SSE #270

Sports Science Exchange (2025) Vol. 38, No. 270, 1- 6

MUSCLE PROTEIN METABOLISM AND PROTEIN REQUIREMENTS FOR FEMALE ATHLETES: ALIGNING SCIENCE WITH SEX-SPECIFIC NEEDS

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KEY POINTS

- Regular exercise places increase demands on nutrient needs, including protein; dietary protein supports tissue remodelling during exercise recovery.
- Dietary essential amino acids are crucial for muscle growth, recovery and adaptation, regardless of the sport, age or sex.
- Sex-based differences in dietary protein needs are, if they exist at all, minimal.
- Dietary protein needs do not change substantially, or at all, across the menstrual cycle or with the use of oral contraceptives.
- Age-related muscle loss and anabolic resistance appear to be primarily driven by aging itself, rather than estrogen deficiency.
- Athletes should distribute protein intake evenly across the day, every 3-4 hours (~0.31 $g \cdot kg^{-1} \cdot meal^{-1}$; ~0.14 $g \cdot lb^{-1} \cdot meal^{-1}$) to support muscle growth.
- Individuals should target intakes of 1.4–1.6 $g \cdot kg^{-1} \cdot day^{-1}$ (0.6-0.7 $g \cdot lb^{-1} \cdot day^{-1}$) total protein, with higher intakes of >1.6 and up to 2.2 $g \cdot kg^{-1} \cdot day^{-1}$ (0.7-1.0 $g \cdot lb^{-1} \cdot day^{-1}$) recommended during periods of energy restriction or heavy training.

INTRODUCTION

Athletes undertake exercise that can place exceptional stress on their musculoskeletal and metabolic systems. Skeletal muscle plays a crucial role in generating the force and power required for sport-specific movements, maintaining joint stability and contributing to overall metabolic health and adaptation. As such, maintaining and developing skeletal muscle mass is vital across all sports.

One key factor in supporting muscle adaptation is dietary protein, which facilitates muscle repair, remodeling and growth after training and competition. Adequate protein intake promotes recovery and preserves lean mass, especially during periods of high training loads or energy restriction. Together, muscle and protein intake support athletic performance, recovery and resilience.

While the core principles of protein metabolism apply to all athletes, unique physiological factors, including fluctuating hormone levels across the menstrual cycle, hormonal contraceptive use and life stage transitions like menopause, may influence how female athletes respond to training and nutrition. Yet, despite growing interest, research examining these sex-specific responses remains limited, leaving major gaps in our understanding of female athlete physiology (D'Souza et al., 2023; Elliott-Sale et al., 2021). Understanding these potential differences is essential for developing evidence-based strategies that optimize training outcomes and long-term health in female athletes. This Sports Science Exchange (SSE) article examines protein strategies specifically designed for female athletes to enhance their performance, recovery and overall well-being.

MUSCLE PROTEIN METABOLISM

Skeletal muscle adapts to stimuli such as exercise and nutrition through the dynamic processes of muscle protein synthesis (MPS) and muscle protein breakdown (MPB) – collectively termed muscle protein turnover. When MPS exceeds MPB, muscle enters a net anabolic state, promoting growth (hypertrophy), repair and remodeling (Joanisse et al., 2020). Resistance exercise (RE) stimulates MPS through skeletal muscle contraction and serves as its primary driver. Dietary protein enhances this response by providing essential amino acids (EAAs), which serve as the building blocks of new muscle protein, and one EAA – leucine – that acts as signaling molecule to promote MPS (Smith et al., 1992).

