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Review

The role of nutrition and physical activity in frailty: A review

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SUMMARY

Frailty is a clinical syndrome with a worldwide prevalence of 5–27% among those aged over 65 years. Frailty is characterised by loss of muscle strength and impaired physical function, and is associated with increased falls, hospitalisation and death. Nutritional deficiencies and low physical activity are common in this age group due to ill health, disability and reductions in enthusiasm, food intake and therefore, energy availability. Both low physical activity and inadequate dietary intake have a significant role to play in the onset and progression of frailty, primarily through bone and muscle health implications. Frailty is, however, preventable and reversible, and several interventions have been carried out to offset and reverse the condition. This article reports the recent evidence on the role of nutrition and physical activity in the pathogenesis of frailty and provides a critical review of previously implemented interventions focussed on physical activity and nutrition to prevent and reduce frailty among older adults.

1. Introduction

Frailty is a prevalent clinical syndrome among older adults [1] and has been described as the most problematic expression of population ageing [2]. Frailty is a significant predictor of utilisation of most medical and social care services [3] and has a number of consequences for older adults, including an increased risk of falls, fractures, overnight hospitalisation and death [4].

Frailty has been theoretically defined as a compromised ability to cope with everyday stressors due to aging-associated functional decline in multiple physiological systems [5]. In the absence of a gold standard, several methods of defining and diagnosing frailty have been developed; the two most frequently used being the Frailty Index [6] and the Frailty Phenotype [7]. The Frailty Index can be used only after a comprehensive geriatric assessment has been performed and comprises a 70-item checklist of health deficits and conditions [8], while the Frailty Phenotype is based on a pre-defined set of five criteria; involuntary weight loss, exhaustion, slow gait speed, weakness and sedentary behaviour [7]. It is suggested that these two methods should complement eachother in geriatric evaluation rather than be treated as alternatives [8].

The prevalence of frailty in community-dwelling elderly, defined as those aged over 65 years [9], ranges between 4.9% and 27.3% worldwide, with pre-frailty ranging from 34.6% to 50.9% [1]. In Ireland, the weighted prevalence of frailty amongst the elderly is 24%, according to the Irish Longitudinal Study of Ageing (TILDA) [3]. Two important contributors to frailty include low nutrient intake [10] and sedentary behaviour [11] as outlined in Fig. 1. Several nutrients have demonstrated their role in maintaining physical function in the elderly through the optimisation of bone and muscle health, and nutrient deficiencies have consistently been linked to physical decline [12–16]. Further, physical activity is closely related to the incidence of frailty, and those with a sedentary lifestyle are exposed to a significantly greater risk of developing the syndrome [11].

Frailty is, however, a reversible condition [17], and numerous strategies have been implemented in an attempt to reverse it or delay its onset and progression. The majority of successful interventions focus on physical activity [18,19], while some strategies feature a nutrition component, either solely [20], or in combination with physical activity [17,21], yet the value of the contribution of nutrition is not fully understood. The role of nutrition and physical activity in the pathogenesis of frailty are discussed in detail in this review, together with the effectiveness of strategies that have been previously implemented to improve physical function among the elderly.

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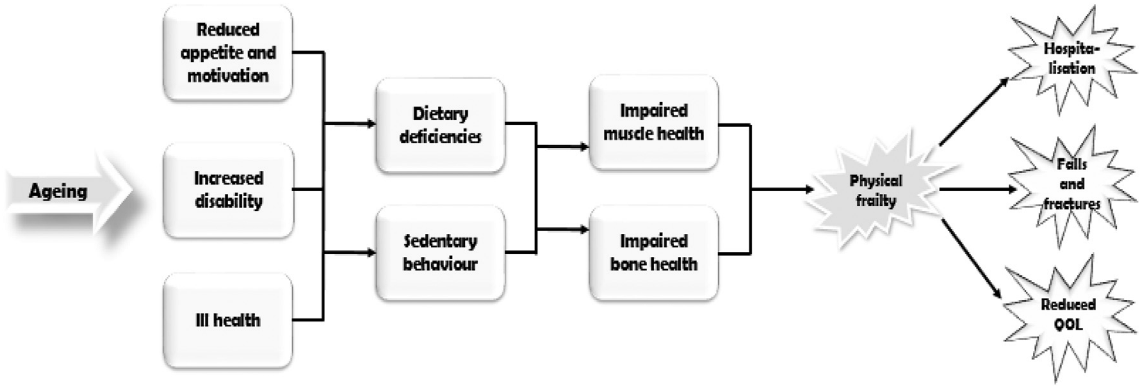

Fig. 1. The pathogenesis and consequences of frailty. QOL: Quality of Life.

2. Malnutrition as a contributor to frailty

2.1. Inadequate protein and energy intakes

Energy and protein adequacy are crucial for bone protection, muscle health and functionality [10,22–25], which bears particular importance for the elderly due to the susceptibility of these tissues to age-associated deterioration [26]. Despite the importance of these dietary components, deficiency and associated health consequences are often reported in this age group (Table 1).

2.1.1. Energy deficiency

To promote healthy weight maintenance among the elderly, the World Health Organisation (WHO) Nutritional Guidelines for Healthy Ageing recommend a daily calorie intake of 1.4–1.8 times

Table 1
Nutrition and physical activity contributors to frailty.

