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Muscle power and nutrition

Introduction

Maintenance of mobility, independence and quality of life during the aging process and as people reach advanced age is one of the core goals of geriatric medicine. The understanding of sarcopenia, a key component for functional capacity, has therefore become a key focal point over the past decade. The term sarcopenia was originally defined as the age-related loss of muscle mass [1]. As the Greek origin of sarcopenia translates to "loss of flesh" and therefore focuses on muscle mass, some authors have suggested that the term dynapenia would be a more appropriate and accurate term for describing age-associated loss of muscle strength [2]. It has been shown within the past decades that muscle mass is not the only determinant of muscle strength. Data from the Health ABC study [3] and experimental results have indicated that a decline in muscle strength is very often much more rapid compared to age-related loss of muscle mass [4]. Many data suggest that loss of muscle strength may be potentially attributed to activation of motor neurons (central) and reduction in the intrinsic force-generating capacity of skeletal muscle [5]; therefore, the mechanisms accounting for a decline in muscle strength, also called dynapenia, should more appropriately be attributed to a combination of neural and muscular factors. Additionally, concomitant diseases may accelerate muscle loss due to systemic inflammation processes. This is why an international consensus guideline committee has proposed an approach to diagnosing malnutrition/sarcopenia in adults based on the etiology that also incorporates the present understanding of inflammatory responses to disease and trauma [6].

As the term sarcopenia is widely recognized and used in the clinical context and practice, the current narrative review adopts the definition of sarcopenia suggested by the European working group on sarcopenia in older people (EWGSOP) and highlights the possible impact of nutrition on muscle mass and function in older subjects. The review especially highlights the role of individual nutrients, such as proteins, amino acids and vitamins and discusses future developments to be expected in the field of nutritional medicine, especially those that may impact muscle physiology in an aging population.

Defining the end points of muscle strength and power in old age

Defining the impact of nutrition on muscle strength requires a clarification of terms as there are several perspectives on this topic. On the molecular level, sarcopenia results from an imbalance between skeletal muscle protein synthesis and the degree of protein breakdown. Muscle fiber size and the number of fibers decline with advancing age. From epidemiological data it is estimated that humans lose 24–27 % of muscle mass in the last decade of life. These data mainly derive from either laboratory studies with rats and mice or clinical studies in humans using muscle biopsies; however, data from basic scientific research involving older people using invasive tissue collection are rare. These observations indicate that most of the mechanistic and molecular scientific data have been gathered from rodent models and caution should therefore be exercised in extrapolation to human sarcopenia [7] and especially careful with respect to extrapolation to older persons.

The measurement of muscle mass in humans in the clinical setting is difficult and time-consuming. Most of the available methods vary in degrees of accuracy and difficulty. The most direct measurement currently available is urinary creatinine which is measured over 24 h periods [8]. Methods that are more indirect include anthropometry [9], bioelectrical impedance analysis (BIA) and imaging techniques, e.g. dual energy X-ray absorptiometry (DXA), computed tomography, magnetic resonance imaging and ultrasound [10].

The assessment of muscle strength requires a voluntary effort by the test subject and greatly depends on the muscle groups tested. Muscle contraction by maximized electrical stimulation is usually used in laboratory settings. There are various reports in the literature regarding whether or not advancing age reduces the motor neuron activation capacity of skeletal muscles. Several studies have examined the effect of age on central activation of the knee extensor, elbow flexor and dorsiflexor muscles. Due to functional differences, variations within activation profiles were also found for different muscle regions [11].

The clinical measurement of muscle function mainly relies on easy to perform functional tests with the resulting data applied to provide endpoints for clinical interventions. The principal tests performed include the knee extensor test and the measurement of grip strength [11]. Grip strength has also been demonstrated to be a predictor of upper and lower extremity muscle power, of knee exten-

Doris Eglseer and Ruth Poglitsch contributed equally to this publication.

sion torque and cross-sectional area of calf muscle [1, 12].