PROTEIN REQUIREMENTS TO MAXIMIZE MPS AND PERFORMANCE

To optimize the MPS response to training, understanding protein timing and dosing is essential. Following protein ingestion, MPS rates peak and return to baseline within ~2 hours, even when amino acids remain available (Atherton et al., 2010). Research indicates that a per-meal protein dose of ~0.31 g of protein per kilogram of body weight per meal (~0.14 g/lb) elicits a maximal MPS response (Moore, 2019). Intake beyond this threshold does not further increase MPS, emphasizing the importance of distributing protein evenly across meals. Supporting this, Areta et al. (2013) showed that consuming protein every 3 hr post-RE resulted in higher rates of MPS over 12 hr, compared to intake every 1.5 or 6 hr. Similarly, distributing protein evenly across breakfast, lunch and dinner stimulates MPS more effectively than concentrating the majority of protein intake in a single meal, such as dinner (Mamerow et al., 2014). However, Trommelen et al. (2023) recently challenged the idea of protein distribution and proposed that the anabolic response to protein ingestion has no upper limit. Whether or not this has practical applications requires further investigation into relevant markers of amino acid oxidation following a large bolus of protein. Nonetheless, aiming to distribute protein evenly across meals remains a sound strategy to maximize the MPS response to training. While per-meal protein dosing and distribution matter, total daily intake also plays a key role. Although intakes above 1.6 g•kg^{-1}•day^{-1} (~0.7 g•lb^{-1}•day^{-1}) may not provide extra hypertrophic benefits in healthy adults (Morton et al., 2018), athletes may benefit from higher intakes within the recommended range, 1.4-2.0 g•kg^{-1}•day^{-1} (~0.64-0.91 g•lb^{-1}•day^{-1}), to support higher training loads and maintain lean mass during periods of energy deficit (Campbell et al., 2007).

SEX-SPECIFIC PHYSIOLOGY AND PROTEIN METABOLISM

Despite relatively small sex-based differences in protein metabolism (Smith et al., 2009), most exercise nutrition research continues to focus on males. Only 0-8% of exercise nutrition studies involve female-only participants, partly due to the added complexity of accounting for hormonal fluctuations across the menstrual cycle (Smith et al., 2022).

The menstrual cycle is a defining feature of female physiology, characterized by cyclical fluctuations in estrogen and progesterone that may influence multiple body systems, including skeletal muscle (D'Souza et al., 2023; Smith et al., 2014; Stone et al., 2025; Sung et al., 2014). The cycle consists of two main phases: the follicular and luteal phases, separated by ovulation. The follicular phase, which begins with menstruation, is characterized by a gradual increase in estrogen levels. Around mid-cycle, ovulation occurs, marked by a peak in estrogen, followed by a sharp decline. The luteal phase follows, characterized by a rise in both estrogen and progesterone (Figure 1). While ovulation is often assumed to occur 14 days following the start of menstruation, emerging data highlight substantial inter- and intra-individual variability

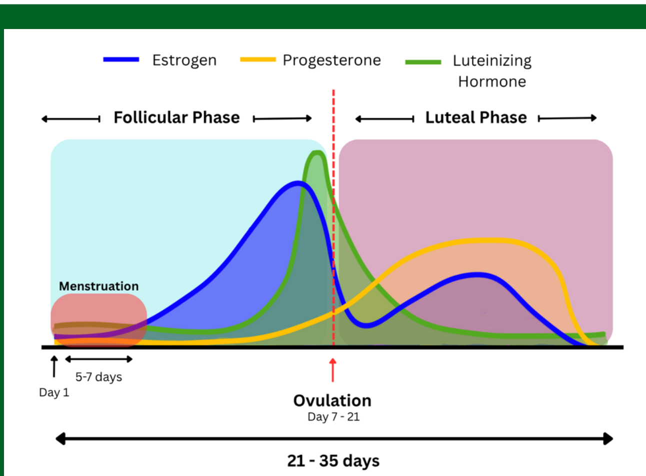

Figure 1: Hormonal fluctuations across the menstrual cycle (~21–35 days) include the follicular and luteal phases. Estrogen (blue) peaks before ovulation, triggered by a surge in luteinizing hormone (green). Progesterone (yellow) rises post-ovulation. Menstruation begins on Day 1 and typically lasts 5–7 days. Note the wide variability in the phase lengths.

in ovulation timing, ranging from day 7 to 21 of the cycle (Colenso-Semple et al., 2023; D'Souza et al., 2023).

