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Review

The Impact of Protein in Post-Menopausal Women on Muscle Mass and Strength: A Narrative Review

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Abstract: Background: Menopause is a significant period in the life of a female; many hormonal and lifestyle changes occur, which can have a catastrophic effect on their health and well-being. Amongst these changes is the loss of muscle mass and strength. Resistance training is recommended for post-menopausal women; however, the role of protein in muscle mass and strength in this population is unclear. Methods: This narrative review discusses the research evidence regarding daily protein needs, dose and timings of intake, and protein quality. Results: Observational and interventional studies suggest post-menopausal females should ingest at least the RDA 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ of protein, the dosing at each meal maybe important. Both whey and soy protein may provide some benefit to muscle strength. Conclusions: Overall, there is limited evidence and not of high quality, making it difficult to make inferences about the protein needs of post-menopausal females.

Keywords: hormone; lean mass; muscle function; menopause

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1. Introduction

The transition into menopause marks a significant phase in a woman's life and natural menopause is diagnosed at one year following the cessation of menses [1,2]. However, natural menopause is a process over time rather than something that occurs at a single time point [1]. Women can live a third of their lives in a post-menopausal state, so knowledge of the effects of menopause and any interactions with dietary intakes on health parameters is important. Body composition changes during menopause, including increases in adiposity, particularly in abdominal adiposity, and decreases in lean, bone, and muscle mass [3], have the potential to impact the risk of chronic health conditions, well-being, and quality of life.

2. Hormone Changes during Menopause

With menopause, there are hormonal fluctuations. The sex hormone levels decrease, and although the main focus is usually estrogen, other hormones are also altered. In a longitudinal study (12 years) of 160 Swedish females, 7 to 12 months after the final menstrual cycle, serum Follicular Stimulating Hormone (FSH) concentration increased on average by 68% [4]. Alongside this, there was an average decrease of 60% in estradiol and a 32% decrease in estrone concentrations compared to 1–6 months prior to the final menstrual cycle. The decline in estrogen with menopause is associated with a decrease in growth hormone (GH), insulin-like growth factor (IGF-1), and dehydroepiandrosterone (DHEA), a reduction in muscle protein synthesis, and an increase in catabolic factors, including the pro-inflammatory cytokines, e.g., tumor necrosis factor-alpha (TNF-α) and interleukin 6 (IL-6) [5,6]. The early dramatic change in hormones is then followed by a more gradual decline during early post-menopause; see Table 1 for hormone values between pre- and post-menopause.

Table 1. Published hormonal concentrations regarding the pre-, peri- and post-menopause stages of otherwise healthy women (values presented as mean ± standard deviation unless otherwise stated).

Hormone	Pre-Menopause	Peri-Menopause	Post-Menopause
Estrone (E1)		299 ± 171 [4]	216 ± 104 pmol.L^{-1} 3 years: 148 pmol.L^{-1} [4]
Estradiol (E2)	75.0 ± 1.7 pg.mL^{-1} [7]	Early 73.6 ± 1.9 pg.mL^{-1} Late: 51.8 ± 6.0 pg.mL^{-1} [7]	40.2 ± 6.5 pg.mL^{-1} [7]
Progesterone	27.3 ± 9.95 nmol.L^{-1} [4].	22.4 ± 15.1 nmol.L^{-1} [4].	≤2 nmol.L^{-1} [4].
Follicular Stimulating Hormone (FSH)	19.5 ± 0.4 IU.L^{-1} [7]	Early: 30.5 ± 0.8 IU.L^{-1} Late 87.2 ± 4.9 IU.L^{-1} [7]	109.7 ± 5.3 IU.L^{-1} [7]
Luteinising Hormone (LH)	3.7 mIU.L^{-1} Range 2.83–5.90 mIU.mL^{-1} [8]	Early: 7.2 mIU.L^{-1} Range: 4.05–13.28 mIU.mL^{-1} Late: 8.8 mIU.L^{-1} Range: 7.7–26.3 mIU.mL^{-1} [8]	Very Early: 30.05 mIU.L^{-1} Range 17.48–35.78 mIU.L^{-1} Early: 33.30 mIU.L^{-1} Range: 20.80–43.90 mIU.L^{-1} Late: 30.55 mIU.L^{-1} Range: 23.5–38.48 mIU.mL^{-1} [8]
Testosterone	25–30 months pre: 1.5 ± 0.48 nmol.L^{-1} [4]	1–6 months pre: 1.7 ± 0.5 nmol.L^{-1} [4]	13–24 months post: 1.4 ± 0.47 nmol.L^{-1} 85–96 months post: 1.2± 0.38 nmol.L^{-1} [4]
IGF-1	Normative data 95% CI females 21–23: 144–541 ng.mL^{-1} [9]	166.07 ± 6.63 ng.mL^{-1} [10] *	138.89 ± 7.85 ng.mL^{-1} [10]
GH		1.8 ± 0.8 mU.L^{-1} [11] *	1.0 ± 0.6 mU.L^{-1} [11]
DHEAS	109 ug.dL^{-1} [12] ‡	Early: 108 ug.dL^{-1} Late: 112 ug.dL^{-1} [12] ‡	Early: 112 ug.dL^{-1} Late: 108 ug.dL^{-1} [12] ‡

* classed as pre-menopausal but no information on time before menopause onset as a cross-sectional study but likely peri-menopausal based on age ‡ Data are taken from the figure.

2.1. Stages of Menopause

The stages of the female life cycle are not always clearly defined. However, recently some standardisation has been proposed with a ten-stage categorisation [13]. Premenopause, or the reproductive years, are stages −5 (early) to −3a (late). Menstrual flow status is defined as regular in stages −5 to −3b, with subtle changes in the menstrual cycle, i.e., flow and length at stage −3a, which occur alongside a low antimüllerian hormone (AMH), Inhibin B, and Antral Follicle Count. FSH is defined as low in stage −3b, but variable in stage −3a. The menopause transition is divided into two stages; early stage −2; and late stage −1. Early transition is defined as having consecutive menstrual cycles of variable length (≥7 days), increased variability of FSH, and low AMH, Inhibin B, and Antral Follicle Count. Late transition is defined as amenorrhea of ≥60 days, FSH ≥ 25 IU.L^{-1}, and low AMH, Inhibin B, and Antral Follicle Count. Post-menopause is divided into four stages; early stages +1a (1 year post-menopause), +1b (2 years post-menopause), +1c (3–6 years). Stage +1a and 1b are characterised by variable FSH, low AMH, and Inhibin B, and very low Antral Follicle Count. In stage +1c, FSH stabilises and AMH, Inhibin B, and Antral Follicle Count are all very low. Stage +2 is late menopause and is the remainder of life. For full details see Harlow et al. [13].