Since publication of the comprehensive geriatric assessment tool (CGA), various tests to determine complex physical functioning taking into account nutritional status have been published. At the current time, experts are agreed on the value of the short physical performance battery (SPPB) [13] to test mobility and muscle strength of lower limbs. This test battery includes gait speed, standing balance (three or five tasks), the chair stand test with modifications of the narrow walk test, dynamic balance (two tasks) and shoulder rotation; however, it should be mentioned that in addition to the SPPB, other test batteries are also in daily clinical use to determine complex physiological muscle functioning and physical activity.

Role of protein in treatment of low muscle strength and power

A recent consensus statement [14] described the causes of sarcopenia as multifactorial, including factors such as muscle disuse, altered endocrine function, chronic diseases, inflammation, insulin resistance and nutritional deficiencies. The current narrative review article focuses only on the impact of nutrition on muscle functioning determined with clinical functional assessments.

Proteins are essential components of muscle metabolism. There is consensus among experts that dietary protein contributes to muscle strength and power [15]. Nowadays it is recognized that an adequate protein and energy intake is indicated as a main effective nutritional strategy to prevent and treat sarcopenia and related loss of functional capacity [16].

The current recommended dietary allowance (RDA) for protein in all adults is 0.8 g/kg body weight (BW)/day. Age-related changes in muscle metabolism, immunity and hormone levels are not considered in these recommendations. It seems noteworthy that epidemiological data indicate that older people are at risk for inadequate protein intake. It has been reported that 32–41 % of women and 22–38 % of men older than 50 years consume less than the RDA of protein [17]. In addition the anabolic responses to protein intake decrease in older people and chronic as well as acute diseases lead to higher protein wasting. To overcome these physical changes in aging and to maintain muscle strength and physical function, the key PROT-AGE study group recommended a higher protein intake in older people than in younger people [18]. The average daily intake should be increased in older people to 1.0–1.2 g/kg BW/day compared to the RDA. In older people with acute or chronic diseases such as frailty, osteoporosis, pressure ulcers, chronic obstructive pulmonary disease (COPD) or cardiac diseases, a dietary protein intake of 1.2–1.5 g/kg BW/day is specifically recommended. Older adults with severe illness or injury or with severe malnutrition may need up to 2.0 g/kg BW/day. People suffering from chronic kidney disease without dialysis should limit protein intake and thus represent an exception regarding high protein intake recommendations [18]. A recent systematic literature review showed that nutritional supplementation containing an optimal amount of protein, mostly rich in special amino acids, may not only increase muscle mass but may also improve muscle strength and muscle power. There is evidence that protein-rich supplements increase handgrip strength, leg strength and the ability to climb stairs [16]; however, simply increasing dietary protein over the long term to counteract anabolic resistance in older age may not be effective on its own. Sometimes it may be observed that extra protein supplementation is not effective for reasons not yet well understood. It seems that clinical success of nutritional interventions using protein supplementation is influenced by various other factors apart from just adding protein. This may also explain the lack of evidence coming from various interventional studies which have been carried out to show a benefit in terms of physical functioning due to protein supplementation.

