**Multistate Research Activity Accomplishments Report**

**Project/Activity Number**: NC1184

**Project/Activity Title**: Molecular Mechanisms Regulating Skeletal Muscle Growth and Differentiation

**Period Covered**: 10/01/2018-9/30/2019

**Date of This Report**: 11/19/19

**Annual Meeting Date(s)**: 10/25-26/19

**Station Participants**:

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**Brief Summary of Minutes of Annual Meeting:**

The annual NC1184 technical committee meeting was held on October 25 and 26, 2019 at the Mississippi State Animal and Dairy Science Building, hosted by Dr. Derris Burnett of the Department of Animal and Dairy Sciences, Mississippi State University. On October 25th, the group was welcomed by Dr. Wes Burger, Director of the Mississippi State Agricultural and Forestry Experiment Station, who shared information about the area, college, and experiment station. The group then began with oral station reports.

At 9 AM, the group had a conference call with Dr. Mark Mirando, USDA/NIFA, who outlined current funding opportunities, the USDA NIFA budget, statistics on the number of proposals submitted annually and funding rates, and an update on NIFA’s move from Washington, D.C. to Kansas City. A question and answer session followed Dr. Mirando’s update. After the call with Dr. Mirando, the groups continued with station reports.

A lunch break was kindly provided by the meats group at MSU. After lunch, station reports continued in the afternoon. At the conclusion of the station reports, Dr. Dave Gerrard discussed the needs for the project re-write.

The group voted to hold the 2021 meeting at the University of Georgia, to be hosted by Dr. John Gonzalez.

That evening, the group met for dinner at the MAFES Enology Laboratory. The following morning, the group met at the Mississippi State Animal and Dairy Science Building for tours of the new building, labs, classrooms, and the new Meat Science lab.

The 2020 meeting will be held at the University of Connecticut, hosted by Dr. Sarah Reed.

**Accomplishments:**

**Objective 1: Characterize the signal transduction pathway that regulates skeletal muscle growth and metabolism including the influence of endogenous growth factors and various production practices.**

**South Dakota Station:**

1. Experiments related to coated and non-coated steroidal implants in finishing steers detailing molecular, physiological, and feedlot growth performance in both a large (performance only) and small pen setting were completed. Information on satellite cell populations, muscle isoform type, and carcass quality grade were also investigated.

**Wyoming Station:**

1. RBM20-dependent regulation of muscle gene splicing in skeletal muscle.
   1. Evaluated how insulin and thyroid hormone (T3) regulates gene splicing in a RBM20-dependent manner in rat skeletal muscle.
   2. Investigated how insulin and T3 regulates gene splicing through cell signaling pathway both in vivo and in vitro.

**Alabama Station:**

1. Characterization of myogenic stem cell heterogeneity and fiber morphometrics in two divergently selected broiler chicken lines. Published a peer-reviewed journal article in *Poultry Science* and presented results to Alabama poultry industry professionals at stakeholder meetings.
2. Impact of in ovo thermal manipulation on broiler chicken muscle development, growth, and satellite cell activity. Presented an abstract at the 2019 Poultry Science Association and shared results with stakeholders that will change the way poultry hatchery managers manage incubators in commercial broiler hatcheries to improve muscle growth efficiency and meat yield in broilers.

**Mississippi Station:**

1. Research trial using 60 heifers subjected to determine the impact nutrient restriction and maternal melatonin supplementation during gestation on offspring growth and development. This project involves a team of reproductive physiologists, veterinarians, and growth biologists. C-sections conducted at 240 days to collect the developing fetus for necropsy and muscle sample collection.
2. Research trial using 80 commercial hogs in which the temporal and spatial regulation of marbling growth and development along the length of the LM will be determined. We have collected over 700 biopsy samples for analysis in this project. Characterization of adipogenic, myogenic, and other regulatory gene expression is ongoing.

**Illinois Station:**

1. An experiment to determine the effects of with porcine respiratory and reproductive syndrome virus infection and mitigation of that infection by soy isoflavone supplementation on muscle and adipose tissue deposition was completed. Despite a reduction in feed intake from the infection, compensatory gain was not altered in infected animals.

**Kansas Station:**

1. A decrease in glycolytic flux alters the localization of metabolic proteins and promotes a loss of muscle mass.
2. Activation of insulin signaling via Akt/S6K rescues muscle mass.

