Effects of Different Dietary Proteins and Amino Acids on Skeletal Muscle Hypertrophy in Young Adults After Resistance Exercise: A Systematic Review

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ABSTRACT
This article reviews the available literature on which proteins, amino acids, or combination of both seem to be optimal to enhance hypertrophy after resistance exercise in young adults. Depending on the content of essential amino acids and particularly leucine, either an immediate ingestion of ~20 g milk protein followed by a similar amount ~1 hour later, or a single bolus of ~40 g seems to be suitable. Greater amounts might be necessary if a protein of lower quality is chosen (i.e., plant-based proteins) to match the required amino acid quantities and facilitate muscle growth.

INTRODUCTION
Investigating skeletal muscle hypertrophy is important for numerous reasons. Recreational and professional athletes can benefit from hypertrophy as a muscle with increased cross-sectional area (CSA) can exert more force, eventually leading to greater strength and power potential (39). Muscle hypertrophy has vital implications not only for performance but also from a health perspective. Muscle tissue plays a major role in regulating our metabolism and consequently all diseases that are related to it (34,43). Furthermore, building up muscle tissue in young subjects could be a promising intervention to battle increasingly prevalent diseases such as sarcopenia or cachexia, which are related to muscle loss and muscle weakness (5,52). Starting early enough with this could be particularly important, as humans have been reported to become resistant to anabolic stimuli during aging (10,33,36,65). How to optimally stimulate skeletal muscle hypertrophy in young healthy adults through exercise is a controversial topic (14).

Skeletal muscle hypertrophy occurs when the aggregate of muscle protein synthesis (MPS) exceeds the aggregate of muscle protein breakdown (MPB) for an extended period of time, resulting in a positive net protein balance (NPB). It is well-established that in order to stimulate this process, it is essential to overload the muscle (27,28). However, it has been shown that in a fasted state and without sufficient protein intake, the anabolic effects after RE are diminished, as both MPS and MPB rise in a similar fashion resulting in a negative NPB (1,22,46,60).

Essential amino acids (EAAs) play a key role, as they increase MPS and minimize MPB, causing a higher NPB compared with a mixture of nonessential amino

KEY WORDS: milk; whey; casein; soy; leucine; protein; resistance training; hypertrophy
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amino acids (AAs) (60). The EAA leucine has been suggested as a MPS key modulator by increasing the activity of important signaling proteins (19). Sufficient protein intake seems to be important to maximize the contractile protein accretion after RE, and this seems to be partially dependent on the EAA content of the consumed protein. A protein high in EAA and with a high digestible indispensable amino acid score may be termed as a "high-quality protein" (23).

Examples of high-quality protein sources include whey-, casein-, multicomponent proteins or even AA supplements such as branched-chain amino acids (BCAA) or pure leucine. This review will overview the effects of different dietary proteins ingested immediately before, during, or after RE. It has been shown that the anabolic effects of RE differ depending on certain factors, such as level of experience of the subjects, training volume, and training intensity. Therefore, the protocols of the reviewed studies will be elucidated in detail to allow for the results to be put in an appropriate perspective.

SEARCH STRATEGY
A systematic PubMed database search was performed using combinations of the following terms: "protein ingestion," "casein," "whey," "soy," "egg," "beef," "leucine," "amino acids," "resistance training," "resistance exercise," and "weightlifting." Language of the studies was limited to English (Figure).

CRITERIA
This review included studies that looked at the effects of more than one protein or AA source during their respective experiments. The subjects in those studies had to undergo at least 1 bout of intense RE, and indicators of skeletal muscle hypertrophy had to be measured before and after the intervention. Examples of such indicators are acute changes in muscle protein turnover or long-term changes in body composition and muscle size. All studies administered the protein in a time frame of 90 minutes before, during, or after RE as this seems to be crucial for the hypertrophic response (1,22,45,53).

Studies with older (+40 years) or diseased subjects were excluded (Table 1).

A total of 5,868 articles were initially found. Of this, 12 studies till July 2013 fulfilled the defined inclusion criteria and were included in this review.

DIFFERENT PROTEIN SOURCES ON MUSCLE PROTEIN TURNOVER AND HYPERTROPHY
Seven studies analyzed milk proteins (whey and casein) and their different effects on postexercise muscle anabolism or chronic changes in body composition. Four of them compared the results with soy protein.

