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women

Systematic Review

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Abstract: As women age, they typically experience a progressive decrease in skeletal muscle mass and strength, which can lead to a decline in functional fitness and quality of life. Resistance training (RT) has the potential to attenuate these losses. Although well established for men, evidence regarding the benefits of RT for women is sparse and inconsistent: prior reviews include too few studies with women and do not adequately examine the interactive or additive impacts of workload, modalities, and nutritional supplements on outcomes such as muscle mass (MM), body composition (BC), muscle strength (MS), and functional fitness (FF). The purpose of this review is to identify these gaps. Thirty-eight papers published between 2010 and 2020 (in English) represent 2519 subjects (mean age = 66.89 ± 4.91 years). Intervention averages include 2 to 3 × 50 min sessions across 15 weeks with 7 exercises per session and 11 repetitions per set. Twelve studies (32%) examined the impact of RT plus dietary manipulation. MM, MS, and FF showed positive changes after RT. Adding RT to fitness regimens for peri- to postmenopausal women is likely to have positive benefits.

Keywords: weight training; strength training; peri-menopause; post-menopause; intervention; middle-aged women

1. Introduction

Aging is typically accompanied by a progressive decrease in skeletal muscle mass (sarcopenia) and strength, which leads to a decrement in functional fitness and activities of daily living [1]. Compared to men, women typically have more frequent and severe problems with sarcopenia, functional capacity, frailty and disability [2]. Causes of muscle and bone mass and strength in women are multi-factorial, and include a loss of estrogen and physical inactivity.

Estrogen has wide-ranging physiological effects—from reproduction, to preventing vascular inflammation to helping with bone integrity—and it has an impact on metabolism due to the fact that estrogen receptors are found in bone, tendons, ligaments and muscles. In addition, estrogen has an anabolic effect on building these tissues [3]. Estrogen plays a major role in the formation of connective tissue changes in response to physical activity involving mechanical forces (e.g., resistance training) [4]. Therefore, some researchers have concluded that a loss of estrogen is likely a significant contributor for age-related decreases in muscle mass, muscle quality and strength [5–7].

Physical inactivity is a second major contributor to a loss of muscle and bone mass, quality, and strength [8]. As women age, they typically become less active. The good news is that physical activity is a modifiable, non-pharmacological treatment for muscle and bone loss [9].

Resistance training (RT) is a documented physical activity strategy that can be used to combat some of the deleterious effects of aging and menopause on muscle mass and strength. Resistance training consists of free weights (e.g., dumbbells, barbells, and kettlebells), medicine balls or sandbags, weight machines, elastic bands, TRX straps, and even one's body weight.

While the majority of studies have established the benefit of RT on body composition, strength and functional fitness in men [10,11], information on the positive impact of RT is inconclusive in women. To date, reviews have examined the impact of exercise in postmenopausal women based on combined training (aerobic + resistance training) [12], whole-body vibration training [13] and high-intensity interval training (HIIT) training [14]. Marin-Cascales et al. synthesized 15 studies that examined the impact of combined training in older women [12]. Results varied based on participant age, region trained and variance in training routine. They concluded that combining RT and weight-bearing or aerobic exercise can prevent muscle and skeletal loss in women as they age, but that results were inconsistent. They also called for additional examination and comparison of various training loads and intensities on muscle composition and strength. None of the reviews to date have examined the literature relative to beneficial changes based on workload, RT modality or dietary manipulation solely in women. For example, one recent meta-analysis that included 10 studies examined the effect of creatine supplementation during RT in older adults [15]. Data were not disaggregated by sex, and only 2/10 (20%) of the studies were conducted exclusively with women. These researchers concluded that compared to RT alone, creatine plus RT increased fat-free mass (FFM), 1 repetition maximum (RM) chest press, and 1RM leg press.

Thomas et al. conducted a systematic review of the impact of adding protein supplementation to RT in older adults [16]. In their sample, 68% of the subjects were female and 32% were male, but results were not disaggregated by sex. They concluded that protein supplementation did not augment the effects of RT except for some measures of muscle strength found in 3/15 (20%) of the studies. They also mentioned that differences in protein dosage, timing, and ingestion frequency may have impacted the results. Liao et al., who also combined men and women in a systematic review and meta-analysis, concluded that adding protein to RT resulted in greater lean mass and leg strength gains than RT alone (standard mean differences of 0.58 and 0.69, respectivelyear), and that gains in lean mass and leg strength were greater in those with a BMI ≥ 30 kg·m^{-2} than in those with a BMI < 30 kg·m^{-2} (standard mean difference of 0.53 and 0.88, respectively [17].

Given inconclusive findings to date and the lack of a review examining the impacts of RT on older women, the purpose of this paper is to review the literature on the impact of RT on body composition (BC), muscle strength (MS), and functional fitness (FF) in older women. A secondary aim is to quantify workload and summarize RT modalities and nutritional manipulations in the literature. A third aim is to identify potential gaps to guide future research. We chose to limit our review to the most recent publications (2010–2020) with healthy populations to provide an updated and focused review on this topic.

2. Materials and Methods

The 2015 version of the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) checklist was utilized to ensure that recommended items were addressed in this systematic review [18]. Specifically, this review verifies eligibility criteria, information sources, search strategy, data management strategy, study selection process, data and data collection processes, outcomes included, and data synthesis. Per PRISMA instructions, we also provide a synthesis of the quality of existing studies, using PEDro [19].

2.1. Research Questions

Our primary research questions were: What are the characteristics and dosages of exercise programs? (e.g., length in weeks, times per week, sets/repetitions/number of exercises, nutritional manipulations, and RT modalityear) and what can be concluded about this body of literature in terms of effects on body composition, muscle strength, and functional fitness? Secondary questions were: What is the quantity and quality of the literature in this area? Who has been included in these studies (age, ethnicity, number of subjects)? What are some of the limitations and future research directions in this area?

2.2. Literature Search

2.2.1. Search Strategy

A rigorous literature search was conducted to identify papers relevant to our research topic. Table 1 contains a list of the databases searched and Boolean connectors utilized. An advanced search process was utilized to limit publications to peer-reviewed journal articles in English, published between 2010 and 2020. This publication period was selected because there was a significant increase in literature published on this topic after 2010, and topics studied have become more advanced. After the aforementioned search, additional papers were generated by searching reference lists and PubMed links to "similar articles." Articles that combined resistance training with other types of exercise (e.g., aerobic activity, stretching activities) were not included due to the potential difficulty interpreting the unique effects of resistance training compared to other types of training. In addition, studies that examined acute effects of resistance training were not included.