These dynamic and sometimes unpredictable hormonal shifts create a unique and variable endocrine environment for female athletes, with potential implications for metabolism, training adaptations and nutritional needs. This variability makes menstrual cycle phase tracking more complex in practice and raises challenges when interpreting findings based on poorly tracked or assumed cycle phases. As such, considerations around study design and cycle verification are critical when evaluating research that compares or manipulates menstrual cycle phases (Elliott-Sale et al., 2021).

Despite these methodological challenges, early research suggests that estrogen supports skeletal muscle repair and anabolism (Lowe et al., 2010), while progesterone, predominant in the luteal phase, may influence appetite regulation, resting metabolic rate (RMR) and protein turnover (Benton et al., 2020; Tucker et al., 2024). For instance, increased protein oxidation during endurance exercise performed in the luteal phase was reported in early studies (Lamont et al., 1987), leading some experts to recommend that female athletes may benefit from targeting greater dietary protein intakes during this time (Sims et al., 2023). However, calculations of the extra protein oxidized show that the differences are trivial (3-5 g). More recent evidence challenges the need for menstrual phase-based adjustments to protein intake. D'Souza et al. (2023) and Kuikman et al. (2024) found no significant differences in respiratory exchange ratio and RMR across phases. Similarly, Colenso-Semple et al. (2025a) reported no differences in the MPS or MPB response to resistance exercise across the menstrual cycle.

While it remains unclear whether small increases in amino acid oxidation during the luteal phase occur, any such changes appear to be minor and are unlikely to meaningfully impact performance and recovery. Additionally, luteal-phase increases in appetite may naturally lead to higher energy and protein intake, helping offset any minor increases in protein turnover, without the need for deliberate changes (Rogan & Black, 2023; Tucker et al., 2024).

Therefore, current evidence does not support greater protein consumption during the luteal phase as a necessary strategy (Colenso-Semple et al., 2025a). Instead, the emphasis should remain on consistently meeting total daily protein goals (1.4-1.6 g•kg^{-1}•day^{-1}; 0.6-0.7 g•lb^{-1}•day^{-1}) and distributing intake evenly across meals (every 3-4 hr), regardless of menstrual cycle phase. This approach offers a practical, evidence-based foundation for optimizing muscle recovery and performance in naturally menstruating females.

HORMONAL CONTRACEPTIVES

It is important to recognize that not all female athletes experience natural menstrual cycles. More than half of pre-menopausal athletes report using some form of hormonal contraception to manage reproductive health, regulate menstrual cycles and/or reduce cycle-related symptoms (Mercer et al., 2020).

Hormonal contraceptives typically deliver synthetic forms of estrogen and/or progesterone as progestins, which can suppress the body's natural hormone production and influence ovulation and menstrual regularity (Stone et al., 2025). Combined oral contraceptives (containing both estrogen and progestin) are taken daily and generally suppress ovulation. Other options, including progestin-only pills, subdermal implants or hormonal intrauterine devices (IUDs), primarily act by altering cervical mucus and the endometrial lining, although their effects on ovulation vary depending on the formulation, dose and route of administration (D'Souza et al., 2023; Stone et al., 2025). As a result, these options create differing patterns of systemic versus local hormone exposure, which may influence physiology and training responses to different degrees (Stone et al., 2025). Understanding these distinctions is important when evaluating how hormonal contraceptives might interact with nutrition and recovery strategies in female athletes.

Despite their widespread use, the effects of hormonal contraceptives on protein metabolism remain underexplored. Of the limited research available, oral contraceptives (OCs) are the most studied. Colenso-Semple et al. (2025b) examined MPS across the active and placebo phases of second-generation OCs and found no differences between phases at rest or following RE. Interestingly, the authors also found no significant differences in MPS between OC users and those who naturally menstruate, suggesting that OC use does not significantly impact protein metabolism or alter protein requirements in female athletes.