**California Station:**

1. Determined that feeds enriched with alternative methionine sources (roasted cowpea and sunflower seed meal) affected broiler growth and was associated with reduced white striping in breast muscle, relative to a typical conventional commercial diet.

**Florida Station:**

1. Developed and validated gel electrophoresis method for separation of bovine myosin heavy chain isoforms
2. Established parameters of mitochondria function differ in longissimus muscle of heat tolerant (Brahman, *Bos indicus*) vs. heat stress susceptible (Angus, *Bos taurus*) steers

**Idaho Station:**

* 1. Evaluated the role of polyamines in bovine and commercial myoblast cell lines determination, differentiation, proliferation and fusion.
  2. Evaluated the impacts of adipocytes on the differentiation and fusion of cultured myoblasts/myocytes.
  3. Assessed the stage specific impact of varied doses of polyamines on the myogenic regulatory factor mRNA abundance

**Indiana Station:**

1. Used cell and molecular biology techniques, animal models and human subjects to study molecular regulation of muscle growth and metabolism. Trained 3 postdoctoral fellows, 5 graduate students and 3 undergraduate students in various research projects; developed new research techniques (methods).

**Iowa Station:**

1. Completed an objective evaluation of autophagic dysfunction in limb muscle and diaphragm in two mouse models of DMD.
2. Constructed a working model of heat stress-mediated muscle dysfunction that posits heat stress causes mitochondrial dysfunction and subsequent impairments in autophagy. Missing from this model, however, was a heat-sensitive trigger linking heat stress-mediated changes to mitochondrial and metabolic dysfunction. Our most current data indicate that the Ca2+ pump, SERCA, is modified with heat stress, which would necessarily impair its capacity to clear Ca2+, and lead to mitochondrial dysfunction. Moreover, this may be related to changes in thyroid hormone.
3. Discovered that barrows are resistant to heat stress-related muscle dysfunction. This resistance extended to a host of variables, pathways, and cellular processes that we have previously reported were dysfunctional in gilts subjected to similar thermic challenges. Moreover, this resistance was repeatable as it was found in an independent set of barrows subjected to a similar heat stress.

**North Carolina Station:**

1. Demonstrated that chicken myotubes respond positively to ammonia while rodent myotubes respond negatively.
2. Demonstrated that ammonia induces a fast fiber type shift in avian muscle, but a slow phenotype shift in mammalian

**Nebraska Station:**

1. Identified likely mechanisms underlying intrinsic deficits in functional capacity of IUGR fetal myoblasts. Reduced capacity for proliferation and differentiation was associated with increased responsiveness to inflammatory signals, including TNFα, TLR4, and IL-6.

**Texas Station:**

1. Generated high –throughput RNA sequence of microRNAs from 74 longissimus lumborum biopsies from F3 Bos indicus x Bos taurus steers. These sequence data are coupled with extensive meat and carcass phenotypes.
2. Student researchers presented data at scientific conferences and evaluated the impacts of specific microRNAs on meat quality attributes including tenderness and intramuscular fat deposition.
3. Analyses of sequence data are currently being evaluated.

**Utah Station:**

1. Determined that estrogen (E2) and trenbolone acetate (TBA) work through a non-genomic mechanism to increase proliferation of primary bovine satellite cells.
   1. Primary bovine satellite cells were isolated from six beef calves that weighed approximately 600 pounds and had never received an implant. Cells were then grown in culture and treated with actinomycin D (AD), a non-specific inhibitor of translation. Treatments included control, control + AD, E2 + AD, and TBA + AD.
   2. We found that both TBA and E2 are able to increase proliferation of bovine satellite cells in the presence of AD, indicating that both TBA and E2 increase proliferation through a non-genomic mechanism.
2. Gained insight into the relationship between TBA and polyamines and how these different molecules work to increase proliferation and differentiation of primary bovine satellite cells
   1. Primary bovine satellite cells were isolated from six beef calves weighing approximately 600 pound each that had never received an implant before. Cells were then grown in culture and treated as a control or with TBA, a polyamine precursor (methionine or ornithine) or one of the polyamines (putrescine, spermine or spermidine).
   2. We found that TBA, polyamines and polyamine precursors are all capable of increasing the proliferation rate of bovine satellite cells.