Tipton et al. (59) included 23 healthy, young, untrained subjects of both genders. Subjects had to perform a single bout of leg extension, consisting of 10 sets of 8 repetitions (reps) at 80% of the 1 repetition maximum (IRM) of the subjects, with a 2-minute break between each set. One hour after this bout, 20 g of whey protein (2.3 g leucine), casein protein (1.7 g leucine), or placebo (water) were ingested by the subjects. Vastus lateralis biopsies were taken 55 minutes before, immediately before, and 120 minutes and 300 minutes after RE. Leg blood flow was measured 45–35 minutes before and at 40–45 minutes, 80–90 minutes, 115–120 minutes, 200–210 minutes, and 290–300 minutes after exercise. Blood samples were taken at 17 points from 35 minutes before exercise to 300 minutes after exercise. Appearance of AAs (phenylalanine and leucine) in the blood and muscle was measured, and NPB was calculated using the following formula: NPB = (blood flow across the leg) × (arterial AA concentration − venous AA concentration).

Whey protein ingestion resulted in a more rapid increase and larger peak in leucine concentrations in blood and muscle than casein ingestion, likely because of different digestive properties of the proteins (2,20,21). However, in terms of the potential hypertrophy (NPB), no significant difference between the groups was observed. The placebo had no effect on the values.

Wilkinson et al. (64) compared a milk protein containing drink (fat-free milk) with an isonitrogenous and isoenergetic soy protein drink. Eight young subjects who were regularly engaged in RE (≥4 days per week) participated in 2 bouts of a unilateral leg workout, separated by ≥1 week. Three standardized exercises (leg press, leg curl, and leg extension) were executed, each for 4 sets at 80% of the 1RM with 2-minute rest between each set. After the exercise, either the soy or milk drink was ingested. Both included 182 g of protein, 1.5 g of fat, and 23 g of carbohydrates (CHO). Muscle biopsies were taken immediately before and after RE, at 60 minutes, 120 minutes, and 180 minutes after workout. Blood samples were drawn 90 minutes before exercise, directly before and after exercise, and 30, 60, 90, 120, and 180 minutes after RE. Blood flow was measured before and after workout, as well as every hour after RE up to 180 minutes. Similarly to Tipton et al. (59), fractional synthesis rate (FSR in percentage per hour) was calculated as described by Phillips et al. (46). NPB was calculated by subtracting fractional breakdown rate from FSR. The fat-free milk stimulated FSR to a substantially greater extent (34%) than the soy drink, resulting in a significantly greater NPB area under the curve (AUC). This indicates that milk proteins are a better stimulator of postexercise muscle anabolism in young resistance athletes than soy protein.

In a follow-up study by Hartman et al., 56 college students who were previously not experienced in RE completed a 12-week trial. Before the start of the program, subjects were randomly assigned to 1 of the 3 groups (milk, soy, or control) (29). Each subject was trained 5 days per week on a rotating split program. The split program consisted of 3 different types of sessions, for a total of 60 RE sessions over the course of the 12 weeks. During the trial, load was progressively increased (starting at 80% 1RM), whereas the number of reps per set decreased. Immediately after each workout and again 1 hour later, each subject consumed a drink. The drink was either skim milk (17.5 g of
protein, 25.7 g of CHO and 0.4 g of fat), an isoenergetic and isonitrogenous soy beverage, or an isoenergetic control drink consisting of maltodextrin. Changes in fat- and bone-free mass and type 1 and type 2 fiber CSA were measured using dual-energy x-ray absorptiometry (DEXA) and muscle biopsies of the vastus lateralis, respectively. Both methods were used twice: before the start of the RE regimen and after the completion of the 12-week program.

The greatest gains in lean mass and CSA could be observed in the milk protein group, followed by the soy protein and the control groups. These findings suggest that a combination of milk proteins (i.e., whey and casein) is superior to soy protein or CHO alone in terms of promoting hypertrophy in young resistance trained men.

