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The Relevance of Diet, Physical Activity, Exercise, and Persuasive Technology in the Prevention and Treatment of Sarcopenic Obesity in Older Adults

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The aging population faces two conditions that threaten healthy aging: high fat mass (obesity) and low muscle mass and function (sarcopenia). The combination of both—referred to as sarcopenic obesity—synergistically increases the risk of adverse health outcomes. The two conditions often co-occur because they reinforce each other and share common etiologies, including poor nutrition and inactivity. All aging people are at risk of gaining weight and losing muscle mass and could benefit from improvements in physical activity, exercise and dietary intake. one specific window of opportunity is during the transient time of retirement, as older adults already need to restructure their daily activities. It is key to change lifestyle behavior in a sustainable manner, providing scientifically proven, personalized, and acceptable principles that can be integrated in daily life. Health technologies (e.g., applications) can provide promising tools to deliver personalized and appealing lifestyle interventions to a large group of people while keeping health care costs low. Several studies show that health technologies have a strong positive effect on physical activity, exercise and dietary intake. Specifically, health technology is increasingly applied to older people, although strong evidence for long term effects in changing lifestyle behavior is generally lacking. Concluding, technology could play an important role in the highly warranted prevention of sarcopenic obesity in older adults. Although health technology seems to be a promising tool to stimulate changes in physical activity, exercise and dietary intake, studies on long lasting effects and specifically targeted on older people around the time of retirement are warranted.

Keywords: sarcopenic obesity, nutrition, physical activity, blended care, eHealth, elderly

INTRODUCTION

Two severe public health threats strike Europe: obesity and sarcopenia, defined as loss of skeletal muscle mass and function (1, 2). Both obesity and sarcopenia predispose for comorbidity, immobility, dependency, disability, low quality of life, and many unhealthy life years (3–5). Obesity and sarcopenia synergistically reinforce each other in vicious cycles of increases in fat mass and muscle loss through reduced mobility, dependency and disability (2). The concept of sarcopenic obesity has been introduced to describe the association and co-occurrence of these two phenotypes (3, 6). The exact prevalence of sarcopenic obesity highly depends on the criteria used and the awareness of this relatively new condition, as obesity can mask the reduction in muscle mass (6), but is estimated around 12.6% in men and 33.5% in women by the National Health and Nutrition Examination Survey. These rates highly increase with age, reaching 48% in men and 27,5% in women, in those aged 80 years and above (4, 7). The negative clinical impact of sarcopenic obesity on health, quality of life and health cots is enormous (8–10). This negative impact is particularly present in the aging population, where physical inactivity, limited exercise and poor nutritional intake (both over and under consumption of nutrients) may even further lead to metabolic and clinical complications (11–13). To improve physical activity, exercise and nutrition, digital technologies have caught the interest of behavioral scientists and technology developers (14). The use of personalized digital health technologies (eHealth) and blended care (combination of eHealth and face-to-face contact) can be a promising strategy to support people in their challenge to follow a healthier lifestyle (15, 16). Digital health technologies can be used to target the upcoming population of older people, a population that is expected to increasingly use internet and mobile devices such as smartphones and tablets. Possible, one specific window of opportunity is during the transient time of retirement, as older adults already need to restructure their daily activities. In this paper we describe how and why older adults, specifically those in the phase of retirement, could benefit from health technologies focused on dietary intake, physical activity and exercise. To understand the need for such interventions we provide a brief overview of the interplay between sarcopenia and obesity at old age and the essence to focus on both dietary intake, physical activity and exercise.

THE INTERPLAY BETWEEN OBESITY AND SARCOPENIA IN OLD AGE

Aging *per se* leads to gradual changes in body composition with increases in fat mass and decreases in muscle mass. Aging is associated with a reduction in skeletal muscle fiber size and number, a reduction in muscle mass and quality, a reduction in oxidative capacity and with an increased muscle fat infiltration. All together leading to a reduction of muscle strength and power, subsequently causing mobility disability and functional impairment, a condition named sarcopenia (2). Muscle mass generally peaks at the end of the third decade of life, after which it declines by approximately 0.37 and 0.47% per year in women and men, respectively. The etiology of this age-related muscle loss is multifactorial (2). It may result from metabolic conditions including chronic inflammation, hormonal changes, oxidative stress, skeletal muscle mitochondrial and stem cell dysfunction (17–20) as well as lifestyle factors including sedentary behavior, low physical activity and poor nutrition including protein and micronutrient deficiencies (21, 22). Aging is also associated with relative or absolute increments in body fat, which may lead to or worsen pre-existing overweight and obesity (23–25).

Furthermore, old age epitomizes the synergistic interactions between obesity and sarcopenia. A reduction in muscle mass directly leads to lower whole-body metabolic rate and reduced oxidative capacities. This leads to lower energy expenditure from basal metabolism, which may contribute to further weight gain, which is mostly fat mass, particularly if protein intake is too low (26). In turn, excess body fat may enhance age-associated systemic and tissue inflammation, oxidative stress, mitochondrial dysfunction and insulin resistance with direct negative impact on skeletal muscle (3, 27, 28). For example, in the presence of positive energy balance and limited adipose tissue expandability to store excess lipids, ectopic muscle fat infiltration commonly occurs. This muscle fat infiltration is associated with poor muscle quality (3, 29) and is associated with insulin resistance (30) leading to further reduction of muscle strength and endurance (31, 32). Furthermore, both obesity and low muscle mass may be associated with anabolic resistance—the limited skeletal muscle protein synthetic response after an anabolic stimulus, for example, protein intake or physical activity (33–38). Nevertheless, how this mechanism works remains to be elucidated as recent studies did not find an association of obesity or fat intake on muscle protein synthesis (39, 40).

Other, age-associated, causes that have been suggested are among others lipotoxicity, inflammation, insulin resistance (type II diabetes) and low physical inactivity (41).

