Proceedings of the Nutrition Society

cambridge.org/pns

The Nutrition Society Scottish Section Conference 2025 was held at the University of Dundee on 1st–2nd April 2025

Conference on 'Understanding the role of sex and gender in nutrition research'

Symposium: Influence of sex and gender in nutrition research

Review Article

Cite this article: Holliday A, Barrett M, and Cox N (2026). Dysregulated gut hormone responses to nutrient ingestion in older adults with low appetite: a mechanism of anorexia of ageing? *Proceedings of the Nutrition Society*, page 1 of 6. doi: 10.1017/S0029665126102183

Received: 24 November 2025
Revised: 31 December 2025
Accepted: 7 January 2026

Keywords:
Ghrelin; GLP-1; PYY; Satiety; Ageing

Corresponding author:
Adrian Holliday;
Email: Adrian.holliday@newcastle.ac.uk

Dysregulated gut hormone responses to nutrient ingestion in older adults with low appetite: a mechanism of anorexia of ageing?

Adrian Holliday[1,2], Matthew Barrett[1,2] and Natalie Cox[3]

[1]School of Biomedical, Nutritional, and Sport Sciences, Faculty of Medical Sciences, Newcastle University, Newcastle Upon Tyne, UK; [2]Human Nutrition and Exercise Research Centre, Population Health Sciences Institute, Newcastle University, Newcastle Upon Tyne, UK and [3]Academic Geriatric Medicine, Faculty of Medicine, University of Southampton, Southampton, UK

Abstract

Anorexia of ageing – the age-related reduction in appetite and food intake – is a public health concern for an ageing global population. However, current understanding of the aetiology of the condition is limited. In this review, evidence of gut hormone responses to feeding in older adults is reviewed, and it is proposed that a dysregulation of this process is a mechanism driving low appetite in later life. The evidence is synthesised to critically present this case, spotlighting recent data demonstrating a highly anorexigenic gut hormone profile in older adults exhibiting low appetite, which is not observed in older adults exhibiting a 'healthy' appetite. These findings and this theory are interrogated with an appreciation that appetite control is complex and multifactorial, not least in the context of anorexia of ageing; it is posited that changes in gut hormone secretions are *a* mechanism rather than *the* mechanism, but propose that this may explain certain presentations of anorexia of ageing. The current knowledge base is contextualised for practical implications and priorities for future research are highlighted.

Anorexia of ageing (AA) is defined as a decline in appetite and caloric intake seen with increasing age (Morley, 1997)[1]. Despite no single, universally accepted method to identify those with AA, a loss of appetite is thought to directly affect between one in five and one in two older adults. van der Meij *et al.*[2] reported 22% of community-dwelling older adults in the USA exhibited poor appetite, while Vazquez-Valdez and co-workers[3] reported a 30% prevalence of low appetite amongst community-dwelling older adults in Mexico. Prevalence is higher among those in care settings[4], further increasing to ~45% of hospitalised older adults[5]. A recent meta-analysis from Fernandez *et al.*[6] pooled data from 36 studies and over 29 million over-60-year-olds from multiple settings, reporting a global AA prevalence of 23%.

AA gives rise to individual, societal, and economic consequences. Those with AA experience a reduced quality of life[7,8] and increased risk of undernutrition, sarcopenia, and frailty[9]. Low appetite and a resultant reduction in food intake results in insufficient intakes of certain nutrients and foods, such as protein, fibre, and fruits and vegetables[2], while both low protein and energy intake contribute to accelerated sarcopenia[10]. Those with AA have an approximate two-fold increased risk of disability[3,11] and are two-and-a-half times more likely to suffer with sarcopenia[10]. Consequently, those with AA have an 83% higher risk of all-cause mortality[12]. As such, AA can be considered a precursor or 'pathway' to frailty and frailty-related outcomes[13]. The cost of AA and consequent frailty on healthcare services must also be acknowledged. Research suggests that undernourished adults require three times greater health and social costs compared with adequately nourished adults[14], while healthcare costs are four times higher for older adults with severe frailty, compared with their fit counterparts[15]. Given the global ageing population and the current trajectory of an increase in those living with frailty[16], addressing AA – its causes and consequences – should be deemed a public health priority.

While the aetiology of AA remains to be fully elucidated, the phenomenon is almost certainly multifactorial. AA likely results from physiological, pathological, and social changes associated with ageing[17]. A greater understanding of the causes of AA will help to develop effective treatment strategies, reducing both the social and economic burden. This review will briefly highlight current knowledge of the aetiology of AA, with a focus on the role of gut hormones.

Aetiology of anorexia of ageing

Appetite control is complex and multifactorial. Consequently, changes in appetite and eating behaviour in later life must be viewed through a multifaceted lens. The role of cognitive, emotional, societal, and environmental inputs and influences cannot be overlooked.

For example, it has long been appreciated that widowhood can result in a reduction in energy intake, associated with reductions in mealtime enjoyment, loss of appetite, and loss of interest in food[18]. Relatedly, low mood is associated with poor appetite in later life[19], with older adults suffering with depression more likely to lose weight[20]. Further, psychological factors and traits relating to resilience and mood – such as a determination not to 'give up' and to 'be positive' – have been identified as mediators of social and environmental determinants of eating behaviour[21].

