Journal of Obesity & Metabolic Syndrome 2017;26:181-187
https://doi.org/10.7570/jomes.2017.26.3.181

Review

jomes
pISSN 2508-6235
eISSN 2508-7576

Heterogeneity in Trajectories of Body Mass Index and Their Associations with Mortality in Old Age: A Literature Review

Hiroshi Murayama[1,*], Benjamin A. Shaw[2]

[1]*Institute of Gerontology, The University of Tokyo, Tokyo, Japan;* [2]*Department of Health Policy, Management and Behavior, School of Public Health, State University of New York at Albany, NY, USA*

This article reviewed studies to investigate the association between trajectories of body mass index (BMI) and mortality among older adults. Investigators conducted a systematic search of published peer-reviewed literature in the PubMed database, and three articles that satisfied the inclusion criteria for the review were identified. All of these studies used group-based trajectory models to identify distinct BMI trajectories. Two studies were derived from the U.S. and used data from the Health and Retirement Study, with up to nine repeated observations. Most of the BMI trajectories in older Americans were increasing and fell primarily within the overweight and obese ranges. The other study was from Japan and used nationwide data, with up to seven repeated observations. BMI trajectories identified in the older Japanese were mostly decreasing and fell primarily within the normal weight range. Although the distribution of BMI trajectories was different between the two nations, the findings from these three studies consistently demonstrated that people with stable overweight trajectories had the lowest all-cause mortality rates in both countries. Beyond this, however, these studies suggested that priorities for weight control in old age should likely differ between Western and non-Western countries. Research regarding BMI trajectories and mortality in old age is very limited at present. Evidence from countries other than the U.S. and Japan is warranted in order to validate current findings and guide the development of local clinical and public health strategies for body weight management aimed at improving the health and survival of older adults.

Key words: Body mass index, Literature review, Mortality, Older adults, Trajectories

Received March 8, 2017
Reviewed March 23, 2017
Accepted April 20, 2017

*Corresponding author
Hiroshi Murayama

http://orcid.org/0000-0003-2991-7763

Institute of Gerontology, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Tel: +81-3-5841-0232
Fax: +81-3-5841-1662
E-mail: murayama@iog.u-tokyo.ac.jp

INTRODUCTION

Body mass index (BMI) is an important predictor of mortality risk.[1-6] However, increasing evidence suggests that this association is not as strong in older populations as it is in younger groups.[4,7-10] Moreover, in contrast to the general population, older populations tend to exhibit a reverse J-shaped or L-shaped association between BMI and all-cause mortality[11-13], which has also been found in Asian counties.[4,14-16] More specifically, these studies report that underweight is an important predictor of mortality, while overweight has the lowest mortality risk in old age. This pattern of association has been referred to as the "obesity paradox."[17]

Although many previous studies have used BMI measured only at one point in time to predict subsequent mortality, they overlooked the possibility that weight changes occurring over time might also affect one's risk of dying. To address this gap, several studies have analyzed mortality risk in relation to weight changes between two points in time. Particularly, it has been reported that, in older adults, weight changes between two points in time predict mortality better than a single weight assessment.[18] More recently, Cheng et al.[19] have published a meta-analysis of the association between weight change and all-cause mortality in old age, focusing on 17 articles. They report that both weight loss and weight gain show associations with higher mortality, with pooled relative risks (95% confidence interval) of 1.67 (1.51-1.85) for weight loss and 1.21 (1.09-1.33) for weight gain. Such findings highlight a potential adverse effect of weight change on all-cause mortality in later life.

In addition, Cheng et al.[19] reported no potential difference in the deleterious effects of weight loss and gain on mortality across geographic regions (Western countries vs Asian countries), as well as by age, sex, or follow-up duration. They demonstrated that, to date, there have been just two studies from Asian nations exploring the linkage between weight change during a certain period of time and all-cause mortality in old age: one from Japan and the other from Hong Kong. Nanri et al.[20] reported that, among Japanese adults aged 60-69 years, weight loss of more than 2.5 kg and weight gain of more than 5 kg over a five-year period were both associated with a greater risk of mortality than weight change within 2.5 kg, even after adjusting for potential covariates. Ho et al.[21] illustrated that, after controlling for potential covariates, weight loss of 2 kg or more during a two-year observation period was associated with higher mortality rates among Hong Kong Chinese people aged 70 years and over compared to no weight change.