However, some evidence points to potential differences between OC formulations. For example, Hansen et al. (2011) reported variations in MPS between different generations of OCs. Whether these differences translate into meaningful changes in dietary protein needs remains unclear. As such, while current evidence does not support modifying protein intake based on contraceptive use, further research, particularly involving newer and less-studied contraceptive methods, is warranted to guide individualized recommendations for female athletes.

HORMONAL TRANSITIONS ACROSS THE LIFESPAN: MENOPAUSE

Hormonal transitions beyond the menstrual cycle and OC use, including pregnancy and menopause, introduce longer-term shifts in endocrine profiles that may influence metabolism and muscle adaptation (Smith et al., 2014).

Pregnancy introduces a dramatic and sustained rise in estrogen and progesterone to support fetal growth (Lindberg et al., 1974). Unfortunately, its direct effects on skeletal muscle metabolism remain largely understudied. As a result, specific dietary recommendations for this demographic cannot be made at this time.

In contrast, the transition through perimenopause and menopause involves a gradual non-linear decline in ovarian hormone production, particularly estrogen, accompanied by age-related reductions in muscle mass, strength and function (Smith et al., 2014). Perimenopause is often marked by anabolic resistance in skeletal muscle, where skeletal muscle becomes less responsive to dietary protein and resistance exercise (Moore, 2014).

Some experts recommend that peri- and post-menopausal athletes aim for the higher end of the protein intake range (1.8-2.0 g•kg^{-1}•day^{-1}; ~0.82-0.91 g•lb^{-1}•day^{-1}), based on a theory that estrogen plays a role in muscle maintenance (Pellegrino et al., 2022; Sims et al., 2023). However, these estimates exceed any evidence supporting their recommendation, and current evidence shows that age-related muscle loss and anabolic resistance are primarily driven by aging itself, rather than estrogen deficiency (Greendale et al., 2019). Consistent with this, estrogen-based hormone replacement therapy does not prevent muscle loss (Javed et al., 2019).

Importantly, physical activity status also appears to play a key role, highlighting the lack of association between estrogen levels and muscle mass (Moore, 2021). Masters athletes, for example, may be less susceptible to the age-related decline in muscle mass and may retain greater sensitivity to dietary protein than age-matched sedentary individuals (Moore, 2021).

Taken together, these findings suggest that peri- and post-menopausal athletes likely do not require different protein targets than pre-menopausal athletes, as current athletic guidelines already fall within the higher protein range (i.e., 1.6 g•kg^{-1}•day^{-1}; 0.7 g•lb^{-1}•day^{-1}) and are more than sufficient to support muscle maintenance and growth. We acknowledge, however, that more research in active female populations is needed to confirm whether individualized adjustments are beneficial. Focusing on consistent protein intake in the ranges recommended here, alongside resistance exercise training, remains a sound strategy across life stages.

PROTEIN REQUIREMENTS DURING ENERGY DEFICIENCY

Female athletes participating in endurance, aesthetic or weight-class sports are particularly vulnerable to periods of low energy availability (LEA), which may be intentional (e.g. to meet body composition goals) or unintentional due to high training volumes and inadequate fueling (Holtzman & Ackerman, 2021). While brief or moderate LEA may not cause immediate harm, prolonged and severe exposure can lead to relative energy deficiency in sport (REDs), a condition associated with impaired performance, menstrual dysfunction and adverse effects on skeletal muscle health (Mountjoy et al., 2023).

To counteract the suppression of MPS that accompanies LEA and preserve lean body mass, resistance exercise should be prioritized, and daily protein intake should be increased for athletes (Phillips & Van Loon, 2011; Areta et al., 2014). For female athletes in a caloric deficit, protein intakes exceeding 2.0 g•kg^{-1}•day^{-1} (~0.91 g•lb^{-1}•day^{-1}) may help maintain lean mass and support recovery despite an energy-constrained environment. It is, however, crucial to recognize that the primary driver of lean mass retention in an energy deficit is muscle loading, rather than protein intake (Longland et al., 2016).

