ASSOCIATIONS AMONG DIETARY PROTEIN INTAKE, PHYSICAL ACTIVITY, AND MUSCLE QUALITY IN YOUNG ADULTS

By:

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(Under Direction of Ellen Evans)

ABSTRACT

This study explored the associations between dietary protein intake quantity and source and muscle capacity and quality controlling for physical activity and resistance training. Emerging adults (n=122; aged 18-20) were assessed for dietary intake. Muscular strength was determined via an isokinetic knee extensor assessment and muscular power was determined using a leg rig. DXA scans were conducted to estimate lean body mass and lean mass of contracting muscle. Muscle quality was calculated as strength relative to the contracting muscle (N·m/kg) and power relative to the contracting muscle (watts/kg). The results indicated higher dietary intakes of total and animal protein were associated with greater muscle capacity for strength and power. Additionally, higher relative animal protein intake was associated with greater absolute and relative power. Males and females differed in the relationships between protein intake and absolute and relative strength as well as relative animal protein intake and muscular power (all $p<.05$).

INDEX WORDS: Animal protein, Plant protein, Protein, Muscle quality, Strength, Power, Muscle capacity, Emerging adults

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Significance

Muscle quality is often described as intramuscular composition or a muscle's strength relative to its size but a more practical translational interpretation is a muscle's ability to function [1]. Proper muscle function is essential for all individuals from recreationally active young adolescents to older adults trying to maintain independence. The American College of Sports Medicine and the U.S. Department of Health and Human Services (DHHS) advocate moderate intensity physical activity and muscle strengthening activities in their guidelines as a means to improve and maintain general health and fitness, specifically muscular fitness [2, 3]. The current Physical Activity Guidelines by the DHHS even make specific recommendations for children and adolescents detailing that this group should perform muscle-strengthening activities at least 3 days per week [2]. Higher levels of muscular fitness are just one of the many adaptations gained from muscle strengthening exercises which can lead to improved muscle quality and function [4]. Improved functioning translates to an increased ability to perform daily activities without fatigue and is associated with lower risk of developing future disease conditions [5, 6]. The strength training policy statement for children and adolescents issued by the Council on Sports Medicine and Fitness confirmed this stating resistance training has a beneficial effect on body composition, blood lipid profile, bone mineral density, mental health, and even cardiovascular fitness [7-10]. *Given the numerous benefits that an adequate and healthy muscle quality can* *have on both current and predictive health outcomes it is vital to understand lifestyle factors that influence it.*

Numerous factors play an important role in shaping muscle quality for an emerging adult including chronological age, maturation, resistance training, physical activity habits, genetics, and dietary intake. Protein consumption is a key determinant in muscular health because developing muscle is an anabolic process requiring protein synthesis to outweigh protein degradation. Thus an adequate amount of protein must be consumed to rebuild damaged tissue after an exercise stimulus [11]. When this condition is met, gains in muscle size and strength have been documented [12-14] and muscle loss is attenuated in distinct populations [15-18] which equates to improved muscle quality and functional health [19].

Current nutrition guidelines emphasize achieving a certain quantity of protein to maintain or improve muscle quality however the source or quality of protein may be equally as important. Without enough animal protein or failure to pair plant protein sources properly to achieve a complete amino acid profile, muscle quality may suffer as all essential amino acids must be consumed for proper tissue growth, repair, and maintenance [20]. When comparing the relative benefit of the two protein sources, however, the majority of studies focus primarily on lean body mass and not strength which is influenced by cross-sectional area and neuromuscular aspects [21]. However, from both a clinical and recreational standpoint, focusing on absolute strength and power as well as relative strength and power of the contracting tissue, which reflects the quality of the muscle, may be more beneficial to gain insight on overall muscle function. *There is a need to address the potential impact of varying dietary intakes of animal and plant protein sources on muscle capacity (i.e. strength and power) and quality in young adults.*

Additionally, current research comparing the protein sources focuses primarily on outcomes related to resistance training interventions in men only. There are a lack of studies investigating how each source of protein alters muscle quality for both men and women participating in their routine activities, which may not include a resistance training program designed to enhance size, strength, and power. Amongst the studies examining sex differences in muscle quality and capacity, the majority of reports fail to account for diet. *Thus, there is also a need to characterize the potential impact that sex may have on the association between dietary animal and plant protein intakes and muscle quality in young adults engaging in typical physical activity behavioral patterns.*

Specific Aims

Specific Aim 1:

To determine the association between dietary protein quantity and source and muscle capacity and quality, after accounting for physical activity and strength training, in emerging adults.

H1: Individuals consuming greater total dietary protein and greater dietary animal protein (absolute grams and relative to total caloric intake) will have greater muscle capacity and quality controlling for physical activity levels and strength training frequency.

Specific Aim 2:

To determine if the relations among dietary protein quantity and source and muscle capacity and quality differ based on sex, controlling for physical activity and strength training.

H1: The associations between dietary protein quantity and source and muscle capacity and quality will be similar in men and women after controlling for physical activity and strength training.

Public Health and Scientific Significance

In decades past, it was originally thought that strength training for youth and adolescents could have detrimental impacts on growth plates, linear growth, and cardiovascular health but these speculations have been proven false [7, 9, 22-25]. Currently, organizations such as the American Academy of Pediatrics, the American Orthopaedic Society for Sports Medicine, the American College of Sports Medicine, the DHHS and the National Strength and Conditioning Association all advocate for muscle strengthening programs for adolescents and emerging adults and believe they are an effective means of improving health and muscle quality [2, 3, 7, 8]. The emerging adult population, often defined as traditional college-aged young adults, can be thought of as nearly chemically mature. The importance of resistance training and muscle quality is not limited just to functional ability but it is also relevant to promote bone, metabolic and mental health [2, 7-9]. In children, adolescents, and young adults, higher levels of muscular fitness are inversely related with cardiometabolic risk factors, inflammatory proteins, and insulin resistance [4]. Increased muscular strength throughout adolescence and into early adulthood is also inversely related with adiposity and can be an accurate predictor of future health status [2, 4, 6]. *The widespread positive effects that muscle quality, and the muscle capacity components it composes such as strength and power, potentially have major implications for the health status of emerging adults.*

Protein is a key determinant of muscle quality as amino acids serve as the backbone of skeletal muscle and the source of protein has different effects on muscle physiology [20]. Because muscle is in a constant state of synthesis or degradation, amino acid availability and nitrogen retention are key determinants for which state muscle is in and animal and plant proteins vary in these characteristics [20, 26-28]. Additionally, males and females differ in protein intake patterns as well as muscle capacity, muscle fiber composition, and enzymatic activity [29-33]. The relationship between the aforementioned multiple factors is unexplored in emerging adults. *The importance of muscle capacity and quality for the health status of emerging adults is paramount and the role that dietary protein may plan in muscular health may differ by sex.*