Contributor	Estimated prevalence in community-dwelling elderly	Criteria for increased risk of frailty	Proposed mechanism
Energy deficiency	16-89% [27,28]	Dietary intake ≤21 kcal/kg/day [10] OR BMI <22 kg/m^2 [29]	Loss of muscle mass [30] Increased risk of osteoporosis [24,29] Low energy availability for exercise participation [31]
Protein deficiency	10-24.9% [32,33]	Dietary intake: <66 g (males) <55 g (females) [10] OR Serum albumin <40 g/dL [34]	Bone pathways: • Growth hormone imbalance reduces osteoblast activity [35] Muscle pathways: • Low protein available to stimulate MPS [36] • Anti-oxidant effects of plant protein improve muscle repair and muscle cell apoptosis [37,38] • Anti-inflammatory effects of plant protein reduce risk of muscle loss [37,39]
Vitamin D deficiency	77–87% [40]	Dietary intake: <1.4 μg (males) <1.1 μg (females) [10] OR Serum 25OHD <15 ng/ml [41]	Bone pathways: • Increased PTH release causing increased bone resorption [42] Muscle pathways: • Hindered regulation of muscle cell genes [43] • Calcium and phosphate imbalance [43]
Vitamin B12 deficiency	~64.2% [44]	Serum B12 < 221 pM [45]	Bone pathways: • Accumulation of HCY in bone tissue causing bone loss [46] Muscle pathways: • Increased HCY alters muscle tissue ATP levels and muscle fibre size [47]
Sedentary behaviour	67% [48]	9.5 h per day sedentary [11]	Bone pathways: • Decreased BMD and increased risk of fractures (mechanism unclear) [49] Muscle pathways: • Increased inflammation (due to interactions with CRP & IL-6) causing increased muscle loss [39,50]

BMD Bone Mineral Density; CRP C Reactive Protein; HCY Homocysteine; Il-6 Interleukin-6; MPS Muscle Protein Synthesis; PTH Parathyroid Hormone.

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the basal metabolic rate (BMR), depending on an individual's level of physical activity [51]. Based on this, the European Food Safety Authority (EFSA) recommend that the average energy intake of those aged over 60 years should fall within the range of 1982–2890 kcal/day for men, and 1625–2316 kcal/day for women [52]. However, a number of age-associated factors can reduce appetite, food intake and, consequentially, energy intake in the elderly [53], and evidence suggests that energy deficiency is a concern in this cohort [28]. It has been reported, following an international meta-analysis, that energy intakes of older adults are 18% lower than younger adults [54] and energy intakes were found to be short of recommendations in as much as 89% of adults aged over 60 years in one study [28]. Low energy intakes are associated with physical decline, both directly [10], and indirectly due to the resulting prevalence of underweight in this age group [30]. Additionally, with lower energy intakes and reduced energy availability, there is a reduced participation in physical activity among the elderly [31], further increasing the risk of frailty due to increased sedentary behaviour [11].

Energy intakes in Irish elderly are declining [40,55]. The 1990 Irish National Nutrition Survey (INNS) found that although energy intakes decreased with age, they were generally adequate, with average energy intakes for elderly males and females at 2281 and 1689 kcal/day, respectively [55]. However, the 2011 National Adult Nutrition Survey (NANS) showed that the energy intake of Irish elderly declined to an average of 1984 kcal/day for men and 1554 kcal/day for women [40]; both of which fall short of EFSA recommendations [52]. This may be a result of the increasing age of the population [56], with more people reaching the oldest-old age category; assuming that this is the age category with the lowest energy intakes, as energy intakes have shown to decline progressively with age [40,53].

Energy intake is directly linked to physical function in the elderly, with the prevalence of frailty being higher in those with lower intakes [10]. It has been suggested that an energy intake of ≤21 kcal/kg/day is significantly associated with frailty, with an odds ratio (OR) of 1.24 (adjusted for confounders), compared to those with intakes >21 kcal/kg/day [10]. More recently, it has been found that with every 100 kcal increase in energy intake, the odds of being frail fell 5% lower [57]. Suboptimal energy intake has also been linked to the prevalence of sarcopenia [22], a syndrome characterised by age-associated muscle wasting, which has been considered one of the main physical drivers of frailty and a precursor syndrome of the condition [58].

Inadequate energy intake often results in underweight; the prevalence of which in community-dwelling older adults varies significantly between countries, ranging from 8.7% in Germany [59] to 38% in India [60]. Table 1 shows how energy deficiency resulting in underweight and low body mass index (BMI) has been linked to a number of health outcomes in the elderly. Osteoporosis, a condition of weakened and porous bone is closely related to the incidence of frailty [61] and rates of these conditions are significantly higher in underweight individuals compared to those in normal weight and/or overweight classifications [24]. The risk of a low bone mineral density (BMD) increases 12-fold and 26-fold in males and females, respectively, when BMI falls below 22 kg/m^2 [29].

Underweight is also suspected to be a significant predictor of poor physical function in the elderly, with the worst overall physical performance observed in those who are underweight compared to both normal weight and overweight individuals [30]. This is particularly significant in lower limb strength/endurance tests, as underweight participants have lower volumes of muscle mass [30]; a notable consideration as low muscle strength has been considered among the most prevalent components of frailty [62]. Additionally, being underweight can result in further reduced food intake due to oral health deficits, impairment of swallowing, non-functional tongue movement and aspiration pneumonia [63], creating a detrimental cycle as outlined in Fig. 2.