Table 1. Sample search string used for this study.

Databases (Hits)	Key Words Used
PUBMED, SPORT DISCUS, CINAHL	(1) strength training; (2) weight training; (3) body weight training; (4) intervention; (5) older women; (6) postmenopausal women; (7) middle-aged women (8) 1 or 2 or 3 or 4 or 5 or 6 or 7 (9) randomized controlled trial; (10) controlled trial; (11) 9 and 10; (12) 9 and 11 (13) Limit 11 and 12 to women (50–70 yearss old) and 2010–2021 and English and humans

2.2.2. Inclusion and Exclusion Criteria

Participants, interventions, comparisons, outcomes and study design (PICOS) criteria were used to determine which papers should be included in this study [20]. Table 2 contains the PICOS criteria we utilized to determine study inclusion.

Table 2. The inclusion and exclusion criteria for selecting the studies based on PICOS criteria.

PICOS Criteria	Inclusion and Exclusion Criteria
Participants	• Participants were between 45 and 80 yearss of age (typically peri-, and postmenopausal) • Eligible samples include healthy, disease-free individuals regardless of body mass index and/or weight status
Interventions	• Primary focus of intervention was resistance training to build muscle mass, strength, or functional fitness, although some interventions combined resistance training with dietary supplements • To prevent confounding influences, interventions that combined resistance training with other types of training (e.g., aerobic) were excluded, as were interventions that included both men and women • Community-based interventions were included; clinical, hospital-based or other inpatient or outpatient interventions were excluded • Interventions at least 8 weeks in length were included; acute studies were excluded • Studies published in English between 2010 and 2020 were included
Comparisons	• Study that compared intervention groups with a control or additional RT intervention group were included
Outcomes	• Strength of any muscle group (1RM or predicted 1RM) • Body mass, lean body mass, fat-free mass, fat mass, muscle mass, % body fat, or other body composition indicators • Functional fitness indicators
Study Design	• Articles with random assignment of participants to study groups were included (RCT)

2.2.3. Quality Assessment

The methodological quality of each study was assessed using the Physiotherapy Evidence Database (PEDro) scale, a rating scale for randomized controlled trials consisting of 11 criteria (PS) [19]. A score of 6 or higher (on a 9-point scale) indicated that the study was of medium to high quality.

3. Results

3.1. Summary of Search Results

The database searches generated 991 records. Titles and abstracts were independently screened for the inclusion and exclusion criteria and 919 papers were removed, leaving 72 papers to be reviewed for eligibility. Of the 72 papers reviewed, 34 did not meet inclusion criteria, and 2 were removed as duplicates, leaving 36 papers. From the remaining 36 papers, reference lists were scanned for additional studies, and "similar articles" were searched in PubMed. As a result of these expanded search strategies, 2 additional resources were added, resulting in a total of 38 papers. A summary of the decision trail used to locate and select studies for this paper is provided in Figure 1.

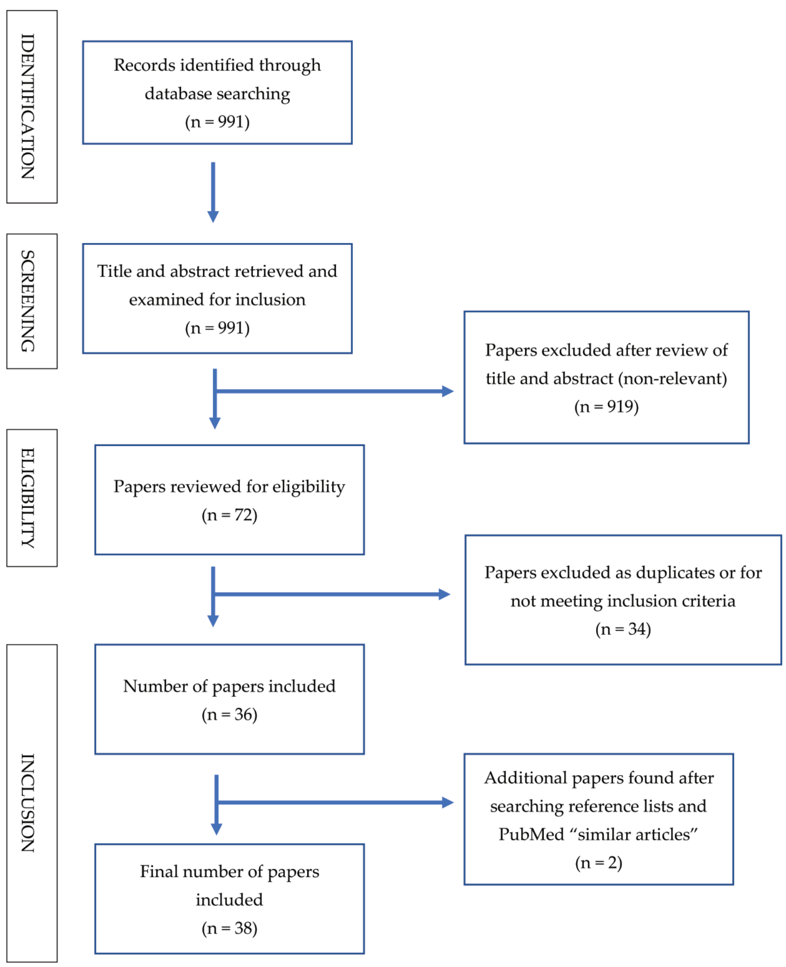

Figure 1. Search strategy and decision trail for selecting included studies.

3.2. Characteristics of Included Studies

Table 3 presents an overall summary table for the 38 papers reviewed. Included in the table are author(s) and years, study purpose, participant description, methods, and results. Information about workload (e.g., sets, reps, number of exercises, total sessions and minutes) and outcomes assessed (e.g., 1RM, %BF, and timed up and go) is included elsewhere in the paper.