The specific nature of the amino acid consumption in dietary proteins has a great impact on the potential for accelerating anabolic effects in muscle. In particular, leucine is recognized as an effective regulator of muscle protein turnover via the mammalian target-of-rapamycin (mTOR) pathway for overcoming the anabolic resistance of aging muscles [19]. There have been few studies that examined the impact of leucine-rich nutritional supplements on muscle strength. A randomized controlled trial [20] (PROVIDE study) that explored the impact of a vitamin D and leucine-enriched whey protein diet on sarcopenia was recently published. A total of 380 non-malnourished community-dwelling older people with mobility limitations were included. Participants were recruited either to an intervention group or to an isocaloric group. The intervention group was given an active nutritional compound including 20 g whey protein, 3 g total leucine, 9 g carbohydrates, 3 g fat, 800 IU vitamin D and a mixture of vitamins, minerals and fibers. The isocaloric group did not receive any protein or micronutrients, only carbohydrates, fat and some trace elements. Permuted block randomization to the active or control group was stratified for SPPB categories. Muscle strength, measured via handgrip strength, improved in the intervention group as well as in the control group but there were no significant differences between the groups. Although there was no significant improvement in muscle strength, there was a significant increase in muscle mass and an improvement in chair stand test results in the intervention group compared to the control group. This study is of significant scientific and clinical interest as it is at the present time the only study which used nutritional supplementation alone and provided data showing an increased muscle mass (better results in chair stand test) among an aging sarcopenic study population. As no physical exercise intervention was included in the PROVIDE study, it could be suspected that nutritional supplementation by itself could be important in treating older sarcopenic people [20].

There is also some evidence to support the view that to maintain muscle strength it may be more effective to combine exercise and nutritional interventions. A controlled clinical trial investigated the effectiveness of a whey protein supplementation of 40 g/day compared to an isocaloric control group. Both groups underwent resistance training. There were improvements in the group receiving nutrition and exercise intervention compared to exercise alone; however, the data did not reach statistical significance [21].

Vitamin D and muscle power

The serum level of vitamin D declines steadily with aging due to inadequate dietary intake, reduced sunlight exposure, impaired capacity of the skin to synthesize vitamin D under the influence of ultraviolet B (UVB) rays and diminished renal conversion of 25-hydroxyvitamin D, 25(OH)D, to its active form [22]. In the USA and Europe up to 40 % of community-dwelling older adults have been observed to have vitamin D deficiency. Low vitamin D levels seem to be associated with a multitude of adverse health outcomes, including osteoporosis, diabetes mellitus, rheumatoid arthritis, several forms of cancer, cardiovascular diseases, cognitive decline, multiple sclerosis and infectious diseases [23]. As many of these diseases are also related to functional limitations, as early as 30 years ago [24] researchers suggested a direct link between hypovitaminosis D and muscle function. Recently published literature showed significant associations between vitamin D and muscle strength. In a cross-sectional analysis in the InChianti cohort, Shardell et al. established a strong and independent association of low vitamin D levels and the functional parameters assessed with operationalized frailty scoring according to Fried's criteria [25]. Similar results were obtained in the Amsterdam longitudinal study [26]. In a prospective study in community-dwelling older citizens, the serum level of vitamin D was found to be a strong and independent predictor of changes not only in muscle mass but also strength over a 2.6-year follow-up period [27]. Despite conflicting data from a review published by Stockton at al. [28], Muir and Montero-Odasso concluded from their meta-analysis that studies with a daily dose of 800 IU or more vitamin D demonstrated beneficial effects on balance and muscle strength in older adults with higher 25(OH)D levels; however, the magnitude of the effects was small [29].

Results of an interventional randomized controlled trial in older persons with limited mobility showed that a combination of 21 g protein, 10 g essential amino acids, 3 g leucine and 800 IU vitamin D consumed twice daily over a period of 12 weeks significantly improved muscle mass and chair stand test results in older adults [30]. Based on all these findings, it is currently recommended to measure serum levels of 25(OH)D in all sarcopenic patients and to prescribe vitamin D supplements of 800 IU/day to those with values lower than 40 ng/ml [17]. Based on the previously mentioned scientific findings, the Society for Sarcopenia, Cachexia and Wasting Disease [31] recommended for the management of sarcopenia a total protein intake of 1–1.5 g protein/kg BW/day, a leucine-rich balanced essential amino acid mix and an adequate supply of vitamin D, stating that doses up to 50,000 IU/week are regarded as safe.

