7	HY	36	324	392	219	66.1	19.7	13.2
260-7	HY	30	356	389	224	67.1	19.7	12.3
225-7	HY	35	350	411	233	63.5	23.1	13.2
230-7	HY	37	430	532	315	61.3	26.6	11.3
262-7	HY	33	409	547	332	62.0	26.0	10.9

1 -7: born in 1967; -8: born in 1968

2 He - Hereford; Hy - Hybrid

Table 2. Birth weights, slaughter weights and ages at slaughter for the 12 steers from which samples were taken

Identification[1] (Tag no.)	Breed of[2] dam	Weight at birth (kg)	Age at slaughter (days)	Live weight at slaughter (kg)	Weight of carcass (kg)	% lean of carcass	% fat of carcass	% bone of carcass
257-8	HY	32	221	191	96	68.1	12.4	19.5
210-8	HE	31	244	189	97	66.0	16.8	17.2
269-7	HY	33	249	259	140	61.2	24.1	13.8
205-7	HY	32	300	274	142	60.0	25.7	13.4
267-7	HE	29	297	274	153	56.6	29.3	13.2
261-7	HY	29	299	273	155	61.0	25.0	13.6
253-7	HE	34	372	370	206	58.7	27.4	13.2
217-7	HY	33	372	385	215	59.4	27.5	12.3
234-7	HY	31	360	369	218	58.5	27.8	12.8
242-7	HY	29	372	391	218	60.1	27.2	12.3
240-7	HY	35	440	437	267	56.5	32.6	10.2
227-7	HY	35	445	478	289	55.6	33.5	10.4

1 -7: born in 1967; -8: born in 1968

2 He - Hereford; Hy - Hybrid

Table 3. Birth weights, slaughter weights and ages at slaughter for the 16 heifers from which samples were taken

Identification[1] (Tag no.)	Breed of[2] dam	Weight at birth (kg)	Age at slaughter (days)	Live weight at slaughter (kg)	Weight of carcass (kg)	% lean of carcass	% fat of carcass	% bone of carcass
267-8	HE	30	12	38	22	66.9	11.2	21.9
268-8	HE	30	16	43	25	64.9	10.6	24.2
341-8	HY	20	89	83	49	68.1	13.7	18.2
255-8	HY	29	87	88	51	70.0	7.6	22.6
241-8	HY	25	234	188	89	63.1	19.4	17.4
221-8	HY	29	240	191	97	60.1	23.7	16.4
214-7	HY	31	333	264	136	60.9	24.0	14.3
218-7	HE	31	310	259	139	58.2	28.6	12.5
220-7	HY	30	337	263	141	61.2	24.0	14.0
206-7	HY	26	334	272	146	58.6	27.5	13.3
244-7	HY	32	405	350	201	57.4	32.3	9.6
235-7	HY	33	401	349	202	57.1	30.1	11.9
204-7	HY	33	417	367	209	56.9	31.3	11.1
241-7	HE	31	399	352	209	54.9	34.6	9.8
255-7	HE	33	424	427	253	52.5	35.8	10.8
207-7	HY	33	444	449	267	54.1	34.8	10.5

1 -7: born in 1967; -8: born in 1968

2 He - Hereford; Hy - Hybrid

Table 4. Percentages[1] of muscle constituents in the longissimus dorsi from the 16 bulls used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
265-8	3.62	77.29	.66	.93	2.980	1.392	1.088	.352	.030	3.44
266-8	4.61	76.70	.44	.91	2.845	1.344	1.056	.388	.029	3.98
371-8	5.16	77.30	.48	.84	2.847	1.471	1.104	.264	.032	4.22
375-8	9.91	77.61	.63	.98	2.800	1.394	1.056	.326	.047	4.16
228-8	19.00	76.63	.89	.86	2.904	1.552	1.136	.324	.046	4.32
259-8	18.38	76.52	.85	1.09	3.057	1.584	1.216	.326	.048	4.30
259-7	28.30	75.50	1.20	.96	2.966	1.517	1.216	.297	.031	4.59
231-7	30.92	76.08	.81	.97	2.988	1.519	1.134	.279	.044	4.16
211-7	35.81	77.10	1.10	.85	2.882	1.584	1.139	.248	.031	4.03
243-7	32.79	75.37	1.43	1.00	2.986	1.616	1.088	.354	.033	4.31
232-7	42.00	75.00	1.25	.90	3.290	1.681	1.136	.310	.045	4.11
265-7	44.88	74.52	1.25	.61	3.237	1.684	1.152	.359	.062	4.05
260-7	48.90	74.18	1.32	.81	3.305	1.808	1.264	.372	.032	3.77
225-7	44.93	74.42	1.43	1.01	3.319	1.853	1.184	.329	.048	4.23
230-7	60.00	72.60	1.86	.97	3.487	1.823	1.266	.357	.033	4.39
262-7	62.39	71.68	1.90	.92	3.502	1.904	1.296	.322	.050	3.99