On top of the above-mentioned metabolic interactions, sarcopenia and obesity also interact in daily life. Obesity often promotes inactivity, as routine activities of daily living—walking, climbing stairs, maneuvering in public spaces—are more difficult for obese individuals, let alone participation in leisure activities or exercise programs (42). In addition, a frequently forgotten issue is that muscles in obese persons need to move a higher body mass, so even an apparently normal muscle strength may not be enough to perform activities that would be feasible with a lower body weight. Furthermore, another important cause of sarcopenic obesity may stem from weight cycling that can occur in obese people. Indeed, it has been shown that successive periods of weight loss and regain promote sarcopenia through a higher recovery of fat mass than fat free mass during weight regain (43, 44). Specifically, weight loss alone is already a risk for sarcopenia as approximately 25% of the lost weight is attributable to fat free mass (26). Through all of the above combined mechanisms, obesity leads to sarcopenia and vice versa with strong synergistic vicious cycles that are particularly dangerous in older adults (3, 4, 12). Older adults should therefore be stimulated to prevent weight gain and preserve muscle mass.

LOSE THE FAT, PRESERVE THE MUSCLE—THE ESSENCE OF DIET, EXERCISE AND PHYSICAL ACTIVITY

To prevent or treat sarcopenic obesity, it is essential to prevent weight gain or lose fat mass, while preserving muscle mass (45–49). Exercise is a promising tool to tackle both sarcopenia and obesity. First of all because exercise can cause, if not compensated with higher caloric intake, a negative energy balance leading to loss of fat mass (50, 51). However, people tend to overcompensate increased physical activity by reducing other activities (more sitting versus walking) and/or increasing their energy intake (52). Second, exercise and physical activity can have beneficial effects on physical performance (e.g., strength, gait speed, balance) and stimulates muscle mass gain or maintenance (53). Recent guidelines from the WHO state that older adults should undertake regular physical activity of at least 150–300 min of moderate-intensity aerobic physical activity or 75–150 min of vigorous-intensity aerobic physical activity for substantial health benefits. In addition, older adults should do muscle strengthening activities at moderate or greater intensity that involve all major muscle groups twice weekly. General guidelines for a resistance-type exercise training suggest to train with a load of 60–80% of 1RM, 3–4 sets per muscle group with 1–2 min rest intervals, allowing muscle mass preservation and/or gain in older adults (54, 55). These guidelines, however, are mainly based on apparently healthy (older) adults and certainly more research is needed in more frail or sarcopenic obese adults. Studies that do include sarcopenic obese older adults generally observe beneficial changes in body composition and physical performance following resistance-type exercise training (55–59).

In addition to exercise, nutrition is key to counteract both sarcopenia and obesity. In essence, obesity is a result of an excess consumption of energy as compared to individual needs, whereas sarcopenia can be caused by an inadequate dietary intake, particularly protein. A hypocaloric diet may therefore be very efficient to lose weight, but with insufficient proteins, it can be detrimental for muscle mass maintenance (48, 55). In order to optimally promote muscle protein synthesis and to maintain or to regain muscle mass, it has been recommended to reach a dietary protein intake of 1.0–1.2 g/kg body weight instead of the recommended 0.8 g/kg body weight in healthy adults (60). During weight loss a higher than 1.2 g/kg body weight level is even recommended (61). In addition to the amount of protein, other aspects of an overall healthy diet play an important role in promoting muscle health and body composition including vitamins, antioxidants, protein quality and timing of protein, and the overall quality of the diet (21, 62–65).

To target both sarcopenia and obesity in sarcopenic obese older adults, a combination of both exercise and nutrition seems most appropriate. Energy restriction alone can be successful for body weight loss, but can be costly is terms of losses in muscle mass (48). Indeed, weight loss studies show the ability to improve physical performance to some extent with exercise or diet alone, but are more effective when the exercise and diet are combined (66). The benefits of protein supplementation during prolonged exercise training in both younger and older subjects has been confirmed by meta-analysis (67). Concluding, current evidence suggests that a modest hypocaloric diet with sufficient proteins combined with exercise can be effective to counteract sarcopenic obesity in older adults. Nevertheless, feasible studies that combine nutrition and exercise strategies and take into account feasibility are highly warranted in specifically older people with sarcopenic obesity.

WINDOW OF OPPORTUNITY: RETIREMENT

It is important to adapt a healthy lifestyle early in the lifespan to prevent overweight, obesity and sarcopenic obesity in later life (68). Even so, interventions to improve lifestyle in later life can still be of paramount importance. For several reasons we believe that one specific window of opportunity to improve lifestyle behavior is during the transient time of retirement. First, changing a lifestyle is by no means easy. Older adults that go through the work-retirement transition already need to restructure their lifestyle, habits and daily activities. Second, generally retirees are motivated to establish new daily routines, to enhance opportunities for social interactions and personal challenges, and to increase recreational physical activity to satisfy needs that had been previously fulfilled by their work (69). Third, with current life expectancy, adopting a healthy lifestyle around the age of retirement could offer sufficient time to prevent unhealthy aging and dependency in later life for a substantial period of time. Last, demographic changes make that there is an upcoming wave of people that will enter retirement. Effective interventions in this large group of people can therefore have major public health impact.

Nevertheless, despite the motivation and timing, making actual changes to improve lifestyle behaviors proofs to be difficult. Indeed, unfortunately, during the transition from working life to retirement, the risk to lose muscle mass and gain fat mass may increase rapidly (70–73). People may spend more leisure time with feasting food habits while leading an inactive lifestyle. This leads to an acceleration in the ongoing process of age-related gain in fat mass and loss of muscle mass, causing a high risk of developing sarcopenic obesity. Although a large proportion of older adults experience a reduction in physical activity and gain weight during the transition from work to retirement, there are important differences between subgroups (74, 75). For example, it was shown that men retiring from strenuous jobs tend to gain weight, while those retiring from sedentary jobs usually experience no weight gain (70, 71), and persons who are already overweight often gain more weight in the retirement phase than persons who start retirement with normal weight (72). Also, older retirement age, higher occupational status and fewer chronic diseases were associated with increases in physical activity level in retirement (76). In order to stimulate a more healthy lifestyle after retirement there is a need for effective intervention strategies that consider individual as well as population-based and environmental factors and specifically stimulate sustainable behavioral changes. In previous lifestyle interventions that were successful on the short term, dietary habits and physical activity levels often revert to the levels before the intervention period (77, 78). Interventions aiming to increasing physical activity among people in retirement emphasize the importance of provide tailored and adaptable exercise programs (79, 80). Digital technologies can help to stimulate long term changes, take into account personal motives and threats, previous occupation, goals, opportunities and wishes, account for population and environmental factors, and potentially reaches a large number of individuals at relatively low costs (81, 82). Upcoming older adults and retirees have less digital literacy than their older peers, making them more qualified to use digital technology (83).