However, biological inputs are irrefutably consequential. This is perhaps best argued by highlighting the commonality of age-related weight loss and reductions in food intake across numerous species, from primates[22] to rodents[23], fish, birds, and invertebrates[24]. Colman *et al.*[25] observed mid-life onset of sarcopenia in rhesus macaques, with a muscle mass loss of 20% in later life. This coincides with evidence of declines in dietary intake in rhesus macaques with advancing age[26]. This preserved trait suggests an evolutionary conservation, highlighting a strong genetic and biological drive for a reduction in appetite in later life.

Biological systems influence both hedonic and homeostatic processes of appetite control. Hedonic influences include palatable cues, particularly taste and smell, from foods that activate neural reward pathways[27]. The taste, sight, and smell of food stimulate flavour centres in the brain which result in a reward value[28,29]. Sensory function is known to diminish with ageing[30], and reductions in sense of smell and taste were indeed implicated in appetite loss [31,32]. However, it is now argued that chemosensory impairments are not related to reduced eating pleasure nor the risk of undernutrition[33,34]. Nonetheless, with large heterogeneity in sensory function in older adults and the impact this may have on eating behaviour[35], taste, smell, and food texture are important considerations for understanding and addressing low appetite and undernutrition[35].

Homeostatic control of appetite refers to mechanisms that match energy intake to energy requirements, alongside maintaining nutrient status. Involving both tonic and episodic inputs, homeostatic appetite regulation is controlled by metabolic, hormonal, and neuronal sensing and signalling from peripheral tissue to the central nervous system to influence eating behaviour[36–38].

Tonic signals are enduring, with a stable influence over appetite and not fluctuating between or within days[37]. These signals convey information regarding energy availability, energy stores, and energy needs from body tissues and cellular metabolism to the brain[39]. A comprehensive discussion of tonic homeostatic control of appetite and energy intake is beyond the scope of this piece; for such, readers are directed to some excellent reviews on this topic [40–42]. Briefly, resting metabolic rate (RMR)[43], activity energy expenditure[44] and total daily energy expenditure (TDEE)[45] are all associated with energy intake, indicating energy requirement is a strong, tonic determinant of appetite and eating behaviour[40]. However, the strength of such relationships in older adults is less well understood. Hopkins *et al.*[46] showed that TDEE predicted energy intake in a cohort of 590 over 50-year-olds. Physical activity also predicted energy intake, but not when adjusting for TDEE[46]. In younger adults, a J-shaped relationship between physical activity and energy intake is largely accepted[39,47], but this has yet to be determined in older adults and our research group has previously postulated a deviation from such a relationship in later life[48].

A relationship between TDEE and energy intake independent of physical activity could indicate that RMR is driving this association. RMR is primarily determined by fat-free mass[49]. Fat-free mass (FFM) is associated with daily energy intake in younger[50,51] and older adults[46], with Hopkins and colleagues showing the mediating effect of RMR on this relationship[51]. In addition to the cross-sectional evidence of Hopkins *et al.*[46], Johnson and co-workers[52] induced a 1.2 kg increase in FFM in older adults through a 12-week resistance training programme, observing a subsequent and related increase in appetite and daily energy intake of 133 kcal. In contrast, FM appears not to be an independent predictor of energy intake, in younger (49, 50) nor older adults[46]. This is despite the anorexigenic action of the hormone leptin, which is released from adipose tissue proportional to adiposity, signalling energy storage to the brain and exerting influence on feeding[53]. However, the influence of leptin on eating behaviour appears particularly potent during periods of energy deficit and is less effective at limiting energy surplus and weight gain with overfeeding[54]. In addition, with high levels of adiposity, the negative feedback action of leptin in the brain appears blunted[55,56]. Nonetheless, leptin concentration has been shown to be higher in older adults[57], which may contribute to AA.

The gut, gut hormones and appetite control

The sensing of acute fluctuations in energy and nutrient status provides episodic signals to influence appetite. Much of this sensing occurs in the gut in response to feeding, and this is one potential physiological site where appetite control inputs may differ in later life. The role of the gut, and specifically gut-derived hormones, in appetite has been reviewed comprehensively elsewhere[58–60]. In brief, the secretion of hormones from the gastrointestinal tract communicates acute nutrient status to other organs of the body. Following food ingestion, nutrients are sensed in the gut by enteroendocrine cells, releasing gut-derived hormones, such as GLP-1, PYY and CCK[58]. These hormones act via the circulation, vagus nerve, and brain stem, stimulating anorexigenic pathways found primarily in the arcuate nucleus of the hypothalamus. As such, they signal an inhibitory feedback loop that terminates feeding and prevents or delays the reoccurrence of food ingestion. Conversely, the hunger hormone ghrelin is secreted during periods of abstinence from feeding. Surging before food ingestion and signalling via the circulation and vagus nerve to stimulate orexigenic pathways in the arcuate nucleus of the hypothalamus, it is thought to act as a 'trigger' for ingestive behaviour. With food ingestion, ghrelin secretion is suppressed, reducing hunger and favouring satiation and satiety. In such a manner, this endocrine communication relays gastrointestinal nutrient status to the brain, providing episodic signals that align with food intake throughout a day.