CHAPTER 2

LITERATURE REVIEW

Muscle Quality Defined

Currently there is no consensus on a universal definition for muscle quality. Many believe it is most closely related to strength as a common viewpoint of muscle quality is strength per unit of muscle mass but nevertheless a single assessment protocol has yet to be established. It is widely accepted that better muscle quality translates to improvements in a muscle's ability to function [1]. There are a multitude of factors that contribute to overall muscle function and quality such as fiber type, muscle architecture, metabolic properties, neural activation, and fat infiltration. Muscular size is another common parameter used to describe muscle quality and muscular cross-sectional area is generally greater in young individuals compared to old individuals, which is one of the many explanations why young adults generally function better than older adults [29]. Performance outcomes are also improved with greater muscle size but size alone can be misleading in terms of overall muscle quality [34]. Variations in fiber type, neural activation, non-contractile components, and intramuscular lipid droplets create a misalignment between size and strength measurements [35]. Both muscle strength and power are reported to be reflective of muscle function and therefore provide more insight as to overall muscle quality [1, 4, 7, 8, 34]. *The misalignment between muscle size or mass and its ability to produce force has been documented across multiple muscle groups and in both sexes which signifies a need to account for more than just size when estimating muscle quality [36-38]. Moreover, there is a* *need to measure both muscle strength and power in order to accurately characterize the muscle quality of an emerging adult.*

Muscle Quality Importance Across the Lifespan

The primary outcomes of improved muscle quality will be improved force capacity and physical function making daily activities easier. A muscle's force producing capacity is composed of mainly two elements, strength and power. Muscular strength is the maximum amount of force or torque a muscle can generate for one single repetition [4]. Although the majority of current research regarding muscle strength as it relates to function has been in older adults, improved strength amongst adolescents has also been documented to enhance physical health, motor control, and mobility [8, 39]. For example, just as higher lower extremity strength has translated to better function, mobility, and gait efficiency in older adults [40-42], higher lower extremity strength has translated to improved mobility and sprint and jump performance in younger adults [39, 43].

Skeletal muscle power is the product of the force and velocity of a contraction and can be viewed as a muscle's ability to produce force quickly [44]. Higher lower extremity power has been demonstrated to correlate with improved step height, chair rise time, functional status, and mobility in older adults [45-47] which compare to increases in vertical jump, mobility, and general physical performance in late adolescents [39, 43, 48]. *The combination of strength and power play a key role in physical functional health across the lifespan and combined are accurate indicators of muscle quality in the emerging adult population.*

Dietary Protein and Muscle Tissue

Dietary protein intake theoretically plays a role in muscle quality because protein is composed of amino acids which serve as the foundation for muscle tissue. Because of the wide variation in protein amino acid composition, each protein affects the human physiology differently [20]. Measures such as the Net Protein Utilization and Protein Digestibility Corrected Amino Acid Score (PDCAAS) are indicators of protein quality [20]. For example, beef has a net protein utilization of 73 out of 100 while black beans have a score of 0 indicating beef has a much greater percentage of absorbed nitrogen retention [28]. When the body does not ingest sufficient nitrogen it will break down lean tissue to maintain nitrogen balance leading to catabolism [26, 27]. Additionally, certain animal products such as milk, eggs, and beef all have a PDCAAS of 1.00, 1.00, and .92 out of 1.00, respectively, meaning the amino acids in these foods are highly digestible and can be utilized for protein synthesis [20, 28]. On the contrary, plant proteins such as peanuts and wheat gluten only score a .52 and .25 respectively, representing that the essential amino acids will be limited [28]. However, an exception for plant protein is soy protein which has a PDCAAS of 1.00 but some scholars believe this number is deceiving as certain antinutritional factors such as lectins, tannins, and trypsin inhibitors present in certain plant proteins such as soybeans reduce hydrolysis of the protein, increase the loss of endogenous protein, and diminish amino acid absorption [28, 49].

Data suggests that whey, despite having the same PDCAAS score as soy protein, stimulates muscle protein synthesis to a greater extent than soy [50] and animal proteins generally have higher digestibility compared to plant proteins [51]. Although measures such as the Net Utilization and PDCAAS do not exactly represent a protein's anabolic potential, they do affect muscle protein synthesis [52]. Other measures such as urea conversion however do impact a skeletal muscle's anabolic response to protein and plant proteins generally convert more readily to urea which would diminish their anabolic potential [53-56]. Whey protein, a milk derivative, also displays less amino acid oxidation compared to soy protein suggesting that the animal protein is superior in stimulating muscle protein synthesis compared to plant protein [50]. *Because of the increased digestibility, absorption, and higher essential amino acid concentration, animal proteins stimulate greater post prandial muscle protein synthesis than plant proteins but there is a need to determine how these attributes potentially influence muscle quality in recreationally active emerging adults*.

Protein Intake and Muscular Overload

Currently, the Institute of Medicine recommends that the average adult obtain 0.88 grams of protein per kilogram of body weight and sets a range of 10-35% of daily energy intake (kcal) to be derived from protein [57] while the more recently published European Safety Authority Guidelines recommend .83 grams of protein per kilogram of body weight [58]. Increased protein intake above the Recommended Dietary Allowance (RDA) in combination with resistance training has been documented to increase protein synthesis, muscle mass, and strength [12-14, 59]. For example, when 3.3 g/kg vs 1.3 g/kg of protein (per body weight) was consumed over 4 weeks in combination with a resistance training protocol, the higher intake group accumulated significantly more muscle mass [59]. In general, diets containing higher protein intakes above the RDA have been reported to elicit greater muscle protein synthesis and augment hypertrophic gains [12, 60]. Additionally, strength athletes are advised to eat 1.4-1.8 g/kg of protein per day to maintain a positive nitrogen balance [61]. More current systemic reviews and randomized control trials support these earlier findings suggesting that to obtain and preserve muscle quality one must consume at minimum the RDA of protein and in order to maximize strength training protocols one must consume more than the RDA [62-64]. *The current scope of research primarily dealing with protein intake focuses on adaptations to resistance training programs* *however it is unknown if diets higher in protein are associated with improved muscle quality in an emerging adult population with variable physical activity patterns.*

Implications of Protein Quality for Muscle Quality

Although anabolic responses to muscle strengthening activities are assumed from muscle protein synthesis outcomes, they fail to provide a quantitative estimation of size, strength, or power. Improved muscle protein synthesis, digestibility, and absorption would indicate the muscle could repair or recondition more quickly when consuming animal proteins compared to plant proteins. However, this does not directly correlate with long term phenotypic or performance outcomes. Data suggests that milk or whey promotes greater gains in lean body mass compared to an isonitrogenous amount of soy protein when given the same resistance training protocol [65, 66]. However, when the essential amino acid content is standardized between animal and plant protein sources, similar gains in muscle mass have been reported [67, 68]. Interestingly, when total protein quantity reaches a threshold of .78 g/kg of body weight, the differences in hypertrophic gains between different animal and plant based diets were also negated [69]. It was originally reported that omnivorous diets produce significantly greater increases in lean body mass and type II muscle fiber size [70] but when protein intake was measured in a range of .78-1.15 g/kg of body weight the distinct dietary groups produced similar results [69]. *Thus, further research is needed to examine the association among dietary protein quantity and source and muscle capacity and quality in young adults not undergoing prolonged exercise, specifically resistance training, interventions.*