INNOVATIVE STRATEGIES

Digital technologies are promising to stimulate sustainable health behavioral change. Web-applications, wearable devices and mobile health applications, for example, may comprise tailored information, behavior change techniques including goalsetting and monitoring which motivate users to change behavior and manage their disease adequately at relatively low costs (81, 82). Since technologies play a key role in everyday life, there is a major increase in the development and use of mobile lifestyle interventions. It is expected that the face-to-face management of health disorders will gradually shift to a more technology supported approach, reducing the large burden on health personnel and resources (84). Successful health technologies are frequently based on well-grounded cognitive behavioral strategies incorporating psychological elements. Persuasive technology aims to change people's attitudes and behaviors and is an essential instrument to enhance online and offline adherence (85, 86), promote self-management abilities (87, 88) and feeling of competence (89). Persuasive technology for supporting health behavior of older adults often applies techniques such as: personalisation, suggestion, goal-setting, simulation and reminders (59, 90–92). However, it is not always clear how these theories lead to design criteria in health technology and the mechanisms of effective intervention studies are understudied (93, 94).

Previous reviews and meta-analyses have shown that digital health technologies can be an effective vehicle to promote a healthy lifestyle among people of various ages (81, 95–99). Tailored technology-supported physical activity, exercise and nutrition interventions have demonstrated positive effects on physical activity levels, dietary fat intake, fruit and vegetable consumption (89, 100, 101), body weight, blood pressure, fasting plasma glucose and blood lipids (102, 103). Also in older adults aged 55 years and over, digital technology has shown beneficial effects on lifestyle behavior, although the long-term effects were less clear (96, 97). Specifically, there are several studies that show effectiveness of digital health technologies on increasing protein intake among community dwelling elderly (104, 105). Moreover, home-based digital technology-based programs showed successful results in improving multiple facets of sarcopenia including muscle mass and muscle strength in older adults (99, 106, 107). The use of blended care, the combination of face-to-face counseling with health technology, is more and more used (108, 109). These blended interventions are more effective than "stand-alone" interventions without professional guidance (110). The integration of online and offline leads to improved adherence rates which is crucial for the effectiveness of digital health technologies (82). The personal contact that offers among others empathy, personal assistance and coaching, and warmth could be of specific importance for older adults (94). One good example of a blended care intervention for older adults, that was built on well-described theoretical principles of behavior change is the VITAMIN trial (111). This trial was developed to counteract the decline in physical functioning and sarcopenia using a blended-care home-based exercise and dietary protein intervention and showed positive effects on among others muscle mass, muscle strength and protein intake, but not on physical performance in healthy older adults (55 years and over) (110, 112). However, whether this approach also works for frail older people and people with or at risk for sarcopenic obesity should be further explored.

Designing and implementing digital technology for older adults demands additional caution. When implementing persuasive technology for vulnerable people, care needs to be taken for ethical concerns. For example taking into account users' interests and their autonomy (113). Furthermore, when designing technology for long term adherence by older adults, personal influential factors as digital competency and attitude toward digital solutions need to be taken into consideration (89). Although the majority of older adults have a positive attitude toward eHealth, not all older adults own a smartphone or are able to the device in its full potential (114). With the rise of adoption rate of smartphones among older adults, the non-adoption group might become smaller over the years (83). Still, at this moment it remains highly relevant, as there are many countries where large portions of older adults not frequently use modern technology as smartphones and social media (115). Furthermore, visual impairments and reduced fine motor skills become more present as the age rises. These personal age-related factors are not fully taken into consideration in current applications (114). Even so, when eHealth is used in a proper, individualized and, safe way, older adults seem to have a positive attitude toward digital technology (116), which offers opportunities to develop eHealth applications to improve physical activity, exercise and dietary intake in a sustainable manner (82). However, there is a need for well-designed health applications for older people in general, or those going through retirement, that aim to prevent or treat sarcopenic obesity.

CONCLUSION

There is an urgent need to prevent and treat sarcopenic obesity. To achieve this, a combination of limited energy intake with adequate dietary protein and sufficient exercise and physical activity are needed (45–49, 55, 117). Sole focus on physical activity during weight loss may lead to insufficient effects regarding both the reduction of fat mass and the preservation of muscle mass. Sole focus on energy restriction can be successful for body weight loss, but can be costly is terms of losses in muscle mass (48). With the rapid development of technology that is getting more accessible and easier to use for older adults, there is a huge potential to develop health technologies that target the growing population of 50 years and above. More specifically, health technology can be applied to the growing group of people that enter retirement and help them to build long-term changes. This group is at high risk for sarcopenic obesity, but motivated to adapt a healthy lifestyle behavior in their new daily routines. For optimal results these innovative strategies have to be based on behavior change principles and are preferably applied as blended care.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

JS, MT, RB, SB, JB, YB, AC-J, DE, ET, BV, TV, AT, and PW contributed to conception of the paper. JS wrote the first draft of the manuscript. MT, RB, SB, JB, YB, AC-J, DE, ET, BV, TV, AT, and PW wrote sections of the manuscript and contributed to manuscript revision, read, and approved the submitted version. All authors contributed to the article and approved the submitted version.