Research on weight change and mortality has the potential to yield important insights with regard to clinical and public health approaches to body weight management. However, prior research has commonly categorized trajectories of change in body weight using assignment rules that are based on a priori, subjective criteria (e.g., 5 kg gain or loss from baseline body weight), measured at only two points in time over a relatively short interval, e.g., 2 to 5 years. As body weight can fluctuate substantially over the adult life course, weight changes measured at multiple time points over an extended period can provide additional important information. Only a small number of studies have attempted to assess underlying body weight growth curves, i.e., trajectories of body weight, involving both initial levels of body weight and their rates of change over time) in old age.[22,23] This approach assumes population homogeneity (i.e., a presence of a single group with an average trajectory) with respect to body weight change over time.

However, it is more likely that systematic population heterogeneity exists in the pattern of body weight change over time, perhaps reflected in qualitatively distinct subgroups of the population with regard to body weight trajectories. Therefore, the assumption of population homogeneity might be too simplistic. By identifying and modeling heterogeneity in the BMI trajectory within a given population, it is then possible to assess whether specific trajectory subgroups carry differential mortality risks, ultimately helping to guide the development of individualized targeted interventions.

Group-based trajectory models represent a statistical approach that can be useful for understanding this type of population heterogeneity.[24-28] This technique assumes the presence of and identifies latent groups of individuals who share a particular developmental trajectory of some attribute, thereby allowing a better understanding of the pattern of change in the variable of interest. The technique has been used extensively in criminology and behavioral research and less in medicine and public health research. Therefore, the number of studies utilizing this approach and examining the association between patterns of BMI trajectories and mortality among older adults might be quite small. However, even though the current research is limited, a review of existing published articles should lead to a better understanding of the most important future directions for this topic. The purpose of this study, therefore, was to review studies that utilized group-based trajectory models to investigate the association between the long-term trajectory of BMI and mortality risk among older adults.

PubMed search for BMI trajectories and mortality

We used the PubMed database to conduct a systematic search of peer-reviewed studies on the relationship between BMI trajectory and mortality, published before January 31 2017. The following keywords were used in the search: ["body mass index" OR "body weight"], ["trajectory" OR "pattern"], ["mortality"], and ["elderly" OR "older"]. Keywords were combined in the searches. When the searches were completed, we first reviewed the title, keywords, and abstracts. If this initial review suggested that the study was relevant, we then reviewed the full text of the article for final selection.

The search included original articles published only in English. Additional inclusion criteria were the following: (1) the study used BMI or body weight as a main predictor; (2) the study set mortality as a main outcome (and included any type of mortality); (3) the

 https://doi.org/10.7570/jomes.2017.26.3.181

study included non-institutionalized individuals in the sample; and (4) the study focused on BMI trajectories during middle and old age.

Main results

These search strategies identified three articles suitable for review.[29-31] Table 1 shows the characteristics of the three reviewed articles, including information on the study sample (study country, dataset, sample characteristics, and sample size), approach to identifying BMI trajectories (observation points, measurement method of height and weight, and statistical model), details of the survival analysis (outcome, follow-up, statistical model, and covariates), and main results.

Two of the reviewed articles used data from the U.S. Health and Retirement Study (HRS)[29,30], and the other, from Japan, used the National Survey of Japanese Elderly.[31] The sample in the HRS was community-dwelling individuals aged 51-61 years at baseline, and both HRS-based studies used the nine-wave panel data from 1992 to 2008 (16 years). The Japanese sample consisted of community-dwelling individuals aged 60 years and older at baseline, and the study used the seven-wave panel data from 1987 to 2006 (19 years). Each of the three studies employed different analytic models to identify distinct BMI trajectories, respectively: a semiparametric group-based trajectory analysis, a growth mixture model, and a group-based mixture model. However, it is known that these models produce comparable trajectories[32] and are collectively called "group-based trajectory models."[24-28] With these approaches, it is recommended that the best-fitting model be chosen on the basis of the Bayesian Information Criterion (BIC) scores and an examination of 95% confidence intervals.[27] Typically, investigators estimate models with some trajectories (e.g., 1, 2, 3, …, n), select the best fitting model by comparing the BIC associated with various solutions and the average posterior probabilities of group membership, and evaluate whether successive models identify additional distinct groups as indicated by non-overlapping confidence intervals.