Table 3. Summary of strength training intervention studies in 45–80-year-old women (2010–2020)

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
Aguiar et al. [21]	7	Examine the effects of long-term creatine supplementation combined with resistance training on body composition, 1RM, and functional fitness	18 Brazilian women (64.9 ± 5.0 years)	Double-blind, randomly assigned to creatine (CR; 5 g/d) or placebo (PL) Grp + RT intervention
Barbalho et al. [22]	4	Compare effects of different RT volumes on body comp, muscle strength, and functional fitness of older women	376 Brazilian women (71.29 ± 5.77 years)	Randomly assigned to 12 wks of low- or high-volume (LV or HV) resistance training
Bocalini et al. [23]	4	Investigate the impact of circuit-based exercise on body composition in obese older women	70 Brazilian women (64 ± 3.67 years)	Randomized into six groups by BMI (appropriate wt (AW), control AWC), trained AWT, overweight (OW), OWC OWT, obese (OB), OBC, OBT
Carneiro et al. [24]	4	Analyze the effect of resistance training (RT) performed at different weekly frequencies on body comp and flexibility in older women	53 Brazilian women (67.3 ± 5.45 years)	Randomly assigned to perform RT either 2x/wk (G2) or 3x/wk (G3)
Carrasco-Poyatos et al. [25]	3	Compare effect of two different training interventions on body comp and functional fitness in older women	60 Spanish women (68.92 ± 4.42 years)	Block randomization used to assign participants to Pilates group (PG), RT group (RT) and control group (CG)
Cavalcante et al. [26]	5	Compare the effect of different RT frequencies on total, android, gynoid and trunk body fat in overweight/obese older women	57 OW/OB Brazilian women (66.9 ± 5.3 years)	Randomly assigned to 2x/wk RT (2X) 3x/wk RT (3X) or control non-exercise (CG)

Table 3. *Cont.*

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
Coelho-Junior et al. [27]	6	Compare a daily undulating periodization (DUP) intervention, combining resistance training (RT) + power training (PT) with non-periodized RT (NP) and control (CG) for improvements in body composition and physical function in older women	42 women from Brazil, Italy and Spain (66.8 ± 5.4 years)	Randomized into NP, DUP or control group (CG)
Correa et al. [28]	5	Evaluate and compare adaptations of older women who participated in three types of strength training	58 women from Brazil and the USA (67 ± 5 years)	Randomized to experimental (n = 41) and control (CG n = 17) First 6 wks = traditional strength training for lower extremities; next EG divided into three grps: traditional group (TG), power group (PG) (concentric phase of contraction at high speed) and rapid strength group (RG) (lateral box jump exercise)
Cunha et al. [29]	4	Compare single set vs. multiple sets of resistance training (RT) in untrained healthy older women	62 Brazilian women: control (69.03 ± 4.92 years)	Randomized to single set RT (SS, 1 set), multiple set RT (MS, 3 sets), or non-training control (NC)
Daly et al. [30]	4	Evaluate whether a multi-nutrient-fortified milk drink (MFMD) could enhance effects of exercise on body comp and functional muscle power	244 Australian women (55.5 ± 5 years)	Double-blind, placebo-controlled randomized trial: Ex + MFMD or Ex + PL; supplemental dry powder: 30 g twice daily + 150 mL of cold water in a plastic shaker
de Resende-Netro et al. [31]	5	Compare the effects of 12 week functional and traditional training on joint mobility, gait, and muscle strength, and verify the maintenance of effects after 8 wks detraining in older women	52 Brazilian women (64.7 ± 4.33 years)	Randomized into three groups functional training (FT), traditional training (TT) and stretching control (SC); 12 weeks training followed by 8 weeks de-training w/post measurement

Table 3. *Cont.*

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
de Resende-Netro et al. [32]	5	Investigate whether functional training has similar effects to traditional training on body comp, muscle strength and power in older women	47 Brazilian women (64.84 ± 4.32 years)	Randomized and crossover clinical trial with block randomization into 3threegroups: functional training (FT) traditional training (TT) or stretching control (SC)
dos Santos et al. [33]	5	Analyze the effects of a pyramid system performed with two repetition zones (narrow and wide) on body comp and muscular strength in older women	39 physically independent older women from Spain (67.8 ± 5.4 years)	Randomly assigned to RT intervention which completed 3 sets—one with 12/10/8 (narrow reps (NR)) and one with 15/10/5 (wide reps (WR))
dos Santos et al. [34]	5	Analyze the effects of the pyramidal resistance training system with two repetition zones on body comp and cardiovascular risk factors in older women	59 Spanish women (67.3 ± 4.4 years)	Randomly assigned to three groups: non-exercise control (CON), narrow pyramid reps (NP: 12/10/8) and wide pyramid reps (WP: 15/10/5)
Francis et al. [35]	4	Compare the effects of RT and protein supplementation (RT + PRO) to PRO on upper-leg lean tissue mass, muscle quality and functional capacity	57 Irish women (61.1 ± 5.1 years)	Single-blinded, randomized, controlled design; All women consumed 0.33 g/kg milk-based protein for 12 weeks; 29 of 57 also engaged in progressive resistance training (PRT)
Gadelha et al. [36]	3	Examine the effects of RT on sarcopenic obesity in older women	243 women from Brazil (67.27 ± 5.04 years)	Random assignment to control group (CG) or RT group
Gualano et al. [37]	6	Examine the efficacy of creatine supplementation, associated or not with resistance training, in older women	60 women from Brazil (65.78 ± 5 years)	Double-blind, randomized, placebo-controlled trial with 4 comparison groups: placebo (PL), creatine only (CR onlyear), placebo with resistance training (PL+RT) or creatine with resistance training (CR+RT)

Table 3. *Cont.*

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
Kim et al. [38]	4	Evaluate the effectiveness of RT + amino acid supplementation in enhancing muscle mass and strength in older sarcopenic women	155 Japanese women > 75 year	RCT with four groups: exercise + amino acid (EX + AA), exercise only (EO), amino acid only (AAO) or health education (CTRL); AA = 3 g of leucine-rich AA 2 x a day for 12 wks
Letieri et al. [39]	6	Compare the effect of RT using different occlusion pressures, followed by 6 wks detraining on the muscular strength levels of older women	56 recreationally active women from Brazil (68.8 ± 5.09 years)	Randomized controlled trial of 16 wks RT + 6 wks detraining; randomized into 5 groups: low-intensity w/ high blood flow restriction (LI+BFR_H); low-intensity with low blood flow restriction (LI+BFR_L), high-intensity (HI); low-intensity (LI); and control group (CG)
Liao et al. [40]	4	Investigate the effect of elastic band resistance training (ERT) on muscle mass and physical function in older women	56 women from Taiwan with sarcopenia or obesity (67.3 ± 5.1 years)	RCT with assignment to ERT or control (CTL)
Mori et al. [41]	4	Evaluate the effectiveness of whey PRO, ingested after resistance exercise, in increasing muscle mass and physical function among older women	81 Japanese women (70.6 ± 4.3 years)	RCT with three groups: Exercise + PRO (1.2 g/kg body mass+) (EX+PRO), exercise-only group (EX), protein-only group (PRO)
Nabuco et al. [42]	5	Investigate the effects of whey protein (WP) supplementation (35 g) consumed either immediately pre or post RT on muscle mass, muscular strength and functional capacity in pre-conditioned older women	70 older women from Brazil	Randomly assigned to: whey protein pre-RT and placebo post-RT (WP-PL), placebo pre-RT and WP post-RT (PL-WP), or placebo pre and post (PL)