**Connecticut Station:**

Effects of restricted maternal nutrition and realimentation during gestation on ovine fetal muscle development

Histological analysis of fetal muscle tissues (days 50, 90, and 130) to determine changes in fiber cross-sectional area, Pax7(+) cells, and muscle fiber typing is complete and the manuscript is in progress.

Effects of poor maternal nutrition during gestation on ovine fetal muscle development

Completed proteomic analysis of longissimus dorsi muscle from offsprin gof over-, restricted- and control-fed ewes at days 90 and 135 of gestation and within 24 hours of birth. Proteomics data has been statistically analyzed and is currently being processed for final preparation for publication.

**Washington Station:**

1. Defining the roles of retinoic acid signaling in early skeletal muscle development.
   1. Vitamin A administration in neonatal calves can enhance muscle growth, which results in higher lean/fat ratio and better meat quality.
   2. Continue to define the molecular mechanisms regulating early formation of muscle cells and test the role of retinoic acid signaling in early embryonic development and mesoderm formation.

**Virginia Station:**

1. Heat stress induces metabolic adaptations in meat production animals which decrease lean mass and increase adiposity.
   1. Could be mediated through alpha-AR expression, as alpha2-ARs are inhibitory to the beta-AR pathway and direct nutrients away from oxidation towards storage. Alpha-AR expression is increased during HS and appears negatively correlated with measures of animal performance.
2. Calcium and phosphate are necessary for normal muscle development, and deficiencies cause altered satellite cell function and reduced muscle accumulation.
   1. Dietary deficiency reduced proliferating satellite cells *in vivo* compared to adequate and excess diets. However, *in vitro* SC from excess diets tended to proliferate less than SC from adequate diets with deficient diets being intermediate and not different from the two. Similarly, myoblast fusion rates were greatest in adequate diets.
3. Citrulline supplementation to sheep and horses (155 ug/kg) results in increased plasma citrulline, arginine, and glutamine. No differences in capillary density were noted.
4. Determination of dietary and physiological factors that control muscle growth in neonates, and whether nutritional manipulations could be used to enhance growth in the perinatal period.
   1. Despite receiving the same amount of diet per unit of body weight, the efficiency of protein deposition was greater in pigs fed intermittently compared to those fed continuously. This increase is ascribed to a greater stimulation of protein synthetic pathways by intermittent feeding and occurred in response to a rise in insulin and amino acids. Current work is focused on understanding whether the beneficial effects of intermittent feeding on muscle growth will also enhance the development of other vital organs in the body.
5. Completed a study that looked at long-term branched-chain amino acid supplementation as dietary intervention to enhance growth of low-birthweight neonatal pigs.

**Objective 2: Characterize the cellular and molecular basis of myogenesis**

**Wyoming Station:**

1. The role of RBM20 in the regulation of skeletal muscle regeneration.
   1. Completed muscle injury model in WT and RBM20 KO rats and investigated whether deficiency of RBM20 affects skeletal muscle regeneration.
   2. Investigated how deficiency of RBM20 impairs the process of muscle regeneration.

**Alabama Station:**

1. Effects of dietary amino acid density on growth performance, satellite cell activity, collagen gene expression, and the incidence of wooden breast in broilers.
   1. Ongoing work is being conducted to investigate the impact of reducing dietary amino acid density during the starter period and how it impacts the progression of satellite cell function and collagen infiltration in wooden breast affected broilers.
2. Effect of maternal and post-hatch dietary inclusion of 25-hydroxycholecalciferal (25OHD3) on broiler chicken muscle growth characteristics and *in vivo* satellite cell activity
   1. Determining the effects of dietary inclusion of the vitamin D metabolite, 25-hydroxycholecalciferol in commercial broiler production systems will positively impact the way the poultry industry feeds broiler breeder hens and their offspring to improve feed efficiency and meat yield.

**Illinois Station:**

1. Work is ongoing to characterize the influence of infection during gestation on offspring muscle development. To date, two cohorts of sows have been infected with porcine respiratory and reproductive syndrome virus during mid-gestation.

**Kansas Station:**

1. Damaged muscle tissue results in activation of the innate immune system which further drives muscle degeneration.
2. Histological measurement of poultry *pectoralis major* muscle from embryos injected with 2.5 mM of nicotinamide riboside at day 10 of incubation, indicate there was no effect on muscle fiber cross-sectional area. Therefore, it is hypothesized improvements in *pectoralis major* muscle weight may have been due to increases in muscle fiber number during myogenesis.
3. Injecting nicotinamide riboside into the yolk of avian embryos at day 10 of incubation did not increase muscle mitochondria content.