Based on those findings, Candow et al. (13) hypothesized that whey protein would support fat-free mass gains in young adults to a greater degree than soy protein or an isoenergetic maltodextrin supplement. Twenty-seven untrained subjects were randomly assigned into 3 groups: whey protein, soy protein, and placebo (maltodextrin). Each participant received a prepacked bag containing one of the supplements. They were instructed to ingest 1.2 g per kg bodyweight of the supplement, 0.4 g per kg bodyweight before and after RE, as well as before bed. The weight training program was composed of a 3-day rotating split, with 6–9 exercises per session and 4–5 sets per exercise at 60–90% of their IRM for 6–12 reps, for a total study duration of 6 weeks. All participants had to report their dietary intake of 3 days during the first and last weeks. No significant difference in dietary habits between the groups or weeks was observed. Mean calorie intakes ranged from 2,978 ± 702 to 3,129 ± 591 kcal per day and protein intakes from 1.6 ± 1.3 to 1.9 ± 1.3 g per kg bodyweight per day. However, it is important to mention that the supplementary protein intake of the whey and soy groups was not included in these data, meaning that most subjects were likely to not only match but also clearly exceed the recommended protein requirements for athletes engaged in RE (37,38,47,50). As a result of this trial, the whey and soy protein groups showed significantly greater gains in LBM (measured by DEXA) than the placebo group. In this study, the hypothesis that whey

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**Table 1**

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<thead>
<tr>
<th>Criteria</th>
<th>Included</th>
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<tr>
<td>Age</td>
<td>&lt;40 y</td>
<td>≥40 y</td>
</tr>
<tr>
<td>Protein/amino acid source</td>
<td>≥1</td>
<td>≤1</td>
</tr>
<tr>
<td>Health status</td>
<td>Healthy</td>
<td>Diseased</td>
</tr>
<tr>
<td>Timed ingestion</td>
<td>±90 min of RE</td>
<td>&gt; ±90 min of RE</td>
</tr>
<tr>
<td>Resistance exercise</td>
<td>≥1 bout per study</td>
<td>No RE</td>
</tr>
<tr>
<td>Indicators of muscle growth measured</td>
<td>Yes</td>
<td>No</td>
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</table>
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protein would support muscle growth to a greater extent than soy protein could not be confirmed.

Tang et al. (56) investigated whether there is a different effect for the isolated proteins of milk (whey and casein) compared with soy. In contrast to Tipton et al. (59), this study found a significant difference between casein, soy, and whey on MPS. Eighteen young and healthy subjects experienced in weight-lifting (2–3 sessions per week) completed this trial. A single bout of 2 unilateral leg exercises was performed: 4 sets of leg press and leg extension at 100% of their previously determined 10–12 RM with 2-minute rest between each set. Immediately after RE, a drink of 21.4 g of whey, 21.9 g of casein, or 22.2 g of soy protein was ingested. Each drink contained approximately 10 g of EAA. A continuous l-[ring-13C6] phenylalanine infusion, blood samples, and muscle biopsies were used to measure MPS at rest, after the consumption of the drink and up to 180 minutes after the workout. Despite similar EAA content in all drinks, the ingestion of the whey drink resulted in a significantly greater AUC of leucine and higher MPS than the ingestion of soy or casein. Therefore, whey protein seems to be a more potent stimulator of acute muscle anabolism after RE than casein or soy. Several authors suggested that this might be because of the faster absorption rate of whey when compared with other proteins that are similar in EAA content (2,20,21). However, an infusion protocol of only 3 hours postprandially is unlikely to catch the slow acting effects of casein on MPS and could therefore show an incomplete picture.

Reitelseder et al. (49) conducted another study comparing whey with casein. They confirmed what Tipton et al. (59) found and could not replicate Tang et al. (56). They had 17 subjects not experienced in RE perform 10 sets of 8 reps at 80% of their 1RM with 3-minute rest between the sets. After RE, a drink of either whey, casein (0.3 g per kilogram lean bodyweight), or control (non caloric) was ingested. MPS was measured in a similar way as described in earlier studies (46,56,59,64). Compared to the study by Tang et al., the infusion protocol of this investigation was twice as long and assessed changes in MPS over a 6 hour period. Whey ingestion was followed by a greater peak in MPS during the early phase (1–3 hours), whereas casein caused a higher elevation during the later phase (3–6 hours), resulting in a similar mean MPS over the total period (1–6 hours). This is supporting the idea that the slower absorption kinetics of casein requires a longer infusion period to allow for a comprehensive comparison to its effects on MPS versus whey protein. However, it was a special form of casein that was used in this trial. Unlike micellar casein that is found in bovine milk and was used in the other experiments mentioned above, this form (calcium caseinate) has different digestive properties that are more similar to whey protein. Micellar casein is not acid soluble causing it to be digested more slowly, whereas caseinates are acid soluble and release their AAs much more rapidly into the intestine, bloodstream, and ultimately peripheral tissues (18). Therefore, the results of this study cannot be applied to the most common form of casein (micellar casein) and are likely to be directly linked to this particular form of casein (caseinate).