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REFERENCES

1. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. *Age Ageing.* (2010) 39:412–23. doi: 10.1093/ageing/afq034
2. Cruz-Jentoft AJ, Sayer AA. Sarcopenia. *Lancet.* (2019) 393:2636–46. doi: 10.1016/S0140-6736(19)31138-9
3. Barazzoni R, Bischoff SC, Boirie Y, Busetto L, Cederholm T, Dicker D, et al. Sarcopenic obesity: time to meet the challenge. *Clin Nutr.* (2018) 37(6 Pt A):1787–93. doi: 10.1016/j.clnu.2018.04.018
4. Batsis JA, Villareal DT. Sarcopenic obesity in older adults: aetiology, epidemiology and treatment strategies. *Nat Rev Endocrinol.* (2018) 14:513–37. doi: 10.1038/s41574-018-0062-9
5. Beaudart C, Zaaria M, Pasleau F, Reginster JY, Bruyere O. Health outcomes of sarcopenia: a systematic review and meta-analysis. *PLoS ONE.* (2017) 12:e0169548. doi: 10.1371/journal.pone.0169548
6. Donini LM, Busetto L, Bauer JM, Bischoff S, Boirie Y, Cederholm T, et al. Critical appraisal of definitions and diagnostic criteria for sarcopenic obesity based on a systematic review. *Clin Nutr.* (2019) 39:2368–88. doi: 10.1016/j.clnu.2019.11.024
7. Batsis JA, Mackenzie TA, Lopez-Jimenez F, Bartels SJ. Sarcopenia, sarcopenic obesity, and functional impairments in older adults: National Health and Nutrition Examination Surveys 1999–2004. *Nutr Res.* (2015) 35:1031–9. doi: 10.1016/j.nutres.2015.09.003
8. Atkins JL, Wannamathee SG. Sarcopenic obesity in ageing: cardiovascular outcomes and mortality. *Br J Nutr.* (2020) 124:1102–13. doi: 10.1017/S0007114520002172
9. Du Y, Wang X, Xie H, Zheng S, Wu X, Zhu X, et al. Sex differences in the prevalence and adverse outcomes of sarcopenia and sarcopenic obesity in community dwelling elderly in East China using the AWGS criteria. *BMC Endocr Disord.* (2019) 19:109. doi: 10.1186/s12902-019-0432-x
10. Xiao J, Cain A, Purcell SA, Ormsbee MJ, Contreras RJ, Kim JS, et al. Sarcopenic obesity and health outcomes in patients seeking weight loss treatment. *Clin Nutr ESPEN.* (2018) 23:79–83. doi: 10.1016/j.clnesp.2017.12.004
11. Oikawa SY, Holloway TM, Phillips SM. The impact of step reduction on muscle health in aging: protein and exercise as countermeasures. *Front Nutr.* (2019) 6:75. doi: 10.3389/fnut.2019.00075
12. Koliaki C, Liatis S, Dalamaga M, Kokkinos A. Sarcopenic obesity: epidemiologic evidence, pathophysiology, and therapeutic perspectives. *Curr Obes Rep.* (2019) 8:458–71. doi: 10.1007/s13679-019-00359-9
13. Bauer JM, Cruz-Jentoft AJ, Fielding RA, Kanis JA, Reginster JY, Bruyere O, et al. Is there enough evidence for osteosarcopenic obesity as a distinct entity? a critical literature review. *Calcif Tissue Int.* (2019) 105:109–24. doi: 10.1007/s00223-019-00561-w
14. Barak A, Hen L, Boniel-Nissim M, Shapira N. A comprehensive review and a meta-analysis of the effectiveness of internet-based psychotherapeutic interventions. *J Technol Hum Serv.* (2008) 26:109–60. doi: 10.1080/15228830802094429
15. Della Mea V. What is e-health (2): the death of telemedicine? *J Med Internet Res.* (2001) 3:E22. doi: 10.2196/jmir.3.2.e22
16. Eysenbach G. What is e-health? *J Med Internet Res.* (2001) 3:E20. doi: 10.2196/jmir.3.2.e20
17. Dalle S, Rossmeislova L, Koppo K. The Role of Inflammation in Age-Related Sarcopenia. *Front Physiol.* (2017) 8:1045. doi: 10.3389/fphys.2017.01045
18. Bian A, Ma Y, Zhou X, Guo Y, Wang W, Zhang Y, et al. Association between sarcopenia and levels of growth hormone and insulin-like growth factor-1 in the elderly. *BMC Musculoskelet Disord.* (2020) 21:214. doi: 10.1186/s12891-020-03236-y
19. Romanello V, Sandri M. Mitochondrial quality control and muscle mass maintenance. *Front Physiol.* (2015) 6:422. doi: 10.3389/fphys.2015.00422
20. Domingues-Faria C, Vasson MP, Goncalves-Mendes N, Boirie Y, Walrand S. Skeletal muscle regeneration and impact of aging and nutrition. *Ageing Res Rev.* (2016) 26:22–36. doi: 10.1016/j.arr.2015.12.004
21. Hengeveld LM, Wijnhoven HAH, Olthof MR, Brouwer IA, Simonsick EM, Kritchevsky SB, et al. Prospective associations of diet quality with incident frailty in older adults: the health, aging, and body composition study. *J Am Geriatr Soc.* (2019) 67:1835–42. doi: 10.1111/jgs.16011
22. Hengeveld LM. Prospective associations of protein intake parameters with muscle strength and physical performance in community-dwelling older men and women from the Quebec NuAge cohort. *AmJ Clin Nutr.* (2021) 113:972–83. doi: 10.1093/ajcn/nqaa360
23. Seidell JC, Visscher TL. Body weight and weight change and their health implications for the elderly. *Eur J Clin Nutr.* (2000) 54(Suppl 3):S33–9. doi: 10.1038/sj.ejcn.1601023
24. Ponti F, Santoro A, Mercatelli D, Gasperini C, Conte M, Martucci M, et al. Aging and imaging assessment of body composition: from fat to facts. *Front Endocrinol.* (2019) 10:861. doi: 10.3389/fendo.2019.00861
25. Atlantis E, Martin SA, Haren MT, Taylor AW, Wittert GA. Florey adelaide male aging s. lifestyle factors associated with age-related differences in body

composition: the florey adelaide male aging study. *Am J Clin Nutr.* (2008) 88:95–104. doi: 10.1093/ajcn/88.1.95

