Chapter 14
Nutrition and Exercise to Maintain Physical Functioning During Ageing

Pol Grootswagers, Marco Mensink, and Lisette de Groot

Abstract During ageing, losses in muscle mass and muscle strength are common. Unfavourable changes in muscle architecture and neurological activation of muscle tissue decrease the unit-specific muscular output, also known as muscle quality. Together, the losses in the muscular domains lead to lower physical functioning and thereby jeopardise one's independence and quality of life.

This chapter explains the age-related declines in muscle mass and quality, and how nutrition and exercise can be strategically used to prevent and counter these declines. Due attention is given to the role of nutrition and exercise in light of age-related syndromes and critical life events where muscular losses are accelerated.

Keywords Physical functioning · Exercise · Muscle quality · Nutrition · Sarcopenia · Frailty

Together with exercise, good nutrition is key for optimal muscle health and physical functioning. When people get older, their level of physical functioning becomes an important factor in their quality of life. The body's physical condition determines the level of independence and the activities one can join and is therefore of vital importance for healthy ageing. Thereby, physical functioning is the foundation of the extent to which an older person can still be physically, mentally, and socially active. The aim of this article is to explain how physical functioning normally declines during ageing and how this decline can be prevented or addressed with nutrition and exercise strategies.

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S. I. S. Rattan and G. Kaur (eds.), *Nutrition, Food and Diet in Ageing and Longevity*, Healthy Ageing and Longevity 14, https://doi.org/10.1007/978-3-030-83017-5_14

14.1 Age-Related Physical Decline

A high level of physical functioning is hard to maintain throughout ageing. During ageing, several biological processes have to be fought to preserve as much of the functional capacities a person has around the age of thirty. Estimations show that after the age of thirty, people lose around three to eight per cent of muscle mass every decade (Holloszy 2000, Melton et al. 2000). Such loss implies that if a person has 35 kg of muscle mass at the age of 30, this person might end up with between 23 and 30 kg muscle mass remaining at the age of 80. One of the reasons for this age-related loss in muscle mass is a decreased exposure to anabolic stimuli later in life, such as physical activity (McPhee et al. 2016), protein intake (Tieland et al. 2012a) and anabolic hormones (Morley 2017). Additionally, the anabolic response to these stimuli is blunted in older people, a phenomenon that is termed anabolic resistance (Burd et al. 2013).

Underneath this visible muscle mass decline, a change that is less obvious, but arguably as important, is happening: a declining muscle strength. During ageing, muscle strength is decreasing at a much faster rate than muscle mass does (Fig. 14.1). The estimated loss in muscle strength is between 10 and 20% per decade up to the age of 70 (Hughes et al. 2001) and between 20 and 30% in the decades thereafter (Goodpaster et al. 2006). The loss in muscle strength is considered a more important risk factor for functional decline than the loss in muscle mass (Schaap et al. 2013). Muscle strength might, therefore, be more relevant than muscle mass for quality of life of older adults. This notion is confirmed by the work of Balogun et al. (Balogun et al. 2017). They compared community-dwelling older adults in the lowest 20% of handgrip strength or lower-limb muscle strength with those with normal strength

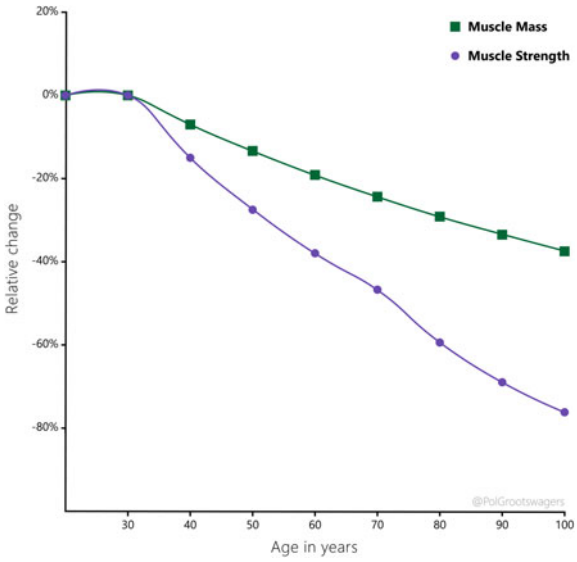

Fig. 14.1 Trajectories of ageing-induced losses in muscle mass (Holloszy 2000, Melton et al. 2000) and muscle strength (Hughes et al. 2001; Goodpaster et al. 2006). Note that the gap between muscle mass and strengths widens over the course of ageing, indicating loss of muscle quality

levels, and found a significant and clinically meaningful lower health-related quality of life over ten years of follow-up for those with low strength. The associations between low appendicular mean mass and health-related quality of life were weaker, indicating that muscle strength is a stronger determinant of quality of life than muscle mass (Balogun et al. 2017).