SPORT-SPECIFIC PROTEIN STRATEGIES

Endurance exercise and resistance exercise training both influence muscle protein balance, but their effects differ in magnitude and mechanism. RE leads to robust increases in MPS that exceed MPB, promoting a net anabolic state that can last for 48-72 hr (Miller et al., 2005; Wilkinson et al., 2008). In contrast, endurance exercise also stimulates MPS, particularly mitochondrial protein synthesis, to support recovery and adaptations, but the overall response is smaller than that observed with RE (Atherton & Smith, 2012).

Endurance training also increases amino acid oxidation, particularly that of the branched-chain amino acid leucine (Phillips et al., 1993), which may further elevate protein requirements in these athletes. Accordingly, Williamson et al. (2023) recommend female endurance athletes target approximately 1.89 g•kg^{-1}•day^{-1} (~0.86 g•lb^{-1}•day^{-1}) of protein on training days, a value beyond the upper end of current athletic guidelines. However, a systematic review by Mercer et al. (2020) found that average protein requirements were similar across aerobic endurance, resistance and intermittent exercise lasting 60-90 min. Thus, it may be primarily endurance athletes engaging in prolonged or intense training, particularly when carbohydrate availability is limited, who benefit most from the higher protein intakes (Tarnopolsky, 2004).

Regardless of training type, regularly consuming sufficient protein, distributed evenly across meals and snacks, supports recovery, adaptation and performance. Tailoring protein strategies to the athlete's sport, energy demands and training goals remains key to optimizing outcomes.

PROTEIN REQUIREMENTS FOR THE PLANT-FOCUSED ATHLETE

Ethical, environmental and health-related motivations have contributed to a growing number of athletes adopting vegetarian and plant-focused diets. In a large sample of 1628 female runners, ~40% reported following a vegan diet and 23% a vegetarian diet (Wirnitzer et al., 2022). This shift in dietary preferences raises important questions about the adequacy of plant-based protein sources for optimizing muscle health and athletic performance.

Plant-based proteins are often cited as being inferior to animal-derived proteins due to their lower digestibility and EAA profiles that fall below recommended levels (Moore, 2019; Hoffman & Falvo, 2004). Indeed, animal-based proteins generally elicit a greater anabolic response compared to single-source plant proteins (Moore, 2019). However, when consumed in sufficient quantities and with complementary protein sources, vegan and plant-based diets can support an anabolic response comparable to or even exceeding that of animal-based proteins (Vesanto et al., 2016). Matthews et al. (2025) recently stated that, "…protein quality improves when using processing and cooking methods that reduce antinutrients, denature proteins, and reduce food particle size and structure". This conclusion is also similar to that of Nichele et al. (2022), who showed that as long as plant-focused and vegan athletes meet their energy needs, and especially if they consume protein targets that are recommended here, it is unlikely that their protein intake will impair any exercise training-induced adaptation.

Multiple studies have established a dose-response relationship between protein intake and MPS, with ~0.31 g/kg (~0.14 g/lb) of body weight per meal eliciting a maximal MPS response (Moore, 2019). For plant-based athletes, achieving this per-meal threshold using diverse protein sources (e.g., legumes, whole grains, soy, nuts, seeds) is critical to ensure adequate EAA availability to support adaptation.

Current evidence suggests that vegetarian and vegan diets do not inherently disadvantage athletes in terms of muscle balance, provided total daily protein intake is adequate and strategically distributed (Sims et al., 2023). Nonetheless, continuous research, particularly in female athletes, is needed to establish optimal intake targets and validate efficacy across menstrual and menopausal transitions.

PUTTING IT INTO PRACTICE

Understanding the science is important, but applying it in real-world settings is what ultimately supports athlete health and performance. The following evidence-based recommendations provide a practical guide to help female athletes and their support teams optimize protein intake across training contexts, life stages and dietary preferences (Figure 2).