Observational data suggests that females who are dedicated followers of vegetarian diets do not have as much muscle mass compared to those abiding by omnivorous eating patterns suggesting that animal protein intake is an independent predictor of muscle mass index in healthy women while plant protein is not, even when both groups exceeded the RDA for protein intake [71]. A weakness of this particular conclusion however is the estimates in lean tissue were made indirectly from an equation. Another key limitation in assessing study results contrasting vegetarian and omnivorous diets is most studies fail to specifically categorize vegetarians. For example, a vegan vegetarian will have far different dietary habits including protein intakes compared to a lacto-vegetarian and both of these groups will differ greatly compared to a lacto-ovo-vegetarian. Additionally, estimating lean tissue quantity alone is also not enough to provide an accurate indication of functional outcomes [35]. *The proposed study will go beyond current research, which primarily investigates lean body mass changes in response to acute periods of planned protein intake manipulation, to contrast the performance aspects of muscle capacity and quality which may be influenced by chronic dietary intakes varying in animal and plant protein in young adults.*

Dietary Protein and Muscle Quality: Potential Influence of Sex

The research examining the differences between males and females in terms of muscle quality and muscle capacity documents that men have larger fibers and as a result can produce more absolute force [29, 30, 32, 72]. However, when lean tissue mass is taken into account there appears to be no difference in terms of relative strength between the sexes [29, 30]. Although there have been reports of variations in muscle fiber composition and enzymic activity by sex [30, 32], this does not appear to affect the strength per unit of cross sectional area [73]. Additionally, both sexes display a similar ability to respond to a resistance training exercise stimulus in terms of both size and strength gains [73, 74].

One reason men and women respond to an exercise stimulus in a similar fashion and have similar relative muscle quality is because young men and women are very similar in protein metabolism. When expressed relative to lean tissue mass, women and men display similar intracellular amino acid turnover rates and muscle fractional synthetic rates suggesting similar amino acid kinetics between the sexes [75]. Additionally, both sexes produce similar intracellular signaling patterns in response to an exercise stimulus suggesting that when activity is equated, the sexes will have similar physiologic responses [76]. However, research has yet to determine how quantity of protein intake affects each sex differently with regard to muscle quality and muscle capacity.

In addition, males and females have different protein intake patterns. Emerging adult men consume roughly 1% more total daily energy intake from protein [33] and 47% more total protein on a daily basis [31] than females but it is unknown if this higher relative percentage and absolute quantity leads to improved muscle quality. Moreover, previous studies failed to account for diet when detailing similarities in muscle quality. Males also consume 5% more of their total daily protein from animal sources and females consume 4% more from plant sources [31] but the impact of this intake variation on muscle quality has yet to be investigated as well. Prior reports acknowledge the instrumental role habitual physical activity and resistance training have on protein metabolism in each sex; however, this also remains incompletely characterized. *There is a need to explore the potential impact of sex on the associations of dietary protein intake and muscle quality as the tangential literature suggests that sex differences exist in dietary protein amount and source and habitual physical activity/exercise patterns but not muscle quality.*

CHAPTER 3

ASSOCIATIONS AMONG DIETARY PROTEIN INTAKE, PHYSICAL ACTIVITY, AND MUSCLE QUALITY IN YOUNG ADULTS

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Abstract

This study explored the associations between dietary protein intake quantity and source and muscle capacity and quality controlling for physical activity and resistance training. Emerging adults (n=122; aged 18-20) were assessed for dietary intake. Muscular strength was determined via an isokinetic knee extensor assessment and muscular power was determined using a leg rig. DXA scans were conducted to estimate lean body mass and lean mass of contracting muscle. Muscle quality was calculated as strength relative to the contracting muscle (N·m/kg) and power relative to the contracting muscle (watts/kg). The results indicated higher dietary intakes of total and animal protein were associated with greater muscle capacity for strength and power. Additionally, higher relative animal protein intake was associated with greater absolute and relative power. Males and females differed in the relationships between protein intake and absolute and relative strength as well as relative animal protein intake and muscular power (all $p<.05$).

Introduction

Muscle quality is often described as intramuscular composition or a muscle's strength relative to its size but a more practical translational interpretation is a muscle's ability to function [1]. Proper muscle function is essential for all individuals from recreationally active young adolescents to older adults trying to maintain independence. The American College of Sports Medicine and the DHHS advocate moderate intensity physical activity and muscle strengthening activities in their physical activity guidelines as a means to maintain general health and fitness, or improve muscular fitness [2, 3]. The DHHS report also makes specific recommendations for children and adolescents detailing the recommendation that this group should perform these muscle strengthening activities at least 3 days per week [2]. Higher levels of muscular fitness are just one of the many adaptations gained from muscle strengthening exercises which can lead to improved muscle quality and function [4]. Improved functioning translates to an increased ability to perform daily activities without fatigue and is associated with lower risk of developing future disease conditions [5, 6]. The strength training policy statement for children and adolescents issued by the Council on Sports Medicine and Fitness confirmed this stating resistance training has a beneficial effect on body composition, blood lipid profile, bone mineral density, mental health, and even cardiovascular fitness [7-10]. Given the numerous benefits that an adequate and healthy muscle quality can have on both current and predictive health outcomes it is vital to understand lifestyle factors that influence it.

Numerous factors play an important role in shaping muscle quality for an emerging adult including chronological age, maturation, resistance training, physical activity habits, genetics, and dietary intake. Protein consumption is a key determinant in muscular health because developing muscle is an anabolic process requiring protein synthesis to outweigh protein degradation meaning an adequate amount of protein must be consumed to rebuild damaged tissue after an exercise stimulus [11]. When this condition is met, gains in muscle size and strength have been documented [12-14] and muscle loss is attenuated in specific populations [15-18] which equates to improved muscle quality and functional health [19]. Current nutrition guidelines emphasize achieving a certain quantity of protein to maintain or improve muscle quality however the source or quality of protein may be equally as important.

Animal and plant proteins have different amino acid compositions which affect human physiology and muscle differently [20]. Measures such as the Net Protein Utilization and Protein Digestibility Corrected Amino Acid Score (PDCAAS) are indicators of protein quality [20]. For example, beef has a net protein utilization of 73 out of 100 while black beans have a score of 0 indicating beef has a much greater percentage of absorbed nitrogen retention [28]. When the body does not ingest sufficient nitrogen it will break down lean tissue to maintain nitrogen balance leading to catabolism [26, 27]. Additionally, certain animal products such as milk, eggs, and beef all have a PDCAAS of 1.00, 1.00, and .92 out of 1.00 respectively meaning the amino acids in these foods are highly digestible and can be utilized for protein synthesis [20, 28]. On the contrary, plant proteins such as peanuts and wheat gluten only score a .52 and .25 respectively representing that the essential amino acids will be limited [28].