The observation that muscle strength is lost at a higher rate than mass reveals that muscle function is not solely determined by muscle mass. The functioning of a muscle beyond its mass can be called muscle quality (Barbat-Artigas et al. 2012). A pragmatic definition of muscle quality is function per mass and can be calculated as muscle strength or power per unit of mass, volume or cross-sectional area (Barbat-Artigas et al. 2012). A more sophisticated way of evaluating muscle quality is to examine the determinants of relative muscle strength themselves (Correa-de-Araujo et al. 2017). Four important determinants of muscle quality are type II muscle fiber atrophy, mitochondrial functioning, fat infiltration, and neuromuscular activation (Fig. 14.2). The bottom layer of Fig. 14.2 shows the lifestyle factors that can improve determinants of muscle quality (explained in part 4).

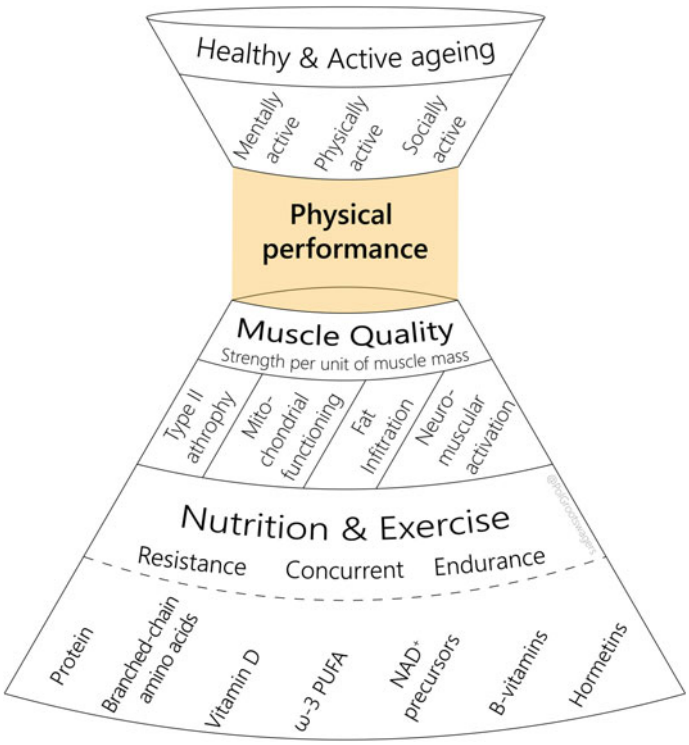

Fig. 14.2 Schematic representation of the possible influence of nutrition and exercise on healthy ageing via muscle quality-related mediators of physical performance

14.2 Ageing Syndromes

Over the last decades, several forms of physical dysfunction have been classified into ageing phenotypes. The most important syndromes that are not always related to diseases are malnutrition, sarcopenia and frailty. Here, we shortly touch upon these three phenotypes and describe how they can be addressed via nutritional therapies.

Malnutrition is defined as 'a state resulting from lack of intake or uptake of nutrition that leads to altered body composition (decreased fat free mass) and body cell mass leading to diminished physical and mental function and impaired clinical outcome from disease' (Cederholm et al. 2017) It can be assessed via multiple screening tools, such as MNA, MST, SNAQ^{RC} and NUFFE, which are tailored to various settings (Power et al. 2018). The estimated prevalence of malnutrition is 11% in community-dwelling older adults (Schilp et al. 2012) and even higher in more vulnerable populations, with 35% in those receiving home-care (Schilp et al. 2012) and 38% in patients admitted to geriatric wards (Kruizenga et al. 2016). Malnutrition is strongly related to morbidity (Abizanda et al. 2016), mortality (McMinn et al. 2011) and functional impairments (Kiesswetter et al. 2014).

A clinical nutritional treatment against malnutrition is oral nutritional supplementation (ONS). These supplements contain all macro- and micronutrients and have shown to be effective in increasing body weight (Milne et al. 2009). Novel formulations of ONS aim to additionally target the physical condition of patients via potent nutrients such as whey protein, leucine, HMB, ursolic acid, and vitamin D (Grootswagers et al. 2018; Deutz et al. 2016; Bauer et al. 2015). These novel formulations have shown promising results on hospital readmission, chair stand test, and gait speed (Grootswagers et al. 2018; Deutz et al. 2016; Bauer et al. 2015).