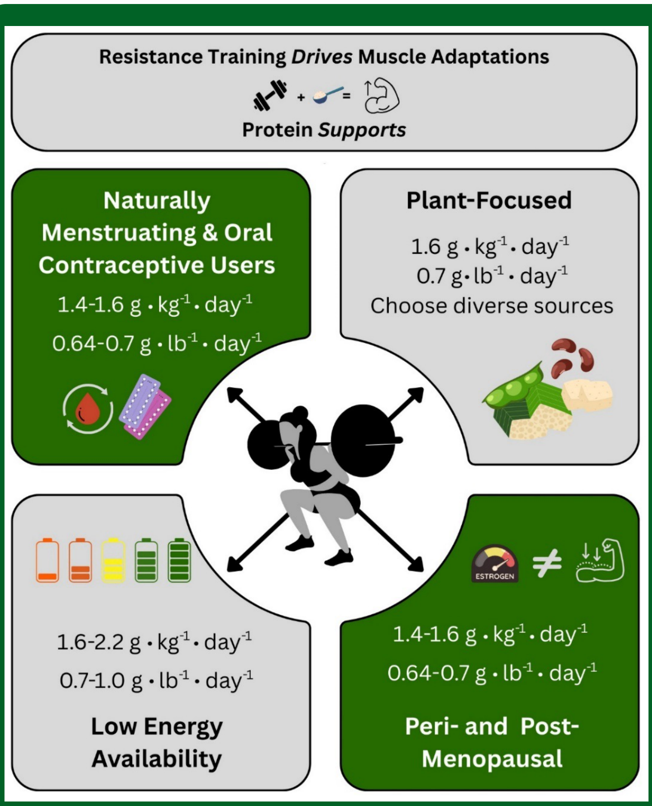

Figure 2: Recommended protein intake to support exercise-induced muscle adaptations in female athletes. Resistance exercise is the primary driver of positive muscle mass adaptations (growth, strength, retention), while dietary protein serves a supportive role. Naturally menstruating, oral contraceptive users, and peri- or post-menopausal athletes: 1.4 – 1.6 g•kg^{-1}•day^{-1} (0.64-0.7 g•lb^{-1}•day^{-1}). Plant focused and athletes with low energy availability: 1.6 – 2.2 g•kg^{-1}•day^{-1} (0.7-1.0 g•lb^{-1}•day^{-1}).

PRACTICAL APPLICATIONS

- Use a food-first approach, but consider supplementation if protein needs are not being met through diet alone.
- Distribute protein intake evenly across the day (every 4-5 hr) to support MPS, and target 1.4 – 1.6 $g \cdot kg^{-1} \cdot day^{-1}$ (0.64-0.7 $g \cdot lb^{-1} \cdot day^{-1}$) total protein, with higher intakes of >1.6 and up to 2.2 $g \cdot kg^{-1} \cdot day^{-1}$ (0.7-1.0 $g \cdot lb^{-1} \cdot day^{-1}$) recommended during periods of energy restriction or heavy training.
- For eumenorrheic athletes, no major adjustments to protein intake are needed across the menstrual cycle; instead, focus on consistency and respond to natural appetite changes throughout the cycle.
- Athletes using oral contraceptives can follow standard protein recommendations.
- Plant-focused athletes should emphasize a variety of protein sources and may require ~10% higher total intake to compensate for lower EAA content.

SUMMARY

Female athletes undergo unique hormonal transitions and physiological demands that can influence their nutritional needs throughout their lifespan. Despite persistent myths and limited sex-specific research, the current body of evidence supports a consistent, individualized approach to protein intake. This approach prioritizes total daily intake, thoughtful meal distribution and dietary context, rather than unnecessary adjustments based solely on the menstrual cycle phase or contraceptive use. Whether navigating energy deficits, menopause or plant-based diets, resistance training combined with protein intakes of 1.4-1.6 $g \cdot kg^{-1} \cdot day^{-1}$ forms the cornerstone of muscle health, performance and long-term well-being. Empowering female athletes with clear evidence-informed guidance is key to supporting adaptations and fueling success.

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