Recently, another comparison between whey and casein did not show any significant differences between changes in body composition (63). Wilborn et al. had 16 female basketball players participate in this trial of 8 weeks. They participated in 4 whole-body RE sessions per week, which were not specified in terms of intensity. Subjects performed 3 conditioning units per week suited toward basketball. The subjects were randomized into a whey or casein protein group. Both groups consumed either an isocaloric portion of 24 g casein or whey immediately after each of the 7 training sessions of the week. By the end of the 8 weeks, both groups had increased muscle mass and strength in a similar manner. However, the lack of a nonprotein control group makes it difficult to distinguish the effects of the training protocol from the protein supplementation.

Taken together, these results indicate that a combination of milk proteins as it is naturally occurring in bovine milk seems to be superior to soy protein in promoting hypertrophic gains in young healthy adults (29,56,64). When looking at the effects of the isolated milk proteins, whey protein seems to be more facilitating in the early phase after RE, whereas casein ingestion results in a slower, but more prolonged effect on MPS (49,56).

It has been suggested that the main reason for soy protein being less potent in augmenting MPS, despite its high-quality AA profile and fast digestion rate, is the way it is partitioned. Its AAs seem to be primarily distributed to the splanchic region and less toward peripheral tissues like muscle (3,24,57).

THE ROLE OF LEUCINE AND OTHER AMINO ACIDS

Results from Wilkinson and Hartman et al. suggest that milk may be an efficient postworkout nutrition and protein source (29,64). The protein in bovine milk as used in those studies usually contains 20% whey to 80% casein protein (31). A combination of whey and casein protein could be a promising workout beverage. However, substantial differences in absorption kinetics and time effects of whey and casein were observed, leaving the question whether it is possible to ameliorate the effects of fast- and slow-acting proteins on lean mass accretion by combining them. The exact role of AAs within proteins or added to them remained unclear.

Kerksick et al. (35) compared the effects of 3 different postworkout drinks on body composition after 10 weeks of RE. Thirty-six subjects were assigned to either a whey and casein protein blend (48 g: 40 g of whey and 8 g of casein), a whey protein that was stacked with BCAAs and glutamine (48 g: 40 g of whey, 3 g of BCAAs + 5 g of L-glutamine), or an isonenergetic CHO placebo that had to be ingested in a 2-hour window after RE or in the morning (9 AM) on training-free days.
The participants were experienced in weightlifting and completed a 10-week RE program (4 sessions per week), with 7–8 exercises and 21–24 sets per session, respectively. Over the course of the study, the training loads were progressively increased, and each set throughout the entire program was executed until the subjects could not perform another complete repetition. The preplanned reps ranged from 6 to 10 per set for most of the exercises and 25 per set for abdominal exercises. Similarly to Candow et al. (13), the subjects were instructed to report their dietary habits over a 4-day period before the start of the trial, during weeks 2, 5, 8, and 10 of the program. Energy intake from group to group and week 0–10 varied between 29.2 and 39.8 kcal per kilogram bodyweight and protein intake from 1.4 to 2.5 g per kilogram bodyweight, respectively. Although there was no statistical difference between the groups, it is important to note that every single subject was close to matching or even exceeding the recommended protein intake per day for RE athletes (37,38,47,50). As a result of this trial, significant gains in LBM measured by DEXA occurred in the whey plus casein group only, indicating that this protein blend would be advantageous compared with whey protein that was stacked with EAA and glutamine, which had no effect on body composition.

