Selection for muscling affects carbohydrate and fatty acid metabolism in beef cattle

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by

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Declaration

I hereby declare that this thesis is my own account of my research and contains as its main content, work which has not previously been submitted for a degree at any tertiary education institution.

Signed ________________________________ Date ____________________________

Peter McGilchrist
Summary

Genetic selection to enhance muscularity in beef cattle is desirable to increase retail beef yield and the profitability of the beef industry. However it is unknown how selection for greater muscling will impact on intermediary and muscle energy metabolism which may influence certain attributes of meat quality. In order to assess these impacts of selection for greater muscling in cattle, the physiological mechanisms that underpin the increase in retail beef yield must be identified. This thesis examined the impact of selection for greater muscling on: retail beef yield; muscle glycogen; whole body insulin responsiveness; adrenaline responsiveness of muscle, adipose and liver tissue; and proportion of glycolytic and oxidative myofibres and enzyme activities.

This study used 11 high (High), 10 low (Low) and 3 high muscled steers with a myostatin mutation (High\textsuperscript{Het}) from an Angus herd which had been visually selected for divergence in muscling over 15 years.

The results of the yield test performed at bone-out showed that the High\textsuperscript{Het} and High muscled steers were the highest yielding with the lowest proportion of fat, while the Low muscling animals were the lowest yielding with the highest proportion of fat. Muscle glycogen and lactate concentration were analysed from four muscle biopsies, taken between 18 and 24 months of age, from the \textit{m. semimembranosus} (SM), \textit{m. semitendinosus} (ST) and \textit{m. longissimus thoracis et lumborum} (LTL) of each animal. The muscle glycogen concentrations which were 6.1\% higher in the High steers compared to the Low animals while the High\textsuperscript{Het} did not differ from either group.
The effect of selection for muscling on whole body insulin responsiveness was measured using the hyperinsulineamic-euglyceamic clamp technique. Insulin was constantly infused at 2 levels, glucose was concurrently infused to maintain euglyceamia, and the steady-state glucose infusion rate (SSGIR) indicated insulin responsiveness. At the low insulin infusion rate of 0.6 mU/kg/min, the SSGIR was 73% higher for the High muscling genotype animals when compared to the Low. At the high insulin infusion rate of 6.0 mU/kg/min, these differences were proportionately less with the High and the High$^{\text{Het}}$ genotypes having only 27% and 34% higher SSGIR than the Low muscled genotype. The High muscled cattle also had 30% higher plasma IGF-1 concentrations compared to the Low muscled cattle. The increased whole body insulin responsiveness in combination with higher IGF-1 concentrations in the High muscled steers is likely to initiate a greater level of protein synthesis, which may partially explain the increased muscle accretion in these animals. Increased insulin responsiveness in the High steers would also increase glycogenesis in the muscle, aligning with the glycogen results.

The effect of selection for muscling on adrenaline responsiveness was measured using 7 adrenaline challenges ranging between 0.2 to 3.0 µg/kg liveweight. Plasma was analysed for NEFA, lactate, glucose and growth hormone concentration and area under curve (AUC) over time was calculated to reflect the tissue responses to adrenaline. The High steers had 30% lower lactate AUC than the Low steers at challenges greater than 2 µg/kg live weight, indicating lower muscle responsiveness at the highest adrenaline doses causing less glycogenolysis. This result also aligns with these animals having more muscle glycogen, thus more muscular animals may reduce the incidence of dark, firm, dry meat that is caused by low levels of glycogen at slaughter. At all levels of
adrenaline challenge the High steers had at least 30% greater NEFA AUC, indicating that their adipose tissue was more responsive to adrenaline, resulting in greater lipolysis. In agreement with this response, the High steers had a higher plasma growth hormone concentration, which is likely to have contributed to the increased lipolysis evident in these animals in response to adrenaline. This difference in lipolysis may in part explain the reduced fatness of muscular cattle. There was no effect of selection for muscling on liver responsiveness to adrenaline.