Although measures such as the Net Utilization and PDCAAS do not exactly represent a protein's anabolic potential, they do affect muscle protein synthesis [52]. Other measures such as urea conversion however do impact a skeletal muscle's anabolic response to protein and plant proteins generally convert more readily to urea which would diminish their anabolic potential [53-56]. Whey protein, a milk derivative, also displays less amino acid oxidation compared to soy protein suggesting that the animal protein is superior in stimulating muscle protein synthesis compared to plant protein [50].

Although anabolic responses to muscle strengthening activities are assumed from muscle protein synthesis outcomes, they fail to provide a quantitative estimation of size, strength, or power. Improved muscle protein synthesis, digestibility, and absorption would indicate the muscle could repair or recondition more quickly when consuming animal proteins compared to plant proteins. However, this does not directly correlate with long term phenotypic or performance outcomes. When comparing the relative benefit of the two protein sources however, the majority of studies focus primarily on lean body mass and not strength which is influenced by cross-sectional area and neuromuscular aspects [21]. However, from a clinical, public health, and recreational standpoint, focusing on absolute strength and power as well as relative strength and power of the contracting tissue which reflects the quality of the muscle, may be more beneficial to gain insight on overall muscle function.

Additionally, the emphasis on current research comparing the sources focuses on outcomes related to resistance training interventions in men only. There are a lack of studies investigating how each source of protein alters muscle quality for both men and women participating in their routine activities which may not include a resistance training program designed to enhance size, strength, and power. Amongst the studies examining sex differences in muscle quality and capacity, the majority of reports fail to account for diet. The impact of diet is especially important because males and females have different protein intake patterns with males consuming more protein and greater animal protein compared to females [31, 33].

In this context the aim of the present study was to determine the association between dietary protein quantity and source and muscle capacity and quality, after accounting for physical activity and strength training, in emerging adults and determine if the relationships differ based on sex. It was hypothesized that individuals consuming greater total dietary protein and greater dietary animal protein (absolute grams and relative to total caloric intake) will have greater muscle capacity controlling for physical activity levels and strength training frequency and the associations between dietary protein quantity and source and muscle capacity and quality will be similar in men and women.

Materials and Methods

This study was a secondary analysis using the dataset of The Strong Bones Study, the dissertation project of Dr. Simon Higgins conducted under the mentorship of Dr. Ellen Evans. The Strong Bones Study was a cross sectional study examining late adolescents, aged 18-20, n = 150, 80 female;70 male. The study was conducted Fall 2016-Spring 2017 and focused on identifying the factors contributing to bone status. Among the topics explored in the parent study were dietary intake (particularly vitamin D and calcium), alcohol intake, leg power as measured by vertical jump, leg strength as measured by knee and ankle extension torque, physical activity habits, health history and other factors known to influence bone health such as supplementation and medication use. A preliminary visit was conducted to access anthropometric measures and explain the study, followed by a secondary visit 7-10 days later to collect habitual dietary and PA data.

Participants

Participant recruitment was stratified by BMI in an attempt to get a wide range of body composition profiles, dietary and physical activity patterns and a representative sample. The participant distribution pattern was an attempt to mimic current BMI trends as approximately one-third of Americans are obese, two-thirds are overweight or obese, and one-third is within a normal BMI [77]. Additional inclusion and exclusion criteria were as follows:

Inclusion / Exclusion Criteria:

- UGA Student
- Freshman or Sophomore
- Aged 18 - 20 years
- Fluent in English
- Free of orthopedic limitations that preclude participation in exercise and PA
- Non-Smoker
- Not pregnant, planning to become pregnant in the next 6 months, or given birth in the last 12 months
- Not taking medications known to affect habitual dietary intake or physical activity related behaviors
- No current diagnosed eating disorder
- Has not undergone recent weight loss surgery (bariatric or gastric bypass)

If a subject became pregnant, developed an orthopedic limitation, or was diagnosed with an eating disorder during the study, they were excluded from participating in any future measurements. Participants were educated on the potential radiation exposure from a DXA scan and a pregnancy test was offered to all females prior to testing. Participants that were unwilling to undergo a DXA scan, record a detailed diet log, or wear an activity monitor were excluded.

Recruitment

Throughout the Fall 2016 and Spring 2017 academic calendar, potential participants were identified using the Office of Registrar and a scripted email was sent out to all qualifying freshman and sophomore students enrolled at the University of Georgia. In addition to the mass email, advertising took place via flyers distributed around campus. Interested participants were instructed to complete an online screening assessment and upon giving consent to participate in the screening survey, participants answered a series of questions to determine their eligibility. In order to clarify any ambiguous information or expectations, a member of the research team was in communication with the potential participant via their preferred method (email or phone) specified when consent was given. Eligible participants were contacted within 7 days of their completion of the online survey to inform them of their eligibility, schedule the initial visit, and answer any remaining questions the participant had.

Procedures and Measurements

Medical and Health History: General health history was collected to assess both past and current medical conditions and determine current medication use. Questions specifically addressed factors that could influence dietary and physical activity habits or primary outcomes of body composition including bone status such as medication use, supplement use, history of eating disorders, prior orthopedic limitations, smoking history, current activity habits, and family history of disease.

Anthropometric Measures: Anthropometric measurements included weight and standing height. Weight was measured to the nearest 0.1 kg using an electronic scale (Seca Bella 840, Columbia, MD). Barefoot standing height was measured to the nearest 0.1 cm using a wall mounted stadiometer (Novel Products Inc., Rockton, IL).

Body Composition - DXA: To assess whole body and regional body composition participants underwent a whole body DXA scan (Delphi-A Hologic Inc.). To ensure quality, daily calibration was checked against the manufacturer's standard phantom readings and the same technician performed all the scans. Regional analysis of DXA scans were performed to estimate lower limb lean tissue used in the power assessment and quadriceps lean tissue used in the isokinetic knee extensor strength assessment. Whole body DXA scans were cut below the pelvis and lower limb lean tissue was apportioned to the weight of the tissue in the non-dominant leg below the acetabulum and ischium. A similar process was used, delineating tissue cut below the patella to obtain contracting lean mass used in the isokinetic knee extension.

Muscle Strength, Power, and Quality: Muscular strength and power was assessed in the non-dominant leg. Muscular strength was assessed at the knee joint via muscular isokinetic knee extensor strength on a Biodex (Biodex System Pro 4, Biodex Medical Systems, INC., New York). Participants were positioned per manufacturer guidelines and performed 5 practice trials to gain familiarity with the movement. Subjects were then given a 30 second rest interval and performed 5 maximal effort voluntary contraction trials. Peak torque was recorded in Newton meters (N·m). The maximum strength recorded represents the muscle capacity of the knee extensor muscles (MC-S) and the maximum strength relative to the contracting muscle represents the muscle quality (MQ-S).

The Nottingham Leg Extensor Power Rig (Medical Engineering Unit, University of Nottingham Medical School, Nottingham, UK) was used to assess lower body muscle power. Participants were given a warm up period to get accustomed to the kinetics of the machine followed by 10 trials where maximum force output in watts was recorded. Participants were instructed to push the pedal as hard and as fast as possible. The maximum power output recorded indicates the total muscle capacity of the subject (MC-P) and the maximum power output relative to the contracting muscle represents the muscle quality of the subject (MQ-P).