Table 3. *Cont.*

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
Nabuco et al. [43]	2	Evaluate the effects of higher PRO intake on RT induced changes in body composition and strength in untrained postmenopausal women	70 Brazilian women (68.46 ± 4.87 years)	RT intervention with women separated into tertiles of pre-existing PRO intake [low PI (≤0.77 g/kg/dayear), medium PI (>0.77–≤1.0 g/kg/dayear) and high PI (>1.0 g/kg/dayear)]
Nabuco et al. [44]	6	Analyze the effects of whey protein (WP) supplementation and RT on body composition, muscular strength, functional capacity in older women with sarcopenic obesity (SO)	26 sarcopenic (appendicular lean soft tissue (ALST) < 15.02) obese (Fat Mass > 35%) Brazilian women (69 ± 4 years)	Randomly assigned to receive daily, either 35 g WP (WP group) or placebo (PL), combined with supervised 12-wk RT
Nascimento et al. [45]	4	Analyze the effect of RT frequency on muscle mass and changes with detraining in older women	45 physically independent older women from Brazil (68.5 ± 5.15 years)	Randomly assigned to perform 12 wks of RT either two (G2X) or three (G3X) times per week
Rabelo et al. [46]	4	Examine the effects of resistance training on knee extensors peak torque and fat-free mass in older women	154 Brazilian women (67.1 ± 5.9 years)	RT grp vs. control
Radaelli et al. [47]	3	Compare the effects of low- and high-volume strength training on strength, muscle activation and muscle thickness of the lower and upper body and on muscle quality of the lower body in older women	20 Brazilian women (range 60–74 years; mean age not provided)	Randomly assigned to low- (LV = 1 set) and high-volume (HV = 3 sets) groups
Radaelli et al. [48]	5	Compare the effects of 1 or 3 sets of muscle power training on muscle quality, power and functional capacity	26 Brazilian women (60–77 years; mean age not provided)	Randomly assigned into two groups: 1SET and 3SETS

Table 3. *Cont.*

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
Ramirez-Campillo et al. [49]	4	Examine the effects of 12 weeks of high-speed resistance training (HS RT) versus low-speed RT (LS RT) on muscle strength, muscle power, functional performance	45 Hispanic women (67.23 ± 5 years)	Randomly assigned into HS RT, LS RT and control groups
Ramirez-Campillo et al. [50]	4	Compare the effects of two frequencies (2 vs. 3 sessions per week), equated for volume and intensityear) of high-speed resistant training (HS RT) on physical performance in older women	24 women (70.27 ± 6.9 years)	Randomized into HS RT intervention composed of either 2 (RT2) or 3 (RT3) sessions per week (equated for volume and intensityear) or into a control group
Ribeiro et al. [51]	4	Investigate the effect of RT performed in a pyramid (PR) vs. constant (CT) load system on muscular strength and hypertrophy in older women	33 women from Brazil and USA (69.7 ± 5.9 years)	Randomized into two groups: RT + PR or RT + CT load
Riberio et al. [52]	5	Investigate the effect of RT performed on a pyramid (PR) versus traditional (TD) system on muscular strength and muscle mass in older women	25 women (67.6 ± 5.1 years)	Women performed both a PR and TD RT intervention in a balanced crossover design
Souza et al. [53]	4	To compare the effect of conventional RT (CRT) to elastic band RT (ERT) on functional fitness	21 Brazilian women (66 ± 6.0 years)	Randomly assigned to CRT or ERT
Strandberg et al. [54]	4	Evaluate the effects of RT + healthy dietary approach in healthy and physically active older women	55 Swedish women (65–70 years; no mean age given)	Three-arm randomized controlled trial: RT + healthy diet group (RT + HD), RT only (RT), or control (CTL)

Table 3. *Cont.*

[Reference Number] Author(s) (Year)	PS	Study Purpose	Participants (Study Origin, Ethnicity, Age)	Methods
Strandberg et al. [55]	4	Examine changes in skeletal muscle of older women in response to combined RT and N-3 PUFA-rich healthy diet	63 Swedish women (ages 65–70 years)	Three-arm randomized control trial: RT + N-3 PUFA (RT+HD), RT only (RT or CTRL
Sugihara et al. [56]	5	Investigate the effect of whey protein (WP) supplementation on muscular strength, hypertrophy and muscle quality in older women preconditioned to RT	31 Brazilian women (67.4 ± 4.0 years)	Randomized double-blind placebo into WP (35 g) + RT or PLA + RT
Tiggemann et al. [57]	4	Compare the effects of traditional resistance training and power training to determine impact of training intensity on improvements in strength, muscle power, and ability to perform functional tasks in older women	30 women (60–75 years; no mean age given)	Random assignment to traditional resistance training (TRT) or power training group (PT)
Tucci et al. [58]	6	Examine if quadriceps femoris muscle performance of older women can be improved by applying photobiomodulation therapy after a RT intervention	45 sedentary women (>60 years) classified as active or insufficiently active	Randomized controlled trial with assignment into quadriceps femoris RT plus active group (RT + active) or placebo group (RT + placebo) or a control group (CTL)

1RM = 1-repetition maximum; AA = amino acid; AAO = amino acid only; ALST = appendicular lean soft tissue; AW = appropriate weight; CON or CTL only; CRT = conventional resistance training; CT = cnstant load; DUP = daily undulating periodization; ERT = elastic band resistance training; FFM = fat-fr diet; HS RT= high-speedresistance training; HV = high volume; LBM = lean body mass; LI + BFR = low-intensity w/high blood flow restriction; LM = le MFMD = multi-nutrient-fortified milk drink; NPR = narrow pyramidal resistance; OB = obese; OW = overweight; OWOA = overweight older adults; PLA = p PR = pyramid resistance; PRO = protein; SC = stretching control; SO = sarcopenic obesity; TD = traditional system; TRT= traditional resistance training; TT = trad pyramidal resistance; RT = resistance training.

After completing this review, several important trends in the literature were noted.

3.2.1. Participant Characteristics

The 38 studies included in this review enrolled a total sample of 2519 participants (mean sample size = 66 participants) with a mean age of 66.89 ± 4.91 years and an age range of 45–80 years.

