Wien Med Wochenschr (2011) 161/17–18: 409–415
DOI 10.1007/s10354-011-0910-x

Printed in Austria

wmw
Wiener Medizinische Wochenschrift

The role of nutrition in the prevention of sarcopenia

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Received December 27, 2010, accepted (after revision) April 6, 2011, published online July 29, 2011

Die Rolle der Ernährung bei der Prävention von Sakopenie

Zusammenfassung. Der Ernährung wird neben anderen Faktoren wie Hormon- und Entzündungsstatus, Erkrankungen und körperlicher Inaktivität bei der Entstehung von Sarkopenie eine zentrale Rolle zugesprochen. Zusammenhänge zwischen verschiedenen Ernährungsfaktoren und Muskelmasse, Kraft und körperlicher Leistungsfähigkeit wurden in den letzten Jahren in einer wachsenden Zahl von Studien beschrieben. Demnach ist die Vermeidung von Gewichtsverlust und der damit einhergehenden Abnahme der Muskelmasse von zentraler Bedeutung. Adäquate Mengen an hochwertigem Protein sind zur optimalen Stimulation der Muskelproteinsynthese essentiell. Vitamin D, Antioxidantien und ω3-Fettsäuren können möglicherweise ebenfalls dazu beizutragen, den Verlust von Muskelmasse und -funktion zu minimieren. Darüber hinaus sollten Ernährungsprobleme wie Appetitverlust, geringe Essmenge, einseitige Ernährungsgewohnheiten und Gewichtsverlust möglichst frühzeitig erkannt werden. Zugrunde liegende Ursachen müssen identifiziert und rasch beseitigt werden. Schließlich muss die Bedeutung von körperlicher Aktivität, speziell Krafttraining, betont werden – nicht nur um den Muskelaufbau zu erleichtern, sondern auch um Energieverbrauch, Appetit und Nahrungsaufnahme bei älteren Menschen mit Risiko für Mangelernährung zu steigern.

Schlüsselwörter: Sarkopenie, Muskelmasse, Muskelkraft, Leistungsfähigkeit, Ernährung

Summary. Nutrition is regarded as one important contributing factors in the complex etiology of sarcopenia. Associations between several nutritional factors and muscle mass, strength, function and physical performance were reported in a growing number of studies in recent years. Accordingly, the avoidance of weight loss is crucial to prevent the concomitant loss of muscle mass. Adequate amounts of high-quality protein are important for optimal stimulation of muscle protein synthesis. Vitamin D, antioxidants and ω3-polyunsaturated fatty acids may also contribute to the preservation of muscle function. In order to ensure adequate intake in all elderly, nutritional problems like loss of appetite and weight loss should be recognized early by routine screening for malnutrition in the elderly. Underlying causes need to be identified and subsequently corrected. The importance of physical activity, specifically resistance training, is emphasized, not only in order to facilitate muscle protein anabolism but also to increase energy expenditure, appetite and food intake in elderly people at risk of malnutrition.

Key words: Sarcopenia, muscle mass, strength, physical performance, nutrition, dietary intake

Introduction

Sarcopenia, characterized by a loss of muscle mass and strength, is regarded as one of the most meaningful geriatric syndromes [1]. The gradual loss of muscle mass and muscle quality with age is accompanied by a decline in physical activity, functionality and performance and, thus, closely related to the syndrome of frailty, that is characterized by physical weakness, reduced physical activity and performance [2]. An excessive loss of muscle mass and strength results in physical impairment, disability and dependence from others. Less known, a markedly reduced muscle mass also impairs the metabolic adaptation to stress and disease. Thus, optimal preservation of healthy skeletal muscles is highly relevant for independence and self-determined living, health and well-being [1, 3, 4].