**California Station:**

1. When feeding feeds formulated with alternative methionine sources (roasted cowpea and sunflower seed meal) relative to a typical conventional commercial diet, pectoralis major muscle showed no changes in myogenesis yet reduced levels of expression for markers related to inflammation, adipogenesis, and foam cell differentiation of macrophages.

**Ohio and Michigan Stations:**

1. Effect of Thermal Stress on In Vivo Breast Muscle Growth in Turkeys
   1. Poultry selected for growth have an inefficient thermoregulatory system and are more sensitive to temperature extremes
   2. Objective of the current study was to study the effect of cold and hot extremes for the first 3 days after hatch in growth selected and random bred turkeys not selected for growth during the period of maximal satellite cell activity
   3. Results of deep RNA sequencing showed growth selected birds alter genes resulting in reduced muscle growth while slower growing random bred birds responded with changes in lipid related genes suggesting changes in gene expression linked to reduced lipid storage.
   4. Changes with immediate post hatch thermal stress are consistent with maintaining energy metabolism needs required to maintain body temperature.

**Idaho Station:**

1. Evaluated temporal effects of polyamine exposure and variation within two distinct and commonly utilized commercial myoblast cell lines; C2C12 and Sol8 cells.
2. Completed the first experiments validating the expression of muscle specific genes in sablefish (*Anoploma fimbria*) and these serve as important resources for comparative physiological analyses between vertebrate species.

**Nebraska Station:**

1. Demonstrated that disproportional skeletal muscle growth restriction in IUGR fetal sheep is improved by intermittent maternal oxygen supplementation. Skeletal muscle glucose metabolism was also improved at 1 month of age in these lambs.

**New Jersey Station:**

1. The PI embarked on a sabbatical in the laboratory of Joshua Rabinowitz at Princeton University to learn how to conduct stable isotope tracing to measure skeletal muscle metabolism.

**Texas Station:**

1. Initiated analysis of muscle from horses, cattle, and swine for mitochondrial number, function (including the novel mitochondrial capacity analysis, high-resolution respirometry), and health, as well as fiber type, fiber size, and cells involved in fiber regeneration or breakdown. Antioxidant status (glutathione peroxidase or superoxide dismutase activities, for example) will be determined in both blood and skeletal muscle.

**Utah Station:**

1. Gained insight into the relationship between HSPβ1 expression and development of tenderness following an ACTH stress challenge in cattle
   1. Samples were collected from the *longissimus lumborum* of steaks from animals following an ACTH challenge at 2, 12, 24 or 48 hours post challenge. An additional sample was collected at 14 days post-mortem.
   2. Protein expression of HSPβ1, HSPA, PARK7, p-HSPβ1, troponin and tropomyosin was analyzed. We also analyzed serial samples for cortisol levels and a blood CBC.
   3. We observed that there was no difference in expression of any proteins in samples collected at different time points following a stress challenge. However, the stress response varied in animals and that was correlated with expression of HSPβ1. We are currently doing additional analyses to further explore this relationship.

**Connecticut Station:**

Effects of interleukin-8 on myoblast function

Initiated projects to characterize the effects of the cytokine interleukin-8 on myoblast proliferation, differentiation, and protein accretion.

**Objective 3: Characterize mechanism of protein assembly and degradation in skeletal muscle**

**New Jersey Station:**

1. Continued to examine the impact of dietary sulfur amino acid restriction on skeletal muscle protein synthesis using deuterium oxide as a metabolic tracer. Reported that restricting methionine to 0.12 g per 100 g diet (on a zero cysteine background) reduces skeletal muscle protein fractional synthesis rate. A milder, more conventional diet that lowers methionine to 0.17 g per 100 g diet (also zero cysteine) reduced skeletal muscle protein fractional synthesis rates similarly.
2. Initiated development of ribosomal profiling in tissues from mice to reveal the skeletal muscle translatome following changes in nutritional status or activity. We have generated preliminary data in liver and next up will be skeletal muscle. The ultimate goal is to conduct ribosomal profiling in the tissues of mice which received deuterium oxide so two measures of muscle protein synthesis can be compared directly.