Gut hormone responses to feeding in older adults

There is now compelling evidence that gut hormones respond differently to food ingestion in later life, especially in those exhibiting AA. A comprehensive meta-analysis by Johnson *et al.*[57], showed circulating concentrations of some appetite-related hormones differ between younger and older adults. Older individuals demonstrated elevated fasting and postprandial concentrations of CCK, along with a tendency towards increased PYY secretion. However, CCK data should be interpreted with caution. Cross-reactivity with the structurally-similar and much more abundant gastrin renders the validity of some assays questionable[61]. Few studies have directly compared ghrelin concentrations between older and younger adults; while meta-analysis showed no significant age-related differences, it was deemed that

https://doi.org/10.1017/S0029665126102183 Published online by Cambridge University Press

more evidence was needed[57]. Non-significant elevated GIP concentrations were observed in older adults, in both fasted and postprandial states; but these findings were derived for just four studies. No significant age-related differences were identified for GLP-1, but again, data were limited (7 studies) and of high heterogeneity. This evidence base has since been expanded, with Giezenaar *et al.*[62] demonstrating greater postprandial increases in GLP-1 concentration in older versus younger men after the consumption of drinks of varying energy and macronutrient content. Table 1 summarises age-related differences in gut hormones in the fasted and postprandial states.

However, earlier studies may have overlooked key nuances due to their design. Specifically, grouping all older adults together without accounting for appetite status may obscure important differences in gut hormone profiles. Given that approximately 30% of community-dwelling older adults experience AA, it is likely that study samples include individuals with both preserved and diminished appetite. This may mask any dysregulation in gut hormone metabolism that is exclusively seen in those exhibiting altered appetite control. Additionally, due to difficulty in recruiting those with low appetite, in part because of health-related barriers, many studies may have inadvertently underrepresented those with low appetite. These limitations have likely contributed to an incomplete understanding of how ageing influences gut hormone responses.

This issue was recently addressed by comparing gut hormone responses among younger adults, older adults with preserved appetite, and older adults identified as having low appetite[63,64]. Using a novel four-criteria 'phenotyping' method, older adults were considered to be exhibiting low appetite if they met two of the following: low-weight (BMI < 23 kg·m^{-2}[48,65], a score of <15 on the Simplified Nutritional Appetite Questionnaire[66], habitual energy intake <75% of estimated daily total energy requirements (TER;[67]); a laboratory-measured *ad libitum* lunch intake of <25% of estimated TER (based on a typical lunch energy intake of ~27% of total energy intake in UK adults[68]).

Circulating concentrations of ghrelin (total), PYY, and GLP-1 were measured in the fasted state and in response to a 450 kcal, nutrient-balanced porridge meal[63]. Blood samples, along with measures of subjective appetite, were taken before eating and at regular intervals for four hours after the meal. An *ad libitum* pasta-based lunch meal was then provided. Comparisons were made between younger adults and all older adults, and between younger adults, older adults with a 'healthy' appetite, and older adults exhibiting low appetite. This design enabled distinction between differences that appear to be a function of ageing *per se*, and differences that appear unique to older adults with low appetite.

Data revealed no difference in ghrelin response between older adults and younger adults[63]. However, when comparing younger adults, older adults with a healthy appetite, and those exhibiting low appetite, ghrelin was suppressed to a markedly and significantly greater extent in older adults exhibiting low appetite than in younger adults. This was not seen in older adults with a healthy appetite, who showed an almost identical ghrelin profile to younger adults. Similarly, no differences were observed in PYY response between all older adults and younger adults; but there was a marked trend towards a greater response in older adults exhibiting low appetite, compared with younger adults and older adults with a healthy appetite. There was a difference observed in GLP-1 response between all older adults and younger adults, with younger adults experiencing a more rapid elevation in plasma concentrations, while older adults had a delayed but prolonged elevation. However, when comparing the response of younger adults with older adults with a healthy appetite and older adults exhibiting low appetite, this apparent age-related difference was exclusive to those exhibiting low appetite. No difference was observed between young adults and older adults with a healthy appetite[63].

Table 1. Summary of age-related differences in circulating gut hormones. (Adapted from Dagbasi *et al.* 2024)

	Effect of age (older vs. younger adults)	
Hormone	Fasted	Postprandial
Orexigenic hormones		
Ghrelin	↔[57] ↑[64]	↔[57] ↓[64]
Anorexigenic hormones		
CCK	↑[57]	↑[57]
GLP-1	↔ [57, 63]	↔[57] ↑ [63, 78]
PYY	↓[57] ↔[63]	↑ [57, 63]
GIP	↑?[57] ↑[79]	↑?[57] ↔?[80]
Oxyntomodulin	?	?
PP	?	?
Non-gut anorexigenic hormones		
Leptin	↑[57]	↑[57]
Insulin	↑[57]	↑[57]

↔ no difference between older vs. younger adults; ↑ greater concentration in older vs. younger adults; ↓ lower concentration in older vs. younger adults; ? unclear effect of age. CCK, cholecystokinin; GLP-1, glucagon-like peptide 1; PYY, peptide tyrosine-tyrosine; GIP, glucose-dependent insulinotropic polypeptide; PP, pancreatic polypeptide.