26. Backx EM, Tieland M, Borgonjen-van den Berg KJ, Claessen PR, van Loon LJ, de Groot LC. Protein intake and lean body mass preservation during energy intake restriction in overweight older adults. *Int J Obes.* (2016) 40:299–304. doi: 10.1038/ijo.2015.182
27. Furukawa S, Fujita T, Shimabukuro M, Iwaki M, Yamada Y, Nakajima Y, et al. Increased oxidative stress in obesity and its impact on metabolic syndrome. *J Clin Invest.* (2004) 114:1752–61. doi: 10.1172/JCI21625
28. Schenk S, Saberi M, Olefsky JM. Insulin sensitivity: modulation by nutrients and inflammation. *J Clin Invest.* (2008) 118:2992–3002. doi: 10.1172/JCI34260
29. Tardif N, Salles J, Guillet C, Tordjman J, Reggio S, Landrier JF, et al. Muscle ectopic fat deposition contributes to anabolic resistance in obese sarcopenic old rats through eIF2alpha activation. *Aging Cell.* (2014) 13:1001–11. doi: 10.1111/acel.12263
30. Czech MP. Insulin action and resistance in obesity and type 2 diabetes. *Nat Med.* (2017) 23:804–14. doi: 10.1038/nm.4350
31. Marcus RL, Addison O, Dibble LE, Foreman KB, Morrell G, Lastayo P. Intramuscular adipose tissue, sarcopenia, and mobility function in older individuals. *J Aging Res.* (2012) 2012:629637. doi: 10.1155/2012/629637
32. Barrett M, McClure R, Villani A. Adiposity is inversely associated with strength in older adults with type 2 diabetes mellitus. *Eur Geriatr Med.* (2020) 11:451–8. doi: 10.1007/s41999-020-00309-y
33. Guillet C, Delcourt I, Rance M, Giraudet C, Walrand S, Bedu M, et al. Changes in basal and insulin and amino acid response of whole body and skeletal muscle proteins in obese men. *J Clin Endocrinol Metab.* (2009) 94:3044–50. doi: 10.1210/jc.2008-2216
34. Beals JW, Sukiennik RA, Nallabelli J, Emmons RS, van Vliet S, Young JR, et al. Anabolic sensitivity of postprandial muscle protein synthesis to the ingestion of a protein-dense food is reduced in overweight and obese young adults. *Am J Clin Nutr.* (2016) 104:1014–22. doi: 10.3945/ajcn.116.130385
35. Smeuninx B, McKendry J, Wilson D, Martin U, Breen L. Age-related anabolic resistance of myofibrillar protein synthesis is exacerbated in obese inactive individuals. *J Clin Endocrinol Metab.* (2017) 102:3535–45. doi: 10.1210/jc.2017-00869
36. Beals JW, Burd NA, Moore DR, van Vliet S. Obesity alters the muscle protein synthetic response to nutrition and exercise. *Front Nutr.* (2019) 6:87. doi: 10.3389/fnut.2019.00087
37. van Dijk M, Nagel J, Dijk FJ, Salles J, Verlaan S, Walrand S, et al. Sarcopenia in older mice is characterized by a decreased anabolic response to a protein meal. *Arch Gerontol Geriatr.* (2017) 69:134–43. doi: 10.1016/j.archger.2016.11.014
38. Wall BT, Gorissen SH, Pennings B, Koopman R, Groen BB, Verdijk LB, et al. Aging is accompanied by a blunted muscle protein synthetic response to protein ingestion. *PLoS ONE.* (2015) 10:e0140903. doi: 10.1371/journal.pone.0140903
39. Tsintzas K, Jones R, Pabla P, Mallinson J, Barrett DA, Kim DH, et al. Effect of acute and short-term dietary fat ingestion on postprandial skeletal muscle protein synthesis rates in middle-aged, overweight, and obese men. *Am J Physiol Endocrinol Metab.* (2020) 318:E417-E29. doi: 10.1152/ajpendo.00344.2019
40. Kouw IWK, van Dijk JW, Horstman AMH, Kramer IF, Goessens JPB, van Dielen FMH, et al. Basal and postprandial myofibrillar protein synthesis rates do not differ between lean and obese middle-aged men. *J Nutr.* (2019) 149:1533–42. doi: 10.1093/jn/nxz104
41. Boirie Y. Fighting sarcopenia in older frail subjects: protein fuel for strength, exercise for mass. *J Am Med Dir Assoc.* (2013) 14:140–3. doi: 10.1016/j.jamda.2012.10.017
42. Pain H, Wiles R. The experience of being disabled and obese. *Disabil Rehabil.* (2006) 28:1211–20. doi: 10.1080/09638280600554561
43. Rossi AP, Rubele S, Calugi S, Caliari C, Pedelini F, Soave F, et al. Weight cycling as a risk factor for low muscle mass and strength in a population of males and females with obesity. *Obesity.* (2019) 27:1068–75. doi: 10.1002/oby.22493
44. Beavers KM, Lyles MF, Davis CC, Wang X, Beavers DP, Nicklas BJ. Is lost lean mass from intentional weight loss recovered during weight regain in postmenopausal women? *Am J Clin Nutr.* (2011) 94:767–74. doi: 10.3945/ajcn.110.004895