2.2. Estrogen

There are four types of estrogen, but the most common and potent during the reproductive years is estradiol (E2). E2 is essential for muscle health and inflammatory response [14]. Estrogen receptors are found in skeletal muscle fibres, and are known to play a role in muscle regeneration by stimulating the proliferative activity of muscle satellite cells [15,16]. Exercise and muscle damage activates the satellite cells' regenerative function, rebuilding integrity and muscle function [17]. Estradiol not only plays a role in satellite cell activation but is involved in the production of GH and IGF-1 as well as modulation of local and systemic inflammatory responses, [18,19]. For example, with the decrease in E2, there is an increase in IL-6 and TNF-α production. In post-menopausal females, there were significantly lower levels of E2 yet greater levels of TNF-α compared to

pre-menopausal females [20]. These changes promote the accumulation of fat mass and compromise muscle function [21–23], causing sarcopenia [24,25]. Post-menopausal females had less motor unit/muscle activation, muscle quality, and strength compared to pre-menopausal females [20], demonstrating the detrimental health effects of menopause. The association between estrogen and inflammatory cytokines is further supported by in-vitro research. This has shown that 17β-estradiol can inhibit the inflammation-mediated release of some pro-inflammatory cytokines, such as TNF-α, which degrade muscle proteins and reduce the ability to respond to muscle damage [26,27]. Therefore, estrogen promotes an anti-inflammatory and anti-catabolic influence on muscle, especially after exercise [28].

In the six-months around menopause, there is a significant decrease in estradiol from 383 $\pm$ 363 to 182 $\pm$ 163 pmol.L^{-1} [4]. There is also a decrease in El from 299 $\pm$ 171 to 216 $\pm$ 104 pmol.L^{-1}. This is followed by a moderate decline over the following three years for both E1 and E2. At 3.5 years post-menopause, mean values were 102 pmol/L and 148 pmol/L, respectively [4]. The ratio between E1 and E2 increases from about 3 years before menopause [4]. The Best Practice Advocacy Centre New Zealand (bpac^{nz}) states that estradiol ranges from 100 to 1400 pmol.L^{-1} during the reproductive years but is <200 pmol.L^{-1} post-menopause [29].

2.3. Progesterone

Aside from estrogen, the other main female reproductive hormone is progesterone. The production of progesterone by the ovaries ceases after the final menstrual period, contributing to loss of muscular function and muscle mass, and sarcopenia [30].

In the aforementioned study of 160 females, over a 12-year period, the frequency of cycles with progesterone values indicating ovulation (progesterone $\leq$ 10 nmol.L^{-1}) decreased from approximately 60% to below 10% during the 6 years before menopause. Progesterone concentrations in the 72–61 months before menopausal were 27.3 $\pm$ 9.95 nmol.L^{-1} and 22.4 $\pm$ 15.1 I nmol.L^{-1} 6 to 0 months before menopause [4]. During postmenopause, all serum levels of progesterone were low ($\leq$2 nmol.L^{-1}) [4].

2.4. Follicular Stimulating Hormone (FSH) and Luteinising Hormone (LH)

Prior to menopause FSH fluctuates from 3–6 IU.L^{-1} and is continuously >20 IU.L^{-1} post-menopause [29]. Luteinising hormone (LH) ranges between 2 and 75 IU.L^{-1} pre-menopause and is continuously >15 IU.L^{-1} post-menopause [29]. Following menopause, LH significantly decreases. The LH/FSH ratio also reduces over the menopause transition, with pre- and post-menopause values significantly different (0.62 $\pm$ 0.17 vs. 0.42 $\pm$ 0.10, $p < 0.0001$) [4].

2.5. Testosterone

Although not always discussed with menopause, testosterone plays a role in muscle maintenance and muscle growth in females. The small amount of circulating free testosterone is believed to be metabolically active [31]. However, free testosterone declines with age and this decline, particularly in the first few years after menopause, may also result in accelerated loss of muscle mass [32,33]. It has been reported that testosterone declines by approximately 15% in the two-years around menopause, then from three-years post-menopause concentrations stabilise [4].

2.6. Growth Hormone (GH) and Insulin-Like Growth Factor 1 (IGF-1)

Both GH and IGF-1 decrease with age and following menopause, which has implications for body composition, i.e., an increase in fat mass, particularly abdominal fat, and a decrease in lean mass [34]. In 67 females, a significantly lower plasma IGF-1 was found in postmenopausal females (n = 46) as compared to the pre-menopausal (n = 21) group (138.89 $\pm$ 7.85 ng.mL^{-1} vs. 166.07 $\pm$ 6.63 ng.mL^{-1}; $p < 0.01$) [10]. Mean 24 h growth hormone concentrations were also significantly lower in postmenopausal (n = 18, 1.0 $\pm$ 0.6 mU.L^{-1}) than in premenopausal (n = 17, 1.8 $\pm$ 0.8 mU.L^{-1}) females [11].

2.7. Dehydroepiandrosterone (DHEA)

Between the ages of 25–35 years, dehydroepiandrosterone (DHEA) production peaks and then gradually decreases over time, especially at the time of menopause. This is of particular interest as DHEA and its sulfate ester (DHEA-S) can be transformed into estrogens (e.g., estradiol) in specific tissues, including skeletal muscle, producing estrogenic effects [2]. Therefore, the DHEA decline is associated with a decrease in muscle mass and physical performance.

The sulfated conjugate of DHEA is DHEA sulfate (DHEAS). Declines in circulating DHEA/DHEAS are associated with aging and DHEA/DHEAS declines parallel the onset of many age-related chronic diseases [35]. Amongst 1423 females, there was a significant ($p = 0.003$) within-woman increase in DHEAS from early to late perimenopause of 4.27 μg/mL (3.95%) [12]. Of the 1423 females with at least one observation during late perimenopause or early perimenopause, 1202 (84.5%) displayed an early-to-late perimenopause increase in DHEAS. Mean DHEAS levels were similar during late perimenopause and early post-menopause (within 24 months of FMP) but declined significantly between pre-menopause and late post-menopause by 3.96% on average [12].