Zheng et al.[29] reported six distinct trajectories: "class II/III obese upward" (3.4%), "class I obese upward" (11.7%), "overweight obesity" (22.8%), "overweight stable" (29.5%), "normal weight upward" (24.2%), and "normal weight downward" (8.4%). Roughly 15% of the sample was within the obese range, 52% within the overweight range, and 33% within the normal range. Survival analysis indicated that mortality was more likely in individuals with the "class II/III obese upward" trajectory and "normal weight downward" trajectory were more likely to die compared to those with the "overweight stable" trajectory. They also conducted an attributable risk analysis and found that the mortality risks associated with the "class I obese upward" and "class II/III obese upward" trajectories were 3.0% and 4.2%, respectively.

Zajacova et al.[30] stratified data by sex and identified three trajectories in both sexes. The majority exhibited the "overweight stable" trajectory, 92.9% of men and 89.5% of women. Additional trajectories included "obese gaining" (2.8% for men and 6.2% for women) and "obese losing" (4.3% for men and 4.4% for women) trajectories. These researchers found that, among both men and women, people in the "obese gaining" and "obese losing" trajectory groups were about 1.5 times and 3-4 times more likely to die relative to those in the "overweight stable" group, respectively. These risk estimates were calculated without adjustment for potential covariates.

Finally, Murayama et al.[31] analyzed Japanese data and identified four distinct trajectories: "low-normal weight, decreasing" (23.8%), "mid-normal weight, decreasing" (44.6%), "high-normal weight, decreasing" (26.5%), and "overweight stable" (5.2%). Approximately 95% of the Japanese sample were within the normal weight range, and they had decreasing BMI trajectories. Researchers observed that, relative to those with the "mid-normal weight, decreasing" trajectory, those with the "overweight, stable" trajectory and those with the "high-normal weight, decreasing" trajectory had lower mortality risks, and those with the "low-normal, decreasing" trajectory had higher mortality risks.

Comparison across studies

We reviewed articles with regard to the relationship between BMI trajectory and mortality among older people and identified three published studies. A prior meta-analysis concluded that both weight loss and gain were mortality risks in old age.[19] However, although weight change during a short interval measured at two points in time might be associated with increased mortality risk in subsequent follow-up periods, it is important to note that body weight can fluctuate substantially over a given period of time. Therefore, group-based trajectory models, which examine heterogeneity of long-term weight change over time using panel data with

Table 1. Characteristics of three identified studies with regard to BMI trajectories and mortality