Contrary to our initial hypotheses, the High steers had less glycolytic type IIX myofibres in the LTL and larger average cross-sectional area of myofibres in the SM and ST than their Low muscled counterparts. This suggests that myofibre hypertrophy may be a possible mechanism leading to greater muscle mass of these High muscled animals. This also indicates that breeding for more muscular cattle can actually maintain the oxidative capacity of the muscle, a finding supported by the enzymatic results showing that the High muscled steers had lower activity of lactate dehydrogenase and higher activity of citrate synthase and isocitrate dehydrogenase. The High muscled cattle also had a higher concentration of iron in the LTL, and selection for increased muscling had no impact on pH decline or retail colour stability, factors which both affect meat quality.

The aim of the second experiment was to determine if phenotypic measurements taken at the time of grading for Meat Standards Australia (MSA) could explain variance in ultimate pH ($\text{pH}_u$) of carcasses and the probability of a carcass complying with MSA standards for $\text{pH}_u$ ($\leq 5.7$). Analyses of 204,072 carcass records collated by MSA at a Western Australian processor confirmed that more muscular cattle have a higher
compliance rate for pHu. An increase in eye muscle area from 40 to 80 cm², increased pHu compliance by approximately 14%. Therefore animals with greater muscularity had a lower incidence of dark, firm, dry beef supporting the results that High muscled cattle have increased insulin responsiveness, and reduced adrenaline responsiveness, leading to increased glycogen storage at slaughter. Thus, breeding more muscular cattle with eye muscle area greater than 70 cm² may help alleviate the problem of dark, firm, dry beef. As rib fat depth increased from 0 to 20mm, pHu compliance increased by around 10%. Heavier cattle also had higher compliance than lighter cattle, and younger cattle also had higher compliance rates. This highlights the importance of good nutrition and high muscle glycogen storage prior to slaughter to maximise compliance rates.

The final study examined 81 commercially managed High and Low muscled steers and showed that the effects of muscularity on muscle glycogen were variable as pasture quality and availability changed however there were no negative effects of selection for greater muscling on muscle glycogen, glycogenolysis pre-slaughter, or on the incidence of dark, firm and dry carcasses. Animal temperament assessed using crush score and flight speed measurements did however affect muscle glycogen with the more flighty animals having lower muscle glycogen concentrations.
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Publications

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Journal publications submitted:


Conference proceedings:


Abbreviations

ADP  Adenosine diphosphate
AMP  Adenosine monophosphate
ATGL  Adipose triglyceride lipase
ATP  Adenosine triphosphate
AUC  Area under curve
Ca\(^{2+}\)  Calcium
cAMP  3\(^{-}\),5\(^{+}\)-Cyclic adenosine monophosphate
CO\(_2\)  Carbon Dioxide
CoA  Co-enzyme A
COOH  Carboxyl group
CT  Computed tomography
DEXA  Dual x-ray absorptiometry
DFD  Dark, Firm and Dry
EBV  Estimated Breeding Value
EDTA  Ethylenediamine tetra acetic acid disodium salt
EMA  Eye muscle area
FADH\(_2\)  Flavin adenine dinucleotide
G 1-P  Glucose 1-phosphate
G 6-P  Glucose 6-phosphate
GLUT  Glucose transporter
HCO\(_3\)  Hydrogen carbonate
HIEG  Hyperinsulinaemic euglycaemic clamp
H\(_2\)O  Dihydrogen Oxide (water)
HSCW  Hot standard carcass weight
HSL  Hormone sensitive lipase
IGF  Insulin like growth factor
IIR  Insulin infusion rate
IMF  Intramuscular fat
IMP  inosine monophosphate
LTL  longissimus thoracis et lumborum
MLA  Meat & Livestock Australia
mM  milli molar
MRI  Magnetic resonance imaging
mRNA  messenger ribonucleic acid
MSA  Meat Standards Australia
NAD+  Nicotinamide Adenine Dinucleotide
NADH  Reduced Nicotinamide Adenine Dinucleotide
NADP  Nicotinamide Adenine Dinucleotide Phosphate
NADPH  Nicotinamide Adenine Dinucleotide Phosphate (reduced)
NEFA  Non-Esterified Fatty Acid
NH₂  Amine
PFK-1  Phosphofructo kinase-1
pHₙ  Ultimate pH
RBY  Retail beef yield
SM  semimembranosus
SSGIR  Steady state glucose infusion rate
ST  semitendinosus
TGF-β  Transforming growth factor beta
TCA  Citric Acid Cycle
UDP  Uridine diphosphate
USDA  United Stated Department of Agriculture
VFA  Volatile Fatty Acid
VIA  Video image analysis
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