2.1.2. Protein inadequacy

Protein is a macronutrient that demands particular consideration for the elderly due to its potential to prevent the progressive muscle wasting and bone loss that often accompanies ageing [25]. EFSA recommends 0.83 g protein/kg body weight/day for all adults, including the elderly [52]. This recommendation is generally being met, with only 10% of European elderly having inadequate intakes [33]. However, dispute is ongoing as to whether this prescription is actually adequate to meet the needs of the older population [64]. The European Society for Parenteral and Enteral (ESPEN) expert group state that for healthy older people, the diet should provide at least 1.0–1.2 g protein/kg body weight/day and for those at risk of malnutrition or suffering from acute or chronic illness, 1.2–1.5 g protein/kg body weight/day is a more appropriate recommendation [65]. Moreover, it has been suggested that distribution and timing of protein consumption should also be carefully considered for this age group and that each meal should include at least 25–30 g of high-quality protein [66]. The above recommendation accounts for the potential of older adults to develop resistance to the positive effects of dietary protein on protein synthesis [66], a process which allegedly occurs due to a defect in the S6K1 signalling pathway activation, ultimately resulting in a hindered ability of insulin and amino acids to initiate protein translation in older age [67]. Considering this hypothesis, measuring protein status may represent a superior predictor of protein deficiency rates than analysing dietary intake data. Hypoalbuminemia, or low protein status, is diagnosed at a serum albumin level of <40 g/dL and has been detected in as much as 24.9% of community-dwelling older adults [32].

Dietary protein is directly associated with the incidence of frailty [68]. A cohort study of 24,000 elderly females showed that a 20% increase in protein intake was associated with a 32% lower risk of developing frailty [68], while a protein intake of <66 g for males and <55 g for women significantly increased the risk for the condition (OR 1.98) [10]. Furthermore, it has been reported that elderly female subjects in third, fourth and fifth highest quintiles for total protein intake (>69.8 g/day) had significantly (all $p < 0.03$) lower odds for frailty than those in the first quintile [69]. The role of protein in offsetting frailty may be attributed to its contribution to muscle and bone health (Table 1).

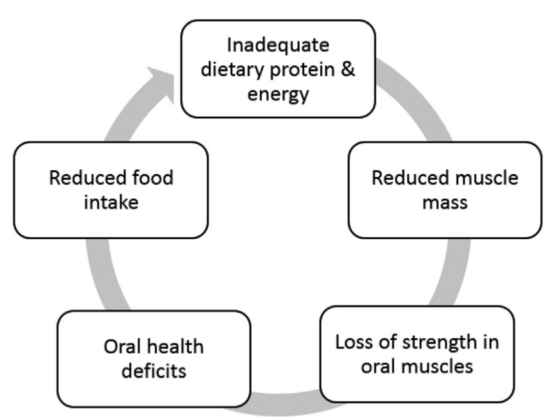

Fig. 2. The cyclical relationship between dietary intake and muscle strength (Information sourced from [25,30,63].

The relationship between dietary protein and muscle health is well established [25,36]. The Health, Aging and Body Composition Study (Health ABC Study) showed that elderly participants in the highest quintile of protein intake involuntarily lost 40% less lean mass and appendicular lean mass than those in the lowest quintile of protein intake over a 3-year period [25]. Accordingly, hypoalbuminemia has also been linked to a 30% higher loss of appendicular skeletal muscle mass amongst the elderly [34], likely due to the central role of dietary protein in stimulating muscle protein synthesis (MPS) [36].

Protein intake has also been linked to BMD and fracture prevention, with animal protein suspected to be of particular importance [23,70]. In one study, protein intake, along with energy and calcium intake, showed the most significant correlations with BMD of all nutrients at almost all of the investigated skeletal sites [70]. Additionally, a diet with a total protein intake of <15% of total energy intake significantly increases risk of osteoporotic fracture (Table 1), the exact mechanism of which remains unclear [23].

2.2. Micronutrient deficiencies

Micronutrient deficiencies are common among the elderly due to a number of factors such as decreased food intake, the cost of micronutrient rich foods and a lack of variety in the diet [71]. Common micronutrient deficiencies reported in this age group include vitamin D and vitamin B12 both of which contribute to functional decline and components of frailty (Table 1).

2.2.1. Vitamin D deficiency

Vitamin D intake is of particular importance to the elderly due to its well-recognised link with bone health [42] and its emerging relationship with strength and function [72]. EFSA recommend a daily intake of 15 μg of vitamin D from dietary sources, and a target serum 25-hydroxyvitamin D (25(OH)D) concentration of least 50 nmol/L (20 ng/mL) for optimal health in adults [52], with no additional guidelines for older adults. However, evidence suggests that these recommendations are not being achieved by this cohort (Table 1).

Vitamin D inadequacy has been consistently described as highly prevalent amongst community-dwelling older adults [40,73]. Data from the European Nutrition and Health Report showed that amongst the elderly, the average intake of vitamin D was well below recommendations in all 13 participating countries [73], Among those aged 65 years and over in Ireland, over half have mean daily intakes of vitamin D less than 5 μg, with 87% of men and 77% of women having daily intakes of less than 10 μg [40].

There has been very limited research to date on the association between dietary vitamin D intake and frailty, despite the abundance of evidence on the relationship between serum 25(OH)D, a marker of hypovitaminosis D, and frailty components (Table 1). One study suggested that a low daily intake of vitamin D (defined as <1.4 μg for men and <1.1 μg for women) was significantly and independently related to frailty incidence in older adults (OR 2.35) [10]. Accordingly, a systemic review and meta-analysis showed that vitamin D supplementation at a daily dose of 20–25 μg, is linked to improved gait speed and muscle strength in the elderly [74], two measurements used for frailty diagnosis [7].