It is unlikely that any single appetitive gut hormone uniquely drives appetite control, and indeed, numerous hormones all change with a degree of synergy in response to feeding. So, while measuring individual hormone responses is common in this field, it is likely to be the gut hormone profile and interplay between hormones that exert appetite control. In appreciation of this, Dagbasi and co-workers[63] calculated an 'anorexigenic response score', as a composite of the responses of ghrelin, PYY, and GLP-1. Anorexigenic response score – expressed as net area-under-the-curve for the postprandial period – did not differ between younger and older adults. However, the score was significantly greater for older adults exhibiting low appetite compared with both younger adults and older adults with a healthy appetite. From these data, we concluded that older adults exhibiting low appetite have augmented gut hormone responses to feeding and this *may* be a causal mechanism of AA[63].

These data appear to vindicate the approach of identifying older adults who exhibit appetite suppression. Simply comparing older adults with younger adults would have failed to observe differences in ghrelin and PYY that appear unique to those exhibiting low appetite[63]. Conversely, findings would have erroneously identified differences in GLP-1 response between younger adults and older adults, when in fact, the data of this study would suggest this is not an effect of ageing *per se*, but unique to those exhibiting low appetite. This would have resulted in misplaced conclusions regarding gut hormone responses in later life and the likely role of appetitive gut hormones in the aetiology of AA.

https://doi.org/10.1017/S0029665126102183 Published online by Cambridge University Press

Of note, 54% of older adults classified using the phenotyping model were identified as exhibiting low appetite[63]. This is substantially higher than prevalence statistics for AA in community-dwelling older adults of ~ 15–30%[2,3,5]. This could indicate the underreporting of mild anorexia in later life, suggesting more older adults than is currently acknowledged may be experiencing low appetite. The observation of gut hormone dysregulation in those who may have 'mild' anorexia indicate a benefit of earlier detection to enable intervention prior to more severe anorexia and consequent undernutrition.

Dagbasi and co-workers[63] interrogated the novel phenotyping model to assess appropriateness and utility for future research in this field. Using the anorexigenic response score as the outcome of interest, regression analysis determined the efficacy of the model for identifying those exhibiting low appetite[63]. The phenotyping model explained 48% of the variance in anorexigenic response score[63]. Interestingly, stepwise regression showed that the model with the strongest predictive power included SNAQ score, habitual dietary intake, and laboratory *ad libitum* energy intake, with BMI not adding to the strength of the model. This is perhaps less surprising than one might initially think, given that BMI is not associated with protein-energy undernutrition[69], and risk of undernutrition is prevalent in ~25% of older adults with a BMI > 25 kg/m^{-2}[70]. In addition, BMI is a poor predictor of mortality in older people, likely due to the crudity of the measure in its inability to discern body composition[71]. Refinement of the model could include the use of lean mass as an alternative to BMI, to account for the composition of body mass. This phenotyping approach appears to be a robust method, and could prove beneficial for implementation in research in this field. Future research should look to confirm this by monitoring changes in dietary intake and body composition over time in those phenotyped as exhibiting low appetite and those phenotyped as having a 'healthy' appetite. If acting as an effective method for identifying early risk of AA, it could be hypothesised that those phenotyped as exhibiting low appetite will be at greater risk of developing undernutrition and experiencing unwanted weight loss and muscle loss.

Only part of the puzzle

Based on these observations, it can be proposed that a dysregulation of the gut hormone responses to feeding is *a* mechanism of AA, but not *the* mechanism. As previously mentioned, AA is multifactorial and it is likely that those experiencing AA will do so because of multiple and differing mechanisms, which may work synergistically or in isolation. Indeed, even the nature and manifestation of AA itself are not uniform. In qualitative research exploring AA, older individuals use discrete narratives of the experience that can be broadly outlined as increased or early feelings of satiety, or a general disinterest in food[72]. These narratives are not always consistent with perceptions of what appetite *is* or *should be* to the individual, whether a predominantly pleasure-seeking experience driving a desire to eat or a sensation that reflects underlying homeostatic mechanisms controlling energy intake and requirements. This inconsistency is interesting and may suggest that fundamental changes to biological mechanisms are a primary driver of AA rather than behavioural factors. Instead, eating behaviour may be more influential in the way older people adapt (or maladapt) to AA and thus upon consequent health trajectories[72].