Authors	Country, dataset, study objects	Approach to identifying distinct BMI trajectories			Survival analysis			Main results	
		Observations	Measurement methods of height and weight	Statistical model (time scale)	Outcome, follow-up	Statistical model	Covariates	Identified BMI trajectories	Survival analysis
Zheng et al.[29]	U.S. Health and Retirement Survey U.S. adults aged 51-61 at baseline (n=9,538)	Up to 9 observations between 1992 and 2008 (16 years)	Self-reported	Semiparametric group-based trajectory model (age)	All-cause Until September, 2011	Cox proportional hazard model	Sex, race/ethnicity, marital status, educational level, smoking status, physical activities, activities of daily living limitations, angina, heart failure or heart attack, arthritis, bronchitis or emphysema, cancer, diabetes, stroke, bone fracture, and self-rated health	Six distinct trajectories were identified. 1) Class II/III obese upward (3.4%): started with a BMI of 40.8 at age 51 and increased to a BMI of 42.9 at age 77 2) Class I obese upward (11.7%): started with a BMI of 33.1 at age 51 and increased to a BMI of 34.9 at age 77 3) Overweight obesity (22.8%): started with a BMI of 28.9 at age 51 and increased to a BMI of 30.6 at age 77 4) Overweight stable (29.5%): started with a BMI of 25.8 at age 51 and slowly increased to a BMI of 26.9 at age 77 5) Normal weight upward (24.2%): started with a BMI of 23.1 at age 51 and slowly increased to a BMI of 23.6 at age 77 6) Normal weight downward (8.4%): started with a BMI of 20.5 at age 51 and slowly decreased to a BMI of 19.4 at age 77	People in the overweight stable trajectory had the highest survival rate, followed by those in the overweight obesity, normal weight upward, class I obese upward, normal weight downward, and class II/III obese upward trajectories. Class II/III obese upward trajectory (HR=1.83 [95% CI, 1.52-2.21]) and ormal weight downward trajectory (1.64 [1.43-1.88]) were associated with higher mortality risk compared to overweight stable trajectory; while HRs of the other trajectory groups were not statistically significant (1.11 [0.97-1.28] for class I obese upward, 0.99 [0.88-1.11] for overweight obesity, and 1.09 [0.98-1.22] for normal weight upward)
Zajacova et al.[30]	U.S. Health and Retirement Survey U.S. adults aged 51-61 at baseline (n=9,703)	Up to 9 observations between 1992 and 2008 (16 years)	Self-reported	Growth mixture model (time from baseline)	All-cause Until 2008 (survival status was collected in each observational point except the first observation in 1992)	Discrete-time survival mixture model	Unadjusted	Three distinct trajectories were identified. 1) Stable overweight (92.9% for men; 89.5% for women): initial BMI was distributed around the low-overweight range and slightly increased over the follow-up duration (started with a BMI of 26-27 at baseline and increased to a BMI of 28 over 16 years from baseline) 2) Obese gaining (2.8% for men; 6.2% for women): steadily increased weight over time (started with a BMI of 31 in men and 36 in women at baseline and increased to a BMI of 41 for men and 43 for women over 16 years) 3) Obese losing (4.3% for men; 4.4% for women): decreased weight over time (started with a BMI of 36 in men and 39 in women at baseline and increased to a BMI of 30 for men and 32 for women over 16 years)	Relative to the stable overweight group, men and women in the obese gaining groups had about a 50% higher odds of mortality (OR=1.46 [P=0.129] for men and 1.54 [P<0.001] for women) Men and women in the obese losing groups were about 3-4 times more likely to die during follow-up compared with those in the reference stable overweight group (OR=2.78 [P<0.001] for men and 3.66 [P<0.001] for women)
Murayama et al.[31]	Japan National Survey of the Japanese Elderly Japanese adults aged 60 and over at baseline (n=4,869)	Up to 7 observations between 1987 and 2006 (19 years)	Self-reported	Group-based mixture model (time from baseline)	All-cause Until December, 2012 (13.8 years of average follow-up per participant)	Cox proportional hazard model	Age, sex, marital status, currently working, education, annual household income, weight (kg), number of cigarettes smoked per day, number of drinking days per month, frequency of exercise, history of cardiovascular disease, stroke, lung disease, liver disease, and kidney disease, self-rated health and functional status at baseline, and entry wave	Four distinct trajectories were identified: 1) Low-normal weight, decreasing (23.8%): started with a BMI of 18.7 at baseline and decreased to a BMI of 17.8 over 19 years of follow-up. 2) Mid-normal weight, decreasing (44.6%): started with a BMI of 21.9 at baseline and decreased to a BMI of 21.0 over 19 years 3) High-normal weight, decreasing (26.5%): started with a BMI of 24.8 at baseline and slightly decreased to a BMI of 24.2 over 19 years 4) Overweight stable (5.2%): started with a BMI of 28.7 at baseline and remained stable over time.	The "low-normal weight, decreasing" subgroup had the highest mortality risk, followed by the "mid-normal weight, decreasing," the "high-normal weight, decreasing," and the "overweight, stable" subgroups Relative to those with a mid-normal weight, decreasing BMI trajectory, those with an overweight, stable BMI trajectory (HR=0.72 [95% CI, 0.54-0.96]) and those with a high-normal weight, decreasing BMI trajectory (0.82 [0.72-0.93]) had lower mortality. Those with a low-normal, decreasing BMI trajectory had higher mortality (1.17 [1.02-1.33])

BMI, body mass index; CI, confidence interval; HR, hazard ration; OR, odds ratio.

https://doi.org/10.7570/jomes.2017.26.3.181

multiple BMI data points, can facilitate our understanding of distinct patterns of BMI change and the associated risks of mortality. Moreover, as trajectory models can identify individuals with distinct BMI trajectories, this type of analysis offers potential for helping investigators and practitioners in targeting different interventions specific to each trajectory group.

Of the three identified articles, two were conducted in the U.S. and the other in Japan. Even though the two U.S. studies were based on the same data, each identified different patterns of BMI trajectory. Zheng et al.[29] reported that the six-trajectory model provided the best fit for the data compared with other models, based on the BIC index. They also noted that the three-trajectory model identified by Zajacova et al.[30] risked concealing heterogeneity in BMI trajectories because this model collapsed most respondents (approximately 90% in both sexes) with underweight, normal weight, overweight, and obesity into the "overweight stable" trajectory group. These different findings from the same data suggest that more research is needed regarding strategies on the best-fitting, group-based trajectory model.