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 5. Percentages[1] of muscle constituents in the semitendinosus from the 16 bulls used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
265-8	1.31	77.52	.63	.83	3.205	1.681	1.040	.342	.031	3.56
266-8	1.78	77.00	.44	.79	3.209	1.744	.958	.403	.030	4.13
371-8	2.79	76.48	.52	.97	3.270	1.792	.992	.326	.046	4.00
375-8	4.07	77.24	.68	.91	3.110	1.567	.960	.388	.062	4.31
228-8	6.47	76.60	.75	1.00	3.225	1.633	1.042	.372	.062	4.46
259-8	6.40	76.62	.75	1.04	3.287	1.648	1.152	.341	.031	4.03
259-7	9.82	75.81	1.06	.97	3.295	1.633	1.167	.371	.032	4.42
231-7	10.78	76.23	.95	1.00	3.225	1.696	1.088	.326	.047	4.19
211-7	10.90	76.03	1.22	.91	3.214	1.584	1.104	.388	.032	4.17
243-7	11.52	76.28	.85	1.01	3.250	1.600	1.119	.419	.033	4.36
232-7	15.40	75.00	1.00	.96	3.456	1.746	1.118	.417	.047	4.06
265-7	17.48	75.69	.90	.94	3.363	1.712	1.105	.419	.062	3.98
260-7	17.00	74.89	1.00	.96	3.408	1.697	1.200	.372	.031	4.31
225-7	16.71	75.30	.79	1.03	3.467	1.729	1.184	.403	.030	4.33
230-7	21.99	74.22	1.16	1.01	3.488	1.760	1.233	.388	.046	4.68
262-7	23.00	73.59	1.14	.53	3.639	1.871	1.182	.374	.062	4.70

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 6. Percentages[1] of muscle constituents in the rhomboideus from the 16 bulls used.

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
265-8	.62	78.57	.66	.77	2.980	1.392	.977	.434	.028	3.09
266-8	.82	79.43	.54	.80	2.845	1.344	.960	.419	.030	3.23
371-8	1.32	79.00	.69	.83	2.847	1.471	.928	.372	.031	3.76
375-8	2.32	79.40	.58	.84	2.800	1.392	.864	.419	.047	3.52
228-8	3.35	78.41	.93	.85	2.904	1.552	.896	.357	.032	3.33
259-8	3.50	77.70	.83	.86	3.057	1.584	.912	.388	.046	3.63
259-7	5.07	77.69	1.14	.85	2.966	1.521	1.040	.341	.033	3.56
231-7	6.29	77.60	.99	.86	2.988	1.519	.977	.295	.062	3.60
211-7	6.32	78.22	1.26	.86	2.882	1.584	.944	.233	.029	3.63
243-7	5.72	77.90	.77	.87	2.986	1.616	.896	.386	.031	3.92
232-7	10.39	76.00	1.10	.73	3.290	1.681	.977	.434	.030	3.50
265-7	10.20	76.28	.97	.80	3.237	1.680	.945	.403	.048	3.41
260-7	11.33	75.76	1.11	.65	3.305	1.808	.944	.388	.031	3.28
225-7	11.77	75.70	1.12	.86	3.319	1.856	.929	.372	.030	3.71
230-7	14.30	74.21	1.34	.88	3.487	1.823	1.152	.371	.031	3.33
262-7	16.21	74.24	1.29	.86	3.502	1.904	1.056	.373	.047	3.55