Physical Activity and Strength Training Behavior: In order to assess physical activity and sedentary behaviors with the highest degree of accuracy, both subjective and objective measures were used. Physical activity (PA) and sedentary behavior were reported subjectively using the International Physical Activity Questionnaire [78] and the Sedentary Behavior Questionnaire [79]. Additionally, physically activity and sedentary time were measured objectively using the Actigraph GT3X+ accelerometer (Actigraph, LLC, Fort Walton Beach, FL) with Firmware v3.2.1. Participants were required to wear the accelerometer on their right hip during all waking hours over a 7-consecutive day period. To be included in the analysis, a participant had to have worn the accelerometer at least 4 weekdays and at least one weekend day with >10 hours of wear time for each day. Activity was recorded utilizing 15 second epochs and the VM3 vector magnitude cut points: 0-2690 represents light activity, 2691-6166 represents moderate activity, and ≥6167 represents vigorous activity. Average moderate to vigorous physical activity (MVPA) per day in minutes constituted ≥2691. Weighted average [(weekday*5) + (weekend*2) /7] was used to represent mean weekly PA variables. Participants also completed a written log detailing the times they put the monitor on and took it off for sleeping and other activities such as aquatic activities, activities where the monitor might be at risk of damage such as rugby, or bathing.

Resistance Training Frequency (RT) was assessed in the Health History Questionnaire. Participants were instructed to indicate how many days per week they performed activities to strengthen or tone their muscles.

Dietary Intake: Dietary intake data was recorded using a 3-day diet recall. The 3-day diet recall required participants to keep a detailed recording of all food and drinks over a 3-day period between the first and second visit. At the initial visit, participants were provided with an example of a completed dietary log and educated on serving size using food models. Participants were instructed to include 2 weekdays and 1 weekend day in order to be reflective of their overall dietary patterns and were reminded not to deviate from their normal consumption. If a participant was unsure about the specifics of a certain food they were encouraged to take pictures, write down recipes, and consult with the research team. Upon completion at the second visit, a trained interviewer went over the completed log with the participant to ensure quality and accuracy. Dietary data was analyzed using the Nutrition Data Systems for Research (NDSR; University of

Minnesota, Minneapolis, MN). Dietary monitoring occurred within the same 7-10 period as the PA assessment.

Data Analyses and Statistical Power

SPSS for Windows (IBM SPSS Statistics 24, 64-bit) was used to conduct data analysis. Because this study was a secondary analysis, no a priori power calculations were conducted. Outliers were considered all participants that were >3.0 standard deviations from the mean value for all dietary protein intake variables of interest in terms of both quantity and quality, muscle capacity and quality outcomes, total body mass, and whole body lean mass. All outliers (n = 22) were removed from the dataset. A priori significance was set at α=.05. All descriptive statistics are reported as mean ± SD. For every combination of major outcome variables, the normal distribution of residuals, linearity, multicollinearity, and homogeneity of variance were assessed. Bivariate relationships between continuous variables were analyzed and correlation coefficients with partial correlations were used to adjust for potential confounders. Linear regression analysis was utilized to determine independent associations between dietary protein quantity and quality and outcome variables, MQ-S and MQ-P.

Results

Males and females did not differ on age, average MVPA, or average RT however males were taller, had more body mass, more lean mass, and a greater BMI than females (all differences $p<.05$; see Table 1). As expected males had, on average, 56% greater MC-S; however unexpectedly, males also had 10% greater MQ-S. Similarly, males also had 46% greater MC-P; however, they did not differ on MQ-P (see Table 2).

Dietary outcomes of interest can be found in Table 3. Males had more daily energy intake and protein intake per day compared to females (both $p<.05$). The sources of protein also differed between the sexes. Males ate more total animal protein than females as well as relatively more animal protein when normalized per body weight, as a percentage of total kcal, and as a percentage of total protein intake (all $p<.05$). Males also ate more total plant protein than females but less relative plant protein when expressed as a percentage of daily caloric and protein intake ($p<.05$).

General dietary protein intake in relation to body weight and whole body lean mass for each sex can be found in Table 4. Total protein intake, regardless of unit of expression, was not related to body mass or lean mass in females ($p>.05$). Interestingly, males with more lean mass generally ate less animal protein per day ($r = -.28$, $p<.05$). When total protein intake relative to total calories was examined no relations with body mass or lean mass were observed in either sex. When protein source was examined there was a significant negative relationship between percent of total calories consumed from plant protein and total body mass in females ($p<.05$).

Correlations between protein intake and muscle capacity and quality controlling for sex, MVPA, and RT can be found in Table 5. Higher absolute total protein intake and animal protein intake were associated with greater MC-S and MC-P ($p<.05$). Total plant protein intake also had significant correlations with MC-S and MQ-P although in the positive and negative directions, respectively. When animal and plant protein were expressed as a percentage of total calories or a percent of protein intake, animal protein had significant positive associations for MC-P and MQ-P while plant protein had significant negative associations (all $p<.05$).

Correlations between protein intake and muscle capacity and quality controlling for MVPA and RT in males can be found in Table 6. The strongest correlation existed between total plant protein intake and MC-S ($r = .40$, $p<.05$); however, all expressions of absolute protein intake were also positively associated with MC-S (r range = .29 to .38, all $p<.05$). Total protein intake was also positively related to MQ-S ($r = .27$, $p<.05$). Total protein intake was not associated with MC-P however total animal protein intake was significantly related ($p<.05$). Percent of total calories from animal protein and percent of total protein intake from animal sources also had a significant positive association with MC-P while percent of protein intake from plant sources had a significant negative relationship with MC-P (all $p<.05$). The associations between percent of protein intake from the varying sources for MQ-P were similar in direction and magnitude. However, MQ-P differed from MC-P in that significant negative associations existed between total plant protein intake and percent of total calories from plant protein with MQ-P ($p<.05$).

Similar correlations were conducted between protein intake and muscle capacity and quality controlling for MVPA and RT in females (Table 7). Unlike males, there were no associations between dietary protein intake, regardless of expression, and MC-S, MQ-S, MQ-P. Females however, like males, had a significant positive association between animal protein intake and MC-P.

The relationship between percent of total calories from animal protein or plant protein and MQ-P was assessed for males (Appendix A) and females (Appendix B) in a regression model which also included MVPA and RT. Both beta values, for males and females, that examined percent of total calories from animal protein and MQ-P were in the positive direction while the beta values evaluating percent of total calories from plant protein and MQ-P were in the negative direction; however, only total calories from plant protein and MQ-P in males was significant. In the male regression model, both MVPA and RT were significant or trended towards significance while neither predicting factor was significant in the female model ($p>.05$).

Similar regression models were assessed for MQ-S. The relationship between percent of total calories from animal protein and plant protein and MQ-S was assessed in a regression model which also included MVPA and RT. Appendix C outlines the male regression model while Appendix D details the female model. There was no significant association between animal protein or plant protein and MQ-S in either sex. Lastly, unlike power, MVPA and RT were not significant in either model ($p>.05$).