Nutrition is an important modulator of health and well-being in the elderly. Inadequate nutrition contributes to the progression of many chronic diseases, and is also regarded as one important contributing factor in the complex etiology of sarcopenia. Besides hormonal and inflammatory changes, neurodegenerative processes and reduced physical activity, inadequate

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nutrition may contribute to the development of sarcopenia and aggravate the inevitable age-related loss of muscle mass and function [5, 6].

Vice versa, sarcopenia may compromise adequate nutrition. If physical activity and performance are reduced, shopping and cooking may become burdensome and exhausting. The ability to prepare adequate meals may be impaired, and appetite reduced due to absent activity. In frail elderly who need support from others for basic activities of daily living, the risk of inadequate intake is further increased. Thus, a vicious cycle may develop where sarcopenia and malnutrition mutually amplify one another.

Some years ago, the relation between dietary intake and physical performance was comprehensively examined in the InCHIANTI study. In this community-based study in Northern Italy among more than 800 healthy elderly, Bartali et al. [7] found that an energy intake in the lowest quintile, i.e. below 21 kcal/kg body weight and day, was related to physical frailty, defined as having at least two of the following characteristics: low muscle strength, feeling of exhaustion, low walking speed and reduced physical activity. After adjusting for energy intake, also a low intake of protein, vitamin D, E, C, folate and a low intake of more than 3 nutrients at the same time, were significantly related to frailty. In the same study, an inadequate intake of energy was related to functional nutrition related problems like difficulties with chewing, self-feeding, shopping, carrying a shopping bag or cooking [8].

In recent years, a growing number of studies confirmed the relationship between several nutritional factors and muscle mass, strength, function and physical performance. In the following, the present knowledge about the role of nutrition in the prevention of sarcopenia will be reviewed and practical nutritional recommendations derived.

Table 1 shows possible mechanisms how nutrition may affect muscle mass and function.

Tab. 1: Nutrition and sarcopenia – possible mechanisms

Deficiency of	
• Energy	→ Weakness, fatigue
	→ Weight loss → Muscle mass ↓
• Protein	→ Limitation of muscle protein synthesis (MPS)
• Vitamin D	→ Muscle weakness, limitation of MPS
• Antioxidants	→ Oxidative damage of muscle tissue ↑
• Ω3-fatty acids	→ Inflammation↑

Energy intake – weight loss

For the maintenance of muscle mass and physical function, the amount of food and energy consumed is of primary importance. Skeletal muscles, in addition to the energy needed for motor activity and contractions, permanently need energy for their own metabolism and subsistence. A lack of energy may compromise mitochondrial energy metabolism of muscle fibres and lead to muscle fatigue, weakness and debility. In the long run, a reduced intake of energy results in muscle atrophy. If body weight decreases during periods of starvation, not only fat stores are wasted but always also lean body mass, i.e. muscle mass, is lost. In older adults, weight loss – whether intended or not – affects muscle mass more than in younger adults with comparable weight loss [9]. On the other hand, the compensation of weight loss and increasing lean mass is more difficult in older than in younger people. In the Health, Aging and Body Composition Study, a large cohort study of elderly men and women aged 70–79 years, it has been shown over a four-year period that during weight loss significantly more lean mass was lost than was gained with weight gain [10]. Thus, weight loss, even if partially regained, e.g. after a period of acute illness or stress, may result in a net loss of lean mass, accelerating sarcopenia.

In older adults, weight loss is common as a result of reduced dietary intake [11]. Generally, food and energy intake decline with age due to physiologic changes like reduced appetite, altered taste and smell sensation, slower gastric emptying and altered hormonal responses. In addition, intake is often further reduced as a consequence of physical and mental impairments, chewing or swallowing problems, loneliness or depression. The presence of multiple diseases in many elderly, and accompanying inflammation, pain and multiple medication may also substantially impair dietary intake and lead to weight loss and malnutrition [11, 12].