The effect of high-dose vitamin D may be attributed to its long half-life. Upon ingestion, vitamin D is either converted to 25(OH)D or redistributed into fat, from which it is slowly released over time. By this mechanism, Ish-Shalom et al. [32] suggested that daily, weekly and monthly vitamin D dosing will result in the same circulating concentrations of 25(OH)D over an equivalent period of time. Very recently, there have been discussions among experts on the efficacy of high-dose single regimens of vitamin D. In addition, the question of feasibility of regular laboratory measurements of vitamin D levels in very old persons has been discussed among clinicians and experts. Currently, weekly dosing of vitamin D is recommended according to study data in old-

Abstract · Zusammenfassung

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Abstract

Sarcopenia, as defined by the European working group on sarcopenia in older people (EWGSOP), is a highly prevalent syndrome characterized by age-related loss of muscle mass and muscle strength/power with impacts on physical function, health and quality of life in older people. The complex, multifaceted and still not completely elucidated etiology of sarcopenia and loss of muscle function (dynapenia) poses challenges for the design of interventional studies to combat loss of muscle strength. Several factors, however, have been demonstrated to have major impacts for maintenance of physiological muscle functioning, including nutrition and in particular specific nutrients. For example, proteins, amino acids and micronutrients have been extensively studied regarding their impact on muscle synthesis and metabolism. This literature review focuses on the impact of nutrition on muscle strength and power as it relates to older people given that muscle changes with age can have important implications for health.

Keywords

Muscle strength · Muscle power · Vitamin D · Diet · Protein

Muskelkraft und Ernährung

Zusammenfassung

Sarkopenie ist ein häufiges Syndrom bei älteren Menschen, welches von der European Working Group on Sarcopenia in Older People (EWGSOP) durch eine altersbedingte Abnahme der Muskelmasse und Muskelkraft bzw. -leistung charakterisiert wird. Sarkopenie hat negative Auswirkungen auf die körperliche Funktionsfähigkeit, Gesundheit und Lebensqualität älterer Menschen. Die komplexe und noch immer nicht vollständig verstandene Ätiologie der Sarkopenie und des Verlusts der muskulären Funktion (Dynapenie) ist eine Herausforderung bei der Konzeption von Interventionsstudien. Für mehrere Faktoren konnte bereits gezeigt werden, dass sie die Erhaltung der physiologischen Muskelfunktion wesentlich beeinflussen. Hierzu zählen die Ernährung und insbesondere spezielle Nährstoffe. So wurden beispielsweise Proteine, Aminosäuren und Mikronährstoffe gründlich bezüglich ihres Effekts auf Bildung und Stoffwechsel der Muskulatur untersucht. Das Ziel dieser Literaturübersicht ist es, den Einfluss der Ernährung auf die Muskelkraft und -leistung älterer Menschen darzustellen.

Schlüsselwörter

Muskelleistung · Muskelkraft · Ernährung · Protein · Vitamin D

er populations; however, poor compliance may limit the application of this approach. As discussed in a study by Ilahi et al. [33] 100,000 IU of vitamin D3 dosed every 2–3 months may provide optimal benefits in a general population with baseline 25(OH) D concentrations > 20 ng/ml. Bacon et al. [34] showed similar improvements in the sustainability of 25(OH)D concentrations over the long term by adding 50,000 IU vitamin D3 monthly doses following an initial 500,000 IU vitamin D3 bolus; however, data specifically addressing older people prone to a loss of muscle mass and functional decline are still lacking. Nevertheless, it may be estimated that subannual dosing strategies could strike a balance between the convenience of annual dosing regimens and the poor compliance of weekly dosing and thus serve to maintain 25(OH)D concentrations better in deficient populations.

Omega-3 fatty acids

Omega-3 polyunsaturated fatty acids are widely known to have both actual diverse health benefits and potential additional health benefits. Emerging evidence suggests that omega-3 fatty acids could improve muscle protein metabolism and thereby reduce levels of pro-inflammatory cytokines in older adults. This effect could be accompanied by an increased activation of the mTOR pathway, suggesting that omega-3 fatty acids might directly stimulate protein synthesis. Of the three main omega-3 fatty acids eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and alpha-linolenic acid (ALA), only ALA is an essential fat, while EPA and DHA are modified in the human body based on ALA. Seed oils contain high levels of ALA (e.g. chia seed oil, linseed oil, walnut oil and soybean oil). A positive association has been found between consuming flax oil and grip strength in community dwelling older persons [35] apparently involving ALA.