The majority of participants in these studies were from Brazil (24 studies or 63% included participants from Brazil). Four studies included participants from Spain, three studies included participants from the United States, and a single study was included from each of the following countries: Japan, Sweden, Ireland, Taiwan, Italy and Australia. One study did not identify the ethnic origin of its participants, and one study broadly identified participants as Hispanic.

3.2.2. Summary of Intervention Characteristics

Interventions ranged from 8 to 32 weeks, with an average intervention length of 15 weeks. The majority of interventions were of medium length (>12 weeks but <25 weeks) (n = 34), three interventions were categorized as short length (<12 weeks) [33,34,43], and one intervention was categorized as long length (>25 weeks) [51]. Intervention length was calculated as the number of weeks *actively engaged* in RT. Periods of time spent detraining, learning technique, or testing were not included in this calculation of intervention length. Interventions, on average, had 2–3 training sessions per week (2.5 + 0.51). Session length (minutes) ranged from 15 to 60 min (mean = 48.89 + 14.53 min). The number of sets per session ranged from 1 to 4 (2.45 ± 0.82). Repetitions per set ranged from 1 to 20 (10.76 ± 1.95). The number of exercises performed ranged from 1 to 12 (7.45 ± 1.97).

There is a need to quantify the volume of exercise without including weight (kg) lifted because the weights used in exercises were individually prescribed, based on 1RMs or band colors for a variety of exercises, and often not included in the papers we analyzed for this review. Importantly, if we do not have an estimate for volume of exercise, it is difficult to link intervention outcomes to program design. Therefore, we propose an estimate of participant exposure to exercise in an attempt to quantify the exercise completed in the studies. Participant exposure is the average number of repetitions (which consisted of the midpoint of the target range of reps) × average number of sets (a midrange was used if groups completed different numbers of sets) × number of exercises included in the intervention. Participant exposure values ranged from 64 to 300, with an average of 210.20 ± 75.87. We were not able to calculate participant exposure for five of the studies due to incomplete information; for some studies, due to training variability in the experimental groups, we calculated averages and used those values.

Two other metrics that can be used to quantify participant exposure to exercise are total number of sessions and total minutes of exercise. Total number of intervention sessions ranged from 16 to 96 with an average of 39.20 ± 16.20, and no data were missing. Total minutes of intervention exercise ranged from 462 to 4320 with an average of 1797.20 ± 921.42, and data on minutes per exercise bout were missing for 21 of the studies.

The majority of interventions (n = 17/38 or 45%) increased intensity of workouts using ACSM recommendations for increasing resistance by a specific percentage for upper and lower body once the maximum number of repetitions were completed in consecutive sessions [59]. A smaller number of studies increased intensity using benchmarks on the Omni (n = 5) or Borg (n = 5) rating of perceived exertion (RPE) (10/38 or 26%), increasing the number of kg lifted once the maximum number of repetitions was completed in consecutive sessions (n = 3/38 or 8%), or target heart rate (n = 1/38 or 3%). Two studies standardized their intensity and increased everyone the same amount at the same time, and 5 studies did not specify how they increased intensity.

Many combinations of repetitions and/or sets were examined in the interventions. Specifically, narrow versus wide range repetition zones (12/10/8 vs. 15/10/5) were examined [33,34], low and high volumes of training were compared [22,27,29,51,52], and 2 vs. 3 times per week of training were compared [24,26,45,50].

In addition to manipulating number of sets and repetitions, several different modalities were compared to RT, including pilates [25], power training emphasizing high-speed concentric movements [27,57], blood flow restriction [39], and photobiomodulation [58].

Dietary supplements or dietary modifications are growing in popularity and have been combined with RT interventions with older women. Eight (8) studies examined the impact of protein combined with resistance training on body composition, strength or functional fitness. Nabuco et al. examined the impact of RT plus existing dietary protein levels [43], whereas others fortified dietary intake with protein [30,35,41,42,44,56] or amino acid supplements [38]. Two studies examined the impact of creatine plus resistance training on body composition, strength, or functional fitness [21,37]. Two studies focused on the impact of a healthy diet on body composition, strength and functional fitness [54,55].

One final factor considered when examining intervention characteristics was study adherence, that is, the percentage of exercises sessions attended. When examining study adherence, nearly half of the studies (16/38 or 42%) did not report study adherence.

3.2.3. Study Quality

In general, study quality, as rated using PEDro, could be improved. One study was rated a 2, three studies were rated 3, 18 studies were rated 4, and 9 studies were rated 5. In total, 82% (31/38) of the studies in this review were rated below medium quality. Seven of the 38 (18%) studies were rated medium to high quality. Most studies were rated lower in quality because they did not conceal allocation, and participants, trainers and assessors were not blinded to group assignment, or this was not reported in the paper.

3.2.4. Effects on Body Composition

Table 4 presents a summary of studies showing the relationship between participant exposure, study duration, adherence, and body composition in older women. Some studies did not report all variables included in the table, so the results will focus on the reported variables. Of the studies that reported on muscle mass changes, 100% (2/2) of the shorter-length studies, 95% (20/21) of the medium-length studies, and 100% (1/1) of the longer-length studies reported increased muscle mass, LBM or FFM. Only one medium-length study did not report changes in muscle mass/LBM or FFM after the intervention [27]. Studies did not report changes in percent body fat as frequently as changes in muscle mass. Of the studies that did report percent body fat, decreases were reported in 100% (1/1) of the shorter studies and 3/8 (38%) of the medium-length studies. Other positive changes in body composition reported included better muscle quality and thickness, increased type II muscle fibers, and a decreased sarcopenic obesity index.

3.2.5. Effects on Muscle Strength

Table 5 presents a summary of studies showing the relationships between participant exposure, study duration, adherence, and muscle strength in older women. Of the studies that measured intervention-related changes in strength, all but one [30] reported at least one increase in upper, lower, or total body strength. Other positive changes reported included enhanced muscle activation, increased isometric hand grip strength, and increased isokinetic torque of the knee.

3.2.6. Effects on Functional Fitness

Table 6 presents a summary of studies showing the relationships between participant exposure, study duration, adherence, and functional fitness in older women. Functional fitness was primarily measured using the timed up-and-go test (TUG), number of chair sit-stands in 30 s, and walking or gait speed. Of the studies that measured functional fitness, 100% improved their TUG (6/6), 30 s chair stands (6/6) and walking or gait speed (9/9). Other functional fitness measures included floor get up time, static balance, countermovement vertical jump (muscular power), timed stair ascent and a 6 min walk test.