In several studies the relationship between a poor nutritional status and functional impairment is documented. In the Nun Study in around 500 catholic sisters, weight loss of 3% or more per year was related to a significantly increased risk of becoming dependent in several basic activities of daily living (ADL) [13]. In a recent study in nursing home residents in Nürnberg, we found a BMI below 20 kg/m^2 related to lower handgrip strength and reduced ability to perform basic ADL [14]. In community-living elderly women in Baltimore a BMI below 20 kg/m^2 was associated with greater likelihood of pre-frailty and frailty

after adjustment for potential confounders than a higher BMI [15].

On the other hand, overweight and obesity were also found to be related to functional impairments. In fact, many elderly are obese and sarcopenic at the same time – a phenomenon called sarcopenic obesity. Affected persons with low muscle mass but high fat mass were found to be at very high risk of disability [16, 17]. Weight loss at the expense of lean mass in very obese patients may result in sarcopenic obesity. Excess energy intake in combination with inactivity, low-grade inflammation, hormonal changes and low protein intake (see below) may also contribute.

In summary, independent of original weight or nutritional status, loss of body weight results in loss of muscle mass, and is related to poor functionality and outcome.

Protein and amino acids

Since skeletal muscles mainly consist of protein, and muscle protein synthesis can be stimulated by dietary protein, the role of protein intake in the development of sarcopenia is of particular interest.

The relation between protein intake and muscle mass and function, and the detrimental effects of low protein intake in this respect have been reported by Castaneda et al. [18] in a study comparing daily protein intake levels of 0.45 and 0.92 g/kg body weight and day over 9 weeks in 12 elderly women. The low protein intake resulted in significant losses of lean body mass, especially muscle mass, and muscle strength, whereas muscle mass and function were maintained at the higher intake level. As already mentioned, the InCHIANTI study reported an increased risk of frailty in healthy elderly with low protein intake. In participants in the lowest protein intake quintile (<66 g/d in men, <55 g/d in women; corrected for energy intake) the risk of frailty was nearly doubled compared to participants with higher intake [7].

Only recently, some epidemiologic evidence for a relationship between the amount of protein consumed and the preservation of muscle mass emerged. In the already mentioned Health, Aging and Body Composition Study, three-year decrease in lean mass and in non-bone appendicular lean mass was found to be about 40% less in participants in the highest quintile of protein intake (median intake 1.1 g/kg) compared to the lowest quintile (median intake 0.7 g/kg) [19].

In a small cross-sectional study of 38 healthy women aged 66 ± 5 years, significant correlations between muscle mass and total protein intake and between muscle mass and animal protein intake were observed. Stepwise regression analysis showed animal protein intake to be the only independent predictor of muscle mass [20]. Superiority of animal protein compared to vegetable protein has also been shown at the molecular level. In a study with 12 elderly women, a high-animal protein diet resulted in greater muscle protein synthesis than a high-vegetable protein diet [21]. This may be explained by the fact that mainly essential amino acids and, in particular, leucine are responsible for the anabolic effect of amino acids in skeletal muscles [22].

Besides the amount and kind of protein, the distribution of protein intake over the day was found to be important with respect to protein turnover. In elderly people, higher protein turnover and better nitrogen retention were observed, with three meals per day and providing 80% of the daily protein intake to elderly women at lunchtime (pulse feeding), compared with an equal distribution of protein in four meals (spread feeding) [23].

Very large amounts of protein at one meal, however, do not seem to be more effective than moderate servings. Paddon-Jones and Rasmussen [22] reported that a large single portion of 340 g lean beef (containing 90 g protein) does not elicit a greater anabolic effect than a serving one-third the size. They conclude that ingesting more than 30 g protein at a single meal may be an inefficient means of stimulating muscle protein synthesis. This is in agreement with a recent study that showed no benefit of very large amounts of protein for 10 days (3.0 *vs.* 1.5 g/kg) in terms of muscle protein synthesis [24].