3. Menopause Health, Body Composition and Muscle Function

Associated with menopause are many symptoms and health concerns, particularly body composition, especially changes in muscle [3]. Compared to premenopausal females, post-menopausal females are 4.88 times more likely to develop abdominal obesity, with central obesity fat mass increasing by 1.7% annually (mean absolute gain of 0.45 kg) [36]. During the menopause transition, muscle mass loss is also accelerated, with reports of lean body mass (LBM) decreasing by 0.5% (a mean annual absolute loss of 0.2 kg) [36]. Aging is also associated with many muscle changes. For females, the menopause transition and the associated hormonal changes accentuate the modifications to the aging muscle. The odds of sarcopenia, a condition characterised by a loss of muscle mass and strength, are substantially elevated among post-menopausal females (odds ratio [OR] 2.99, 95% CI, 1.38–6.51) [37]. This is likely in response to hormonal changes (estrogen and testosterone decreasing), the activation of inflammatory pathways, fat infiltration into the muscle, apoptosis, altered mitochondrial function, neuromuscular junction insufficiency, myofiber loss, impairment of capillary blood flow, difficulty in muscle repair and regeneration (mostly due to decreased muscle satellite cell number), and inflammation [38]. In addition, menopause is associated with altered lifestyle factors such as reductions in activity levels and changes in dietary intake (malnutrition, protein deficiency) [2], further contributing to reductions in muscle strength and mass. This suggests that modifying lifestyle factors, i.e., dietary intake (particularly protein), may have the potential to attenuate some of these muscular changes.

These multifactorial changes result in net muscle atrophy as degradation exceeds synthesis, which ultimately leads to sarcopenia [39]. Sarcopenia is associated with adverse outcomes such as falls, fractures, physical disability, and mortality [39]. There does not appear to be one specific criterion for sarcopenia. Still, there is consensus amongst the European Working Group on Sarcopenia in Older People (EWGSOP) [39], the Asian Working Group for Sarcopenia (AWGS) [40], and the European Society of Clinical Nutrition and Metabolism, the Special Interest Group (ESPEN-SIG) [41] and the International Working Group on Sarcopenia (IWGS) [42] that low muscle strength and/or function forms part of the diagnostic criteria, with the AWGS, ESPEN-SIG, and IWGS also including low muscle mass [40–42].

Given the increased risk of sarcopenia following menopause and the catastrophic consequences of the condition, it is essential to evaluate the potential nutritional factors that could be implicated. These muscle strength and mass decreases occur due to muscular, neuromuscular, and lifestyle factors. For example, menopause is associated with reductions in exercise and activity levels. Dietary changes also occur, including a drop in dietary protein intake. These changes are likely associated with the hormonal changes that occur during this period in a woman's lifecycle (inactivity, sedentary behaviors) and

nutrition (malnutrition, protein deficiency) in addition to hormonal changes (estrogen or testosterone decreased) [2]. This suggests that lifestyle, i.e., dietary factors (particularly protein intake) could potentially be modified to attenuate these muscular changes. Progressive resistance exercise training is known to be effective in increasing strength, muscle mass, and endurance [28] and there are guidelines for the prescription of exercise to treat sarcopenia [43,44]. Resistance exercise alone is beneficial for muscle mass, and the available evidence suggests that aging populations, including menopausal females, should engage in resistance exercise [28]. Although physical activity levels on the whole decline during the menopause transition, a number of females adhere to the physical activity and resistance training guidelines yet still struggle with changes in body composition. Those who do not meet the physical activity guidelines should be encouraged to increase their activity levels and include resistance training each week. However, it is possible that nutritional intakes may also contribute to the changes in body composition in post-menopausal females, particularly amongst active post-menopausal females. Protein is a potent anti-sarcopenic stimulus and has been promoted to aging persons participating in resistance exercise [45]. Protein and resistance training have been described as having important positive implications for health, and are the most commonly utilised non-pharmacological strategies for the health of older populations [46]. A meta-analysis of intervention studies incorporating resistance training and protein supplementation showed a beneficial effect of protein supplementation on muscle mass and strength (handgrip strength) amongst adults (male and female) aged over 60 years with sarcopenia [47].

The availability of protein (amino acids) has beneficial effects on muscle anabolism, lean mass, and strength and can increase IGF-1 concentrations [48–50]. These tools have the potential to attenuate the risk of sarcopenia in menopausal females, and so promoting well-being, independence, and health in this population. Therefore, this review discussed the evidence regarding protein intake, muscle mass, and function in post-menopausal females.

4. Protein Intake

The dietary intake of proteins has an impact on the levels of the body's regulatory proteins and growth factors involved in muscle growth [51]. Therefore, adequate protein intakes are essential for attenuating the risk of sarcopenia and loss of strength amongst post-menopausal females [52]. The recommended protein intake for the general population is 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ (recommended daily amount, RDA). However, greater intakes are suggested for athletic populations and muscle hypertrophy [53], although this recommendation is based on studies mainly conducted on young, mainly male athletes. Furthermore, the PROT-AGE expert group recommendations suggest that older adults should consume more protein than younger people, and the requirements for healthy older populations should be 1.0–1.2 $g \cdot kg^{-1} \cdot d^{-1}$ to maintain muscle mass [54], which is well above the RDA. The higher recommendations reflect the reduced ability of the skeletal muscle to respond to both amino acid and insulin levels, termed 'anabolic resistance' [55], as well as the increased need for protein as estrogen decreases due to the associated chronic inflammation [56].

Despite the importance of protein, the evidence suggests that protein intakes decrease across the menopausal transition [2,57]. Willougby et al. (2024) showed a significantly lower protein intake (relative to body mass) in untrained post-menopausal females (0.81 ± 0.23 $g \cdot kg^{-1} \cdot d^{-1}$) compared to untrained pre-menopausal females (1.47 ± 0.27 $g \cdot kg^{-1} \cdot d^{-1}$) ($p = 0.011$), this was not seen for any other macronutrient (fat nor carbohydrate) [20]. Not only could the reductions in protein intake have implications for muscle mass from a muscle growth standpoint, but as protein intake is known to promote satiety [58], it could also have body weight implications [58]. Low protein intakes may result in overall increased energy intakes (due to increased carbohydrate and fat intakes), leading to body weight (fat mass) gains. However, research suggests that despite weight gain during menopause, energy intake decreases during this period (~254 $kcal.d^{-1}$) [59], which likely reflects a decrease in energy expenditure.