The presence of discrete AA manifestations, which potentially have differing underlying mechanisms, is important to consider when designing further investigation. Certainly, gut hormone dysregulation would align with feelings of increased satiety described by some older adults, which is important, yet we acknowledge it does not explain the full spectrum of the phenomenon. Other biological mechanisms for AA, such as the potentially appetite-suppressive effects of age-related inflammation[73,74], alongside impaired sensory function with ageing, indicate a broad spectrum of potential underpinning elements. Thus, gut hormone dysregulation should currently be considered a key part of the wider puzzle that is AA as it is currently defined.

What next for research in this space?

Recent findings of amplified gut hormone responses to feeding in those older adults with low appetite has advanced our understanding but also raised several interesting questions to address. Firstly, such responses were observed for GLP-1, PYY and ghrelin. However, there are numerous other gut-derived hormones which exert appetitive effects, such as cholecystokinin (CCK), oxyntomodulin, pancreatic polypeptide (PP), and glucose-dependent insulinotropic polypeptide (GIP). Identifying responses of these hormones to feeding in older adults with low appetite would provide a thorough profile of the appetitive gut hormones.

Enhanced gut hormone responses to food intake may reflect an increased sensitivity of the gut to nutrients in some older individuals. This heightened responsiveness could contribute to disrupted hormone regulation and diminished appetite, potentially due to the gut overreacting to nutritional stimuli. This theory has been posed and discussed in detail elsewhere[75]. In brief, research is needed to enhance our understanding of any changes in nutrient transit, sensing, digestion, and absorption – as well as changes in gut function and physiology – in older adults with AA[75]. A first step may be to determine if the observed augmented gut hormone response is common to all nutrients or is nutrient-specific. The test meals of Dagbsi *et al.*[63] and Holliday *et al.*[64] were a mixed-nutrient meals; it may be of interest to explore gut hormone responses to carbohydrate, fat and protein specifically in older adults exhibiting low appetite. Once it is identified whether any amplified gut hormone response is common to all nutrients or is nutrient-specific, specific, targeted nutrient sensing and signalling pathways can be explored.

The findings of augmented gut hormone responses to feeding in older adults exhibiting low appetite are limited to cross-sectional observation. Consequently, it could be argued that these altered gut hormone responses may be a consequence of low appetite or weight loss, rather than a cause. It was demonstrated that BMI was not a predictor of anorexigenic response score – a composite of GLP-1, PYY, and ghrelin responses – which would indicate that low BMI, at least, is not driving dysregulated hormone responses[63]. Those with a high BMI were not included, and hence it cannot be determined that a relationship between BMI and gut hormone response is not present in older adults at higher BMI values. Given that dysregulated or differing hormone responses are observed with excess adiposity in younger adults (e.g., in PYY[76], and in ghrelin[77]), this may also be prevalent in later life. Nonetheless, longitudinal observation is needed to confirm the direction of the relationship between low appetite and amplified gut hormone responses.

In conclusion, contemporary evidence indicates that amplified gut hormone responses to feeding is observed in older adults with low appetite, but may not be present in those with a 'healthy',

https://doi.org/10.1017/S0029665126102183 Published online by Cambridge University Press

unaffected appetite. As such, gut hormone dysregulation appears not simply a function of ageing, but may be *a* fundamental driver of AA. Further research is needed to substantiate this, both in terms of direction of causality and the deeper underpinning mechanisms for a hypersecretory response to nutrient ingestion. However, it must be appreciated that broader evidence of the characteristics of AA indicate strong influence of social factors, sensory decline, and biological systems other than gut hormones. This supports the notion of different mechanisms, aetiology, and manifestations of AA, which aligns with the multifactorial complexity of appetite control. The potential for different 'types' of AA needs further consideration, as it will influence not only our understanding of the underlying mechanisms, but also the identification of at-risk populations and associated risk factors, and future treatment strategies.

Acknowledgements. The authors would like to acknowledge co-authors of previous work integral to the content of this review. Specifically, we would like to thank Aygul Dagbasi and Jordan Warner.

Author contributions. AH conceived the idea for the review. AH, MB, and NJC wrote the manuscript. All authors have read and approved the final version of the manuscript.

Financial support. No external funding was received for the conductance of this research. Matthew Barrett is the recipient of a Newcastle University Faculty of Medical Sciences PhD Studentship Award.

Competing interests. The authors declare no conflicts of interest.

Ethical statement. Ethical approval was not required for this review.