Discussion

Understanding the relationship between dietary protein intake and muscle capacity and quality in emerging adults, especially with regard to potential sex differences, is of public health interest. The associations between both protein quantity and source and muscle quality has not yet been characterized in emerging adults or examined with regard to potential sex differences. The first aim of the study was to determine the association between dietary protein quantity and source and muscle capacity (MC; Strength or Power) and quality (MQ; Strength or Power), after accounting for physical activity (MVPA) and strength training (RT), in emerging adults. Individuals consuming more total protein and more animal protein had higher MC-S and MC-P. Additionally, individuals consuming a greater percentage of their calories and protein from animal sources displayed greater MC-P and MQ-P while those consuming more plant protein from total calories and as a percentage of protein displayed lower MC-P and MQ-P. The secondary aim of the study was to determine if the relations among dietary protein quality and source and muscle capacity and quality differ based on sex. Males displayed significant relations between absolute protein intake (total, animal, and plant protein) and MC-S while females did not. Males also had significant relationships between total protein intake and MQ-S, percent of total calories from animal protein and MC-P, total plant protein intake and MQ-P, percent of total protein intake from animal sources with MC-P and MQ-P, and percent of total protein intake from plant sources with MC-P and MQ-P. The only relationship that was similar between the sexes was between total animal protein intake and MC-P.

Previous reports have indicated men consume more total protein, more total animal and plant protein, and a higher percentage of animal protein than females [31, 80]. This study supports these findings and furthers knowledge as the present study captures emerging adults aged 18-20 while the pervious works details adolescents aged 12.5-17.5 and individuals ≥19 years of age. The study also supports previous findings in that larger individuals tend to eat more total protein as estimated by grams/day consumed per kg of body weight [80]. Because males tend to be larger than females, it is expected that their total protein intake on average would exceed that of females. Further research however, is needed to explore behavioral choice reasons as to why men consume more animal protein than women in terms of relative energy intake.

In this cohort a higher total protein intake was related to higher muscle strength and power. However, it was also observed that males tended to eat more protein than females and males have higher absolute strength and power compared to females [30, 81]. The current findings of the present study suggest higher total protein intake is related to increased MC-S and MC-P; however, the association is not robust (Table 5). Protein serves as the building blocks for muscle and a positive nitrogen balance is necessary to gain positive strength adaptations in response to muscular loading, therefore when activity is equated in terms of MVPA and RT, our data suggests that those individuals with higher protein intake tend to optimize the strength and power adaptations to these activities. However, when each sex was analyzed separately, the relationship only held true between total protein intake and MC-S and MQ-S in males (Table 6). Additional research is needed to examine the physiological mechanisms accounting for the sex differences in that only males had significant associations between total protein intake and MC-S and MQ-S and neither sex had a significant relationship between total protein intake and power.

Excluding resistance training interventions, the relationship between source of protein intake and strength is relatively unexplored in the literature in this age cohort. In another cross-sectional study higher consumers of animal protein were found to have more muscle mass and animal protein was a significant predictor of muscle mass [71]. However, no reports of strength were assessed and the population studied was middle-aged females. The results of the present study indicate higher consumers of animal protein, in terms of total grams per day, have greater MC-S and MC-P. Higher consumers of plant protein in terms of grams per day also had a significant positive association with MC-S. When expressed as a percentage of total calories animal protein had a significant positive correlation with MC-P and MQ-P while plant protein had negative correlations with each outcome. When each source was expressed as a percentage of total protein, a significant positive correlation remained between animal protein intake and MC-P and MQ-P and a significant negative correlation remained between plant protein intake and MC-S and MQ-P. Lastly, total animal protein intake also had a significant positive correlation with MC-P and total plant protein intake had a negative correlation with MQ-P. Collectively, this suggests that animal protein may have a small but significant positive impact on MC-S and MC-P as well as MQ-P.

There were however, notable differences when the associations were assessed in each sex separately. Males had the same protein and MC-S patterns as the combined group while females had no associations for protein intake and MC-S. Unlike the combined group, males had a significant association between total protein intake and MQ-S. The differences in muscle quality between the sexes contrast findings in previous reports however the present study accounted for protein intake as a factor while previous reports did not and protein intake varied between the sexes [29, 30, 73]. Additional sex differences were found in the associations between relative dietary animal and plant protein intake as a percentage of total caloric intake and as percentage of protein intake with MC-P and MQ-P. Males generally had stronger positive associations between the animal protein intake variables and MC-P and MQ-P as well as stronger negative associations between the plant protein intake variables and MC-P and MQ-P compared to females. A previous report detailed males have greater absolute and relative power than females but the present study furthers research by adding a dietary component [72]. Differences in both protein intakes and power outcomes between the sexes could be an explanation as to the possible differences in association; males tended to eat more animal protein from an absolute and relative standpoint and have higher absolute power performance outcomes thus creating a greater data range to broaden their associations. Future research should focus on examining the mechanistic differences between relative power and relative strength outputs between the sexes as well as understand how dietary protein intake can modulate each force measure.

Although there is a neural element in both strength and power adaptation, the explanation that animal protein is correlated with higher strength and power is theoretically plausible given the differing amino acid composition between the sources. Skeletal muscle is in a constant state of being either synthesized or degraded and amino acid availability has been identified as a key regulator of muscle synthesis [82-84]. Source of protein has an influential role in amino acid availability and plant proteins lack all of the essential amino acids required for protein synthesis [20, 85, 86]. Plant proteins are also lower in leucine which is deemed to be the most important amino acid in muscle protein synthesis [85, 87]. A significant negative association between total plant protein intake and MQ-P exists for the group possibly due to subjects not obtaining all of the essential amino acids from their plant protein intake or inadequate leucine intake, although this speculation requires additional research.

Previous research has documented that protein has an influential role in determining muscular power in healthy adults [88-90]. Studies indicate that without adequate protein, muscular power is attenuated and higher levels of protein intake are correlated with greater muscle power [88-91]. Results from the present study corroborate these findings in that higher total protein intake was significantly associated with greater MC-P. The novel findings suggest higher total animal protein intake as well as a higher percentage of animal protein intake from total calories and protein were also significantly associated with greater MC-P. It should be noted however, individuals who consumed more protein and animal protein tended to be larger and also male. When males were analyzed separately the relationship between percent of total calories from animal protein and MC-P remained significant while there was no significant association in females although the sample size was ~18% larger (n = 56 and 66 for males and females, respectively).

Lastly, it should be noted that the associations between protein intake and the strength outcomes, both MC-S and MQ-S, did not mirror the power outcomes, both MC-P and MQ-P, for the entire group and they were also different between the sexes. The difference between the strength and power results may be due, in part, to the physiological mechanisms of adaptation and stimulation for each force output. Strength adaptation can be mediated by almost any method of activity or exercise provided the given stimulus is sufficient to stimulate the muscle greater than normal. Power training, on the other hand, takes into account velocity of the movement and has a more pronounced neural element to adaptation therefore the adaptation would not only be geared to the magnitude of the general stimulus and dietary nitrogen intake to stimulate muscle protein synthesis but also the specificity of movement and neural components involved [92]. Further research is needed to explain how the adaptation of each force output is mediated by dietary intake, in particular protein source, especially when comparing males and females.