**Impact Statements:**

Objective 1:

Changes in knowledge:

1. TBA and E2 increase proliferation of bovine satellite cells through a non-genomic mechanism
2. dietary deficiency of Ca and P during the neonatal period reduced proliferating satellite cells in vivo.
3. ammonia induces a fast fiber type shift in avian muscle, but a slow phenotype shift in mammalian muscle
4. selection for faster growing turkeys resulted in reduce expression of genes related to muscle growth in response to thermal stress while slower growing rando-bred birds responded with changes in lipid related genes.
5. IUGR skeletal muscle and myoblast deficits were associated with adaptive changes in β adrenergic and inflammatory signaling pathways;
6. Damaged muscle tissue results in activation of the innate immune system which further drives muscle degeneration;

Objective 2:

Changes in knowledge:

1. Insulin and T3 can regulate muscle gene splicing in a RBM20 dependent manner through non-genomic pathway in heart muscle, but both genomic and non-genomic pathways in skeletal muscles. RBM deficiency alters myogenic regulatory factor expression and myoblast function

Objective 3: None to report.

**Collaborative Grants:**

Strasburg, G. (PD), Velleman, S.G., and Reed K.N. AFRI. “Influence of Thermal Challenge on Turkey Muscle Development and Meat Quality.” $975,000. 3/2014 – 2/2019.

Selsby, J. (PD), Baumgard, L. and Rhodes, R. (Co-PD). AFRI. “Therapeutic approaches to heat stress: targeting mitochondria.” $497,000. 01/2018 – 12/2021

**Collaborative Publications:**

Apaoblaza A, Gerrard SD, Matarneh SK, Wicks JC, Kirkpatrick L, England EM, Scheffler TL, Duckett SK, Shi H, Silva SL, Grant AL, D.E. Gerrard. [Muscle from grass- and grain-fed cattle differs energetically.](https://www.ncbi.nlm.nih.gov/pubmed/31734468) Meat Sci. 2019 Nov 6;161:107996. doi: 10.1016/j.meatsci.2019.107996.

Smith, Z.K., B.P. Holland, A.B. Word, G.I. Crawford, W.N. Nichols, B.L. Nuttleman, M.N. Streeter, J.P. Hutcheson, and B.J. Johnson. 2019. Effects of a single intial and delayed release implant on arrival compared with a non-coated initial implant and a non-coated terminal implant in heifers fed across various days on feed. Translational Animal Science doi: 10.1093/tas/txz127

Smith, Z.K., J.K. Kim, and B.J. Johnson. 2019. Biological responses to coated and non-coated steroidal implants containing trenbolone acetate and estradiol benzoate in finishing steers. J Anim Sci Accepted on Aug. 26, 2019: JAS-2019-3369.R2

Yang, Z., M.S. Hasan, J.K. Htoo, D.D. Burnett, J.M. Feugang, M.A. Crenshaw, and S.F. Liao. 2019. Effects of dietary supplementation of L-methionine vs. DL-methionine on performance, plasma concentrations of free amino acids and other metabolites, and myogenesis gene expression in young growing pigs. Transl. Anim. Sci. 3:113-123. <https://doi.org/10.1093/tas/txy109>.

Barnes, N.E., K.M. Mendoza, G.M. Strasburg, S.G. Velleman and K.M. Reed. 2019. Thermal challenge alters the transcriptional profile of the breast muscle in turkey poults. Poult. Sci. 98:74-91.

Ahmadpoura, A., C.C. Reichhardta, R.G. Christensena, N.E. Inecka, G.K. Murdoch, and K.J. Thornton Understanding the relationship between trenbolone acetate and polyamines relative to proliferation of bovine satellite cells. Submitted to Domestic Animal Endocrinology for review

Chen Z., R. Maimaiti, C. Zhu, H. Cai, A. Stern, P. Mozdziak, Y. Ge, S.P. Ford, P.W. Nathanielsz, and W. Guo. 2018. Z-band and M-band titin splicing and regulation by RNA binding motif 20 in striated muscles. J Cell Biochem. 119:9986-9996. <https://doi.org/10.1002/jcb.27328>

Zhao, L., Y. Huang, and M. Du. (2019). Farm Animals for Studying Muscle Development and Metabolism: dual purposes for animal production and human health. Animal Frontiers, 9:3.

Zhang, S., Y. Zhang, X. Zhou, X. Fu, J. Michal, G. Ji, M. Du, and Z. Jiang. (2018). Alternative polyadenylation drives genome-to-phenome information detours in the AMPKα1 and AMPKα2 knockout mice. Sci Rep, 8: 6462.