References

1. Morley, J.E. (1997) Anorexia of aging: physiologic and pathologic. *American Journal of Clinical Nutrition* **66**, 760–773.
2. van der Meij BS, Wijnhoven HAH, Lee JS, *et al.* (2017) Poor appetite and dietary intake in community-dwelling older adults. *J Am Geriatr Soc* **65**, 2190–2197.
3. Vázquez-Valdez OE, Aguilar-Navarro S & Ávila-Funes JA (2010) Association between anorexia of aging and disability in older community-dwelling Mexicans. *J Am Geriatr Soc* **58**, 2044–2046.
4. Donini LM, Dominguez LJ, Barbagallo M, *et al.* (2011) Senile anorexia in different geriatric settings in Italy. *J Nutr Health Aging* **15**, 775–781.
5. Cox NJ, Morrison L, Ibrahim K, *et al.* (2020) New horizons in appetite and the anorexia of ageing. *Age Ageing* **49**, 526–534.
6. Fernandez SSM, Cipolli GC, Merchant RA, *et al.* (2025) Global prevalence of anorexia of aging: a systematic review and meta-analysis. *Maturitas* **198**, 108603.
7. Di Francesco V, Pellizzari L & Corrà L (2018) The anorexia of aging: impact on health and quality of life. *Geriatr Care* **4**.
8. Rasheed S & Woods RT (2013) Malnutrition and quality of life in older people: a systematic review and meta-analysis. *Ageing Res Rev* **12**, 561–566.
9. Landi F, Calvani R, Tosato M, *et al.* (2016) Anorexia of aging: risk factors, consequences, and potential treatments. *Nutrients* **8**, 69.
10. Landi F, Liperoti R, Russo A, *et al.* (2013) Association of anorexia with sarcopenia in a community-dwelling elderly population: results from the ilSIRENTE study. *Eur J Nutr* **52**, 1261–1268.
11. Landi F, Russo A, Liperoti R, *et al.* (2010) Anorexia, physical function, and incident disability among the frail elderly population: results from the ilSIRENTE study. *J Am Med Dir Assoc* **11**, 268–274.
12. Landi F, Liperoti R, Lattanzio F, *et al.* (2012) Effects of anorexia on mortality among older adults receiving home care: an observational study. *J Nutr Health Aging* **16**, 79–83.
13. Merchant RA, Woo J & Morley JE (2022) Anorexia of ageing: pathway to frailty and sarcopenia. *J Nutr Health Aging* **26**, 3–5.
14. Russell A & Elia M (2014) Nutrition screening surveys in hospitals in the UK, 2007–2011. BAPEN, Redditch, UK.
15. Fogg C, England T, Zhu S, *et al.* (2024) Primary and secondary care service use and costs associated with frailty in an ageing population: longitudinal analysis of an English primary care cohort of adults aged 50 and over, 2006–2017. *Age Ageing* **53**.
16. Fogg C, England T & Daniels H (2025) Prevalence and severity of frailty amongst middle-aged and older adults conveyed to hospital by ambulance between 2010 and 2017 in Wales. *Age Ageing* **54**(5), afaf124.
17. Wysokiński A, Sobów T & Kłoszewska I (2015) Mechanisms of the anorexia of aging—a review. *AGE* **37**, 81.
18. Rosenbloom CA & Whittington FJ (1993) The effects of bereavement on eating behaviors and nutrient intakes in elderly widowed persons. *J Gerontol* **48**, S223–S229.
19. Cox NJ, Howson F, Ibrahim K, *et al.* (2022) Mood and physical activity are associated with appetite in hospitalised older men and women. *Age Ageing* **51**.
20. DiPietro L, Anda RF, Williamson DF, *et al.* (1992) Depressive symptoms and weight change in a national cohort of adults. *Int J Obes Relat Metab Disord* **16**, 745–753.
21. Bloom I, Lawrence W, Barker M, *et al.* (2017) What influences diet quality in older people? A qualitative study among community-dwelling older adults from the Hertfordshire Cohort Study, UK. *Public Health Nutr* **20**, 2685–2693.
22. Tardif SD, Mansfield KG & Ratnam R (2011) The marmoset as a model of aging and age-related diseases. *ILAR J* **52**, 54–65.
23. Blanton CA, Horwitz BA, Murtagh-Mark C, *et al.* (1998) Meal patterns associated with the age-related decline in food intake in the Fischer 344 rat. *Am J Physiol* **275**, R1494–502.
24. Christian CJ & Benian GM (2020) Animal models of sarcopenia. *Aging Cell* **19**, e13223.
25. Colman RJ, McKiernan SH & Aiken JM (2005) Muscle mass loss in rhesus monkeys: age of onset. *Exp Gerontol* **40**, 573–581.
26. Mattison JA, Black A, Huck J, *et al.* (2005) Age-related decline in caloric intake and motivation for food in rhesus monkeys. *Neurobiol Aging* **26**, 1117–1127.
27. Saper CB, Chou TC & Elmquist JK (2002) The need to feed: homeostatic and hedonic control of eating. *Neuron* **36**, 199–211.
28. Rogers PJ & Hardman CA (2015) Food reward: what it is and how to measure it. *Appetite* **90**, 1–15.
29. Rolls ET (2016) Reward systems in the brain and nutrition. *Annu Rev Nutr* **36**, 435–470.
30. Brenowitz WD, Kaup AR & Lin FR (2018) Multiple sensory impairment is associated with increased risk of dementia among black and white older adults. *J Gerontol* **74**, 890–896.
31. Schiffman SS (1997) Taste and smell losses in normal aging and disease. *JAMA* **278**, 1357–1362.
32. Aschenbrenner K, Hummel C, Teszmer K, *et al.* (2008) The influence of olfactory loss on dietary behaviors. *Laryngoscope* **118**, 135–144.
33. Arganini C & Sinesio F (2015) Chemosensory impairment does not diminish eating pleasure and appetite in independently living older adults. *Maturitas* **82**, 241–244.
34. Tomić-Obrdalj H, Palfi M & Keser I (2024) Investigation of associations of nutritional status and the olfactory function and perception of salty taste in the population of elderly nursing home residents. *Clin Nutr Open Sci* **57**, 150–162.
35. Giles H, Zannidi D, Clegg ME, *et al.* (2025) A systematic review of the factors affecting textural perception by older adults and their association with food choice and intake. *Appetite* **214**, 108202.
36. Campos A, Port JD & Acosta A (2022) Integrative hedonic and homeostatic food intake regulation by the central nervous system: insights from neuroimaging. *Brain Sci* **12**, 431.
37. Hopkins M, Kristine B & Anna M (2017) Mechanisms responsible for homeostatic appetite control: theoretical advances and practical implications. *Expert Rev Endocrinol Metabol* **12**, 401–415.
38. Neary NM, Goldstone AP & Bloom SR (2004) Appetite regulation: from the gut to the hypothalamus. *Clin Endocrinol* **60**, 153–160.