Although our data are of interest, several limitations need consideration above the cross-sectional nature of the study. One of the major limitations of the study was accounting for resistance training. A questionnaire regarding frequency of resistance training (days per week) was used to assess resistance training. Importantly, resistance training is notably challenging to measure. Frequency is both easy to measure and has been deemed an appropriate measure of a behavior [93, 94]. Duration tends to be overestimated in questionnaires while intensity is subject to individual perceptions [95, 96]. Training intensity, volume, specific activity performed, or body part trained was not asked. There were also subjects consuming less than the RDA of iron and B12 and it is unknown if these individuals were deficient in iron and B12. However, there was no relationship between iron or B12 intake and muscle capacity or quality outcomes and females and males did not differ significantly on either iron or B12 intake (data not shown).

The results also depict emerging adults with at least college entry education level therefore the results may not be reflective of other populations. Participants knew they were involved in an investigation examining dietary and muscle performance outcomes therefore they may have shifted their behavior and reporting for a multitude of reasons. Lastly, even though subjects received both instruction and education on reporting dietary intake, the information collected is dependent on self-reported subject participation. Despite these limitations, the objective muscle capacity measures as well as body composition measures highlight the strengths of the study and help contribute to the development of the literature regarding protein intake and muscle capacity and quality in this population of interest.

In conclusion the findings from this study confirm that males have higher protein intake and animal protein intake than females. Secondly, higher total protein intake is associated with greater absolute muscular strength and higher animal protein intake is associated with greater absolute muscular strength and power. Additionally, a higher percentage of calories consumed from animal protein and higher percent of protein intake from animal sources are associated with greater MC-P and MQ-P while the inverse holds true for plant protein intake. Thirdly, our data suggest that males and females differ in their associations between protein intake and muscle capacity and quality outcomes in that males have stronger positive associations between animal protein intake and MC-P and MQ-P as well as stronger negative correlations between plant protein intake and MC-P and MQ-P. Males also have a significant relationship with absolute protein intake regardless of source and MC-S as well as total protein intake and MQ-S while females do not. Future research should focus on different ranges of activity, resistance training patterns, and other behavioral determinants that link dietary protein intake and muscle capacity and quality with a special emphasis on distinguishing sex differences.

CHAPTER 4

CONCLUSION

The associations between dietary intake and outcomes of muscle capacity and muscle quality were assessed in 122 college students (54% female). Participants were tested for muscle capacity inclusive of absolute strength and power measured in peak knee extensor torque (Nm) and max power (watts) via a Biodex and Nottingham Leg Rig respectively. Subjects were also assessed for their relative muscle quality denoted as knee extensor torque per quad lean mass (Nm/kg) and relative max power per lower extremity lean mass (watts/kg). Males were found to be taller, have greater body mass, lean mass, and body mass index. Males were also found to have greater MC-S and MC-P indicating greater muscle capacity and greater MQ-S indicating greater muscle quality than females. In addition to energy intake, males also had greater total protein, animal protein, and protein relative to body weight and caloric intake intakes compared to females.

Quantity of total protein intake was not associated with body mass or lean mass in either sex. There were however differences when protein source was examined in relation to body mass and lean mass. Interestingly, men who had more lean mass consumed less total animal protein. Additionally, females with greater body mass consumed less of their total calories from plant protein.

Higher dietary intakes of total, animal, and plant protein were associated with greater MC-S. Higher total protein and total animal protein intakes were also related to greater MC-P. Total plant protein intake, on the other hand, was negatively related to MQ-P. Percent of calories from animal protein and percent of protein intake from animal sources were positively associated with MC-P and MQ-P while calories from plant protein and percent of protein from plant sources had negative associations. Many of these correlations remained the same when males were analyzed independently from females however in males total protein intake was also correlated with greater MQ-S. The only association that was similar between females and males was greater animal protein intake was related to higher MC-P.

Muscle quality has a significant impact on the health of younger populations in particular emerging adults. It is beneficial to identify the components that are associated with muscle quality as these factors play a critical role in physical functioning. Future research should focus on the different behavioral determinants that connect protein intake and muscle capacity and quality with a distinct spotlight on potential sex differences.

Table 1. Participant Characteristics

	Male (n = 56)	Female (n = 66)
Age (years)	19.8 ± .6	19.6 ± .8
Height (inches)*	69.3 ± 3.3	67.3 ± 3.3
Body Mass (kg)*	75.0 ± 10.2	61.5 ± 8.5
Lean Mass (kg)*	58.1 ± 10.6	51.4 ± 11.1
BMI (kg/m^2)*	23.4 ± 2.7	22.2 ± 2.4
MVPA/day (min)	91.5 ± 26.3	84.4 ± 27.7
Resistance Training Frequency (days/week)	3.2 ± 1.9	2.6 ± 1.7

Values reported as mean ± standard deviation.
*Significant difference between Sex, $p<.05$

Table 2. Muscle Capacity and Muscle Quality

	Male (n = 56)	Female (n = 66)
MC-S (N·m)*	158.7 ± 30.9	101.9 ± 19.8
MQ-S (N·m/kg)*	20.5 ± 2.6	18.7 ± 2.8
MC-P (watts)*	251.9 ± 64.0	172.3 ± 38.3
MQ-P (watts/kg)	23.1 ± 5.6	22.1 ± 4.2

Note. MC-S Muscle Capacity Strength; MQ-S Muscle Quality Strength; MC-P Muscle Capacity Power; MQ-P Muscle Quality Power. Values reported as mean ± standard deviation.
*Significant difference between Sex, $p<.05$

Table 3. Dietary Protein Intake Outcomes

	Male (n = 56)	Female (n = 66)
Total Energy Intake (kcal)*	2888.4 ± 729.5	1967.6 ± 606.6
Total Protein Intake (g/day)*	133.3 ± 39.2	79.0 ± 28.0
Total Animal Protein Intake (g/day)*	95.0 ± 36.7	51.3 ± 24.4
Total Plant Protein Intake (g/day)*	36.8 ± 12.7	27.6 ± 9.1
Total Protein Intake per Bodyweight (g/kg)*	1.8 ± .6	1.3 ± .5
Animal Protein Intake per Bodyweight (g/kg)*	1.3 ± .5	0.8 ± .4
Total Protein Intake per Lean Mass (g/kg)*	2.4 ± .9	1.6 ± .7
Animal Protein Intake per Lean Mass (g/kg)*	1.7 ± .8	1.0 ± .6
Total Protein Intake per 1000kcal Intake (g/1000kcal)*	46.9 ± 12.2	40.7 ± 10.2
Percent of Total Calories from Protein (%)*	18.8 ± 4.9	16.3 ± 4.1
Percent of Total Calories from Animal Protein (%)*	13.4 ± 5.0	10.5 ± 4.1
Percent of Total Calories from Plant Protein (%)*	5.1 ± 1.4	5.7 ± 1.5
Percent of Total Protein from Animal Sources (%)*	69.8 ± 11.0	63.1 ± 11.6
Percent of Total Protein Intake from Plant Sources (%)*	29.2 ± 10.5	36.9 ± 11.6