Table 4. Summary of impact of participant exposure, study duration, and adherence in studies that measured body comp

Study and Duration	# Sets	# Reps (Midpoint of Range)	# Exercises	Participant Exposure Score (Reps × Sets × Exercises)	Total Sessions (Times/Wk × Total # Weeks)	Total Minutes (# Sessions × Minutes/ Session)	Adherence	>M F
Short-length study (<12 wks)								
dos Santos [33]	3	10	8	240	24	?	≥85%	
dos Santos [34]	3	10	8	240	24	?	≥85%	
Nabuco [43]	3	10	8	240	24	?	?	
Medium-length studies (≥12 to <24 wks)								
Aguiar [21]	2	12.5	8	200	36	2160	?	
Barbalho [22]	3.75	10	8	240	24	?	95%	
Bocalini [23]	1	Timed reps	12	?	36	1800	>90%	
Carrasco-Poyatos [25]	1	8	8	60	36	2160	?	>
Cavalcante [26]	1	12.5	8	250	40	1200	≥85%	
Coelho-Junior [27]	2	13.5	9	364.5	44	?	89%	
Cunha [29]	2	12.5	8	100 LV or 300 HV	36	540 LV or 1620 HV	≥85%	>b h
Daly [30]	3	9	7	189	48	2880	89%	>i in
Francis [35]	3.5	12	9	378	36	1908	82–86%	>le in
Gadelha [36]	3	10	8	240	72	?	≥75%	>F
Gualano [37]	2	10	7	175	60	?	≥84%	a LB a
Kim [38]	1	8	varying	?	24	?	70–80%	Leg A
Liao [40]	3	10	8	240	36	1980	?	Ex

Table 4. *Cont.*

Study and Duration	# Sets	# Reps (Midpoint of Range)	# Exercises	Participant Exposure Score (Reps × Sets × Exercises)	Total Sessions (Times/Wk × Total # Weeks)	Total Minutes (# Sessions × Minutes/ Session)	Adherence	>M F
Mori [41]	2.5	10	7	175	48	?	87–90%	> Pl
Nabuco [42]	3	10	8	240	36	?	?	Ex PR
Nabuco [44]	3	8	8	192	36	?	?	RT v
Nascimento [45]	1	12.5	8	100	48 (2x) or 72 (3x)	?	92–93% adherence	2
Rabelo [46]	3	10	10	300	72	4320	≥85%	
Radaelli [47]	2	14.5	10	L: 145 H: 435	26	L: 585 H: 1430		
Ribeiro [51]	3	11.5	8	300	96	?	≥85%	B a tra
Ribeiro [52]	3	10	8	240	48	?	≥85%	B an
Strandberg [54]	3	13.5	7	283.5	48	?	?	Le c h
Strandberg [55]	3	13.5	7	283.5	48	?	?	
Sugihara [56]	3	10	8	240	36	1800	?	B an Ll

AA = amino acids; % BF = percent body fat; CTL or CG = control group; EG = experimental group; FFM = fat-free mass; LBM = lean body mass; NC
PUFA = polyunsaturated fatty acids; RT = resistance training.

Table 5. Summary of impact of participant exposure, study duration, and adherence in studies that measured muscular s

Study and Duration	PS	# Sets	# Reps (Midpoint of Range)	# Exercises	Participant Exposure Score (Reps × Sets × Exercises)	Total Sessions (Times/Wk × Total # Weeks)	Total Minutes (# Sessions × Minutes/ Session)	Adherence	1RM Bench or Chest Press	1RM Bicep Curl (or > Timed Curl)
Short-length studies (<12 wks)										
dos Santos [33]	5	3	10	8	240	24	?	≥85%	x	x
Nabuco [43]	2	3	10	8	240	24	?	?		High PRO
Medium-length studies (≥12 to <24 wks)										
Aguiar [21]	7	2	12.5	8	200	36	2160	?	x	x
Barbalho [22]	4	3.75	10	8	240	24	?	95%	x	x
Correa [28]	5	3	?	3 lower body	?	36		?		
Cunha [29]	4	2	12.5	8	100 LV or 300 HV	36	540 LV or 1620 HV	≥85%		x
Daly [30]	4	3	9	7	189	48	2880	89%		
de Resende-Netro [31]	5	2	9	8	144	36	1620	?		
Francis [35]	4	3.5	12	9	378	36	1908	82–86%		
Gualano [37]	6	2	10	7	175	60	?	≥84%	>1RM bench press in RT + CR	
Kim [38]	4	1	8	varying	?	24	?	70–80%		
Letieri [39]	6	4	?	High or low blood flow occlusion	H: 112 or L: 240	48	2160	?		
Nabuco [42]	5	3	10	8	240	36	?	?	>WP vs. PLA	

Table 5. *Cont.*

Study and Duration	PS	# Sets	# Reps (Midpoint of Range)	# Exercises	Participant Exposure Score (Reps × Sets × Exercises)	Total Sessions (Times/Wk × Total # Weeks)	Total Minutes (# Sessions × Minutes/ Session)	Adherence	1RM Bench or Chest Press	1RM Bicep Curl (or > Timed Curl)
Nabuco [44]	6	3	8	8	192	36	?	?	Both>	Both>
Rabelo [46]	4	3	10	10	300	72	4320	≥85%		
Radaelli [47]	3	2	14.5	10	L: 145 H: 435	26	L: 585 H: 1430			
Ramirez-Campillo [49]	4	3	8	8	192	36	?	?	High and low spd > strength	
Ramirez-Campillo [50]	4	3	8	8	2x = 192 3x = 128	2x = 24 3x = 36	2x = 1440 3x = 2160	?		
Ribeiro [51]	4	3	11.5	8	300	96	?	≥85%	Both pyramid and constant training >	
Ribeiro [52]	5	3	10	8	240	48	?	≥85%	Both pyramid and trad >	Both pyramid and trad >
Strandberg [54]	4	3	13.5	7	283.5	48	?	?		
Sugihara [56]	5	3	10	8	240	36	1800	?	Both > WP > PLA	
Tiggeman [57]	4	2	12	6	144	24	?	?		

1RM = 1-repetition maximum; AA = amino acid; CON or CTL = control group; CR = Creatine; FFM = fat-free mass; HV = high volume; KE = knee extension volume; NS = non-significant changes; PLA = placebo; PRO = protein; PS = PEDRO Score; RT = resistance training; WP = whey protein.