4.1. Observational Cross-Sectional Studies

Cross-sectional research studies amongst healthy post-menopausal females have shown that protein intakes above the RDA are associated with lower body fat and lean-to-fat mass ratio. Although the reported average protein intake amongst healthy post-menopausal females is 1.1 $g \cdot kg^{-1} \cdot d^{-1}$ protein, and so exceeding the recommended daily allowance (RDA; 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ protein) [60], one study reported that 25% of participants consumed less than the recommended daily allowance (RDA = 0.8 g/kg/d protein) [60]. The National Health and Nutrition Examination Survey (NHANES) data show that at least 8% of females in the USA consume an insufficient amount of protein [57]. It has also been shown that those who consumed less than 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ had impaired muscle function [60]. One study assessed post-menopausal Brazilian females who were grouped into tertiles: $\leq$0.93 $g \cdot kg^{-1} \cdot d^{-1}$, 0.94 to 1.29 $g \cdot kg^{-1} \cdot d^{-1}$, and $\geq$1.3 $g \cdot kg^{-1} \cdot d^{-1}$ [61] (see Table 2 for details) rather than utilising RDA for grouping, so a direct comparison with meeting the RDA cannot be made. Despite this, they reported differences between the lowest and highest tertile levels, with the lowest intake group having the lowest skeletal muscle mass index and the highest percentage of body fat. However, these results should be interpreted with caution due to potential confounders. For example, the lowest tertile group also had lower mean daily steps, whereas the highest intake group had the longest duration in education. These additional confounders highlight the potential influence of socio-economic status on muscle health, i.e., those in lower socio-economic groups are more likely to have poorer dietary quality and less physical activity, both of which could impact muscle mass and strength independently of protein intake [62–64]. These factors may help explain the differences seen between intervention and cross-sectional studies, as higher protein intake groups may reflect a more 'healthful' dietary intake or lifestyle, especially given the role protein plays in satiety and its association with exercise. A longitudinal observational study of 554 females aged between 65.3 and 71.6 years at baseline was followed up at three years; dietary intakes were measured via three-day diet records, and body composition was measured via DEXA [65]. They showed that at baseline, those with $\geq$1.2 $g \cdot kg^{-1} \cdot d^{-1}$ protein intake had better muscle strength across a range of strength tests, lower body fat, and higher lean mass compared with those of moderate and low protein intakes (0.81–1.19 and $\leq$ 0.8 $g \cdot kg^{-1} \cdot d^{-1}$, respectively). The authors contended that their results support the notion that protein intakes in older females should be higher than 0.8 $g \cdot kg^{-1} \cdot d^{-1}$. Another longitudinal study, this time with a five-year follow-up amongst 862 females, aged 75 $\pm$ 3-year-old females, also showed an association between protein intake and lean mass [66]. The authors concluded that high protein intake is associated with long-term beneficial effects on muscle mass and size, as well as bone mass in older females [66]. A much more extensive study of 24,417 females aged 65 to 79 years as part of the females' health initiative showed that ingesting a larger proportion of total energy intake from protein was associated with a reduced risk of frailty in a dose-dependent manner [67]. Yet, it should be noted that these were females who were many years post-menopause. The question of whether similar findings would be seen in those who have just transitioned cannot be concluded, as aging independent of menopause status likely impacts lean mass. Taken together, these observational studies suggest that higher protein intakes are associated with more positive measures of muscle mass and strength in post-menopausal females.

Table 2. Summary of observational studies on protein intake and muscle amongst post-menopausal women.

Reference	Participants	Protein Intakes	Outcome
Xingqiong et al. (2009) [66]	• N = 862 • Age 75 $\pm$ 3 years	Compared with those in the lowest tertile of protein intake (<66 g/d), women in the top tertile (>87 g/d) had 5.4–6.0% higher whole body and appendicular lean mass	Association between protein intake and lean mass. high protein intake is associated with long-term beneficial effects on muscle mass and size.

Table 2. *Cont.*

Beasley et al. (2010) [67]	• N = 24,417 • Age 65 to 79 years	After adjustment for confounders, a 20% increase in uncalibrated protein intake (%kcal) was associated with a 12% (95% confidence interval (CI) = 8–16%) lower risk of frailty, and a 20% increase in calibrated protein intake was associated with a 32% (95% CI = 23–50%) lower risk of frailty.	A larger proportion of total energy intake from protein was associated with a reduced risk of frailty in a dose-dependent manner.
Gregorio et al. (2014) [60]	• N = 387 • Age 60–90 years (mean 72.7 ± 7.0 y).	Lower <0.8 $g \cdot kg^{-1} \cdot d^{-1}$ Higher ≥0.8 $g \cdot kg^{-1} \cdot d^{-1}$	The higher protein group had lower body mass, and fat-to-lean ratio lower-protein ($p < 0.001$). Composite scores of upper and lower extremity strength were impaired in the low protein group.
Silva et al. (2017) [61]	• N= 130 women • Age 55.2 ± 4.9 years	Low ≤0.93 $g \cdot kg^{-1} \cdot d^{-1}$, Moderate 0.94–1.29 $g \cdot kg^{-1} \cdot d^{-1}$, High ≥1.3 $g \cdot kg^{-1} \cdot d^{-1}$	The lowest-intake group had the lowest skeletal muscle mass index and highest % body fat.
Isanejad et al. (2016) [65]	• N = 554 • Age 65.3–71.6 years	Low ≤ 0·8 $g \cdot kg^{-1} \cdot d^{-1}$ High ≥ 1·2 $g \cdot kg^{-1} \cdot d^{-1}$	High protein had better muscle strength, lower body fat, and higher lean mass.

4.2. Intervention Studies

Although observational studies appear to show beneficial effects of higher protein intakes, they are unable to conclude cause and effect due to the type of these studies. Instead, we must turn to the intervention studies.

A 2018 systematic review and meta-analysis on community-dwelling older individuals included data on 1682 participants from 36 studies. They concluded that habitual protein intakes for most participants were sufficient and that additional protein supplementation did not produce increases in lean body mass, muscle cross-sectional area, muscle strength, or physical performance to a greater extent in comparison to control conditions [68]. Furthermore, they reported that even with a resistance training exercise protocol included, there were no beneficial effects with additional protein [68]. It should be noted that only seven of the included studies exclusively had female participants and only one of these assessed lean mass via DEXA [69]. This study had a low sample size of 12 participants split into two protein intake groups, low (0.45 $g \cdot kg^{-1} \cdot d^{-1}$) and adequate (0.92 $g \cdot kg^{-1} \cdot d^{-1}$), based on nitrogen balance [69]. Of note, the adequate protein intake group only slightly exceeds the protein RDA and was lower than the moderate protein groups and similar to some low protein groups in the observational studies. It was reported that the low protein intake group lost lean mass, and the adequate protein intake group maintained muscle mass [69]. Still, these findings support the notion that at least the RDA should be met by post-menopausal females but do not provide information on whether greater intakes would be of benefit.