Wang, B., C. L. Harris, W. Nie, X. Fu, J. M. Deavila, M. J. Zhu, M. Maquivar, S. M. Parish, J. R. Busboom, M. L. Nelson, and M. Du. (2018). Neonatal vitamin A injection promotes cattle muscle development and increase oxidative muscle fibers. J Animal Sci Biotech, 9: 82.

Li, X., X. Fu, G. Yang, and M. Du. (2019). Review: Enhancing intramuscular fat development via targeting fibro-adipogenic progenitor cells in meat animals. Animal, In press.

**Book Chapters: None**

**Abstracts, Posters, and Professional Presentations:**

Baumgard, LH, Rhoads RP, Ross JW, Keating AF, Gabler NK, and Selsby JT. The intestinal, metabolic, inflammatory and production responses to heat stress. Annual Meeting of the European Federation of Animal Science (EAAP), Ghent, Belgium August, 2019.

Selsby JT, Ganesan S, Rhoads RP, and Baumgard LH. The heat is on: heat stress induces radical change in skeletal muscle. American Society of Animal Scientists, Austin, TX, July, 2019.

**Theses/Dissertations:**

Lisa Armbruster: (MS) Myogeneic and Anabolic Gene Expression in Red and White Muscle of Sablefish during Grow Out. University of Idaho

Stephen Tamm: (MS) Impact of adipocytes on the microniche, proliferation and fusion of cultured myoblasts. University of Idaho

Antonetta Colacchio (MS) Association of carcass maturity grade and genes associated with growth in young heifers. University of Idaho

Avani Gouru (MS) Myogeneic transcription factors and ornithine decarboxylase mRNA are influenced by polyamine supplementation in vitro. University of Idaho

Racheal Lemire (MS) Mississippi State University

Randi Owen (MS) Use of EconomasE to improve mitochondrial biogenesis and capacity in young performance horses. Texas A&M

Hannah Valigura (MS) Influence of supplementation of Saccharomyces cerevisiae fermentation product on inflammation in young horses. Texas A&M

Zhongyue Yang (MS) Effects of dietary supplementation of L-methionine vs DL-methionine on performance, plasma concentrations of free amino acids and metabolites, and myogenesis gene expression in young growing pigs. Mississippi State University

Amanda Liefeld (MS) Effects of restricted maternal nutrition and re-alimentation on fetal muscle development during mid and late gestation in sheep. University of Connecticut

Nicholas Margolies (MS) Role of ATF4 in Dietary Sulfur Amino Acid Restriction.Rutgers

Robert Posont (MS) Understanding neonatal pathophysiology and intervention strategies after sustained maternal inflammation during late gestation. University of Nebraska

Matthew Simmons (MS) A quantitative genetic analysis of the ancestry of Neil Trask line bred Hereford cattle. Texas A&M

Oscar Tejeda (MS) Impact of in ovo thermal manipulation on broiler chicken growth performance, carcass yields, and satellite cell mitotic activity and fiber morphometrics. Auburn University

Graham Williford (Master’s of Agriculture) Texas A&M

Hannah Spaulding (PhD) Stimulation of PGC-1α to attenuate Duchenne muscular dystrophy disease pathology and activate autophagy. Iowa State University

Amanda Brandt (PhD) Regulation of satellite cells by extrinsic factors during recovery from exercise in horses. Virginia Tech

Caitlin Cadaret (PhD) Effects of fetal inflammatory adaptations to maternal stress on subsequent muscle growth and metabolic function. University of Nebraska

Mingming Sun (PhD) Molecular mechanism of Rbm20 in pre-mRNA splicing and its new role in glucose metabolism in skeletal muscle. University of Wyoming

Chaoqun Zhu (PhD) Molecular mechanisms of Rbm20 in titin splicing and heart failure. University of Wyoming

Dylan Klein (PhD) Fit as a Horse: from Skeletal Muscle Metabolism to Whole Body Physiology. Rutgers

Rachel Allyssa Stern (PhD) Myogenic Response to Ammonia Differs Between Avian and Mammalian Species. North Carolina State University

Christine Latham (PhD) Delineating factors that impact lifetime musculoskeletal health in the horse. Texas A&M

**Other Publications and Presentations: None.**