Sarcopenia is defined as 'a progressive and generalised skeletal muscle disorder that is associated with increased likelihood of adverse outcomes including falls, fractures, physical disability and mortality' (Cruz-Jentoft et al. 2019). It is prevalent in an estimated 10% of the older adult population (Shafiee et al. 2017), and has clear detrimental effects on quality of life and independent living of older adults (Dos Santos et al. 2017; Franzon et al. 2019; Tsekoura et al. 2017) New guidelines have put muscle function central in the sarcopenia diagnosis (Cruz-Jentoft et al. 2019), which can be measured as handgrip strength or chair rise test time. Sarcopenia can also be screened for via the SARC-F questionnaire (Malmstrom et al. 2016). The recommended treatment of sarcopenia consists of resistance exercise, ideally in combination with protein or leucine and vitamin D when deficient (Morley 2018, Morley et al. 2010). Recently, sarcopenia was assigned an ICD-10 code (Anker et al. 2016), which greatly advances the recognition of sarcopenia by the international medical community.

Frailty is defined as 'A medical syndrome with multiple causes and contributors that is characterised by diminished strength, endurance, and reduced physiologic function that increases an individual's vulnerability for developing increased dependency and/or death (Morley et al. 2013)' and is prevalent in around 10% in women and 5% in men (Collard et al. 2012). Frailty is usually assessed by Fried's criteria

(Fried et al. 2001). The distinction between frailty and sarcopenia lies in the multidimensional nature of frailty, covering not only physical declines but also cognitive and social deteriorations. Treatment options for frailty include physical exercise, protein and vitamin D (Artaza-Artabe et al. 2016).

Malnutrition, sarcopenia and frailty share common determinants, such as weight loss and muscle weakness. The overlap in the phenotypes leads to the co-existence of multiple phenotypes within the same patient (Cederholm 2015). Researchers, therefore, advised striving towards interventions that treat all three conditions, for instance, by targeting common risk factors (Verstraeten et al. 2021).

14.3 Critical Life Events

The gradual course of physical decline, as described in paragraph 1, reflect population means. However, on the individual level, such a gradual decline is most often no reality. During critical life events, muscle mass, muscle quality and physical functioning can decline rapidly. For instance, during ten days of bed rest, older adults lose around 1 kg of leg lean mass (Kortebein et al. 2007) and 11% of muscle strength (Kortebein et al. 2008). Importantly, the acute declines in muscle-related measures differ between individuals and are strongly related to the patient's age. For instance, for the same amount of bed rest, a young individual loses only 25% of what an older person loses (LeBlanc et al. 1992). The exact reasons for the large differences between young and older adults during similar periods of bed rest remain to be elucidated, but higher cortisol levels and reduced response to anabolic stimuli in older adults seem to play a role (English and Paddon-Jones 2010).

Critical life events are important time-frames for nutritional interventions. With nutrition and exercise, losses in muscle mass and muscle quality can be minimised, possibly preserving independence in daily activities. During and after a hospital stay and other forms of bed rest, careful monitoring of a patient's dietary intake, nutritional intake and physical activity is important. Lifestyle interventions within the capabilities of the patient, and the possibilities of the setting, are recommended to be administered when needed (English and Paddon-Jones, 2010). These interventions should try to include resistance exercise (or, if impossible, aerobic exercise or exercise mimetics) (Kouw et al. 2019), combined with supplementation with anabolic nutrients such as protein (English and Paddon-Jones 2010), leucine (English et al. 2015), or β-hydroxy β-methyl butyric acid (Deutz et al. 2013).

Often, these critical life events occur unannounced and are the result of acute injuries or diseases. In the case of elective surgeries, such as planned joint replacements, preparation for the critical life event is possible. This idea led to the concept of prehabilitation, or the *better in, better out concept* (Hoogeboom et al. 2014). In the weeks leading to surgery, patients are prepared via exercise training programs, often in combination with nutrition. Prehabilitation programs aim to increase muscle mass and function, to create extra capacity to better deal with the inevitable losses during hospital stays. The time window to train patients is short, on average around four