There have also been three studies from Brazil that have investigated dietary interventions to increase protein intakes above the RDA [70–72], see Table 3. The first studied 23 post-menopausal females aged 63.2 ± 7.8 years. The group with higher protein intake (n = 11) consumed ~1.2 $g \cdot kg^{-1} \cdot d^{-1}$ of protein. In contrast, the other group (n = 12) was advised to ingest the RDA of ~0.8 $g \cdot kg^{-1} \cdot d^{-1}$ protein during the ten-week intervention; both groups undertook resistance training three times per week [70]. At the end of the ten weeks, lean mass increased to a similar extent in both groups, likely due to the resistance training stimulus [70]. It is important to note that dietary intakes were assessed via food recall rather than weighed diet records. Both groups increased their protein intake at breakfast, and interestingly, there were no differences in protein intake close to training,

yet this could be an essential time for additional protein to stimulate muscle resynthesis and growth.

Table 3. Summary of intervention studies on protein intake and muscle amongst post-menopausal women.

Reference	Participants	Protein Intervention	Resistance Exercise	Outcome
Castaneda, Charnley, Evans, & Crim (1995) [69]	• N = 12	Low 0.45 $g \cdot kg^{-1} \cdot d^{-1}$ Adequate 0.92 $g \cdot kg^{-1} \cdot d^{-1}$	No	Low protein intake lost lean mass Adequate protein maintained lean mass.
Rossato et al. (2017) [70]	• N = 23 • age 63.2 ± 7.8 years	RDA: ~0.8 $g \cdot kg^{-1} \cdot d^{-1}$ High: ~1.2 $g \cdot kg^{-1} \cdot d^{-1}$ 10 weeks	Yes, 3 times per week	No significant differences between groups.
Nahas et al. (2019) [72]	• N = 47 • RDA n = 25; age 62.0 ± 2.6 years), ~0.8 $g \cdot kg^{-1} \cdot d^{-1}$ • Higher protein (n = 22; age 64.7 ± 2.8 years),	RDA: ~0.8 $g \cdot kg^{-1} \cdot d^{-1}$ High: ~1.2 $g \cdot kg^{-1} \cdot d^{-1}$ 10 weeks	Yes, 3 times per week	Both groups increased functional capacity. Higher protein had minor additional improvements in functional capacity.
Silva et al. (2020) [71]	• N = 26 • aged ≥ 65 years	RDA: 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ Twice RDA: 1.6 $g \cdot kg^{-1} \cdot d^{-1}$ 6 months	No	No difference between groups.
Englert, Bosy-Westphal, Bischoff, & Kohlenberg-Muller (2021) [73]	• N = 54 • age 59 ± 7 years	RDA: 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ High: 1.5 $g \cdot kg^{-1} \cdot d^{-1}$ 12 weeks	No	No significant effects on lean mass loss. Muscle strength may have been preserved with higher protein intakes.

The second study had a more extended intervention period and compared 26 apparently healthy females aged ≥65 years. The protein diets advised were the RDA (0.8 $g \cdot kg^{-1} \cdot d^{-1}$) or twice the RDA (1.6 $g \cdot kg^{-1} \cdot d^{-1}$). Protein intake was assessed by 24 h urinary nitrogen excretion and change in lean body mass was measured by DEXA at three and six-months. They found that a protein intake exceeding the RDA did not increase lean mass, strength, or physical performance over six months [71]. However, this study did not include any resistance training protocol, and the anabolic stimulus of resistance training may be required to optimise increases in lean mass.

A third and larger study was of 47 post-menopausal females randomised to either a normal protein intake dietary plan (n = 25; age 62.0 ± 2.6 years), ~0.8 $g \cdot kg^{-1} \cdot d^{-1}$ (RDA); or higher protein (n = 22; age 64.7 ± 2.8 years), ~1.2 $g \cdot kg^{-1} \cdot d^{-1}$. The dietary plan was provided over ten weeks with a resistance training program three times per week [72]. This study showed increases in functional performance in both groups, with minor additional improvements in functional capacity in the higher protein group. However, it did not induce a greater increase in strength and lean mass quality in either group. Yet it should be noted that the participants in this study were untrained, and the benefits of additional protein may be starker in trained individuals [74]. Furthermore, the study had a ~50% dropout rate, resulting in a small sample size upon completion of the study, and may not have had sufficient power to detect any differences in muscle mass or strength. Again, this study did not specifically modify protein intakes close to the training stimulus where they may have the greatest impact. A study investigating 1.5 $g \cdot kg^{-1} \cdot d^{-1}$ protein intake compared to 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ over 12 weeks, but without exercise, amongst 54 post-menopausal females aged 59 ± 7 years showed no significant effects on lean mass loss [73]. The lack of exercise

could possibly explain the lack of significant effects given the known benefits of exercise and protein on muscle protein synthesis.

Overall, the dietary intervention studies suggest that intakes above the RDA are not beneficial in terms of lean mass or strength, but when combined with resistance training may improve function. However, the number of studies available on post-menopausal females is small and each has limitations including small sample size, all studies were in females around 60 years or older (some time from menopause transition), untrained participants, used food recalls rather than the gold standard weighed food records, and adherence in two of the studies was low, and only two studies included a resistance training program. Probably of more significance is the timing of protein intake, particularly in the post-exercise period, which was not considered in any of these studies. Therefore, there is a need for high-quality intervention studies to investigate the effects of increased protein intake over the menopause transition and early post-menopause years. In particular, there is a need to investigate trained versus untrained females to see if differences in protein needs exist when incorporating resistance training programs. Indeed, it has been proposed that during menopause, females require more dietary protein due to changes in protein breakdown and increased muscle loss. They term this the "protein leverage effect" [60,75]. They analyzed nutritional changes during the menopause transition and identified enhanced body protein breakdown. These protein losses increase the body's appetite for protein, but if intakes are not increased, an excess of non-protein energy intake occurs. According to their modelling based on published research studies, they report how weight gain, adiposity, and lean tissue losses might be ameliorated by slight changes of 1–3% (digestible energy (DE)) in dietary protein concentration, yet the aforementioned interventional studies do not seem to support this model [75].

4.3. Timing

Total daily protein intake is only one factor to consider when discussing intakes. More recently, the timing of intake over the course of the day and in conjunction with exercise has been studied.

Each meal of the day should include at least 20–25 g of protein, and ideally, snacks would also include similar amounts of protein. An acute study showed that protein spread throughout the day with 20 g on four occasions over a 12 h period promoted muscle protein synthesis to a greater extent than 40 g twice a day or 10 g on eight occasions [76]. However, this study was in young, healthy males and only over a 12 h period. In comparison, regular consumption of 1–2 meals a day containing 30–45 g of protein has been suggested for older people (50–80 years); this is based on analysis from the NHANES data and was associated with lean leg mass and strength [77].