Supplementation of protein in addition to usual food intake also generally failed to show beneficial effects on strength and performance. Also in combination with resistance training, additional protein to increase muscle mass and strength has been largely unsuccessful. Several supplementation studies have consistently shown that in elderly subjects, who habitually consume adequate amounts of protein (modestly above 0.8 g/kg), supplemental protein intake, either immediately after or separate from exercise, did not further augment the training-induced improvements in muscle mass and strength [25].

In contrast, several supplementation studies with essential amino acids showed promising results with respect to muscle strength and physical performance. Improved gait speed, floor-transfer and step test are reported in healthy active and sedentary elderly, even without exercise [26–28]. Indeed, these studies were

only of short duration with small groups of participants, and efficacy is presently not proven.

In summary, protein and amino acids, especially essential amino acids and leucine play an important role for muscle protein metabolism, and presumably muscle mass and function. Amount, kind and timing of protein intake seem to be crucial.

Vitamin D

In recent years, vitamin D turned out to be of great importance for muscle function and physical performance.

It has been known for long that severe vitamin D deficiency is accompanied by muscle weakness, pain and gait impairments. After it was discovered that a vitamin D receptor is expressed in human muscle, and that its activation may promote protein synthesis, a number of observational studies consistently reported an association between vitamin D status and muscle features [29–32]. Low serum levels of 25-OH vitamin D were related to low muscle mass, low muscle strength, worse physical performance and frailty. Longitudinally a physical performance decline is reported in relation to a poor vitamin D status, as well as higher risks of developing sarcopenia, becoming frail and being admitted to a nursing home. Furthermore, low vitamin D emerged as an independent predictor of falls.

Low vitamin D levels are common in older persons [33], particularly in nursing home residents [34], where dietary intake and exposure to sunlight are often extremely low. In nursing home residents in Nürnberg, recently a moderate deficiency (<25 nmol/L) was observed in about two thirds (68%), and only 4% had desirable levels above 75 nmol/L [35]. Even in healthy elderly dietary intake, with a median of about 3 µg/d [36], is far from the recommended amount of 10 µg/d [37]. In the InCHIANTI study, a vitamin D intake in the lowest quintile was associated with frailty [7].

Supplementation of vitamin D in double-blind randomized-controlled trials has been shown to increase muscle strength and performance and reduce the risk of falling in community-living elderly and nursing home residents with low vitamin D levels [29–31, 38].

Antioxidants and ω3-fatty acids

In addition to the above mentioned mechanisms, oxidative stress and chronic inflammation are regarded to play important roles in age-related muscle atrophy and functional decline. During oxidative stress, reactive oxygen species (ROS) cause molecular damage in human skeletal muscle by damaging DNA, proteins and lipids. ROS are also able to modulate transcription factors, e.g. NF-κB, and thus interact with the production of proinflammatory cytokines like TNF-α and IL-6. Proteolytic pathways, protein breakdown and apoptosis are boosted with the consequence of fibre atrophy and fibre loss [39].

In the Women's Health and Aging Study (WHAS) in older community-living women, oxidative protein damage was found to be related to reduced grip strength in a cross-sectional analysis [40] and longitudinally to a decline in walking speed over three years [41]. Similarly, inflammatory markers like IL-6 and CRP were related to reduced muscle strength, disability and functional decline [42].

In several studies, dietary intake as well as serum levels of nutrients with antioxidant properties was related to physical capacities. Thus, an association between low intake of carotenoids, vitamin E and C on the one hand and reduced strength [43], reduced performance [43] and frailty [7] on the other hand, was described. Low serum levels of carotenoids, vitamin E and selenium were found to be associated with reduced muscle strength [43–45], reduced physical performance [46] and frailty [47]. Longitudinally a decline in physical performance [36, 46] and an increased risk of becoming frail [48] in the course of 3 or 6 years were observed in elderly persons with low antioxidant serum levels.

Intake of ω3-fatty acids – known for their anti-inflammatory properties – was reported to be related to leg strength and chair-rise capacity [49], intake of fatty fish to grip strength [50]. In the InCHIANTI study, serum levels of ω3-fatty acids were related to physical performance [51].