https://doi.org/10.1017/S0029665126102183 Published online by Cambridge University Press

39. Beaulieu K, Hopkins M & Blundell J (2018) Homeostatic and non-homeostatic appetite control along the spectrum of physical activity levels: an updated perspective. *Physiol Behav* **192**, 23–29.
40. Blundell JE, Gibbons C, Beaulieu K, *et al.* (2020) The drive to eat in homo sapiens: energy expenditure drives energy intake. *Physiol Behav* **219**, 112846.
41. Hopkins M, Beaulieu K, Gibbons C, *et al.* (2000) The control of food intake in humans. In *Endotext* [Feingold KR, Ahmed SF, Anawalt B et al., editors]. MDText.com, Inc., South Dartmouth (MA). PMID: 25905169.
42. Hopkins M, Gibbons C & Blundell J (2023) Fat-free mass and resting metabolic rate are determinants of energy intake: implications for a theory of appetite control. *Philos Trans R Soc Lond B Biol Sci* **378**, 20220213.
43. Caudwell P, Finlayson G, Gibbons C, *et al.* (2013) Resting metabolic rate is associated with hunger, self-determined meal size, and daily energy intake and may represent a marker for appetite. *Am J Clin Nutr* **97**, 7–14.
44. Hopkins M, Duarte C, Beaulieu K, *et al.* (2019) Activity energy expenditure is an independent predictor of energy intake in humans. *Int J Obes* **43**, 1466–1474.
45. Piaggi P, Thearle MS & Krakoff J (2015) Higher daily energy expenditure and respiratory quotient, rather than fat-free mass, independently determine greater ad libitum overeating. *J Clin Endocrinol Metabol* **100**, 3011–3020.
46. Hopkins M, Casanova N & Finlayson G (2022) Fat-free mass and total daily energy expenditure estimated using doubly labeled water predict energy intake in a large sample of community-dwelling older adults. *J Nutr* **152**, 971–980.
47. Mayer J, Roy P & Mitra KP (1956) Relation between caloric intake, body weight, and physical work: studies in an industrial male population in West Bengal. *Am J Clin Nutr* **4**, 169–175.
48. Crabtree DR, Cox NJ & Lim SER (2023) Enhancing the management of anorexia of ageing to counteract malnutrition: are physical activity guidelines optimal? *Aging Clin Exp Res* **35**, 427–431.
49. Ravussin E, Lillioja S & Anderson TE (1986) Determinants of 24-hour energy expenditure in man: methods and results using a respiratory chamber. *J Clin Invest* **78**, 1568–1578.
50. Blundell JE, Caudwell P, Gibbons C, *et al.* (2012) Body composition and appetite: fat-free mass (but not fat mass or BMI) is positively associated with self-determined meal size and daily energy intake in humans. *Br J Nutr* **107**, 445–449.
51. Hopkins M, Finlayson G, Duarte C, *et al.* (2016) Modelling the associations between fat-free mass, resting metabolic rate and energy intake in the context of total energy balance. *Int J Obes* **40**, 312–318.
52. Johnson KO, Holliday A, Mistry N, *et al.* (2021) An increase in fat-free mass is associated with higher appetite and energy intake in older adults: a randomised control trial. *Nutrients* **13**, 141.
53. Havel PJ (2000) Role of adipose tissue in body-weight regulation: mechanisms regulating leptin production and energy balance. *Proc Nutr Soc* **59**, 359–371.
54. Ravussin Y, Edwin E, Gallop M, *et al.* (2018) Evidence for a non-leptin system that defends against weight gain in overfeeding. *Cell Metab* **28**, 289–299.e5.
55. Morton GJ, Cummings DE & Baskin DG (2006) Central nervous system control of food intake and body weight. *Nature* **443**, 289–295.
56. Schwartz MW, Woods SC & Porte D (2000) Central nervous system control of food intake. *Nature* **404**, 661–671.
57. Johnson KO, Shannon OM, Matu J, *et al.* (2020) Differences in circulating appetite-related hormone concentrations between younger and older adults: a systematic review and meta-analysis. *Aging Clin Exp Res* **32**, 1233–1244.
58. Gribble FM & Reimann F (2022) Nutrient sensing in the gut and the regulation of appetite. *Curr Opin Endocr Metab Res* **23**, 100318.
59. Wren AM & Bloom SR (2007) Gut hormones and appetite control. *Gastroenterology* **132**, 2116–2130.