In a review of dietary protein distribution throughout the day, the authors of [78] summarised the observational data as when total protein intakes are above 0.8 $g \cdot kg^{-1} \cdot d^{-1}$, consuming a diet with a balanced protein distribution throughout the day may be superior to promote skeletal muscle-related outcomes. However, when total protein intakes are less than 0.8 $g \cdot kg^{-1} \cdot d^{-1}$, consuming a higher unbalanced protein distribution (where one meal may contain the majority of the dietary protein intake) may be more favourable, because at least one meal may contain sufficient protein to support muscle anabolism. Yet, inconsistent findings were reported for intervention studies. As the authors note, this is likely due to differences in the age of participants, with studies in young populations showing benefits to distributing protein throughout the day, but not so in older populations. Differences between ages may be due to higher amounts of protein required to stimulate muscle protein synthesis in older populations. It has been shown that older individuals require double the amount of protein to maximise muscle protein synthesis (~40 g in older men compared to ~20 g in younger men) following resistance exercise [79]. In practical terms, consuming 40 g of protein may be challenging for those who have reduced energy intake needs and appetite.

Indeed, it is not only protein distribution across the day that needs to be considered, but also timing around resistance exercise. It has been stated that protein intakes could be used to optimise recovery and adaptations to resistance exercise. Muscle protein synthesis is stimulated by protein intake, with a greater effect when protein is consumed close to resistance training [80]. However, a study of 34 post-menopausal females aged 60.9 ± 6.7 years investigated the effects of 30 g protein intake immediately following resistance training compared with delayed intake (~eight hours) over an eight-week period [81]. While both groups showed improvements in lean mass and strength, there was no difference between groups. The protein intake at lunch, about three hours post-exercise, was ~20–34 g in the immediate post-exercise group, and 24–35 g in the delayed group. Again, participants were untrained, and it could be questioned if 30 g of protein is sufficient to maximise protein synthesis given that 40 g has been proposed post-exercise in older populations [79]. This is supported by a study that manipulated whey protein intake of 35 g around resistance exercise over 12 weeks [46]. It showed the beneficial effects of 35 g whey protein pre- or post-resistance training on intracellular water and lean soft tissue compared to no protein pre- or post-training. Another study showed that protein supplementation at breakfast and lunch increases whole-body lean tissue [82]. These studies potentially show that >30 g protein is required for changes in muscle protein synthesis to be seen, but the timing around training does not appear to be as important. This would suggest waiting until the next meal or snack to consume protein may not impact muscle mass or strength, especially relevant for those on a lower energy budget. It is important to consume sufficient amounts of protein regularly (see energy restriction subsection).

4.4. Type of Protein

There is interest in the type of protein that may impact muscle protein synthesis, Many report the benefits of whey protein for optimising muscle protein synthesis, at least in acute studies, due to its high leucine content, which triggers the anabolic response via mTOR activation as well as its potential antioxidative effects [46,83,84]. Also of interest, particularly for menopausal females, could be soy protein. There is also interest in soy protein, as it is high in isoflavones, which have the ability to mimic estrogens in the body.

4.5. Whey

Whey protein has a high leucine content, which triggers the anabolic response as well as having potential antioxidative effects [46,83,84]. A recent systematic review and meta-analysis of whey protein supplementation interventions amongst post-menopausal and older females reported benefits, when combined with resistance training, on lower limb lean mass but not upper limb lean mass in comparison to placebo [85]. Yet no significant benefits were seen in the analysis of studies that did not include a resistance training intervention [85]. Interestingly this meta-analysis did show that when participants were supplemented with whey protein their baseline dietary intakes of protein decreased when no resistance training intervention was included (SMD: −0.0685, 95% CI: −0.396, 0.259). However, all studies included in the analysis had some risk of bias, and thus, the quality was low.

4.6. Soy

Phytoestrogens are a group of biologically active plant-based compounds that have estrogen-like properties [86] and are one of the most commonly used herbal therapies for post-menopausal females [87]. They are found in high quantities in soybeans and soy products, which are exceptionally high in lignans and isoflavones [87]. Isoflavone supplementation over 12 months resulted in increased fat-free mass in obese–sarcopenic post-menopausal females [88]. Some studies show that diets high in soy isoflavones can help to manage sarcopenic obesity, whereas others have shown no beneficial effects irrespective of exercise [2]. A 2013 meta-analysis of nine randomised trials incorporating 528 participants suggested isoflavone supplementation might reduce the bodyweight in

non-Asian post-menopausal females [89]. However, bodyweight changes alone could be due to changes in body fat or lean mass [90], and as no other measures of body composition were included, it is difficult to interpret this finding.

The effects of a combination of milk (a combination of whey and casein proteins), the addition of soy protein, and resistance exercise in postmenopausal females have been assessed [91]. It was found that 16 weeks of 4 times-a-week resistance training with post-exercise consumption of 25 g of soy protein containing 50 mg of isoflavones (32 mg genistein, 15 mg daidzein, and 3 mg glycitein) mixed in 200 mL of skimmed milk that contained 0.31 g lipids, 6.4 g proteins, 10 g carbohydrates, and 0.7 g fiber resulted in greater muscle strength gains than 25 g of maltodextrin (placebo) combined with 200 mL of skimmed milk [91]. However, there were no significant differences in muscle mass [91]. The authors attributed the lack of significant differences in muscle mass to the low leucine content of the intervention. More research with mixed protein types may be the most efficacious strategy to optimise muscle synthesis and overall health of post-menopausal females.

4.6.1. Leucine

The beneficial effects of leucine on sarcopenia have been shown in a systematic review, specifically 1.2–6.0 $g.d^{-1}$ improved lean mass, and this was particularly evident when 85–800 IU Vitamin D was also administered [92]. Conversely, not all studies showed a benefit of leucine supplementation. No statistically significant effects were seen on strength, fat-free mass, or anabolic hormones in 46 healthy but untrained peri- and post-menopausal females consuming either 5 g leucine or a placebo for 10 weeks in combination with a resistance training program [93]. In a follow-up study, this time with energy restriction, more overweight or obese females were able to gain or maintain their muscle mass when taking 10 g leucine compared to a placebo over a 12-week period; however, this difference was not statistically significant [94]. Exercise was recommended in this study (30 min per day) and both groups lost weight over the 12-week intervention; lean mass loss was small in both groups (-1.31 ± 0.38 kg placebo and -0.53 ± 0.45 kg leucine). Protein needs are increased when in energy deficit and given leucine's role in muscle protein synthesis this may explain the difference between study findings.