Rousseau et al. presented data on a positive association between self-reported dietary intake of omega-3 fatty acids and lower extremity function in 247 older people residing in the community or an assisted-living facility [36]. Overall, the number of studies specifically addressing older patients and muscle strength in the light of omega-3 fatty acid consumption is too small to draw coherent conclusions regarding relevant effects of these substances. Currently, there is no established dietary reference intake for these nutrients and there is a lack of interventional studies that show associations with sarcopenia; nevertheless, these preliminary data suggest that an adequate intake of omega-3 fatty acids could represent an effective nutritional remedy for sarcopenia [17].

Concluding remarks and future perspectives

Several complex mechanisms are involved in the development and progression of sarcopenia and decreased muscle function and strength (dynapenia); however, the etiology of sarcopenia and decreased muscle strength is not yet fully understood. As there are numerous underlying causes and mechanisms, it is not surprising that the detection of evidence regarding the efficacy of any interventions including nutritional interventions addressing these causes and mechanisms is challenging [15].

There is evidence that nutrition and nutritional interventions may improve muscle mass and strength in older people. Based on the literature reviewed for this article, it must be noted that the intervention trials most commonly combined nutrition and exercise interventions. It is a common understanding among experts that nutritional interventions to prevent loss of muscle mass and strength have to be provided in combination with physical exercise.

For preventing decreases in muscle strength, protein intake in older people needs to be higher than the current RDA recommendations and should reach 1.0–2.0 g/kg BW/day in patients with severe illness, injury or marked malnutrition. Sufficient total energy intake is therefore a prerequisite. Additionally, higher dietary protein intake seems to have a positive impact on the anabolic effects of resistance training. Leucine-enriched nutritional supplementation may enhance muscle strength but further studies on supplementation of special amino acids are needed to support specific recommendations [18]. In older people 25(OH)D levels should always be taken into consideration. In patients suffering from sarcopenia, supplementation is beneficial. Levels above 100 nmol/l should be achieved, with vitamin D supplementation if necessary [31].

Considering the current literature, a well-balanced diet in older people including sufficient energy and protein intake is recommended. Older persons should therefore consume protein sources containing high-quality proteins as well as leucine-rich foods, e.g. lentils, cowpeas, soybeans, whey and beef meat. Dietary sources of vitamin D, such as fatty fish, tuna and fortified foods should be regularly consumed [37]. The combination of protein (e.g. whey protein supplements, high-leucine supplements and vitamin D) and exercise is superior compared to either intervention alone [20, 38, 39]. The effects of other nutritional approaches, such as antioxidants and omega-3 fatty acids in treating sarcopenia are not yet clear. Further studies in older people are needed to broaden the very limited evidence base currently available.

There are also several other important areas of research that still require further investigation. There is a growing need for in vivo human studies to investigate the impact of nutrients on precise cellular mechanisms that contribute to sarcopenia and the observed age-related changes in the protein synthesis response of skeletal muscle towards exercise and nutritional supplementation. Furthermore, studies are needed to make a better differentiation between the effects of aging and the effects of inactivity on the progression of sarcopenia in older people and the possible positive effects of nutritional interventions towards counteracting this progression. Finally, given the overlap among various factors that may contribute to sarcopenia, studies are needed to adequately define the precise role of impaired protein synthesis on the etiology of sarcopenia relative to other contributing factors, such as diseases and neurological disorders.

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Compliance with ethical guidelines

Conflict of interest. D. Eglseer, R. Poglitsch and R.E. Roller-Wirnsberger state that there are no conflicts of interest.

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