In an attempt to further elaborate on the role of leucine and EAA on MPS, Churchward-Venne et al. (16) looked at the effects of different whey protein dosages, with or without added leucine or EAA. A regular dose of whey protein (25 g) was compared with 2 different groups of suboptimal dosages of whey protein (6.25 g). One group had added leucine, to match the leucine content of the regular dosage in it and the other had added EAA in it, to match every EAA of the regular dosage besides leucine. They hypothesized that adding leucine, but not EAA, would result in a MPS response similar to the group with the complete whey (19,51,60). They had 24 subjects not experienced in RE perform a single bout of unilateral exercise, consisting of 4 sets of 10–12 reps leg extension and leg press at 95% of their previously determined 1RM. Immediately after this bout, they were assigned to 1 of the 3 groups in a single-blended fashion and ingested the beverage. MPS was measured as described earlier, using infusion, blood samples, and a biopsy from the worked muscle (vastus lateralis) (46,49,56,59,64). As a result, they observed equal MPS responses between the groups in the early hours (1–3 hours) after RE, but only the complete whey group (25 g) was able to sustain this response for a prolonged time (3–5 hours after exercise). This implies that despite the fact that leucine was suggested to be indispensable for MPS and NPB to occur, less of it than previously thought might be necessary when other EAAs are available in sufficient amounts. In addition, whey in adequate quantities seems to be a better choice postworkout than little amounts of protein stacked with leucine or other EAAs. Whey in adequate quantities seems to be a better choice after workout than little amounts of protein stacked with leucine or other EAAs.

Reidy et al. (48) compared the effects of whey protein with a protein blend consisting of sodium caseinate (50%), whey, and soy (25% each). Both beverages contained approximately the same amount of leucine (~1.8 g) and EAAs (~8.7 g). Nineteen untrained subjects completed a single bout of leg exercise. They performed 8 sets of 10 reps leg extension at increasing intensity from 55 to 70% of their 1RM with 3-minute rest between the sets. FSR was measured using similar methods as described in earlier studies (16,46,49,56,59,64). The protein drink was ingested 1 hour after RE. Depending on the subjects’ group and their bodyweight (0.3–0.35 g per kilogram bodyweight), they either received ~18 g of whey or ~19 g of the protein blend. The group hypothesized that the individual characteristics of each component of the protein blend would yield unique advantages over whey protein. No significant difference in MPS between the groups could be observed in the early phase after RE. However, as expected, the slower kinetics of the caseinate and the plant protein led to an increased MPS during the late phase (2–4 hours after RE), whereas no increase in MPS could be observed for whey-only at that time. This shifted effect of the slower proteins is also reflected by differences in the rise and fall of AA concentrations in the serum. The authors therefore suggested that a multicomponent protein could be a better choice after RE. Similar to the study by Reitelseder et al. (49), it is important to consider that sodium caseinate just like calcium caseinate does not resemble the digestive characteristics of micellar casein and instead is absorbed much faster (18).

Hendra et al. compared “bioenhanced” whey (20 g of whey + 5 g of leucine) with normal whey (20 g), a placebo (27 g of maltodextrin), and a control group (30). Over 8 weeks of RE, 106 subjects, 49 of them experienced in weight training, trained 3 times per week at 80% of their 1RM with 2-minute rest between the sets. The subjects were randomly assigned into 5 different groups: bioenhanced whey combined with a low-volume RE program, bioenhanced whey plus moderate volume, normal whey plus moderate volume, placebo plus moderate volume, and control plus moderate volume. The different beverages were ingested 30 minutes before and after workout. On rest days, they were instructed to drink it in the morning in a postabsorptive state. Each participant had to report 3 random days of dietary intake (2 week days and 1 weekend day) and was asked to maintain his habits throughout the study. Average kilocalorie intake between the groups ranged from 2,320 ± 129 kcal to 3,029 ± 181 kcal. Protein intake varied from between 0.69–1.96 g per kilogram bodyweight (lowest average group intake) to 1.26–2.86 g per kilogram bodyweight (highest average group intake), respectively. The placebo and control groups consumed significantly less protein than the other 3 groups. However, even in those groups some...
individuals excessively exceeded the recommended (37,38,47,50) protein intake per day. The changes in body composition were evaluated using peripheral quantitative computed tomography. No significant changes in muscle CSA or LBM gains could be observed between the groups, despite the difference in total protein intake.