4.6.2. Vegetarian and Vegan Diets

The EAT-Lancet Commission's recommendation of increased quantity and diversity of plant-protein sources to reduce food waste, provide a sustainable food production model, and improve global human health is estimated to have the potential to prevent ~11 million deaths per year [95]. Although there is no research on vegetarian and vegan diets on muscle mass and strength amongst menopausal females, the increased popularity of these diets means they are worth noting. There are many different types of vegetarian diets but generally compared to an omnivore diet vegan diets are higher in carbohydrates, lower in fat, and slightly lower in protein and leucine [96]. Generally, plant-based proteins are low in essential amino acids [97], meaning they may be less effective in terms of muscle protein synthesis.

Indeed, the anabolic response to the same amount of protein is lower when the protein source is plant-based [98]. Whilst this can be overcome by increasing the amount of protein consumed [99], given the higher protein needs, potential decreases in appetite with menopause, and higher food volume of plant-based protein sources, increasing protein intakes even further could be challenging. It has been speculated that consuming a blend of different plant-based proteins or fortifying plant proteins with the limiting amino acids may be a more appropriate alternative to enhancing the anabolic response [98].

A meta-analysis in older adults showed no statistically significant differences between animal and plant-based proteins for fat-free mass or strength. Yet the plant-based protein interventions were favoured for fat mass loss and lean mass accrual, whereas animal proteins were favoured for knee extension strength [100].

Outside of the impacts on muscle, menopausal females following vegan diets or ovo-lacto vegetarians had lower high-density lipoprotein cholesterol compared to omnivores [101]. Others have shown that an ovo-lacto diet lowered total and low-density lipoprotein cholesterol and triglycerides in postmenopausal females [102,103]. High intakes of plant-based protein have been associated with later onset of menopause [104] and reduced risk of type 2 diabetes, whereas a diet high in animal protein has been associated with increased risk of type 2 diabetes, although this meta-analysis was not specifically on menopausal but a much wider population of adult males and females [105]. It should be noted that the association between high animal protein intake and type 2 diabetes risk could be due to other factors in those foods, i.e., highly processed and high in saturated fat [105].

Therefore, it appears at present that there is no clarity on the long-term effects that a vegetarian or vegan diet could have on post-menopausal women's muscle mass and strength (compared to non-vegetarian diets) and further research is required regarding diet planning for maintaining muscle quality either during the transition through menopause or in the post-menopause years.

4.7. Energy Restriction

One factor that needs to be considered is that menopause transition is associated with gains in fat mass, and many women restrict their energy intake to try to attenuate or reverse this. During periods of energy restriction, there is a need to increase protein intakes above the RDA. It has been reported that lean mass and strength could be preserved if protein intakes were elevated above the RDA during hypocaloric diet-based weight loss periods [106]. Similar findings have been demonstrated in post-menopausal women. During a retrospective analysis of a 20-week weight loss dietary and exercise intervention amongst women aged 50–70 years, the average weight loss was 10.8 ± 4.0 kg, and ~32% of the total weight loss was lean mass [107]. Average protein intake was low, below that of the RDA (0.62 $g \cdot kg^{-1} \cdot d^{-1}$, range 0.47–0.8 $g \cdot kg^{-1} \cdot d^{-1}$). They reported an association between lower amounts of protein intake with significantly less lean mass and appendicular lean mass ($r = 0.3$, $p = 0.01$ and $r = 0.41$, $p < 0.001$, respectively) even after adjusting for body size. This study shows that not meeting the RDA results in higher lean mass loss when energy is restricted, but the effects of increasing protein above the RDA are unknown.

A longer study showed that with 10% weight loss over six months amongst obese post-menopausal women lean tissue was persevered by ~40% with a higher protein intake of 1.2 $g \cdot kg^{-1} \cdot d^{-1}$ compared with the RDA intake of 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ [108]. When combined with resistance training, protein intake was 1.2 $g \cdot kg^{-1} \cdot d^{-1}$ compared to 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ amongst 47 post-menopausal women who increased functional capacity, but not lean mass or strength [72]. Although this study does show some benefits to a modest increase in protein, the protein intakes still did not meet the recommendations for energy restriction. The benefit of very high protein intakes (2.4 $g \cdot kg^{-1} \cdot d^{-1}$) in combination with resistance and anaerobic exercise, and energy restriction over four weeks has been demonstrated; however, this was amongst young male participants [109].

Interestingly, not all energy restriction diet studies have shown a beneficial effect of a higher protein intake on fat-free mass and physical function. Englert et al. (2021) randomly assigned 44 postmenopausal women to either 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ or 1.5 $g \cdot kg^{-1} \cdot d^{-1}$ of protein for 12 weeks [73]. They were followed up after six months of ad-libitum food intake. No differences were found between the two protein regimes at any time point for weight change or body composition. The 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ group demonstrated an improvement in the Short Physical Performance Battery score with weight loss and a decrease in handgrip strength, and these changes were not seen in the 1.5 $g \cdot kg^{-1} \cdot d^{-1}$ group. This study did not include an exercise intervention and measures of body composition were determined by bioelectrical impedance, which may not have been sensitive enough to detect changes between groups.

Acutely, it has been shown that protein intake can increase myofibrillar fractional synthesis rates (FSR) at rest and following exercise [110]. Forty post-menopausal women were split into four groups, three of which had their energy restricted for five days followed by a testing day, and the fourth group maintained energy balance for five days, followed by a testing day [110]. During the testing day, participants' FSRs were measured at rest and for five hours following exercise. The three energy-restricted groups were fed either 15, 35, or 60 g of protein, and the fourth group in energy balance was fed 35 g of protein. With energy restriction, FSR was higher for both the 35 and 60 g protein before and after resistance exercise; there was no statistically significant difference between 35 g and 60 g protein [110]. Unfortunately, as there was only one energy balance group (35 g), the dose response for energy balance cannot be stated. However, there were no differences between the energy balance and energy-restricted diets, contradicting many previous studies in other populations showing a decrease in FSR with energy restriction [111]. This difference may be due to the parallel study design, which may not have had sufficient sensitivity to see differences compared to the cross-over design of previous research.

Therefore, increases in protein intake could aid with the retention of muscle mass and function. The amount of protein in any chosen dietary restriction protocol, e.g., the ketogenic diet, employed may need to be considered before being implemented. The individual circumstances need to be considered when recommending protein intakes to individual post-menopausal women, especially given the increased satiety associated with protein intake. More research is required on the long-term impacts of protein intake on women's body composition, appetite, and health during the menopause transition.

5. Discussion

Age, particularly during the menopause transition, hormonal, and lifestyle changes result in an increase in fat mass and a decrease in muscle mass and strength. These changes elevate the risk for many chronic diseases and can negatively impact quality of life.