Low serum 25(OH)D has also been directly linked to frailty [41,72]. From the National Health and Nutrition Survey (NHANES), it was found that serum 25(OH)D of <15 ng/ml was associated with a 4-fold increase in the odds of frailty [41]. Similarly, a systemic review of observational studies showed that a 10 ng/ml increase in 25(OH)D levels was associated with an 11–12% decreased risk of frailty scores [72]. Although the underlying mechanism was unclear, it is likely that the relationship between vitamin D and frailty is a result of the essential role of vitamin D in optimising bone and muscle health (Table 1).

Low serum 25 (05)D levels have been linked to compromised bone health and a positive relationship has been reported between serum 25(OH)D level and BMD in healthy elderly women [15]. Similarly, it has been found that among older men, the hazard ratio for hip fracture was 2.36 for men in the lowest quartile of total 25(OH)D (<20 ng/mL) compared to those in the top quartile (>28 ng/mL) [75]; Table 1), possibly explained by the tightly controlled feedback cycle between vitamin D and parathyroid hormone (PTH) [42]. It has been suggested, following a meta-analysis of supplementation trials, that treatment with vitamin D and calcium supplementation is associated with a 12% reduction in fractures in older adults [76]. A reduced rate of bone loss of 0.54% and 1.19% has also been found at the hip and spine, when a minimum dose of 800IU (20 μg) of vitamin D has been consumed [76].

Further to playing a role in bone health, studies have also suggested an association between vitamin D, muscle mass and physical strength in older adults [16]. Low 25-hydroxyvitamin D status has shown a significant association with impaired physical performance and lower appendicular lean mass in frail subjects [14], and poorer leg strength and leg muscle quality in the elderly [16]. It has also been suggested that low levels of physical activity may have a further diminishing effect on vitamin D status [16], suggesting a cyclical relationship as highlighted in Fig. 3.

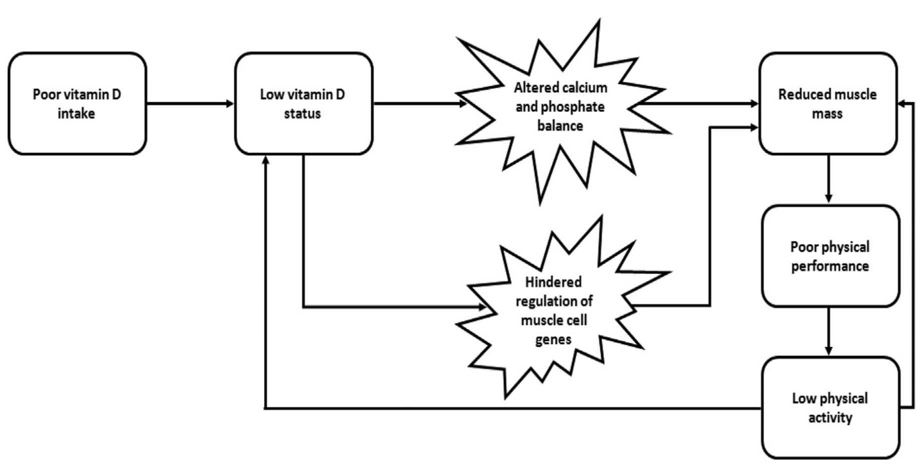

Fig. 3. The relationship between vitamin D, muscle mass and physical activity (Information sourced from [16,42].

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2.2.2. Vitamin B12 deficiency

Vitamin B12 (cobalamin) is crucial for older adults due to its well-recognised functions in cognition and brain ageing [77], while more recently, a link has been found between cobalamin and muscle and bone health [13,45], intensifying its importance for this age group. The dietary reference value (DRV) for cobalamin is set at 4 μg/day for all adults to prevent symptoms of deficiency 52, with no additional guidelines set for older adults.

Dietary intake of vitamin B12 among Irish elderly is within recommendations; 6.4 μg and 6.5 μg average intake for older men and women, respectively [40]. However, Table 1 shows that B12 deficiency is generally quite prevalent among the elderly, possibly explained by food-cobalamin malabsorption, a condition characterised by the inability to release cobalamin from food [78]. Evidence suggests the condition to be the primary cause of vitamin B12 deficiency in adults, accounting for more than 60% of deficiencies in one study [79], followed by pernicious anaemia, an autoimmune atrophic gastritis with a prevalence of 1.9% in the population aged over 60 years [80]. Treatment with oral cobalamin supplementation of 500–1000 μg/day has proven effective at treating deficiency where cobalamin malabsorption is evident, and is equally as effective as intramuscular treatment [79].

Vitamin B12 deficiency has been suspected to contribute to the onset of sarcopenia and dynapenia, with the frequency of these conditions significantly higher in subjects who are B12 deficient [13]. Serum concentration of vitamin B12 was found to be 15% lower in a group of elderly who had sarcopenia, compared to those without the condition [13]. In addition, lean body mass and skeletal muscle mass index are lower in subjects with lower vitamin B12 status [12]. This is possibly a result of the effects of hyperhomocysteinemia, a consequence of low vitamin B12 status, on muscle, as outlined in Table 1 [12].