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 7. Percentages[1] of muscle constituents in the extensor carpi radialis from the 16 bulls used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
265-8	.42	79.60	.67	.75	2.944	1.488	.929	.434	.030	3.12
266-8	.69	79.48	.33	.81	2.901	1.471	.816	.527	.031	3.65
371-8	.83	79.11	.40	.84	2.963	1.584	.883	.403	.047	3.96
375-8	1.30	79.19	.46	.92	2.887	1.456	.881	.434	.049	3.76
228-8	1.94	78.83	.72	.78	2.899	1.552	.833	.357	.062	3.24
259-8	2.21	79.00	.40	.80	3.012	1.536	.910	.419	.031	3.69
259-7	2.91	79.40	.68	.90	2.874	1.552	.912	.342	.032	3.19
231-7	3.43	78.57	.51	.79	3.068	1.488	.946	.419	.062	3.57
211-7	3.33	78.61	.68	.99	2.966	1.584	.944	.341	.030	3.58
243-7	3.41	78.40	.52	.86	3.026	1.537	.929	.450	.033	3.69
232-7	4.39	77.49	.65	.81	3.198	1.681	.959	.402	.047	3.32
265-7	4.86	77.70	.54	.54	3.180	1.696	.960	.403	.062	3.48
260-7	4.47	76.81	.51	.88	3.307	1.664	.991	.465	.031	3.99
225-7	4.56	77.80	.47	.85	3.217	1.712	.992	.371	.016	3.59
230-7	6.32	76.59	.77	1.00	3.287	1.729	1.071	.372	.042	3.98
262-7	6.11	76.42	.92	.88	3.284	1.696	1.071	.388	.045	4.26

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 8. Percentages[1] of muscle constituents in the longissimus dorsi from the 12 steers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
257-8	20.03	76.41	.97	.97	3.223	1.633	1.136	.341	.047	4.05
210-8	21.20	75.38	1.38	1.00	3.315	1.632	1.264	.279	.062	4.23
269-7	25.37	75.56	1.15	.88	3.378	1.729	1.167	.372	.047	3.53
205-7	25.62	74.52	1.78	.83	3.395	1.744	1.184	.357	.049	3.87
267-7	27.60	74.70	1.26	.87	3.437	1.696	1.296	.357	.031	4.25
261-7	31.58	74.70	1.67	.87	3.361	1.664	1.266	.326	.050	3.83
253-7	38.38	73.19	2.12	.91	3.550	1.840	1.200	.388	.045	3.88
217-7	40.80	73.00	2.54	.78	3.515	1.823	1.264	.311	.030	3.84
234-7	40.82	73.63	2.40	.79	3.498	1.777	1.297	.338	.034	4.39
242-7	42.45	73.20	1.88	.87	3.625	1.777	1.377	.310	.032	4.41
240-7	43.70	72.57	2.74	.67	3.603	1.904	1.295	.295	.046	4.36
227-7	48.85	71.84	3.16	.65	3.678	1.967	1.299	.328	.062	4.43

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 9. Percentages[1] of muscle constituents in the semitendinosus from the 12 steers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
257-8	7.55	76.83	1.00	1.07	3.191	1.584	1.088	.357	.047	4.15
210-8	7.05	76.31	.88	.98	3.276	1.616	1.167	.355	.031	4.25
269-7	8.32	76.22	1.19	.86	3.267	1.696	1.071	.372	.048	3.62
205-7	8.53	75.60	.98	1.05	3.403	1.681	1.166	.403	.031	4.38
267-7	8.56	75.35	1.13	.96	3.367	1.664	1.169	.434	.032	4.60
261-7	10.18	75.80	1.06	.88	3.313	1.552	1.248	.405	.051	3.96
253-7	11.03	74.40	1.64	.91	3.431	1.696	1.184	.406	.030	4.05
217-7	12.92	75.19	1.59	.84	3.335	1.618	1.243	.367	.034	3.90
234-7	13.77	74.90	1.61	.87	3.417	1.665	1.244	.419	.028	4.68
242-7	12.50	74.55	1.43	.89	3.505	1.729	1.281	.370	.033	4.36
240-7	15.24	74.07	1.74	.56	3.510	1.777	1.253	.374	.062	4.76
227-7	16.90	73.68	2.00	.73	3.543	1.760	1.285	.388	.065	4.84

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 10. Percentages[1] of muscle constituents in the rhomboideus from the 12 steers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
257-8	3.51	78.10	1.01	.92	2.958	1.536	.896	.403	.031	3.45
210-8	3.43	77.36	1.24	.98	3.042	1.504	1.008	.372	.047	3.76
269-7	4.70	76.70	1.40	.74	3.119	1.808	.800	.372	.031	3.11
205-7	4.49	76.82	1.37	.81	3.109	1.633	.992	.357	.033	3.69
267-7	5.01	75.68	1.63	.82	3.237	1.600	1.071	.419	.030	4.19
261-7	5.20	75.91	1.33	.96	3.233	1.760	.977	.326	.045	3.23
253-7	7.48	74.40	1.79	.83	3.412	1.823	.992	.405	.030	3.52
217-7	8.57	74.51	1.99	.71	3.412	1.840	1.071	.375	.034	3.69
234-7	7.21	74.19	1.99	.79	3.448	1.840	1.023	.432	.032	4.00
242-7	7.75	74.20	1.78	.79	3.493	1.888	1.056	.388	.035	3.65
240-7	9.45	72.84	2.28	.70	3.608	1.952	1.071	.401	.047	3.89
227-7	11.20	72.10	2.48	.64	3.738	2.096	.977	.434	.062	3.94