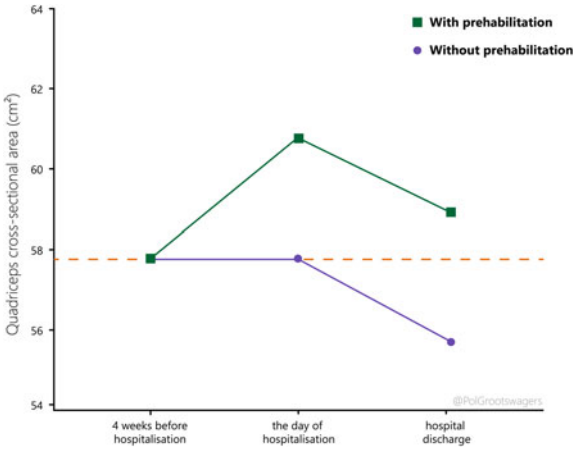

Fig. 14.3 The projected trajectory of the potential of prehabilitation to prevent net losses in muscle mass in older adults during hospitalisation, after plotting the increase found in Grootswagers et al. (Grootswagers et al. 2020)(a, + 5.4%) and the decrease adapted from Kouw et al.[12] (b, −3.4%). The orange dotted line represents the starting level of the quadriceps cross-sectional area

weeks (Moran et al. 2016; Hughes et al. 2019). A high-intensity aerobic interval and resistance exercise training, in combination with protein supplementation, improves muscle mass by 4% and muscle strength by 10%, just enough to prevent losses during hospital stay (Grootswagers et al. 2020) (Fig. 14.3).

14.4 Nutrition and Exercise

Physical functioning can be directly improved via exercise training (Chou et al. 2012). Therefore, exercise is the central aspect of the treatment of sarcopenia (Phu et al. 2015). The role of nutrition is often more indirect and supportive of exercise training, but the potential of nutrition deserves not to be overlooked. Some nutrients have clear anabolic properties and play important roles in muscle protein synthesis, muscle mass maintenance, and muscle repair. Other nutrients are involved in mechanisms that can improve the muscle output, such as force, power and endurance, by improving nutrient availability in the muscle, by improving the quality of the muscle tissue architecture or by improving the neurological activation mechanisms of the muscle.

The main anabolic nutrient is protein. The consumption of proteins elevates concentrations of amino acids and insulin in the bloodstream. The increased concentrations of these anabolic compounds are signaled by receptors located in the sarcolemma and increase the activity of the mammalian target of rapamycin (mTOR) pathway, which is the central pathway in muscle protein synthesis stimulation (McCarthy and Esser 2010) (Fig. 14.4). Leucine, an essential amino acid, has a direct stimulating effect on mTOR (Son et al. 2019) and is proposed as a key amino acid in muscle anabolism (Drummond and Rasmussen 2008). Interestingly, some of the pathways via which protein leads to muscle anabolism are proposed to underly an effect of protein on bone mass, too (**Text box 1**). Importantly, over the course of ageing, the response to anabolic stimuli is blunted. This anabolic resistance can

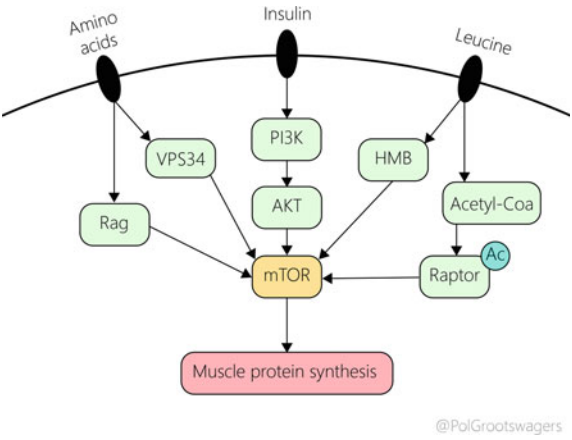

Fig. 14.4 Pathways via which nutrients can induce muscle protein synthesis

be overcome by increasing the nutrient dosage and by increasing physical activity (Burd et al. 2013).

Increasing muscle mass is not the only mode of action via which nutrition and exercise can improve physical performance during ageing. Nutrients are involved in many more pathways that determine muscle output, such as muscle architecture, muscle energetics and neurological activation of the skeletal muscle tissue. The most important determinants of muscle quality where nutrients can play a role are (1) type-II atrophy, (2) mitochondrial dysfunction, (3) fat infiltration and (4) decreased neurological activation. The way in which nutrition and exercise can improve each of these four aspects of muscle quality will be explained below.