In addition, BMI trajectory patterns were quite different for older Americans and older Japanese. When comparing the U.S. research by Zheng et al.[29] with the Japanese research by Murayama et al.[31], we found that trajectories within the overweight and obese ranges accounted for 70% of the U.S. sample, and all of these trajectories were increasing, whereas only a little over 5% of older Japanese followed the "stable overweight" trajectory. Furthermore, BMI changes in the older Japanese were primarily within the normal-weight range (i.e., BMI: 18.5-25.0), and the three trajectories identified within this range were decreasing over time. In particular, approximately 24% of the sample followed the trajectory of "low-normal weight, decreasing," which started with a BMI of 18.7 and decreased to 17.8 over 19 years. By contrast, in the U.S. sample, only 8% had a downward trajectory within the normal weight range. Therefore, older Japanese appear to differ from older Americans not only in terms of the weight distribution at a single point in time, but also in the long-term patterns of weight changes over time.

In terms of survival analysis, findings from the three studies were consistent. Both among older Americans and older Japanese, those who were overweight but stable had the highest survival rate. These findings are also consistent with a prior meta-analysis focusing on BMI (measured at a single point) and all-cause mortality in older adults, which reported that overweight status had the lowest risk of mortality.[33] Similar associations have also been found in several Asian studies.[14-16,34-36] In addition, prior research has found that stable weight status is associated with a lower mortality rate compared to weight change among older adults both in Western and Asian countries.[19] The findings of our review of studies with longer follow-up periods are consistent with these prior findings. Taken together, these findings indicate that older adults with stable overweight trajectories over time have the lowest mortality rates, regardless of whether they reside in Western or non-Western societies.

However, our review suggests that priorities for weight control in older adults might need to differ between Western and non-Western countries. Based on the findings from Zheng and his colleagues[29], it appears that body weight control interventions are most needed for older Americans with the "class I obese upward" and "class II/III obese upward" trajectories because approximately 7.2% of deaths were found in these trajectory groups, according to attributable risk analysis. In contrast, it appears that weight control measures for older adults in Japan should focus on those with the "low-normal weight, decreasing" trajectory because this subgroup had the highest mortality rate.[31] Researchers contended that two factors were related to this result: first, thin people tend to have less energy and nutritional reserves, which results in less resistance to infection;[14,37] second, decreasing body weight is often accompanied by an accumulation of muscle or bone loss[38,39], resulting in a reduced ability to maintain energy balance and the sharing of many immunological and neuroendocrine features of disease-associated wasting syndromes.[40]