Nutritional recommendations

Altogether, there is increasing evidence, confirming the relation between nutrition and muscle health. We have, however, to admit that our present knowledge is still limited. Concrete figures for optimal amounts of nutrients in order to minimize functional decline cannot be derived, official nutritional guidelines for the prevention of sarcopenia are not available. Nevertheless, based on the observations described above, several recommendations can be given that are in line with the general conception of a healthy diet and may contribute to the preservation of muscle mass and strength and the prevention of sarcopenia.

To rank first, the amount of food and energy is crucial to maintain body weight and to avoid weight loss and the concomitant loss of muscle mass. This also applies to overweight and even obese elderly – provided that no medical condition necessitates a reduction of weight. If weight loss is necessary for health reasons, ample amounts of dietary protein and exercise with focus on resistance training are mandatory. The optimal BMI for older people is higher than in younger adults and supposed to be between 22 and 30 kg/m^2. Energy intake should aim at maintenance of the BMI in this range. For most of the elderly, this will be achieved with 24–36 kcal/kg body weight and day – in a 60 kg person equivalent to 1440–2160 kcal/day – mainly depending on physical activity and health status. To judge the adequacy of energy intake in individual subjects, measurements of body weight at regular intervals are essential.

Just as important as an adequate intake of energy is the consumption of high-quality protein in adequate amounts. The current recommendation for persons aged 65 years or older is 0.8 g of good quality protein per kg body weight per day both for men and women, and thus the same as for younger adults [37]. It is assumed that higher amounts may be necessary to minimize the sarcopenic process. Daily amounts of 1.0 up to 2.0 g/kg are discussed, however our knowledge is presently insufficient to derive concrete figures. Until more evidence is available, it seems reasonable to ensure an intake of 0.8–1.2 g/kg in all elderly, particularly in those at risk of malnutrition, e.g. frail and multimorbid elderly. In addition, it seems to be advisable to spread protein intake across the three main meals; an example is given in Tab. 2.

Tab. 2: Example for protein intake at 3 main meals

Breakfast	
1 slice of brown bread (45 g)	3 g
1 bread roll (40 g)	3 g
¼ L milk	8 g
1 egg	6 g
30 g hard chese	10 g
	30 g
Lunch	
150 g meat or fish	27–36 g
1 pt. rice, pasta or potatoes	4–7 g
	31–43 g
Supper	
1 slice wholemeal bread (45 g)	4 g
1 bread roll (40 g)	3 g
30 g soft cheese	6 g
30 g sausage	6 g
40 g curd cheese or 150 g yoghurt	5 g
	24 g

An adequate supply of vitamin D seems to be of major importance for optimal muscle function. Since only a few foods like fatty fish or liver contain noteworthy amounts of vitamin D, nutritional interventions are clearly insufficient to reach recommended serum levels. Usually, vitamin D is mainly produced in the skin with the help of sunlight. In many elderly people, however, also this source of vitamin D is insufficient. Consequently, in persons at risk of vitamin D deficiency, e.g. those with reduced sun light exposure, supplementation is reasonable. A supplemental intake of 700–800 IU/day and serum levels above 75 nmol/L are presently regarded as beneficial for optimal physical performance and fall prevention [31, 38].

Appropriate dietary intake of antioxidants like vitamin E, C, carotenoids, selen and zinc may contribute to improved antioxidant defence, reduce oxidative damage and in this way reduce functional decline. Nutrients with antioxidant properties are widespread in a great number of different foods like fruits and vegetables (vitamin C, carotenoids), vegetable oils, nuts and wheat germs (vitamin E), meat, fish, eggs (selen), whole meal products, meat, eggs, milk and cheese (zinc). Phytochemicals like polyphenols or phytic acid, contained in fruits and vegetables, red wine, tea or cacao for example, may also operate as antioxidants and strengthen antioxidant defence. Thus, nutritional antioxidants are spread over plenty of foods implicating a varied and colorful diet.