45. Theodorakopoulos C, Jones J, Bannerman E, Greig CA. Effectiveness of nutritional and exercise interventions to improve body composition and muscle strength or function in sarcopenic obese older adults: a systematic review. *Nutr Res.* (2017) 43:3–15. doi: 10.1016/j.nutres.2017.05.002
46. Martinez-Amat A, Aibar-Almazan A, Fabrega-Cuadros R, Cruz-Diaz D, Jimenez-Garcia JD, Perez-Lopez FR, et al. Exercise alone or combined with dietary supplements for sarcopenic obesity in community-dwelling older people: a systematic review of randomized controlled trials. *Maturitas.* (2018) 110:92–103. doi: 10.1016/j.maturitas.2018.02.005
47. Hita-Contreras F, Bueno-Notivol J, Martinez-Amat A, Cruz-Diaz D, Hernandez AV, Perez-Lopez FR. Effect of exercise alone or combined with dietary supplements on anthropometric and physical performance measures in community-dwelling elderly people with sarcopenic obesity: a meta-analysis of randomized controlled trials. *Maturitas.* (2018) 116:24–35. doi: 10.1016/j.maturitas.2018.07.007
48. Weinheimer EM, Sands LP, Campbell WW. A systematic review of the separate and combined effects of energy restriction and exercise on fat-free mass in middle-aged and older adults: implications for sarcopenic obesity. *Nutr Rev.* (2010) 68:375–88. doi: 10.1111/j.1753-4887.2010.00298.x
49. Yin YH, Liu JYW, Valimaki M. Effectiveness of non-pharmacological interventions on the management of sarcopenic obesity: a systematic review and meta-analysis. *Exp Gerontol.* (2020) 135:110937. doi: 10.1016/j.exger.2020.110937
50. Villareal DT, Aguirre L, Gurney AB, Waters DL, Sinacore DR, Colombo E, et al. Aerobic or resistance exercise, or both, in dieting obese older adults. *N Engl J Med.* (2017) 376:1943–55. doi: 10.1056/NEJMoa1616338
51. Stoner L, Rowlands D, Morrison A, Credeur D, Hamlin M, Gaffney K, et al. Efficacy of exercise intervention for weight loss in overweight and obese adolescents: meta-analysis and implications. *Sports Med.* (2016) 46:1737–51. doi: 10.1007/s40279-016-0537-6
52. Melanson EL, Keadle SK, Donnelly JE, Braun B, King NA. Resistance to exercise-induced weight loss: compensatory behavioral adaptations. *Med Sci Sports Exerc.* (2013) 45:1600–9. doi: 10.1249/MSS.0b013e31828ba942
53. Peterson MD, Sen A, Gordon PM. Influence of resistance exercise on lean body mass in aging adults: a meta-analysis. *Med Sci Sports Exerc.* (2011) 43:249–58. doi: 10.1249/MSS.0b013e3181eb6265
54. *WHO Guidelines on Physical Activity and Sedentary Behaviour*. Geneva: World Health Organization (2020).
55. Trouwborst I, Verreijen A, Memelink R, Massanet P, Boirie Y, Weijs P, et al. Exercise and nutrition strategies to counteract sarcopenic obesity. *Nutrients.* (2018) 10:605. doi: 10.3390/nu10050605
56. Liao CD, Tsauo JY, Lin LF, Huang SW, Ku JW, Chou LC, et al. Effects of elastic resistance exercise on body composition and physical capacity in older women with sarcopenic obesity: A CONSORT-compliant prospective randomized controlled trial. *Medicine.* (2017) 96:e7115. doi: 10.1097/MD.0000000000007115
57. Huang SW, Ku JW, Lin LF, Liao CD, Chou LC, Liou TH. Body composition influenced by progressive elastic band resistance exercise of sarcopenic obesity elderly women: a pilot randomized controlled trial. *Eur J Phys Rehabil Med.* (2017) 53:556–63.
58. Gadelha AB, Paiva FM, Gauche R, de Oliveira RJ, Lima RM. Effects of resistance training on sarcopenic obesity index in older women: A randomized controlled trial. *Arch Gerontol Geriatr.* (2016) 65:168–73. doi: 10.1016/j.archger.2016.03.017
59. Chen HT, Chung YC, Chen YJ, Ho SY, Wu HJ. Effects of different types of exercise on body composition, muscle strength, and IGF-1 in the elderly with sarcopenic obesity. *J Am Geriatr Soc.* (2017) 65:827–32. doi: 10.1111/jgs.14722
60. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE, et al. Evidence-based recommendations for optimal dietary protein intake in older people: a position paper from the PROT-AGE Study Group. *J Am Med Dir Assoc.* (2013) 14:542–59. doi: 10.1016/j.jamda.2013.05.021
61. Weijs PJM, Wolfe RR. Exploration of the protein requirement during weight loss in obese older adults. *Clin Nutr.* (2016) 35:394–8. doi: 10.1016/j.clnu.2015.02.016