Table 6. Summary of impact of participant exposure, study duration, and adherence on functional fitness (FF) in

Study and Duration	PS	# Sets	# Reps (Midpoint of Range)	# Exercises	Participant Exposure Score (Reps × Sets × Exercises)	Total Sessions (Times/Wk × Total # Weeks)	Total Minutes (# Sessions × Minutes/ Session)	Adherence	<TUG Time
Medium-length studies (≥12 to <24 wks)									
Aguiar [21]	7	2	12.5	8	200	36	2160	?	
Barbalho [22]	4	3.75	10	8	240	24	?	95%	
Carrasco-Poyatos [25]	3	1	8	8	60	36	2160	?	Pilates > RT and CTL
Coelho-Junior [27]	6	2	13.5	9	364.5	44	?	89%	x
Correa [28]	5	3	?	3 lower body	?	36		?	
Daly [30]	4	3	9	7	189	48	2880	89%	
de Resende-Netro [31]	5	2	9	8	144	36	1620	?	
Francis [35]	4	3.5	12	9	378	36	1908	82–86%	
Kim [38]	4	1	8	varying	?	24	?	70–80%	
Liao [40]	4	3	10	8	240	36	1980	?	<TUG score
Mori [41]	4	2.5	10	7	175	48	?	87–90%	
Nabuco [42]	5	3	10	8	240	36	?	?	
Radaelli [47]	3	2	14.5	10	L: 145 H: 435	26	L: 585 H: 1430		
Radaelli [48]	5	2	10	7	L: 70 H: 210	24	L: 720 H: 1200	≥85%	

Table 6. *Cont.*

Study and Duration	PS	# Sets	# Reps (Midpoint of Range)	# Exercises	Participant Exposure Score (Reps × Sets × Exercises)	Total Sessions (Times/Wk × Total # Weeks)	Total Minutes (# Sessions × Minutes/ Session)	Adherence	<TUG Time
Ramirez-Campillo [49]	4	3	8	8	192	36	?	?	High spd < TUG vs. lo spd
Ramirez-Campillo [50]	4	3	8	8	2x = 192 3x = 128	2x = 24 3x = 36	2x = 1440 3x = 2160	?	Both < TUG score
Souza [53]	4	2	12	varied	72	28	462	>80%	
Tiggeman [57]	4	2	12	6	144	24	?	?	<TUG score

CM = countermovement; CON or CTL = control group; FF = functional fitness; H = high volume; L = low volume; NS = non-significant changes; PRO = prot
TUG = timed up and go.

4. Discussion

The purpose of this paper was to review the literature on the impact of RT on body composition (BC), muscle strength (MS) and functional fitness (FF) in older women, typically of peri- to postmenopausal age. We summarized the typical study length (weeks), participant exposure (set/repetitions/number of exercises), total sessions and total minutes. The most important findings were: (a) most studies that tested for increased muscle mass, lean body mass or fat-free mass found increases with RT; fewer studies examined changes in percent body fat, but those that did found no effect of RT on %BF with RT, regardless of length of study, participant exposure or other important variables; (b) all studies that measured strength found that at least one muscle group got stronger with an RT intervention; and (c) all studies that measured functional fitness improved at least one aspect with RT. The pattern of empirical results points to the benefits of RT on muscle strength, and functional fitness examined in our review. The benefits of RT on FFM were also significant, although the findings relative to percent body fat need additional study. Even with these findings, there is still a need for additional studies examining the dose–response effects of RT on older, peri- to postmenopausal women.

Our review reveals a greater degree of consistency in the impact of RT on older women than has been established in prior reviews. We noted that the majority of studies for this review included women from Brazil. This is likely because Brazil made a significant investment in public health research in the mid 2000s [60]. Published research does not enable examination of differential effects among sub-groups of women in peri- to postmenopausal groups. This gap in our knowledge needs to be rectified if we are to provide equitable health care to women and in particular, peri- to postmenopausal women, across social contexts.

All of the studies reviewed included interventions that were more than 8 weeks in duration. In addition, most utilized multiple sets, exercises and repetitions, which were quantified as participant exposure. This could be one reason why the studies reviewed in this paper overwhelmingly found positive increases in muscle mass, muscle strength and functional fitness. It is well documented that exercise dose is related to the amount of positive change [61]. Previous reviews have not attempted to quantify participant exposure due to the lack of published information about the amount of weight lifted. We believe that in the absence of information about weight lifted, as is common in studies that use resistance from body weight, TRX, or elastic bands, it is important to quantify RT exercise as participant exposure.

Resistance training has been shown to consistently increase muscular strength in women, but the impact on muscle mass is still being debated because an increase in muscle strength does not always correspond to an increase in muscle mass, particularly in older women. Interestingly, percent body fat did not consistently change as a result of RT in many of the studies, but this may have been because of possible variability in measures used to detect percent body fat (e.g., skinfold calipers vs. DXA).

The most frequently utilized measures for functional fitness in this review were the timed up-and-go test, the 30 s chair stand, and walking and gait speed. Other measures used less frequently included floor get up time, static balance, countermovement/vertical jump, and stair ascent. Overwhelmingly, these studies demonstrated improvements in functional fitness.

We recommend continuing to standardize reporting requirements for publishing RT interventions and requiring data about sets, repetitions, weights lifted, minutes per session and adherence. Improving detailed information will enable us to better link work performed with outcomes. Inconsistent findings from previous studies are likely due to differences in training interventions (e.g., number of sets, repetitions, and overall weeks of training), heterogeneous samples studied, small sample sizes (combined with lack of statistical power), inadequate doses of resistance training and/or a lack compliance to the training—which was not reported in many cases. We also believe that it is not advisable to include a control group in these studies because comparisons should be made between various types of RT protocols since we concluded that RT has positive effects on body composition, muscular strength and functional fitness.

Overwhelmingly, the studies reviewed in this paper supported the positive benefits of combining protein supplementation with RT for strength gains in women 45 yearss of age and older. Creatine supplementation had some positive benefits as well. Our review is in agreement with two pre-2010 randomized controlled trials conducted with older women consuming a creatine supplement of 0.3 g kg body mass^{-1} three times daily over a 7 day period without exercise training; these studies showed improvement in lower extremity functional capacity [62,63] and increases in upper- and lower-body dynamic strength and mean explosive power [63]. In addition to strength, power, and functional gains without resistance training, creatine may also protect against mitochondrial damage from oxidation that occurs as a result of aging [64].