Evidence suggests a relationship between vitamin B12 status, hyperhomocysteinemia and bone health among the elderly (Table 1). In a cross-sectional study of 118 older subjects, a vitamin B12 status of <221 pM was linked to a significantly lower femur neck BMD compared with a concentration of >221 pM [45]. Elsewhere, data from the Longitudinal Study of Amsterdam showed that a low vitamin B12 status (<200 pM), high homocysteine (HCY) concentration (>15 μM), or having both conditions, was associated with a three times greater risk of fractures, while low vitamin B12 levels were also significantly linked to higher concentrations of bone turnover markers in female elderly [81], with possible mechanisms highlighted in Table 1.

3. Physical activity patterns and frailty

Physical activity has numerous benefits for the ageing population, one of which being its ability to offset frailty [11]. To maintain and optimise fitness and functionality in older adults, The National Guidelines on Physical Activity for Ireland recommends at least 30 min a day of moderate activity on five days a week (or 150 min per week) in addition to endurance and muscle-strengthening activities on at least two days per week [82].

3.1. Physical activity patterns in community-dwelling older adults

Older adults are failing to meet the guidelines of 150 min of moderate physical activity per week [83], potentially as a result of the changing attitudes of ageing individuals to the importance of exercise [84] and the higher incidence of disability in older age groups [85]. Worldwide, the proportion of adults aged over 60 years who are physically inactive, defined as not achieving 600 metabolic equivalent (MET)-min per week, ranges from 40% in Africa to 60% in America [83]. The TILDA study of Irish adults aged over 50 years found two-thirds reported moderate or high physical activity levels, while one-third reported having low levels [86]. However, this data [86] is self-reported through the use of questionnaires, rendering it susceptible to recall and social desirability bias, and objectively assessed data is warranted to give a more accurate representation of physical activity levels in Irish elderly.

In addition to having low physical activity levels, the majority of older adults are sedentary [48]. Sedentary behaviour is defined by the Sedentary Behaviour Research Network as "any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture" [87]. A recent systemic review concluded that, based on objectively assessed data, 67% of those aged over 60 years are sedentary for more than 8.5 h per day, while 65% reported sitting in front of a screen for more than 3 h per day [48]. These figures are concerning, as sedentary behaviour is closely associated with impaired physical function in this age group (Table 1).

3.2. Sedentary behaviours and frailty

Evidence suggests a significant association between sedentary behaviour and physical frailty [88]. In a study of subjects aged over 55 years with, or at high risk of, knee osteoarthritis, the risk of physical frailty was found to increase 36% for each additional hour of sedentary behaviour, independent of time spent in moderate intensity physical activity [88]. Similarly, data from the Survey NHANES showed that 55% of older individuals completing 10,000 steps per day were in the 'non-frail' category, while only 5% of these were in the 'most frail' category [11], implying a significantly lower risk of frailty with more movement and vice versa. Those classified as 'most frail' were found to spend a significantly higher average of 9.5 h per day sedentary, compared to only 8.2 h per day among those in the 'non-frail' category [11].

Although these studies show an association between sedentary behaviour and frailty, they do not investigate the underlying causes of this association and the individual components of frailty. Two important consequences of sedentary behaviour which could explain this correlation include impaired bone health and muscle strength (Table 1).

3.2.1. Impact on bone health

Time spent sedentary is linked to bone health and risk of fractures in elderly subjects [48,49,89]. Among women aged 65 years and over, greater amounts of time spent in sedentary behaviour is associated with lower femoral bone mineral content (BMC) and BMD [89]. Based on these findings, it was estimated that reducing sedentary time by one hour per day would translate to an increase of 0.8% in femoral BMD [89]. Similarly, sedentary behaviour has been linked to an increased risk of fractures in men [49]. In a 35-year follow up study, 20.5% of older males who were considered to be sedentary (self-reported) had suffered from a hip fracture, compared to only 13.3% and 8.4% of those with medium and high physical activity levels [49].

3.2.2. Impact on muscle strength

High levels of sedentary behaviour are linked to reduced muscle strength in elderly subjects [90,91]. The English Longitudinal Study of Ageing (ELSA) revealed a strong relationship between screen-based sedentary behaviour and reduced upper body strength in elderly subjects [91]. TV viewing time was inversely associated with physical activity and those that viewed TV for more than 6 h/day had a lower grip strength of 0.75–1.20 kg in comparison to those viewing TV for less than 2 h/day [91]. Low physical activity

Table 2
Overview of physical activity interventions to improve physical function in the elderly.