14.4.1 Type-II Atrophy

Specific type II muscle fibre atrophy is an important determinant of age-related decreases in muscle mass and quality. In muscle tissue, we distinguish two fibre types: type I and type II (Schiaffino and Reggiani, 2011). Type I fibres have a higher abundance of mitochondria and oxidative enzymes (Schiaffino 2010) and are more abundant in the skeletal muscle tissue of endurance athletes (Wilson et al. 2012). The type II fibres (including type IIa, IIb and IIx) have a higher glycolytic enzyme activity than type I fibres have (Essén et al. 1975), but they are more prone to fatigue (Talbot and Maves, 2016). Type II fibres are more abundant in the skeletal muscle tissue of sprinters and weight lifters (Wilson et al. 2012). During ageing, specific atrophy of type II muscle fibre size occurs. Research shows that the size of type II muscle fibres is 10 to 40% smaller in older compared to young adults (Nilwik et al. 2013; Dreyer et al. 2006; Kosek et al. 2006; Verdijk et al. 2014). Interestingly, one study showed that the difference in type II fibre size fully explained between-group differences in quadriceps size (Nilwik et al. 2013).

The cross-sectional area of type II muscle fibres does not only correlate with muscle mass but also with leg strength (Verdijk et al. 2010). Targeting age-related type II fibre atrophy is, therefore, a potential strategy to improve muscle quality. Studies show promising results on improving type II fibre size via resistance exercise (Charette et al. 1991; Campbell et al. 1999; Hagerman et al. 2000; McGuigan et al. 2001; Claflin et al. 2011; Kryger and Andersen 2007; Suetta et al. 2008; Karavirta et al. 2011; Leenders et al. 2013; Frank et al. 2016; Holwerda et al. 2018; Pyka et al. 1994; Trappe et al. 2000). It should be noted that there is an equal amount of RCTs that fail to show improvements in type II fibre size (Taaffe et al. 1996; Sipila et al. 1997; Godard et al. 2002; Campbell et al. 2002; Brose et al. 2003; Slivka et al. 2008; Cooke et al. 2014; Snijders et al. 2019; Strandberg et al. 2019; Trappe et al. 2001; Mero et al. 2013; Mitchell et al. 2015; Bechshoft et al. 2017), which could be due to different training regimens or duration, sample characteristics, or low sample size. Other types of exercise, such as endurance exercise and electrostimulation, do not seem to improve type II fibre size.

Protein could theoretically augment resistance exercise-induced improvements in type II fibre size by allowing muscle protein synthesis after resistance exercise (Tipton et al. 1999). However, only one trial (Dirks et al. 2017) of a total of nine showed positive effects of protein supplementation on type II fibre size in older adults. Moreover, trials with leucine (Leenders et al. 2011), vitamin D (Vaes et al. 2018; Ceglia et al. 2013), antioxidants (Gouzi et al. 2019), creatine (Brose et al. 2003; Cooke et al. 2014) and chromium picolinate (Campbell et al. 1999, 2002) failed to improve type II fibre size in older adults, suggesting that this determinant of muscle quality should be targeted predominantly via resistance exercise. Resistance exercise could be combined with supplementation of anabolic nutrients to obtain postulated additional improvements in type II fibre size (Little and Phillips, 2009), but this strategy needs further investigation in older adults.

14.4.2 Mitochondrial Dysfunction

Apart from focussing on improving muscle strength via increasing the size of type II fibres, another promising strategy to improve muscle quality is by improving mitochondrial functioning in skeletal muscle tissue. Due to the specific atrophy of type II fibers, muscles of older adults have a higher proportion of type I fibres, which have a greater abundance of mitochondria (Schiaffino 2010). Yet, the number of mitochondria and the mitochondrial oxidative capacity are reduced in older individuals (Sun et al. 2016). Sarcopenic individuals show an even further reduced mitochondrial oxidative capacity (Migliavacca et al. 2019). In these individuals, the biosynthesis of nicotinamide adenine dinucleotide (NAD^+) is also repressed (Migliavacca et al. 2019). Studies show that lower mitochondrial functioning relates to lower physical performance in older adults (Santanasto et al. 2016; Coen et al. 2013).

Nutrition might stimulate mitochondrial functioning via multiple targets (Wesselink et al. 2019). For instance, dietary intake of NAD^+-precursors, such as vitamin B3 and tryptophan, can lead to increased levels of NAD^+ (Rajman et al. 2018; Liu et al. 2018). Moreover, certain bio-actives, such as ursolic acid, seem to directly improve mitochondrial biogenesis in mice models (Chen et al. 2017a). In older adults, the few trials that have tested the effects of different nutrients, or bio-actives, on mitochondrial functioning all found positive results (Pollack et al. 2017; Taub et al. 2016; Alway et al. 2017; de Oliveira et al. 2017). Regarding muscle quality, targeting the mitochondria might be the approach that is most adaptive to subtle changes in the environments, such as obtained by nutritional interventions. Apart from interventions with nutrients or bio-actives, endurance training and high-intensity interval training seem effective in improving mitochondrial functioning too.