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 11. Percentages[1] of muscle constituents in the extensor carpi radialis from the 12 steers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
257-8	2.17	78.80	.61	.86	2.997	1.504	.944	.400	.046	3.29
210-8	2.41	78.18	.72	.99	3.056	1.584	.929	.434	.062	4.09
269-7	2.84	78.33	.89	.73	3.050	1.600	.977	.372	.031	3.18
205-7	2.88	77.90	.57	.84	3.116	1.692	.939	.370	.028	3.92
267-7	3.00	77.80	.75	.79	3.078	1.584	1.023	.388	.032	3.75
261-7	3.02	77.35	.68	.90	3.153	1.696	.948	.371	.047	3.24
253-7	3.91	77.20	.78	.86	3.206	1.729	.960	.375	.030	3.59
217-7	4.18	76.25	.76	.78	3.344	1.792	.992	.434	.034	3.90
234-7	4.31	76.87	.74	.83	3.237	1.744	.931	.436	.062	3.98
242-7	4.22	76.52	.80	.82	3.327	1.823	1.040	.357	.031	3.90
240-7	4.78	76.10	.81	.97	3.369	1.888	.864	.401	.047	3.92
227-7	4.82	74.90	.80	.87	3.580	1.936	1.042	.403	.049	4.30

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 12. Percentages[1] of muscle constituents in the longissimus dorsi from the 16 heifers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
267-8	4.12	77.60	.49	.88	3.081	1.584	.992	.372	.045	3.40
268-8	4.85	77.72	.56	.70	3.079	1.600	1.040	.293	.062	3.48
341-8	10.79	76.90	.55	.95	3.174	1.712	1.056	.279	.047	3.97
255-8	11.16	77.08	.60	1.07	3.180	1.648	1.088	.341	.052	4.17
241-8	17.40	75.73	1.07	1.00	3.301	1.616	1.216	.308	.041	4.11
221-8	19.34	75.77	1.02	1.07	3.324	1.633	1.248	.326	.044	3.99
214-7	29.80	74.85	1.63	1.06	3.353	1.696	1.296	.297	.031	3.83
218-7	26.11	74.60	1.85	.89	3.375	1.777	1.152	.310	.062	4.03
220-7	27.13	73.90	1.88	.90	3.421	1.504	1.377	.357	.047	3.51
206-7	28.09	74.30	1.77	.79	3.419	1.618	1.379	.279	.030	3.54
244-7	39.50	72.15	2.76	.93	3.603	1.777	1.375	.295	.033	3.64
235-7	36.57	73.07	2.58	.90	3.456	1.633	1.392	.324	.042	3.55
204-7	40.85	71.72	2.86	.87	3.603	1.648	1.488	.315	.046	3.18
241-7	39.35	72.28	2.96	.57	3.499	1.664	1.423	.264	.035	3.59
255-7	43.60	70.93	3.55	1.02	3.642	1.712	1.471	.372	.048	3.88
207-7	49.61	70.50	3.75	.93	3.651	1.760	1.504	.295	.031	3.99

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 13. Percentages[1] of muscle constituents in the semitendinosus from the 16 heifers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
267-8	1.52	78.20	.48	.94	3.019	1.516	.960	.374	.049	3.62
268-8	1.75	78.73	.45	.73	2.992	1.519	.977	.341	.062	3.98
341-8	3.99	77.25	.64	.93	3.124	1.614	.992	.371	.031	3.66
255-8	4.37	77.59	.52	1.09	3.081	1.616	.994	.343	.042	4.33
241-8	5.55	76.07	1.00	1.01	3.257	1.584	1.152	.357	.045	4.21
221-8	6.15	76.40	.80	1.07	3.268	1.600	1.104	.419	.047	4.26
214-7	8.10	74.84	1.26	1.17	3.405	1.664	1.200	.372	.030	4.26
218-7	8.59	75.31	1.28	1.03	3.338	1.619	1.155	.370	.060	4.40
220-7	9.33	74.76	1.29	.88	3.451	1.696	1.216	.361	.035	4.21
206-7	9.36	75.05	1.15	1.00	3.402	1.552	1.327	.360	.031	4.06
244-7	11.60	74.17	1.78	.98	3.448	1.667	1.296	.341	.063	4.08
235-7	11.79	74.10	1.45	.93	3.498	1.760	1.281	.356	.027	3.55
204-7	12.52	73.40	1.65	.85	3.597	1.729	1.329	.355	.051	3.72
241-7	12.00	73.73	1.84	1.03	3.479	1.744	1.281	.368	.016	3.69
255-7	13.13	72.72	2.16	1.01	3.620	1.777	1.360	.326	.052	4.15
207-7	15.20	72.68	2.05	.96	3.622	1.729	1.377	.359	.048	4.22