Study reference	Sample Size	Subjects	Description of Intervention overview			Significant Benefits of Intervention
			Duration	Frequency	Components	
Gine-Garriga et al. [19]	51	Frail Age: 83.9 ± 2.8 years	12 weeks	Twice-weekly	Group sessions of functional circuit training for functional balance and lower body strength	BI score ↑ 5.91 units Rapid gait test ↓ 2.53 s Stand up test ↓ 4 s Sustained after training cessation
Cadore et al. [18]	18	Frail Mild dementia After long-term physical restraint Age: 88.1 ± 5.1 years	8 weeks	Twice-weekly	Group sessions of walking, balance and cognitive exercises (4 weeks) Above + Resistance training (4 weeks)	TUG ↓ 12.2 s Isometric hand grip ↑ 1.9 kg Hip flexion strength ↑ 2.8 kg Knee extension strength ↑ 3.0 kg Incidence of falls ↓ 0.94 Not sustained after training cessation
Losa-Reyna et al. [92]	20	Pre-frail & frail Age: 84.2 ± 4.5 years	6 weeks	Twice-weekly	Group sessions of power training and HIIT aerobic training	Frailty status ↓ in 64% of subjects SPPB score ↑ 48% Muscle strength ↑ 34% Muscle power ↑ 47%
Lustosa et al. [93]	32	Pre-frail Females only Age: 72 ± 4 years	10 weeks	Three times per week	Small group sessions of strengthening exercises targeting the lower limbs	TUG ↓ 0.68 s 10MWT ↓ 0.49 s Work/weight at 180° ↑ 5.35% Power at 180°/s ↑ 5.49 W
Sakamoto & Miura [94]	41	In need of medical care Age: 72.5 ± 10.1 years	12 months	Once- or twice-weekly	Individual self-exercise programme including balance and muscle training followed by 30 min group cool-down session	IADL ↑ 1.3 pt OLS-T ↑ 8.7 s FRT ↑ 3.3 cm 5 m NWT ↓ 1.8 s 5 m MWT ↓ 1.2 s TUG ↓ 4.3 s Benefits sustained after training cessation
Matsuda et al. [95]	72	Frail Age: 71 ± 9 years >94% type 2 diabetic and obese	6 weeks	Once-weekly	Individual home-based exercise programmecomprising progressive strength training, balance and gait activities, flexibility and aerobic exercises	Gait velocity ↑ 0.17 m/s TUG ↓ 5.7 s Biceps curl ↑ 35% Chair stand ↑ 59%
Mair et al. [96]	11	Healthy Inactive Females only Age: 67.4 ± 3.53 years	6 weeks	Three times daily on three days per week	Home-based unsupervised exercise programme composed of progressively increasing step exercises while wearing weighted vest	Lower limb power output ↑ 10−11% Stair climb time ↓ 9% Normalised stair climbing power ↑ 10%
Nagai et al. [97]	41	Frail Age: 81.8 ± 7 years	24 weeks	Twice-weekly	Two interventions; 1. RT − Resistance training 2. RPA − RT with instruction to increase physical activity and daily steps and reduce sedentary time by 10% every 2 weeks	RPA group: Daily steps ↑ 129 Knee extension ↑ 1.0 kg/m Leg press ↑ 18.9 kg No significant results in RT group
Cao et al. [98]	20	Healthy Females only Age: 65−79 years	12 weeks	Twice-weekly	Group sessions containing activities of balance, co-ordination, strength training and walking training	Obstacle walk ↓ 4.5% Whole body reaction time ↓ 6.4% CS-30 test ↑ 13.5% No significant improvement observed for balance and flexibility

BI Barthel Index; CS-30 Test 30-s Chair Test; FRT Functional Reach Test; HIIT High Intensity Interval Training; IADL Instrumental Activities of Daily Living; OLS-T One Leg Stand Test; SPPB Short Physical Performance Battery; TUG Timed Up and Go; 5 m MWT 5 m Maximal Walking Time; 5 m NWT 5 m Normal Walking Time; 10MWT 10 Metre Walking Time.

levels and sedentary behaviour are also linked to the prevalence of sarcopenia in elderly subjects [90]. A 5-year follow up study revealed sarcopenia in 14.8% of participants who never engaged in moderate to vigorous physical activity (MVPA), compared with 10.4% and 9% in individuals who reported rare to high engagement in MVPA [90].

4. Strategies to improve functional and nutritional status in the elderly

Numerous interventions have been implemented worldwide in an attempt to improve physical function in the elderly, with most research based around increasing physical activity, with nutrition featuring or supplementing a small proportion (Tables 2 and 3). For the purpose of this review, interventions targeting physical activity and nutrition, individually, will be reviewed, in addition to interventions incorporating a combination of both. All studies discussed are summarised in Tables 2 and 3

4.1. Physical activity interventions to reduce frailty

Evidence suggests that participation in physical activity has the potential to reduce frailty (Table 2). Physical activity interventions that include a combination of exercise types, have been successful

Table 3
Overview of nutrition/nutrition and physical activity interventions to improve physical function among the elderly.