Values reported as mean ± standard deviation.
*Significant difference between Sex, $p<.05$

Table 4. Bivariate Correlations Between Dietary Protein Intake and Body Size

	Body Mass Males (kg)	Lean Mass Males (kg)	Body Mass Females (kg)	Lean Mass Females (kg)
Total Protein Intake (grams/day)	.14	-.26	.14	.11
Total Animal Protein Intake (grams/day)	.08	-.28*	.16	.07
Total Plant Protein Intake (grams/day)	.20	-.03	.02	.14
Percent of Total Calories from Protein (%)	.10	-.17	-.13	.01
Percent of Total Calories from Animal Protein (%)	.07	-.22	-.03	.01
Percent of Total Calories from Plant Protein (%)	.14	.14	-.27*	-.01
Percent of Total Protein from Animal Sources (%)	.01	-.19	.14	.07
Percent of Total Protein from Plant Sources (%)	<.01	.15	-.14	-.07

*Significant, $p<.05$

Table 5. Partial Correlations, Controlling for Sex, Moderate-Vigorous Physical Activity and Resistance Training, Among Muscle Capacity and Quality, and Dietary Protein Intake (n=122)

	MC-S (N·m)	MQ-S (N·m/kg)	MC-P (watts)	MQ-P (watts/kg)
Total Protein Intake (grams/day)	.29*	.13	.19*	.07
Total Animal Protein Intake (grams/day)	.25*	.13	.26*	.17
Total Plant Protein Intake (grams/day)	.23*	.02	-.10	-.23*
Percent of Total Calories from Protein (%)	.14	.14	.18	.15
Percent of Total Calories from Animal Protein (%)	.16	.13	.26*	.23*
Percent of Total Calories from Plant Protein (%)	-.02	-.06	-.20*	-.23*
Percent of Total Protein from Animal Sources (%)	.11	.09	.28*	.26*
Percent of Total Protein from Plant Sources (%)	-.09	-.10	-.24*	-.25*

Note. MC-S Muscle Capacity Strength; MQ-S Muscle Quality Strength; MC-P Muscle Capacity Power; MQ-P Muscle Quality Power.
*Significant, $p<.05$

Table 6. Partial Correlations, Controlling for Moderate-Vigorous Physical Activity and Resistance Training, Among Muscle Capacity and Quality, and Dietary Protein Intake for Males (n=56)

	MC-S (N·m)	MQ-S (N·m/kg)	MC-P (watts)	MQ-P (watts/kg)
Total Protein Intake (grams/day)	.38*	.27*	.19	.03
Total Animal Protein Intake (grams/day)	.29*	.24	.27*	.17
Total Plant Protein Intake (grams/day)	.40*	.17	-.15	-.36*
Percent of Total Calories from Protein (%)	.19	.11	.26	.16
Percent of Total Calories from Animal Protein (%)	.16	.13	.32*	.25
Percent of Total Calories from Plant Protein (%)	.14	-.06	-.16	-.30*
Percent of Total Protein from Animal Sources (%)	.06	.10	.35*	.34*
Percent of Total Protein from Plant Sources (%)	-.01	-.09	-.30*	-.33*

Note. MC-S Muscle Capacity Strength; MQ-S Muscle Quality Strength; MC-P Muscle Capacity Power; MQ-P Muscle Quality Power.
*Significant, $p<.05$

Table 7. Partial Correlations, Controlling for Moderate-Vigorous Physical Activity and Resistance Training, Among Muscle Capacity and Quality, and Dietary Protein Intake for Females (n=66)

	MC-S (N·m)	MQ-S (N·m/kg)	MC-P (watts)	MQ-P (watts/kg)
Total Protein Intake (grams/day)	.11	-.05	.25	.14
Total Animal Protein Intake (grams/day)	.14	-.01	.26*	.16
Total Plant Protein Intake (grams/day)	-.03	-.11	.06	.01
Percent of Total Calories from Protein (%)	.03	.07	.08	.12
Percent of Total Calories from Animal Protein (%)	.10	.09	.17	.18
Percent of Total Calories from Plant Protein (%)	-.20	-.06	-.23	-.15
Percent of Total Protein from Animal Sources (%)	.15	.07	.19	.15
Percent of Total Protein from Plant Sources (%)	-.15	-.07	-.19	-.15

Note. MC-S Muscle Capacity Strength; MQ-S Muscle Quality Strength; MC-P Muscle Capacity Power; MQ-P Muscle Quality Power.
*Significant, $p<.05$

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APPENDICES

Appendix A. Regression Analysis of Independent Predictors of Muscle Quality Power for Males

	Animal Protein Model	Plant Protein Model
Average Total MVPA/day^{+}	-.282 / .030	-.254 / .049
Average Resistance Training Frequency/week^{+}	.218 / .115	.322 / .012
Percent of Total Calories from Animal Protein	.245 / .073	-.280 / .028

Values listed as Standardized Beta Coefficient / P-Value (n=56)
Two separate models were conducted, one for percent of total calories from animal protein and one for percent of total calories from plant protein

Appendix B. Regression Analysis of Independent Predictors of Muscle Quality Power for Females

	Animal Protein Model	Plant Protein Model
Average Total MVPA/day$^+$	.102 / .479	.061 / .661
Average Resistance Training Frequency/week$^+$	-.116 / .402	-.096 / .493
Percent of Total Calories from Animal Protein	.182 / .165	-.149 / .244

Values listed as Standardized Beta Coefficient / P-Value (n=66)
Two separate models were conducted, one for percent of total calories from animal protein and one for percent of total calories from plant protein

Appendix C. Regression Analysis of Independent Predictors of Muscle Quality Strength for Males

	Animal Protein Model	Plant Protein Model
Average Total MVPA/day^{+}	.077 / .582	.071 / .615
Average Resistance Training Frequency/week^{+}	.122 / .418	.179 / .201
Percent of Total Calories from Animal Protein	.141 / .340	-.056 / .690

Values listed as Standardized Beta Coefficient / P-Value (n=56)
Two separate models were conducted, one for percent of total calories from animal protein and one for percent of total calories from plant protein

Appendix D. Regression Analysis of Independent Predictors of Muscle Quality Strength for Females

	Animal Protein Model	Plant Protein Model
Average Total MVPA/day^{+}	-.014 / .921	-.036 / .798
Average Resistance Training Frequency/week^{+}	-.035 / .806	-.026 / .855
Percent of Total Calories from Animal Protein	.092 / .488	-.061 / .635

Values listed as Standardized Beta Coefficient / P-Value (n=66)

Two separate models were conducted, one for percent of total calories from animal protein and one for percent of total calories from plant protein