62. van Dronkelaar C, van Velzen A, Abdelrazek M, van der Steen A, Weijs PJM, Tieland M. Minerals and sarcopenia; the role of calcium, iron, magnesium, phosphorus, potassium, selenium, sodium, and zinc on muscle mass, muscle strength, and physical performance in older adults: a systematic review. *J Am Med Dir Assoc.* (2018) 19:6–11. e3. doi: 10.1016/j.jamda.2017.05.026
63. Bloom I, Shand C, Cooper C, Robinson S, Baird J. Diet quality and sarcopenia in older adults: a systematic review. *Nutrients.* (2018) 10:308. doi: 10.3390/nu10030308
64. Areta JL, Burke LM, Ross ML, Camera DM, West DW, Broad EM, et al. Timing and distribution of protein ingestion during prolonged recovery from resistance exercise alters myofibrillar protein synthesis. *J Physiol.* (2013) 591:2319–31. doi: 10.1113/jphysiol.2012.244897
65. Witard OC, McGlory C, Hamilton DL, Phillips SM. Growing older with health and vitality: a nexus of physical activity, exercise and nutrition. *Biogerontology.* (2016) 17:529–46. doi: 10.1007/s10522-016-9637-9
66. Villareal DT, Chode S, Parimi N, Sinacore DR, Hilton T, Armamento-Villareal R, et al. Weight loss, exercise, or both and physical function in obese older adults. *N Engl J Med.* (2011) 364:1218–29. doi: 10.1056/NEJMoa1008234
67. Cermak NM, Res PT, de Groot LC, Saris WH, van Loon LJ. Protein supplementation augments the adaptive response of skeletal muscle to resistance-type exercise training: a meta-analysis. *Am J Clin Nutr.* (2012) 96:1454–64. doi: 10.3945/ajcn.112.037556
68. WHO. *World Report on Ageing and Health*. Geneva: World Health Organization (2015).
69. Barnett I, Guell C, Ogilvie D. The experience of physical activity and the transition to retirement: a systematic review and integrative synthesis of qualitative and quantitative evidence. *Int J Behav Nutr Phys Act.* (2012) 9:97. doi: 10.1186/1479-5868-9-97
70. Gueorguieva R, Sindelar JL, Wu R, Gallo WT. Differential changes in body mass index after retirement by occupation: hierarchical models. *Int J Public Health.* (2011) 56:111–6. doi: 10.1007/s00038-010-0166-z
71. Stenholm S, Solovieva S, Viikari-Juntura E, Aalto V, Kivimaki M, Vahtera J. Change in body mass index during transition to statutory retirement: an occupational cohort study. *Int J Behav Nutr Phys Act.* (2017) 14:85. doi: 10.1186/s12966-017-0539-2
72. Chung S, Domino ME, Stearns SC. The effect of retirement on weight. *J Gerontol B Psychol Sci Soc Sci.* (2009) 64:656–65. doi: 10.1093/geronb/gbn044
73. Godard M. Gaining weight through retirement? Results from the SHARE survey. *J Health Econ.* (2016) 45:27–46. doi: 10.1016/j.jhealeco.2015.11.002
74. Chung S, Domino ME, Stearns SC, Popkin BM. Retirement and physical activity: analyses by occupation and wealth. *Am J Prev Med.* (2009) 36:422–8. doi: 10.1016/j.amepre.2009.01.026
75. Barnett I, van Sluijs EM, Ogilvie D. Physical activity and transitioning to retirement: a systematic review. *Am J Prev Med.* (2012) 43:329–36. doi: 10.1016/j.amepre.2012.05.026
76. Stenholm S, Pulakka A, Kawachi I, Oksanen T, Halonen JI, Aalto V, et al. Changes in physical activity during transition to retirement: a cohort study. *Int J Behav Nutr Phys Act.* (2016) 13:51. doi: 10.1186/s12966-016-0375-9
77. Murray JM, Brennan SF, French DP, Patterson CC, Kee F, Hunter RF. Effectiveness of physical activity interventions in achieving behaviour change maintenance in young and middle aged adults: a systematic review and meta-analysis. *Soc Sci Med.* (2017) 192:125–33. doi: 10.1016/j.socscimed.2017.09.021
78. French DP, Olander EK, Chisholm A, Mc Sharry J. Which behaviour change techniques are most effective at increasing older adults' self-efficacy and physical activity behaviour? A systematic review. *Ann Behav Med.* (2014) 48:225–34. doi: 10.1007/s12160-014-9593-z
79. Zhang Z, Giordani B, Chen W. Fidelity and feasibility of a multicomponent physical activity intervention in a retirement community. *Geriatr Nurs.* (2020) 41:394–9. doi: 10.1016/j.gerinurse.2019.12.002
80. Rai R, Jongenelis MI, Jackson B, Newton RU, Pettigrew S. Retirement and physical activity: the opportunity of a lifetime or the beginning of the end? *J Aging Phys Act.* (2019) 28:1–11. doi: 10.1123/japa.2019-0023
81. Duan Y, Shang B, Liang W, Du G, Yang M, Rhodes RE. Effects of eHealth-based multiple health behavior change interventions on physical activity, healthy diet, and weight in people with noncommunicable diseases: systematic review and meta-analysis. *J Med Internet Res.* (2021) 23:e23786. doi: 10.2196/23786
82. Buyl R, Beogo I, Fobelets M, Deletroz C, Van Landuyt P, Dequanter S, et al. e-Health interventions for healthy aging: a systematic review. *Syst Rev.* (2020) 9:128. doi: 10.1186/s13643-020-01385-8
83. Anderson M, Perrin W. Tech adoptation climbs among older adults. *Pew Res Center.* (2017).
84. Sequi-Dominguez I, Alvarez-Bueno C, Martinez-Vizcaino V, Fernandez-Rodriguez R, Del Saz Lara A, Cavero-Redondo I. Effectiveness of mobile health interventions promoting physical activity and lifestyle interventions to reduce cardiovascular risk among individuals with metabolic syndrome: systematic review and meta-analysis. *J Med Internet Res.* (2020) 22:e17790. doi: 10.2196/17790
85. Kelders SM, Kok RN, Ossebaard HC, Van Gemert-Pijnen JE. Persuasive system design does matter: a systematic review of adherence to web-based interventions. *J Med Internet Res.* (2012) 14:e152. doi: 10.2196/jmir.2104
86. Fogg BJ. *Persuasive Technology Using Computers to Change What We Think and Do*. Boston, MA: Stanford University (2003). doi: 10.1145/764008.763957
87. Blanson Henkemans OA, van der Boog PJ, Lindenberg J, van der Mast CA, Neerincx MA, Zwetsloot-Schonk BJ. An online lifestyle diary with a persuasive computer assistant providing feedback on self-management. *Technol Health Care.* (2009) 17:253–67. doi: 10.3233/THC-2009-0545
88. Kemmler W, Teschler M, Weissenfels A, Sieber C, Freiberger E, von Stengel S. Prevalence of sarcopenia and sarcopenic obesity in older German men using recognized definitions: high accordance but low overlap! *Osteoporos Int.* (2017) 28:1881–91. doi: 10.1007/s00198-017-3964-9
89. Mehra S, Van den Helder J, KrOse BJA, Engelbert RHH, Weijs PJM, Visser B. Aging and physical activity: a qualitative study of basic psychological needs and motivation in a blended home-based exercise program for older adults. *Self-Determination Theory Healthy Aging.* (2020) 127–44. doi: 10.1007/978-981-15-6968-5_7
90. Lentferink AJ, Oldenhuis HK, de Groot M, Polstra L, Velthuijsen H, van Gemert-Pijnen JE. Key components in ehealth interventions combining self-tracking and persuasive ecoaching to promote a healthier lifestyle: a scoping review. *J Med Internet Res.* (2017) 19:e277. doi: 10.2196/jmir.7288
91. Schembre SM, Liao Y, Robertson MC, Dunton GF, Kerr J, Haffey ME, et al. Just-in-time feedback in diet and physical activity interventions: systematic review and practical design framework. *J Med Internet Res.* (2018) 20:e106. doi: 10.2196/jmir.8701
92. Matthews J, Win KT, Oinas-Kukkonen H, Freeman M. Persuasive technology in mobile applications promoting physical activity: a systematic review. *J Med Syst.* (2016) 40:72. doi: 10.1007/s10916-015-0425-x
93. Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, et al. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med.* (2013) 46:81–95. doi: 10.1007/s12160-013-9486-6
94. Bartels SL, van Knippenberg RJM, Dassen FCM, Asaba E, Patomella AH, Malinowsky C, et al. A narrative synthesis systematic review of digital self-monitoring interventions for middle-aged and older adults. *Internet Interv.* (2019) 18:100283. doi: 10.1016/j.invent.2019.100283
95. Duff OM, Walsh DM, Furlong BA, O'Connor NE, Moran KA, Woods CB. Behavior change techniques in physical activity ehealth interventions for people with cardiovascular disease: systematic review. *J Med Internet Res.* (2017) 19:e281. doi: 10.2196/jmir.7782
96. Jonkman NH, van Schooten KS, Maier AB, Pijnappels M. eHealth interventions to promote objectively measured physical activity in community-dwelling older people. *Maturitas.* (2018) 113:32–9. doi: 10.1016/j.maturitas.2018.04.010
97. Muellmann S, Forberger S, Mollers T, Broring E, Zeeb H, Pischke CR. Effectiveness of eHealth interventions for the promotion of physical activity in older adults: a systematic review. *Prev Med.* (2018) 108:93–110. doi: 10.1016/j.ypmed.2017.12.026
98. Pradal-Cano L, Lozano-Ruiz C, Pereyra-Rodriguez JJ, Saigi-Rubio F, Bach-Faig A, Esquius L, et al. Using mobile applications to increase physical activity: a systematic review. *Int J Environ Res Public Health.* (2020) 17:8238. doi: 10.3390/ijerph17218238