Recently, Joy et al. (32) compared the effects of 48 g of rice protein versus 48 g of whey protein after RE for 8 weeks. Subjects were 24 healthy young males who were experienced in strength training for at least 1 year. The RE protocol consisted of an undulating periodization program for 3 days a week. They performed alternating whole-body sessions at either their 8–12 RM or 2–5 RM. The weights were increased by 2–5% when the desired number of reps was achieved. The authors hypothesized that there would be no difference between the groups, agreeing with earlier assumptions about a "leucine threshold" (4). Indeed, no significant difference between the groups was found.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Protein sources, duration, and outcome</th>
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<tbody>
<tr>
<td>Reference</td>
<td>Protein and amino acid content of the beverages</td>
</tr>
<tr>
<td>Tipton et al. (59)</td>
<td>20 g whey or 20 g casein</td>
</tr>
<tr>
<td>Wilkinson et al. (64)</td>
<td>18.2 g milk protein or 18.2 g soy protein</td>
</tr>
<tr>
<td>Hartman et al. (29)</td>
<td>17.5 milk protein or 17.5 soy protein</td>
</tr>
<tr>
<td>Cadow et al. (13)</td>
<td>~30 g whey, ~30 g soy protein or ~30 g maltodextrin</td>
</tr>
<tr>
<td>Tang et al. (56)</td>
<td>21.4 g whey, 21.9 g casein, or 22.2 g soy protein</td>
</tr>
<tr>
<td>Reitelseder et al. (49)</td>
<td>~20 g whey or ~20 g casein</td>
</tr>
<tr>
<td>Wilborn et al. (63)</td>
<td>24 g whey or 24 g casein</td>
</tr>
<tr>
<td>Kerkisick et al. (35)</td>
<td>40 g whey + 8 g casein or 40 g whey + 3 g BCAAs + 5 g glutamine</td>
</tr>
<tr>
<td>Churchward-Venne et al. (16)</td>
<td>25 g whey, 6.25 g whey + leucine (matched with 25 g whey), 6.25 g whey + EAA (matched with 25 g whey, besides leucine)</td>
</tr>
<tr>
<td>Reidy et al. (48)</td>
<td>~18 g whey or ~19 g protein blend (25% whey, 50% sodium caseinate, 25% soy)</td>
</tr>
<tr>
<td>Herda et al. (30)</td>
<td>20 g whey, 20 g + 5 g leucine, 27 g maltodextrin or placebo</td>
</tr>
<tr>
<td>Joy et al. (32)</td>
<td>48 g whey or 48 g rice protein</td>
</tr>
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</table>
The rice group increased their lean mass by 2.5 kg, which was measured using DEXA. The whey group gained 3.2 kg of lean mass during the intervention. Both increased their 1RM of the performed exercises in a similar manner. The authors concluded that the study provides evidence for the theory of a leucine threshold. They assume that this threshold is within the range of 1.7–3.5 g of leucine. Similar to Wilborn et al., this study was limited by the lack of a control group.

**DISCUSSION**

Although in contrast to the majority of the findings, the results of Herda et al. are in line with a number of other studies that could not find any positive effects for protein or AA supplementation combined with RE (7,12,25,26,61,62). However, it is the only study fulfilling the criteria of this review that failed to show a positive effect of protein supplementation on indicators of skeletal muscle hypertrophy. There are two main reasons that could explain these results. One is that most subjects in the study of Herda et al. were not experienced in RE, and it is a common observation that novice lifters tend to respond markedly well to the onset of RE, unlike advanced athletes. This might be because of a decreased MPS signaling in advanced athletes, caused by chronic loading of the muscles (17,41,42,54). It is possible that the beginners in the study by Herda et al. could have benefited from their initial sensitivity to RE, resulting in significant hypertrophy despite suboptimal nutritional circumstances. The authors agree on the chance that the naturally high basal MPS rates in young men, in conjunction with an efficient RE program, could have already been such a great stimulus that all additional effects of protein supplementation got whitewashed (30). Additionally, some of the subjects in each of the groups exceeded the current recommendations for daily protein intake by a great margin. Potentially, this could have slightly distorted the results despite a significant mean difference in overall protein intake between the groups.