Study Reference	Sample Size	Subjects	Description of Intervention Overview			Effects of Intervention
			Duration	Frequency	Components	
Abizanda et al. [21]	91	Institutionalised Frail Age: 85.6 ± 5.6 years	12 weeks	5 days per week	Intake of 200 ml supplement (300 kcal, 20 g protein, 3 g fibre, vitamin D and calcium) twice daily plus a standard physical training program consisting of flexibility, balance and strengthening exercises	48.4% of participants ↑ SPPB by at least 1 pt 50.5% of participants ↑ SF-LLFDI by at least 2 pts MNA-SF ↑ 0.8 pt
Ng et al. [17]	246	Pre-frail & frail Age: 70 ± 4.7 years	6 months	Nutritional group: once daily PA group: twice-weekly	Five groups; 1. NUT - Nutritional supplementation (vitamin and mineral supplements and protein and fibre rich Fortisip formula taken once daily) 2. COG - Cognitive training (activities to stimulate and enhance information processing, attention and reasoning and problem-solving skills) 3. PT - Physical training (group sessions of moderate intensity for 90 min on 2 days per week for 12 weeks followed by 12 weeks of home exercises) 4. COMB - Combination (nutrition, cognitive training and physical training) 5. Control (care as usual)	At 12 month follow-up; NUT group: Frailty ↓ 16% COG group: Frailty ↓ 16% Knee strength ↑ 1.98 kg PT group: Frailty ↓ 19% Knee strength ↑ 1.41 kg Time to walk 6 m ↓ 1.14 s COMB group: Frailty ↓ 22% Knee strength ↑ 2.35 kg Energy score ↑ 1.32 All other results insignificant
Rydwik et al. [99]	96	Frail Age: 83.2 ± 4.2 years	12 weeks	Nutritional group: 1 individual session + 5 group sessions PA group: twice weekly	Four groups; 1. T - Physical training (1 h twice a week including aerobic exercise, strength training and balance training, followed by 6 months of home exercises unsupervised) 2. N - Nutritional treatment (individual counselling based on food record data and group sessions covering nutrient needs, cooking methods and tastings, supplements prescribed where necessary) 3. T + N - A combination of the above 4. C - Control (general advice on nutrition and exercise)	PAL ↑ 1 level for both the T and T + N groups No significant difference in ADLs between groups at follow up No additional benefits from nutrition component
Schilp et al. [20]	146	Undernourished Age: 80.5 ± 7.5 years	6 months	Dependant on individual needs	Dietary counselling over the phone and face-to-face by trained dieticians focussed on goal setting and overcoming risk factors for malnutrition	No significant impact on body weight, physical performance, handgrip strength or protein and energy intake
Haider et al. [100]	80	Pre-frail & frail Malnourished or at risk of malnutrition Age: 83 ± 8 years	12 weeks	Twice-weekly	Two interventions; 1. PTN - Trained buddies visit subjects at home, perform circuit strength training and discuss fluid, protein and energy intake and nutritional issues with subjects. Healthy eating handbooks also provided. 2. SoSu - Buddies visit subjects at home to provide social support and perform cognitive exercises with the help of guidebook.	PTN group: Handgrip strength ↑ 2.4 kg SPPB ↑ 1.2 pt Balance ↑ 0.4 pt Lower limb muscle strength ↑ 0.6 pt SoSu group: SPPB ↑ 0.5 pt Balance ↑ 0.5 pt All other results insignificant

ADL Activities of Daily Living; MNA-SF Mini Nutritional Assessment – Short-form; PAL Physical Activity Level; SPPB Short Physical Performance Battery; SF-LLFDI Short-form Late Life Function and Disability Instrument.

in improving physical function in frail individuals [18,19]. Frail older subjects attending group exercise sessions focussing on lower body strength and functional balance experienced significant improvements in Barthel Index score (measures performance in activities of daily living) and the rapid-gait and stand-up tests (measures of lower limb function) ($p < 0.001$) after 12 weeks [19]. These improvements were also sustained 24 weeks after training cessation [19]. Similarly, in frail older subjects with dementia, an 8-week multi-component group exercise intervention enhanced the physical performance of subjects, notably improving time taken to complete the timed up and go (TUG) test and handgrip strength ($p < 0.05$) [18]. However, the effects of the intervention were not sustained after 24 weeks of training cessation, suggesting that encouragement should be given to subjects who are suffering from mental decline to continue training post-intervention in order to preserve these benefits.

The beneficial effects of physical training are not limited to frail subjects, as suggested by a 6-week exercise intervention in both pre-frail and frail elderly subjects [92]. The twice-weekly exercise sessions focused on resistance exercises and high intensity interval training (HIIT) style cardiovascular exercises. Induced improvements ($p < 0.05$) were found in short physical performance battery

(SPPB), chair stand test and handgrip strength, in both frail and pre-frail subjects [92]. The intervention improved frailty status in 64% of the subjects and significantly improved frailty score by 1.6 points according to the frailty phenotype, a 5-point measure [92]. Similarly, a 10-week resistance exercise programme was also effective in enhancing the strength and functional capacity of pre-frail subjects [93]. The intervention consisted of strengthening exercises, focussing on the lower extremities, three times per week for 10 weeks and caused significant improvements in TUG time, gait speed and lower limb muscle power ($p < 0.05$) [93].

Although group exercise sessions are more frequently implemented, Table 2 shows how individual training and home sessions can also be effective in enhancing physical performance in the elderly. Frail subjects attending a half-day exercise programme of individualised training including balance and strength training for six months experienced significant improvements in functionality, endurance, activities of daily living and balance function ($p < 0.05$), with the effects were sustained six months post-intervention [94]. Comparably, a home-based individualised exercise programme carried out among frail elderly for a much shorter six-week duration proved effective in enhancing physical performance [95]. The supervised sessions were focused on strength, flexibility, gait, balance and cardiovascular fitness and translated to an average improvement in biceps curl, chair stand, gait velocity and time to complete the TUG test ($p < 0.001$) [95]. Additionally, a six-week home-based weighted step programme was effective in improving lower limb strength and functional ability in healthy elderly women [96]. Subjects were instructed to wear a weighted vest while performing step exercises three times a day on three days per week, unsupervised. After six weeks, subjects experienced an improvement in lower limb power output ($p < 0.05$) and improvement in stair climb time ($p < 0.01$) [96].