99. Yerrakalva D, Yerrakalva D, Hajna S, Griffin S. Effects of mobile health app interventions on sedentary time, physical activity, and fitness in older adults: systematic review and meta-analysis. *J Med Internet Res.* (2019) 21:e14343. doi: 10.2196/14343
100. Broekhuizen K, Kroeze W, van Poppel MN, Oenema A, Brug J. A systematic review of randomized controlled trials on the effectiveness of computer-tailored physical activity and dietary behavior promotion programs: an update. *Ann Behav Med.* (2012) 44:259–86. doi: 10.1007/s12160-012-9384-3
101. Romeo A, Edney S, Plotnikoff R, Curtis R, Ryan J, Sanders I, et al. Can Smartphone apps increase physical activity? systematic review and meta-analysis. *J Med Internet Res.* (2019) 21:e12053. doi: 10.2196/12053
102. Seo YG, Salonurmi T, Jokelainen T, Karppinen P, Teeriniemi AM, Han J, et al. Lifestyle counselling by persuasive information and communications technology reduces prevalence of metabolic syndrome in a dose-response manner: a randomized clinical trial (PrevMetSyn). *Ann Med.* (2020) 52:321–30. doi: 10.1080/07853890.2020.1783455
103. Teeriniemi AM, Salonurmi T, Jokelainen T, Vahanikkila H, Alahaivala T, Karppinen P, et al. A randomized clinical trial of the effectiveness of a Web-based health behaviour change support system and group lifestyle counselling on body weight loss in overweight and obese subjects: 2-year outcomes. *J Intern Med.* (2018) 284:534–45. doi: 10.1111/joim.12802
104. van den Helder J, Verlaan S, Tieland M, Scholten J, Mehra S, Visser B, et al. Digitally supported dietary protein counseling changes dietary protein intake, sources and distribution in community-dwelling older adults. *Nutrients.* (2021) 13:502. doi: 10.3390/nu13020502
105. Marx W, Kelly JT, Crichton M, Craven D, Collins J, Mackay H, et al. Is telehealth effective in managing malnutrition in community-dwelling older adults? A systematic review and meta-analysis. *Maturitas.* (2018) 111:31–46. doi: 10.1016/j.maturitas.2018.02.012
106. Hong J, Kim J, Kim SW, Kong HJ. Effects of home-based tele-exercise on sarcopenia among community-dwelling elderly adults: body composition and functional fitness. *Exp Gerontol.* (2017) 87(Pt A):33–9. doi: 10.1016/j.exger.2016.11.002
107. Muntaner-Mas A, Vidal-Conti J, Borras PA, Ortega FB, Palou P. Effects of a Whatsapp-delivered physical activity intervention to enhance health-related physical fitness components and cardiovascular disease risk factors in older adults. *J Sports Med Phys Fitness.* (2017) 57:90–102. doi: 10.23736/S0022-4707.16.05918-1
108. Aalbers T, Baars MA, Rikkert MG. Characteristics of effective Internet-mediated interventions to change lifestyle in people aged (50) and older: a systematic review. *Ageing Res Rev.* (2011) 10:487–97. doi: 10.1016/j.arr.2011.05.001
109. Simek EM, McPhate L, Haines TP. Adherence to and efficacy of home exercise programs to prevent falls: a systematic review and meta-analysis of the impact of exercise program characteristics. *Prev Med.* (2012) 55:262–75. doi: 10.1016/j.ypmed.2012.07.007
110. van den Helder J, Mehra S, van Dronkelaar C, Ter Riet G, Tieland M, Visser B, et al. Blended home-based exercise and dietary protein in community-dwelling older adults: a cluster randomized controlled trial. *J Cachexia Sarcopenia Muscle.* (2020) 11:1590–602. doi: 10.1002/jcsm.12634
111. Mehra S, Visser B, Dadema T, van den Helder J, Engelbert RH, Weijs PJ, et al. Translating behavior change principles into a blended exercise intervention for older adults: design study. *JMIR Res Protoc.* (2018) 7:e117. doi: 10.2196/resprot.9244
112. van den Helder J, van Dronkelaar C, Tieland M, Mehra S, Dadema T, Visser B, et al. A digitally supported home-based exercise training program and dietary protein intervention for community dwelling older adults: protocol of the cluster randomised controlled VITAMIN trial. *BMC Geriatr.* (2018) 18:183. doi: 10.1186/s12877-018-0863-7
113. Jacobs N. Two ethical concerns about the use of persuasive technology for vulnerable people. *Bioethics.* (2020) 34:519–26. doi: 10.1111/bioe.12683
114. Kuerbis A, Mulliken A, Muench F, Moore AA, Gardner CD. Older adults and mobile technology: Factors that enhance and inhibit utilization in the context of behavioral health. *Ment Health Addict Res.* (2017) 2:1–11. doi: 10.31235/osf.io/3qudt
115. Poushter J. Smartphones are common in advanced economies, but digital divides remain. *Pew Res Center.* (2017).
116. Herrmann M, Boehme P, Hansen A, Jansson K, Rebacz P, Ehlers JP, et al. Digital competencies and attitudes toward digital adherence solutions among elderly patients treated with novel anticoagulants: qualitative study. *J Med Internet Res.* (2020) 22:e13077. doi: 10.2196/13077
117. Abete I, Konieczna J, Zulet MA, Galmes-Panades AM, Ibero-Baraibar I, Babio N, et al. Association of lifestyle factors and inflammation with sarcopenic obesity: data from the PREDIMED-Plus trial. *J Cachexia Sarcopenia Muscle.* (2019) 10:974–84. doi: 10.1002/jcsm.12442

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