60. Holliday A, Horner K & Johnson KO (2025) Appetite-related gut hormone responses to feeding across the life course. *J Endocr Soc* **9**.
61. Rehfeld JF (2025) The relationship between cholecystokinin and gastrin. In *Cholecystokinin*, pp. 179–191 [Feinle-Bisset C and JF Rehfeld, editors]. Academic Press.
62. Giezenaar C, Lange K, Hausken T, *et al.* (2020) Effects of age on acute appetite-related responses to whey-protein drinks, including energy intake, gastric emptying, blood glucose, and plasma gut hormone concentrations —a randomized controlled trial. *Nutrients* **12**, 1008.
63. Dagbasi A, Warner J, Catterall V, *et al.* (2024) Augmented gut hormone response to feeding in older adults exhibiting low appetite. *Appetite* **201**, 107415.
64. Holliday A, Warner J & Hulston CJ (2024) Anorexia of ageing is associated with elevated fasted and lower post-prandial ghrelin, independent of ghrelin O-acyltransferase. *Appetite* **196**, 107259.
65. Winter JE, MacInnis RJ & Wattanapenpaiboon N (2014) BMI and all-cause mortality in older adults: a meta-analysis. *Am J Clin Nutr* **99**, 875–890.
66. Lau S, Pek K, Chew J, *et al.* (2020) The simplified nutritional appetite questionnaire (SNAQ) as a screening tool for risk of malnutrition: optimal cutoff, factor structure, and validation in healthy community-dwelling older adults. *Nutrients* **12**, 2885.
67. Cederholm T, Jensen GL, Correia MITD, *et al.* (2019) GLIM criteria for the diagnosis of malnutrition—a consensus report from the global clinical nutrition community. *Clin Nutr* **38**, 1–9.
68. Pot GK, Hardy R & Stephen AM (2014) Irregular consumption of energy intake in meals is associated with a higher cardiometabolic risk in adults of a British birth cohort. *Int J Obes* **38**, 1518–1524.
69. van der Pols-Vijlbrief R, Wijnhoven HAH & Schaap LA (2014) Determinants of protein–energy malnutrition in community-dwelling older adults: a systematic review of observational studies. *Ageing Res Rev* **18**, 112–131.
70. Sulmont-Rossé C, Van Wymelbeke-Delannoy V & Maître I (2022) Prevalence of undernutrition and risk of undernutrition in overweight and obese older people. *Front Nutr* **9**, 892675.
71. Chang S-H, Beason TS & Hunleth JM (2012) A systematic review of body fat distribution and mortality in older people. *Maturitas* **72**, 175–191.
72. Cox NJ, Morrison L & Robinson SM (2021) Older individual's perceptions of appetite, its loss, influencing factors and adaptions to poor appetite: a qualitative study. *Appetite* **167**, 105609.
73. Sánchez-Sánchez JL, Guyonnet S & Lucas A (2023) Plasma inflammatory biomarkers and anorexia of ageing among community-dwelling older adults: an exploratory analysis of the MAPT study. *J Nutr Health Aging* **27**, 1127–1131.
74. Pourhassan M, Babel N & Sieske L (2021) Longitudinal changes of cytokines and appetite in older hospitalized patients. *Nutrients* **13**.
75. Dagbasi A, Fuller A, Hanyaloglu AC, *et al.* (2024) The role of nutrient sensing dysregulation in anorexia of ageing: the little we know and the much we don't. *Appetite* **203**, 107718.
76. Batterham RL, Cohen MA, Ellis SM, *et al.* (2003) Inhibition of food intake in obese subjects by peptide YY_3–36. *N Engl J Med* **349**, 941–948.
77. Shiiya T, Nakazato M, Mizuta M, *et al.* (2002) Plasma ghrelin levels in lean and obese humans and the effect of glucose on ghrelin secretion. *J Clin Endocrinol Metabol* **87**, 240–244.
78. Giezenaar C, Lange K, Hausken T, *et al.* (2020) Effects of age on acute appetite-related responses to whey-protein drinks, including energy intake, gastric emptying, blood glucose, and plasma gut hormone concentrations —a randomized controlled trial. *Nutrients* **12**, 1008.
79. de Jesús Garduno-Garcia J, Gastaldelli A & DeFronzo RA (2018) Older subjects with β-cell dysfunction have an accentuated incretin release. *J Clin Endocrinol Metabol* **103**, 2613–2619.
80. Geloneze B, de Oliveira MdS & Vasques ACJ (2014) Impaired incretin secretion and pancreatic dysfunction with older age and diabetes. *Metabolism* **63**, 922–929.

https://doi.org/10.1017/S0029665126102183 Published online by Cambridge University Press