14.4.3 Fat Infiltration

The third determinant of muscle quality is the infiltration of fat tissue in the muscle. The cross-sectional images of quadriceps muscle tissue presented in Fig. 14.5 show a clear presence of intramuscular adipose tissue (IMAT) in the 66-year-old person (B) compared to the 24-year-old person (A) (McLeod et al. 2016). While IMAT does contribute to quadriceps volume and to apparent muscle mass, it negatively affects muscle strength (Akazawa et al. 2017, Akazawa et al. 2018) or muscle endurance (Akazawa et al. 2017). Fat infiltration is, therefore, an illustrative cause of a loss in muscle quality, as it directly decreases the muscle strength per unit of muscle size. Fat

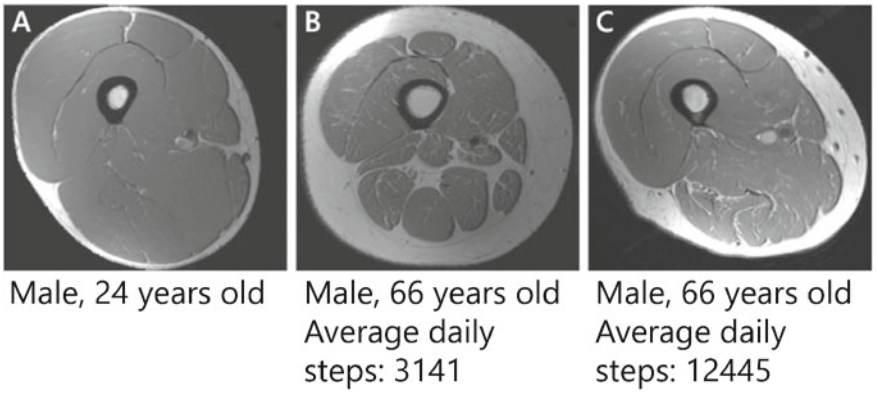

Fig. 14.5 Cross-sectional image of a quadriceps of (A) a 24-year old male, (B) a 66-year old male and (C) a 66-year old male with a high level of physical activity. Adapted from McLeod et al. 2016a (McLeod et al. 2016b), under CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/), and with changes in the number of panels, panel identification letters, and textual description within figures

infiltration may be an essential risk factor for functional decline (Visser et al. 2005). The first studies in older adults show that exercise programs can decrease IMAT (Ikenaga et al. 2017) or prevent IMAT accumulation (Goodpaster et al. 2008). That IMAT accumulation in the muscle is preventable by lifestyle is also visible in Fig. 5c. This quadriceps belongs to a 66-year-old male with a high level of physical activity. The quadriceps of this person shows amounts of IMAT that are more comparable to those of the 24-year-old male (A) than to those of the 66-year-old sedentary male (B). This suggests that physical activity might diminish the effects of ageing on IMAT accumulation. Yet, exercise interventions in older adults have yielded conflicting results.

Apart from physical activity, nutrition might play a role in IMAT accumulation too. Increased IMAT is observed in older adults at risk of malnutrition (Akazawa et al. 2019), with diabetes (Schafer et al. 2010), and it is related to increased insulin resistance (Albu et al. 2005; Goodpaster et al. 2000). These findings highlight the metabolic aspects of IMAT and suggest a role for nutritional interventions to prevent or decrease IMAT build up. The first dietary interventions aimed at lowering IMAT in older adults have been finished recently, with positive results for supplementing whey protein and vitamin D (Yamada et al. 2019; Englund et al. 2019).

14.4.4 Neurological Activation

In some cases, the loss in strength output of a muscle is not caused by morphological changes within the muscle tissue but by decreased neuromuscular activation and the loss of motor units (Clark and Fielding, 2012). Typically during ageing, we observe a loss in voluntary activation (Rozand et al. 2020). That is, the maximum force output generated by a patient's nervous system is lower than the maximum output that can be generated with electrostimulation of the muscle. Decreased voluntary activation is related to decreased physical functioning in older adults (Clark et al. 2011, 2010; Reid et al. 2014). Vitamin D (Dhesi et al. 2004) and homocysteine-lowering nutrients vitamin B6, B12 and folate (Longstreth et al. 1996a, Soumaré et al. 2006) are postulated to improve neuromuscular activation. However, the direct effect of these nutrients on neuromuscular outcomes are rarely measured (Kougias et al. 2018). Nutrients tested in randomised controlled trials that do show to improve neuromuscular activation in older adults are creatine (Stout et al. 2007), milk fat globule membrane (Minegishi et al. 2016) and N-3 fatty acids (Rodacki et al. 2012). The exercise regimens that are most effective in improving neuromuscular activation are resistance training and power training.