The anti-inflammatory effect of ω3-polyunsaturated fatty acids argues for a regular consumption of foods rich in these nutrients, namely vegetable oils like walnut, linseed, rapeseed and soy oil and fatty sea-fish like herring, mackerel or salmon.

Nutritional deficiencies and malnutrition are widespread among the elderly and may develop quickly. Consequently, in addition to these recommendations for food selection, it is important to recognize nutritional problems of elderly people early. Once emerged, loss of appetite, low food intake, unfavorable dietary habits and weight loss should be realized, underlying causes identified and subsequently eliminated. Hence, routine screening for malnutrition in the

Tab. 3: Nutritional recommendations for the prevention of sarcopenia and frailty

Securing of adequate amounts of energy and essential nutrients
• **Energy** ○ 24–36 kcal/kg body weight and day ○ Maintenance of body weight – avoidance of weight loss ○ Avoidance of extreme over- as well as underweight
• **Protein** ○ 0.8–1.2 g high quality protein per kg body weight and day ○ High quality protein sources at each main meal: milk products, mean, fish, eggs
• **Vitamin D** ○ Regular fish consumption ○ Daily exposure to sunlight ○ Supplementation where required
• **Antioxidants** Varied diet rich in fruits and vegetables, plant oils and nuts, whole meal products, meat, milk, cheese, tea, cacao
• **Omega-3-fatty acids** ○ Vegetable oils like walnut, linseed, rapeseed and soy oil ○ Fatty sea-fish like herring, mackerel or salmon
• **Routine screening for malnutrition** ○ Early recognition of nutritional problems – loss of appetite, low food intake, unfavorable dietary habits and weight loss ○ Identification of underlying causes and subsequent elimination

elderly should be mandatory in all health care settings. Recently the short form of the Mini Nutritional Assessment (MNA) has been refined and confirmed as a feasible and valid tool for this purpose [52]. Adequate intake of energy and nutrients should be ensured in all elderly individuals, particularly in those at risk of malnutrition, e.g. frail and multimorbid persons. In addition to adequate nutrition, regular physical training is of utmost importance for the maintenance of muscle mass and function and cannot be emphasized enough.

Nutritional recommendations for the prevention of sarcopenia are summarized in Tab. 3.

Conclusions

Modification of nutrition is an attractive and charming way for the maintenance of muscle mass, function and independence. It does not have any side-effects, and is, at best, accompanied by pleasure and enjoyment.

There is no doubt that nutritional factors play an important role in the development of sarcopenia. Most importantly, weight loss should be avoided in elderly people and an ample intake of high-quality protein ensured. Moreover, foods rich in nutrients with anti-oxidant and anti-inflammatory properties should be selected to counteract oxidative stress and inflammation. Supplementation of vitamin D is necessary in persons with inadequate intake and exposure to sunlight. Nutritional awareness and compliance with these guidelines may have the potential to slow down the progression of sarcopenia with age.

However, many details on how nutrition can prevent or treat sarcopenia are presently unclear. Only few studies are available that directly examined the relationship between nutrient intake, muscle mass and muscle function. These studies do not allow deriving definite conclusions for optimal nutrient amounts in this respect. Long-term studies relating dietary intake to clinical endpoints, like physical performance and independence in daily routines, are clearly needed to elucidate the relationship between nutrition and sarcopenia.

Until more evidence is available, a varied, well-balanced diet containing adequate amounts of the above mentioned nutrients may be the best way to support the prevention of sarcopenia. In addition, early recognition of nutritional difficulties, identification of the underlying causes and subsequent elimination is crucial. Furthermore, the importance of physical activity, specifically resistance training, is emphasized in order to facilitate muscle protein anabolism, increase energy expenditure, appetite and food intake.

Since sarcopenia develops slowly during lifetime, prevention should at best start early and occur throughout adult life.

Conflict of interest

The author declares that there is no conflict of interest.

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