The general population guidelines for protein intake are 0.8 $g \cdot kg^{-1} \cdot d^{-1}$, although some expert groups argue that this should be higher for elderly populations (men and women). Interestingly, the observation and intervention studies have conflicting findings regarding high protein intake and muscle strength. There are physiological mechanisms supporting the notion of a higher protein intake requirement such as anabolic resistance. Observational studies tend to suggest that a higher protein intake is associated with greater muscle strength and lean mass than lower protein intakes (0.8 $g \cdot kg^{-1} \cdot d^{-1}$). In comparison, the limited number of intervention studies have not shown unequivocal benefits to increasing protein intakes above 0.8 $g \cdot kg^{-1} \cdot d^{-1}$. However, these studies, potentially did not have sufficient power to detect a change, did not include a resistance training program (the studies that did include resistance training reported some, albeit minor, improvements with additional protein), or did not use the gold standard dietary assessment methods to evaluate adherence to the diet. Of note, none of the studies used resistance-trained post-menopausal women, for whom the benefits of protein may differ. Furthermore, it would appear that despite protein intakes decreasing during menopause, many women exceed the RDA and are within the 1.0–1.2 $g \cdot kg^{-1} \cdot d^{-1}$ guidelines of PRO-AGE. Therefore, it is possible that some participants assigned to the RDA groups in the dietary intervention studies reduced their protein intake, whereas the high-protein groups maintained their usual intake.

Foods high in protein are often seen as more expensive and may explain a lower protein intake in those with lower socio-economic status [112]. Given this group's higher risk for many chronic diseases and generally earlier transition into menopause [64,113], dietary protein interventions may be most beneficial to them. However, the potential financial barrier of such a dietary recommendation must be considered and highlights the need for public health messages to promote lower-cost protein foods. Future studies may wish to investigate the modification of current dietary intakes to see if this impacts muscle mass or strength. Overall, for the available evidence, it would seem prudent

to encourage post-menopausal women to at least consume the RDA of 0.8 $g \cdot kg^{-1} \cdot d^{-1}$. Whether 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ is sufficient for those following a vegan diet is unclear. Although no research exists specifically on muscle strength or muscle mass in menopausal women, research in other groups suggests that following a well-planned vegan diet should not negatively impact muscle mass or strength.

Another aspect that the intervention studies did not consider is the distribution of protein intakes throughout the day and the dose of protein at each meal and snack. This is an area of protein intake that has only recently received much attention; the evidence would suggest that for the elderly population, although no research specifically in post-menopausal women, a larger dose of protein is required (30–40 g). This may explain the lack of significant effects when a protein supplement intervention post-exercise has been investigated. The studies that used a higher protein dose demonstrated greater improvements than those that provided 20 g of protein supplement. However, the retrospective study design consuming a high-protein breakfast and lunch was associated with improved leg lean mass and strength.

Therefore, it would appear that protein dose in each eating occasion is important 30–40 g of protein in at least 1–2 meals would seem beneficial. This equates to around 1 litre of milk, 100 g pork chop, 100 g chicken breast, 150 g tinned tuna, four eggs, or 400 g lentils; this could be challenging if the individual is on a restricted-energy diet. Therefore, nutritional counselling is essential to ensure sufficient dietary intakes are consumed to prevent nutritional deficiencies. This is particularly true if weight loss is also an intended outcome, as protein intakes during weight loss must be elevated to preserve lean mass. Finally, the importance of protein type and quality for muscle mass and function should be considered. Whey protein is high in leucine, and much research suggests that, at least in the acute term, has the greatest effect on muscle protein synthesis as it has a high rate of absorption and a high leucine content; conversely, soy protein with a high isoflavone content has estrogen-like properties and has the potential to attenuate symptoms associated with the estrogen decline in menopause. Research does suggest soy has positive outcomes on body composition. Future research should investigate a combination of different protein types on muscle outcomes in 30–40 g doses. It is known that all essential amino acids are required in the diet, and it would seem sensible to suggest an array of proteins throughout the day with a focus on whey (for omnivores) post-exercise.

The studies included in this review focused mainly on community-living women aged in their 60s; whether similar findings would be seen for women as they transition through menopause is beyond the scope of this review. Further, the impact of hormone replacement therapy has not been discussed here. However, the majority of the evidence suggests that hormone replacement therapy has positive implications for muscle mass and strength [114]. It should be noted that HRT is not for all menopausal women and decisions on its use should be made in conjunction with a medical professional.

Interventions and messages to increase protein intake also need to consider the effects of protein intake on the risk of chronic diseases such as type 2 diabetes. Although the exact mechanisms are unknown, it has been shown that animal protein intakes are associated with increased risk of type 2 diabetes. Proposed reasons for this association include the other nutrients within high protein foods such as saturated fats; increased glucagon with protein intake, which elevates blood glucose [115]; and the secretion of insulin with protein ingestion, which could lead to hyperinsulinemia a risk factor for insulin resistance [116]. Such associations do not exist for the consumption of plant-based proteins, potentially due to differences in amino acid profiles between plant and animal proteins [105]. Given the beneficial effects of plant-based proteins and the lack of difference between plant-based diets and omnivore diets for muscle strength and lean mass, it would be prudent to focus on encouraging a variety plant-based proteins in the diets of menopausal women.

6. Conclusions

Research on protein intake and muscle mass and strength in post-menopausal women is limited. It should be remembered that protein is only one component of the diet, but it may have important impacts on body composition, particularly in those women who are restricting energy intake for weight loss. Further research is required following dosing and intake timings, especially around exercise, thought to optimise muscle protein synthesis. In addition, the role of resistance exercise should not be underestimated in this population group. There is an evident need for more research among active post-menopausal women.

7. Future Directions

At present, there appears to be a need for larger intervention studies, including resistance training protocols with increased protein intakes, ideally including 1–2 × 30–40 g doses of protein throughout the day, utilising both whey and soy protein. Gold standard measures of dietary intake such as weighed food records at baseline, mid-point, and end of any intervention study. Body composition should be assessed by DEXA using standardised procedures and adequate power calculations need to be completed prior to study commencement. Given changes occur at the start of menopause, interventions early in transition through menopause may elicit greater long-term impact, studies should utilise the SWAN stages of menopause to state the stage of transition participants are in. There is currently no research in this group, potentially due to the high variability in hormonal changes over time between women in this stage. However, research is needed in peri-menopausal women as well to determine if differences in the peri-menopause and post-menopause stages exist. With the rising popularity of vegan and vegetarian diets, there is a clear need to determine the optimal doses and daily protein needs for women following these diets. These studies would require long-term follow-up. Finally, the effects of protein intake longitudinally during menopause could provide a greater understanding of the protein needs of women throughout menopause.

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