14.5 Future

The future of nutrition and exercise for the maintenance of physical functioning during ageing is exciting. Many nutrients have been identified as possible factors in physical functioning. In this final section of the chapter, an overview of the most promising nutrients is given, as well as special attention to the foreseen consequences of a transition to more plant based protein sources.

14.5.1 Vitamin B6, B12 and Folate

The three vitamins B6, B12 and folate act together in the one-carbon pathway, via which they suppress concentrations of homocysteine. Lowering homocysteine concentrations could be a successful strategy to improve physical functioning. Suppressed homocysteine relates to better performance in different domains of physical functioning (Vidoni et al. 2017; Kuo et al. 2007; van Schoor et al. 2012). Elevated homocysteine concentrations could hamper the functioning of mitochondria (Chen et al. 2017b, Ganapathy et al. 2011; Veeranki and Tyagi, 2013) and endothelia (Loscalzo 1996) and are related to increased white matter intensities, which affect the functioning of lower extremities (Longstreth et al. 1996b, Soumare et al. 2006). Therefore, these three B-vitamins could play a role in preserving functional capacities during ageing. Indeed, in the last years, a couple of studies have identified a possible role for B-vitamins in the maintenance of physical functioning during ageing (Behrouzi et al. 2019; Grootswagers et al. 2021; Balboa-Castillo et al. 2018; Struijk et al. 2018).

14.5.2 Omega-3 Fatty Acids and Vitamin D

Fatty fish species, such as salmon, herring and mackerel, are rich in omega-3 fatty acids and vitamin D, and intake of these types of fish are related to improved physical functioning in older adults (Struijk et al. 2018, Rondanelli et al. 2020). Omega-3 fatty acids have anti-inflammatory properties and could thereby target inflammageing (Dupont et al. 2019), one of the hallmarks of ageing. Additionally, omega-3 fatty acids can attenuate anabolic resistance by improving insulin sensitivity and endothelial functioning (Dupont et al. 2019, Smith et al. 2011). When combined with anabolic nutrients such as protein and amino acids, omega-3 fatty acids can improve muscle mass and functioning in older adults (Di Girolamo et al. 2014).

Vitamin D could influence muscle functioning by regulating protein synthesis and mitochondrial functioning (Domingues-Faria et al. 2017). Vitamin D status is related to improved physical functioning in older adults (Bischoff-Ferrari et al. 2004) and seems to be protective against falls (Bischoff-Ferrari et al. 2009). Where we already

saw interactions between vitamin B6, B12 and folate, and between omega-3 fatty acids and protein intake, vitamin D has an interaction with calcium (Lips 2012). These interactions indicate the importance of food matrices: the natural form of foods in which nutrients present themselves together, such as protein, omega-3 fatty acids and vitamin D in fish, or vitamin D and calcium in dairy products. On a higher level, there seems to be an interaction between food items, clustered as food patterns, such as the Mediterranean diet, which is related to improved functionality at higher ages (Shahar et al. 2012; Critselis and Panagiotakos 2020; Milaneschi et al. 2011).

14.5.3 Hormetins

Hormetins are a special group of nutrients, as these components of food often do not have clear biological functions but do seem to play important roles in preventing age-related declines in functioning (Rattan 2008). These compounds cause mild stress in cells. Mild stress is postulated to yield beneficial effects via supercompensation, a phenomenon most known from exercise physiology. Exercise is a stressor for many body systems, but the recovery and supercompensation of the stress improve the functionality of these systems. The overall mechanism is called *hormesis* and works in a similar fashion, where mild stressors to the body, cells, or systems improve the functionality (Gems and Partridge 2008, Rattan 2008). Nutritional hormetins include flavonoids, resveratrol, antioxidants, and ursolic acid. Ursolic acid has shown potential in inhibiting muscle atrophy (Kunkel et al. 2011, 2012) and stimulating mitochondrial functioning (Chen et al. 2017a, Grootswagers et al. 2018). Resveratrol was found to improve mitochondrial functioning (Alway et al. 2017; Pollack et al. 2017) and type-II fiber size (Alway et al. 2017). Flavonoids are part of polyphenols and are found in dark chocolate, tea, coffee, fruits and vegetables, and have been related to improved mitochondrial functioning (Taub et al. 2016) and muscle mass maintenance (Salucci and Falcieri, 2020). There are many more compounds in natural foods that classify as hormetins, and the research outlook into these compounds in relation to ageing is exciting.