The beneficial effects of resistance training on muscle strength are evident [93]. However, interestingly, incorporating increased daily movement with resistance training is more effective in reducing symptoms of frailty when compared with resistance training alone [97]. A 6-month randomised controlled trial on older adults consisting of two interventions; resistance training alone (RT) or resistance training combined with physical education and instruction to increase daily steps (RPA) showed that the RPA intervention had a more significant impact on physical function [97]. Those in the RPA group experienced a significant improvement in lower limb strength, with maximum leg press increasing by 18.9 kg compared to a much slighter increase of 1.4 kg in the RT group. The number of daily steps and participation in light intensity physical activity also increased significantly in the RPA group ($p < 0.05$) post-intervention compared to the RT group [97]. This further supports the feasibility of increased daily movement as an adjunct to resistance training, as reduced sedentary time is linked to a lower incidence of frailty [11,88].

4.2. Physical activity and nutrition interventions to reduce frailty

As highlighted in earlier discussion, nutrition has a notable role to play in the onset and progression of frailty. Despite this, the incorporation of nutrition in community-based frailty interventions is relatively uncommon and the evidence on the effectiveness of incorporating nutrition on physical function does not always concur (Table 3).

Table 3 highlights how the provision of nutrition supplements as an adjunct to physical activity may present a promising means of reducing frailty. An intervention study incorporating an oral nutritional supplement rich in energy, protein, fibre, vitamin D and calcium taken twice daily, combined with a multi-component exercise programme, was effective in enhancing physical performance in institutionalised elderly [21]. Specifically, almost half of the subjects improved by at least one point in the SPPB after 12 weeks and significantly improved their overall nutritional status ($p < 0.05$). These improvements were most pronounced in participants with a higher baseline frailty score [21]. However, this study excluded the measurement of physical activity alone for comparison, and the exact contribution of nutrition in the intervention is therefore uncertain. Another RCT, incorporating nutrition and physical activity, more effectively illustrated the benefits of supplements on physical function in frail and pre-frail elderly [17]. Five different study arms were investigated; nutritional supplementation, cognitive training, physical training, combination treatment (nutritional supplementation and physical and cognitive training) and usual care (control). The nutritional supplements included a nutritionally balanced drink rich in fibre and energy and vitamin and mineral supplements (iron, folate, vitamin B6, vitamin B12, vitamin D and calcium). Both the nutrition supplementation and cognition interventions resulted in an average frailty score reduction of 16% and the physical activity intervention reduced frailty score by 19%, while the combination intervention caused an average reduction of 22% in the frailty score of subjects (all $p < 0.01$ compared to baseline) [17]. These results imply that although the combination of nutritional support, cognitive training and physical activity has the most considerable impact, nutrition alone can also significantly improve frailty status in both frail and pre-frail elderly.

The use of nutritional supplements has proven success in frailty interventions [17,21], but the role of nutrition education in reducing frailty is uncertain [20,99]. One pilot study in community-dwelling frail elderly investigated three different interventions; physical training alone (T group), nutrition alone (N group) and nutrition combined with physical training (T + N group) [99]. The nutrition component involved individual nutrition counselling and group education sessions, while the physical training component included aerobic, balance and resistance training. It was found that the T + N did not experience any additional benefits when compared with the T group, and no significant changes were observed in the N group. Any benefits were therefore attributed to the physical activity intervention [99]. Similarly, an RCT involving undernourished elderly showed that nutrition counselling was unsuccessful in improving functionality [20]. The personalised nutrition consultations were performed by trained dieticians, both over the phone and face-to-face, and focussed on setting nutritional goals and overcoming risk factors for undernutrition. No significant impact was reported on physical performance, handgrip strength or body weight after 6 months of intervention [20]. Interestingly, however, another RCT performed on pre-frail and frail individuals involving nutrition support and physical training did prove effective in increasing strength and function [100]. Trained volunteers visited elderly subjects in their home twice a week for 12 weeks to either; 1) provide nutritional advice and complete strength exercises (PTN group) or 2) provide social support only (SoSu group). The PTN group experienced increased handgrip strength ($p = 0.001$) and improvements in the SPPB ($p = 0.009$), while the SoSu group only experienced an improvement in balance [100]. Similar to Abizanda et al. [21]; the most significant effects were observed in the most frail individuals [100], implying that those with the highest level of frailty have the greatest scope for improvement.

There are limitations to these studies, however, that restrict their applicability. In that of Rydwik et al. [99]; only physical activity level and performance in activities of daily living were recorded and components of frailty were not included as an outcome measure, which would have been useful in determining the effect of nutrition counselling on frailty status. In the study of Schilp et al. [20]; physical activity was excluded from the

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intervention and only nutrition counselling was used, while the combination of these may have been more effective in enhancing functionality. Haider et al. [100], on the other hand, did not measure the effect of physical training alone for comparison, therefore it is unclear whether the nutrition education component actually contributed to the improvement in physical performance or if the same effects could be obtained with physical activity alone. In light of this evidence, further exploration is needed to elucidate the role of nutrition education in frailty interventions.

5. Conclusion

Frailty is a prevalent, yet reversible condition among older adults. Dietary deficiencies and sedentary behaviour are common in this age group and have a significant role to play in the pathogenesis of frailty, primarily through bone and muscle health implications. Improving the diet and increasing physical activity levels presents a promising solution to reducing frailty. Numerous physical activity-based interventions have been implemented in an attempt to prevent and reverse the condition. Nutrition has been included in a small proportion, but its exact contribution is not fully understood. Further research is warranted to elucidate the role of nutrition in strategies to reduce frailty.

Declaration of Competing Interest

The authors declare no conflict of interest.

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