Additional studies have examined the impact of nutritional manipulation or supplements on RT in older women. For example, researchers examined whether long-chain n-3 PUFA (polyunsaturated fatty acids) enhanced adaptations to an 18 week twice-weekly lower-limb resistance training intervention in older women; they found that compared to men who supplemented with long-chain n-3 PUFA, women who supplemented improved muscle function and quality [65]. Other researchers have examined the impact of leucine ingestion (2x daily at 4.2 g/serving) on acute muscle response to RT [66]. More research should be done to examine the effects of nutritional supplements combined with RT in older women to establish consistent and appropriate recommendations.

4.1. Limitations

Although our findings added to the literature related to the health benefits of RT in older women, this group of studies is not without limitations. Limitations identified should be used to plan future research directions and continue to improve the quality of studies with older women. First, most of the women in this review were from Brazil. Although we do not expect ethnic differences in responses to RT, it is important to acknowledge that results may not be generalizable to broader international populations. Second, we did not examine changes in body composition, muscle strength, and functional fitness by age. This was difficult due to the fact that many studies included women within a certain age range and reported mean age without reporting changes or differences by age groupings. Although previous researchers have shown that positive changes slow with age [67], that was not the purpose of this study, and it would not have been possible to conduct an analysis by age groupings due to the way data were reported in the studies included. Third, when measuring body composition, many studies used bioelectric impedance or skinfold calipers instead of DXA, the gold standard. Depending on the skill of the researcher when using skinfold calipers, and the hydration status of the participants who measure body composition with BIA, results may vary significantly. Fourth, muscle strength was mostly obtained using 1RM (dynamic strength) for both upper- and lower-body exercises. Obtaining 1RM was sometimes based on an estimate (e.g., 3RM) and sometimes based on a true 1RM. The quality of 1RM results may depend on the willingness of participants to push themselves and/or on the skill of the person administering the 1RM tests. Fifth, in addition to dynamic strength, isometric strength (e.g., isometric hand grip) was tested. Activities of daily living likely contain both dynamic and isometric strength requirements, so including both in a testing protocol would improve study quality. A sixth concern is that the most frequently utilized functional fitness tests included the TUG, 30 s chair stands, and walking speed. Scores on these tests typically can provide an index of fall risk in older adults [68], so specifically tying RT training protocol and muscles utilized to functional fitness tests performed would also improve study quality. A sixth concern is that although these studies were done with women in peri- to postmenopausal age groups, few studies reported HRT status. Of those that did include HRT status, information about type of HRT or dosage was rarely included. Adding HRT status to these studies would enable examination of the potential impact of hormones on response to resistance training.

Seventh, our review included only studies between 2010 and 2020. Studies published before or after this date may contain additional information. In addition, we proposed a unique way to quantify exercise during the programs (i.e., participant exposure) so we could compare interventions in light of the absence of specific weight (kg) being included for many of the exercises. Clearly, additional metrics are needed to quantify exercise in this population. Our proposed measure is exploratory, and in need of additional verification.

Another concern is that so few studies were categorized as medium to high quality using the PEDro scale. This is likely because it is difficult, in training studies, to include control groups when we know that RT protocols typically have beneficial outcomes in terms of body composition, muscular strength, and functional fitness. In addition, whereas participants and trainers may have been blinded to study conditions, this was not explicitly stated in published papers. A large number of studies did not report adherence to training sessions, thus, the studies did not receive quality points for ensuring that key outcomes were obtained by more than 85% of the participants. Furthermore, allocation concealment, which hides the assignment of participants into treatment groups, was rarely reported in studies. Ultimately, while some studies received low scores on measures of allocation concealment or blinding participants and trainers to group assignment, other measures such as specifying eligibility criteria, random assignment, similar groups at baseline, and reporting between group results for at least one outcome, were regularly reported, and indicative of high quality-research. Again, specifying what constitutes high quality RT research, and standardization of these measures is important. An eighth concern is that although we proposed a strategy to quantify participant exposure, without more information on study adherence, reasons for dropout, etc., it will be difficult to replicate these results, or more importantly, to make specific clinical or exercise recommendations for older women. A related concern is that unmeasured changes in general physical activity over the training period is a plausible threat to internal validity in the studies reviewed. Incremental gains from training may be associated with commensurate increases in general physical activity, which may contribute to gains in mass and strength. Physical activity beyond the study design should be monitored and factored into analyses of future studies. Finally, regardless of which test was utilized, information about tester training and inter-tester reliability was only sporadically provided.

4.2. Future Research Directions

This review identified several areas that should be included in future research studies in order to continue to advance the science related to optimizing RT in older women. Studies comparing individualized and group training would enable the detection of benefits of social engagement, as part of the training regimen. In addition, it would be interesting to conduct a study comparing study results by ethnic group to determine whether differences exist. To our knowledge, no one has examined cost-effectiveness or cost–benefit of RT in this population in terms of health care costs or compared to other modalities of exercise [69]. Further, most studies were completed 2–3 d/wk and most were of medium length. Expanding the length of studies (wks) and/or the number of days/wk for studies would enable further examination of the dose–response of RT in this population, as would including effect sizes and conducting a meta-analysis. Although some studies have examined the impact of nutritional supplements on RT results, there is a need to continue to examine adding protein or creatine or other dietary modifications or nutritional supplements to RT in older women. There is also a need to continue to compare RT modalities beyond free weights, machines, dumbbells, and resistance bands. Comparing traditional RT modalities to interventions that are low cost and home based (e.g., TRX and body weight exercises) is worth examining [12]. Most of the studies summarized overall results and did not break down samples by age group, for example, in 5 to 10-year increments. This made it difficult to ascertain age-related changes and differences. In addition, many authors did not include HRT status, and if they did, information about HRT dosage was rarely included. Future research addressing smaller age ranges and including specific information about HRT would improve the ability to tease out age and hormone-related effects. Finally, although one study each was completed using blood flow restriction and photomobulation, more research is needed to determine modality effectiveness in this population.

5. Conclusions

This review concluded that most RT studies with older, peri- to postmenopausal women showed net positive results. RT, with or without nutritional supplementation, has promise and can improve muscle mass, strength, and key measures of functional fitness. In addition, we highlighted gaps in the research on the efficacy of RT to improve the strength of this group of women. Given the relationship between these outcome measures and key factors supporting independence and quality of life (e.g., ability to engage in activities of daily living and decrease the incidence of falls), it is clear that greater insight about the impact of varied modalities and doses of RT on older women would improve outcomes. More rigorous studies are needed to provide clear recommendations for RT for older women to slow the onset or reduce the severity of sarcopenia and subsequent decline in physical ability and increase in frailty. Research with subjects stratified by baseline levels of muscle mass, strength and functional fitness would yield information to inform prescriptions for training as women experience age-related loss of fitness.

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