14.5.4 Protein Transition

Societal and governmental pressures lead to more and more people transiting from animal-based protein sources to plant-based protein sources. Animal protein has always been considered superior to plant protein in muscle anabolism (Gorissen and Witard, 2018). The quality of these animal proteins, which is based on amino acid composition and bio-availability, is overall higher than that of plant protein. It is therefore not surprising that studies have found greater acute muscle protein synthesis responses to animal products in comparison to soy, wheat or rice protein (Gorissen et al. 2016, Hartman et al. 2007, Phillips 2012, Tang et al. 2009, Wilkinson et al.

2007, Yang et al. 2012). Also, in longitudinal studies, indications for a muscle mass, preserving superiority of animal protein have been found (McLean et al. 2016). On the other hand, there have been some studies that found results suggesting an advantageous role for plant protein in the preservation of physical functioning (Dawson-Hughes et al. 2010; Behrouzi et al. 2019), possibly via alkaline properties (Dawson-Hughes et al. 2008). However, it is possible that in these studies, that were cross-sectional in nature, a confounding effect of dietary quality was present. After all, diets containing many plant proteins also contain many vitamins, minerals, fibers, hormetins and other bioactive compounds found in plants. There is a clear need for controlled, long-term, diet-based studies scrutinising the true consequences of shifting towards plant-based diets in older adults. These diet-based studies should follow a more holistic approach to balance the reductionistic dominance in current evidence – in other words, investigating meals or diets instead of single foods or ingredients (Burd et al. 2019).

14.5.5 Implementation of Effective Interventions

Over the years, many effective lifestyle treatments against malnutrition, sarcopenia and frailty have been identified. Unfortunately, many of these interventions do not find their way to practice (van Dongen 2019). Only by proper implementation of successful interventions in clinical practice, older adults can benefit from the wealth of knowledge that is being acquired by science. Proper implementation is thus very important but also a time-consuming activity. As an example, we showcase the implementation process of an intervention called ProMuscle. ProMuscle started as a clinical trial in 2010 and proved the efficacy of resistance training in combination with protein supplementation on lean body mass and physical performance in frail older adults (Tieland et al. 2012b, Tieland et al. 2012c). The clinical trial was translated to practice and piloted in 2014 (van Dongen et al. 2017) and after adaptations tested for effectiveness in a large practical study between 2016 and 2018 (van Dongen et al. 2020), where it proved to be effective. These positive effects in practice led to the awarding of an official entry in the Dutch Centre of Healthy Living database of governmental approved effective interventions. In future steps, the ProMuscle intervention will be further implemented into regional and national care patterns. With a path of 10 years between clinical study and the official recognition, this example clearly shows that a great effort is needed to successfully implement effective lifestyle treatments in practice. However, the societal impact and the benefits for older adults of proper implementation do evidently outweigh this effort.

14.6 Conclusion

To conclude, declining physical functioning during ageing is a serious problem. Lifestyle interventions have great potential in preventing and treating losses in muscle mass, muscle quality and physical functioning. These interventions should be well-timed and should employ the nutrition-exercise synergism as well as the combined effects of different nutrients in holistic approaches.

Textboxes:

1: Bone

Textbox 1

Aside from the declining muscle mass and muscle quality during ageing, decreases in bone health play important roles in age-related declines in physical abilities. Bone mass declines gradually after the age of 30, and in women, steeply after menopause. Reduced bone mass severely increases the risk of fractures and can result in osteoporosis, a geriatric phenotype prevalent in 9–38% of women and 1–8% of men (Wade et al. 2014). Nutrition plays an important role in bone mass retention during ageing. Notoriously, vitamin D and calcium are related to improved bone health, but supplementation studies are inconclusive (Zhao et al. 2017). Protein intake might play a more important role by stimulation IGF-1 and by increasing dietary calcium uptake (Dolan and Sale 2019), and higher protein intake is indeed related to reduced fracture risk (Groenendijk et al. 2019). Interestingly, vitamin D, calcium and protein are typically present in animal-based foods. A purely plant-based diet might thus jeopardise bone health, a notion that indeed has been observed in longitudinal observational studies, where vegans showed to have 15 times higher fracture risk compared to omnivores (Tong et al. 2020).

Compliance with Ethical Standards

Conflict of Interest All authors declare they have no conflict of interest.

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