Yet it is possible that overall daily protein and calorie intake are paramount to protein ingestion with training. However, there is no doubt that a high-quality protein source enhances acute RE-induced MPS and NPB (16,48,49,56,59,64). Moreover, acute NPB after exercise and EAA ingestion reflects 24-hour NPB (58), and there is evidence for protein to augment long-term LBM gains to a greater degree than placebo or CHO. A recent meta-analysis has shown that improvements in LBM favor protein supplementation over placebo (15). This was regardless of the age or training status of the subjects (15). This indicates that studies unable to find an effect for protein supplementation to further enhance the effects of RE may have been underpowered.

Eventually, based on the current literature, isolated or mixed milk proteins and regular bovine milk seem to have the most potential to facilitate muscle growth compared with other proteins (29,49,56,64).

Bovine milk is, despite its high casein content, rapidly absorbed, resulting in an acute MPS response that is surprisingly close to isolated whey (64). The growth-facilitating effects of milk proteins seem to be greater than for other proteins not only on the short-term but also on the long-term in young healthy adults (29,56,64). Furthermore, both components of milk protein (whey and casein) are high in leucine and other EAs, but only whey seems to effectively augment acute postworkout MPS because of its fast absorbable characteristics (56).

In general, it appears that combining both milk proteins, as it naturally happens in bovine milk, could be a promising strategy in further optimizing the MPS response after RE. The fast-acting characteristics of whey are complemented by the slow-acting characteristics of casein, resulting in a rapid, but also prolonged increase in MPS (49,64). This seems to be the case regardless of the type of casein (29,35,64). Adding other proteins such as soy to those milk protein–based blends might be advantageous as well, but further research is needed to confirm the benefits of such multicomponent proteins (48).

Moreover, adding leucine or other AAs to a sufficient amount of protein, which is already high in EAA, does not seem to further augment skeletal muscle hypertrophy (30,35). However, if the amount of high-quality protein and leucine is below what seems to be the sufficient amount (20 g and 1–1.7 g, respectively) (43,40), adding EAA or leucine could help to still get the optimal, early response after RE (16). Alternatively, exceeding these amounts and consuming enough of a protein that is poor in leucine until one transgresses the proposed threshold of 1–1.7 g could be feasible as well, if a protein of higher quality is not available (32). However, if the amount of protein is insufficient and the shortcoming is compensated with the addition of leucine or EAA, it would be advisable to endorse such a compromise with a full dose of a high-quality protein shortly afterward, as only a complete protein seems to allow for a prolonged MPS (16).

It is difficult to compare acute studies that measured muscle protein turnover with long-term interventions which measured changes in muscle size. Little is known on the long-term adaptations of skeletal muscle to different levels of protein intake and timing. For example, effect sizes of muscle growth found in long-term interventions are commonly substantially smaller than expected based on acute studies that measured muscle protein turnover (30,40). Future experiments should target the physiological changes that might occur between acute studies and long-term interventions. For accurate recommendations, further research is needed to determine the optimal ratio of fast- to slow-acting proteins and the role of other AAs besides leucine. Moreover, other high-quality protein sources such as beef protein or egg protein have been shown to ameliorate muscle protein
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CONCLUSION

Most of the results suggest that ingesting milk protein directly before or after RE is advantageous for individuals interested in optimizing skeletal muscle hypertrophy. The available literature indicates that a combination of fast- and slow-acting milk proteins (i.e., whey and casein) could provide the most perpetual anabolic effects. The exact amount that should be ingested is dependent on the quality of the protein and its content of EAA, specifically leucine, with 1–1.7 g of leucine appearing to be optimal to facilitate muscle protein accretion in young subjects. Approximately 20 g of a milk protein followed by a similar amount ~1 hour later, or alternatively ~40 g in a single bolus feeding seem to be sufficient to maximize the acute MPS response after RE, as well as long-term hypertrophy. Exceeding those amounts might be necessary only if a protein of lower quality (i.e., plant-based protein) is chosen. Particularly, individuals with low protein intake and protein sources of poor quality could benefit from protein supplementation around training.

Conflicts of Interest and Source of Funding:

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REFERENCES


51. Smith K, Reynolds N, Downie S, Patel A, and Rennie MJ. Effects of flooding amino