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 14. Percentages[1] of muscle constituents in the rhomboideus from the 16 heifers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
267-8	.70	78.89	.68	.86	2.843	1.536	.784	.386	.047	2.98
268-8	.78	79.12	.63	.57	2.864	1.552	.833	.372	.032	2.82
341-8	1.49	78.67	.87	.80	2.909	1.555	.800	.419	.062	3.15
255-8	2.10	78.23	.74	1.01	2.924	1.567	.835	.378	.046	3.58
241-8	3.00	77.00	1.36	.87	3.068	1.633	.944	.388	.049	3.59
221-8	3.04	77.51	1.17	.92	3.037	1.567	.944	.351	.044	3.71
214-7	4.72	75.78	1.96	1.02	3.135	1.664	.992	.338	.030	3.45
218-7	4.17	76.00	2.04	.86	3.149	1.648	.977	.355	.051	3.76
220-7	3.83	75.54	2.07	.74	3.164	1.584	1.056	.341	.042	3.17
206-7	4.37	76.05	1.98	.92	3.124	1.569	1.059	.327	.035	3.24
244-7	6.23	73.56	2.99	.82	3.324	1.741	1.071	.326	.033	3.46
235-7	6.91	74.44	2.53	.83	3.315	1.744	1.008	.419	.053	3.53
204-7	7.02	73.60	2.67	.74	3.395	1.856	1.040	.358	.032	3.04
241-7	6.75	73.36	2.82	.81	3.405	1.808	1.052	.357	.031	3.35
255-7	8.11	72.10	3.57	.83	3.476	1.858	1.104	.371	.046	3.55
207-7	7.55	72.15	3.52	.90	3.481	1.823	1.107	.344	.050	3.54

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen

Table 15. Percentages[1] of muscle constituents in the extensor carpi radialis from the 16 heifers used

Tag No.[2]	Weight of muscle (hg)	% Moisture	% Ether Extract	% Ash	% Nitrogen	% MYON[3]	% SARN[3]	% STRN[3]	% NPN[3]	Potassium Concentration (mg/g)
267-8	.60	79.41	.45	.87	2.862	1.456	.929	.326	.045	3.32
268-8	.79	80.17	.42	.62	2.784	1.459	.896	.357	.028	3.20
341-8	1.28	79.40	.51	.86	2.857	1.505	.848	.370	.048	3.19
255-8	1.43	79.22	.44	.92	2.884	1.519	.848	.357	.062	3.40
241-8	1.89	78.79	.64	.97	2.958	1.515	.944	.356	.052	3.29
221-8	2.10	78.83	.57	.91	3.000	1.519	.960	.375	.044	3.55
214-7	2.92	78.30	.80	1.02	2.995	1.617	.965	.368	.033	3.22
218-7	2.95	78.48	.77	.91	3.005	1.536	.929	.371	.029	3.50
220-7	2.79	77.90	.73	.75	3.008	1.631	1.008	.351	.030	3.14
206-7	2.78	78.01	.68	.83	3.033	1.519	1.023	.405	.033	3.69
244-7	3.49	76.68	.96	.80	3.206	1.662	1.040	.403	.031	3.49
235-7	4.05	77.61	.78	.71	3.136	1.635	.992	.358	.047	3.22
204-7	3.62	76.50	.94	.83	3.248	1.681	1.071	.390	.030	3.23
241-7	3.55	76.48	.94	.88	3.223	1.633	1.056	.403	.035	3.34
255-7	4.01	75.90	1.01	.85	3.332	1.729	1.009	.376	.027	3.46
207-7	4.51	76.22	1.00	.89	3.247	1.666	1.104	.389	.049	3.81

1 All percentages are based on fresh muscle tissue

2 -7: born in 1967; -8: born in 1968

3 MYON - myofibrillar nitrogen; SARN - sarcoplasmic nitrogen; STRN - stroma nitrogen; NPN - non-protein nitrogen