CONCLUSION

This review identified three papers focusing on the association between BMI trajectories and mortality in old age. Although the distribution of long-term BMI trajectories was different between older Americans and older Japanese, the finding that those with an overweight stable trajectory had the lowest mortality rate was consistently observed. This research provides insights concerning the complex and dynamic relationship between BMI and mortality in later life that is not captured in research focusing on the mortality risks associated with BMI measured at one point in time or weight change measured at just two-points in time. Evidence from other nations is warranted in order to validate the findings from the U.S. and Japan. Such work can also contribute to development of clinical and public health strategies for body weight management aimed at improving the health and survival of older adults in each country.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Berrington de Gonzalez A, Hartge P, Cerhan JR, Flint AJ, Hannan L, Maclnnis RJ, et al. Body-mass index and mortality among 1.46 million white adults. N Engl J Med 2010;363: 2211-9.
2. Bogers RP, Bemelmans WJ, Hoogenveen RT, Boshuizen HC, Woodward M, Knekt P, et al. Association of overweight with increased risk of coronary heart disease partly independent of blood pressure and cholesterol levels: a meta-analysis of 21 cohort studies including more than 300,000 persons. Arch Intern Med 2007;167:1720-8.
3. Flegal KM, Kit BK, Orpana H, Graubard BI. Association of all-cause mortality with overweight and obesity using standard body mass index categories: a systematic review and meta-analysis. JAMA 2013;309:71-82.
4. Jee SH, Sull JW, Park J, Lee SY, Ohrr H, Guallar E, et al. Body-mass index and mortality in Korean men and women. N Engl J Med 2006;355:779-87.
5. McGee DL; Diverse Populations Collaboration. Body mass index and mortality: a meta-analysis based on person-level data from twenty-six observational studies. Ann Epidemiol 2005; 15:87-97.
6. Prospective Studies Collaboration, Whitlock G, Lewington S, Sherliker P, Clarke R, Emberson J, et al. Body-mass index and cause-specific mortality in 900,000 adults: collaborative analyses of 57 prospective studies. Lancet 2009;373:1083-96.
7. Adams KF, Schatzkin A, Harris TB, Kipnis V, Mouw T, Ballard-Barbash R, et al. Overweight, obesity, and mortality in a large prospective cohort of persons 50 to 71 years old. N Engl J Med 2006;355:763-78.
8. Calle EE, Thun MJ, Petrelli JM, Rodriguez C, Heath CW Jr. Body-mass index and mortality in a prospective cohort of U.S. adults. N Engl J Med 1999;341:1097-105.
9. Kuk JL, Ardern CI. Influence of age on the association between various measures of obesity and all-cause mortality. J Am Geriatr Soc 2009;57:2077-84.
10. Stevens J, Cai J, Pamuk ER, Williamson DF, Thun MJ, Wood JL. The effect of age on the association between body-mass index and mortality. N Engl J Med 1998;338:1-7.
11. Flicker L, McCaul KA, Hankey GJ, Jamrozik K, Brown WJ, Byles JE, et al. Body mass index and survival in men and women aged 70 to 75. J Am Geriatr Soc 2010;58:234-41.
12. Grabowski DC, Ellis JE. High body mass index does not predict mortality in older people: analysis of the Longitudinal Study of Aging. J Am Geriatr Soc 2001;49:968-79.
13. Sergi G, Perissinotto E, Pisent C, Buja A, Maggi S, Coin A, et al. An adequate threshold for body mass index to detect underweight condition in elderly persons: the Italian Longitudinal Study on Aging (ILSA). J Gerontol A Biol Sci Med Sci 2005;60:866-71.
14. Takata Y, Ansai T, Soh I, Awano S, Nakamichi I, Akifusa S, et al. Body mass index and disease-specific mortality in an 80-year-old population at the 12-year follow-up. Arch Gerontol Geriatr 2013;57:46-53.
15. Tamakoshi A, Yatsuya H, Lin Y, Tamakoshi K, Kondo T, Suzuki S, et al. BMI and all-cause mortality among Japanese older adults: findings from the Japan collaborative cohort study. Obesity (Silver Spring) 2010;18:362-9.
16. Yamazaki K, Suzuki E, Yorifuji T, Tsuda T, Ohta T, Ishikawa-Takata K, et al. Is there an obesity paradox in the Japanese elderly population? a community-based cohort study of 13,280 men and women. Geriatr Gerontol Int 2016 Aug 4 [Epub]. https://doi.org/10.1111/ggi.12851
17. Oreopoulos A, Kalantar-Zadeh K, Sharma AM, Fonarow GC. The obesity paradox in the elderly: potential mechanisms and clinical implications. Clin Geriatr Med 2009;25:643-59, viii.
18. Somes GW, Kritchevsky SB, Shorr RI, Pahor M, Applegate WB. Body mass index, weight change, and death in older adults:

the systolic hypertension in the elderly program. Am J Epidemiol 2002;156:132-8.

19. Cheng FW, Gao X, Jensen GL. Weight change and all-cause mortality in older adults: a meta-analysis. J Nutr Gerontol Geriatr 2015;34:343-68.
20. Nanri A, Mizoue T, Takahashi Y, Noda M, Inoue M, Tsugane S, et al. Weight change and all-cause, cancer and cardiovascular disease mortality in Japanese men and women: the Japan Public Health Center-Based Prospective Study. Int J Obes (Lond) 2010;34:348-56.
21. Ho SC, Woo J, Sham A. Risk factor change in older persons, a perspective from Hong Kong: weight change and mortality. J Gerontol 1994;49:M269-72.
22. Botoseneanu A, Liang J. Social stratification of body weight trajectory in middle-age and older Americans: results from a 14-year longitudinal study. J Aging Health 2011;23:454-80.
23. Murayama H, Liang J, Bennett JM, Shaw BA, Botoseneanu A, Kobayashi E, et al. Socioeconomic status and the trajectory of body mass index among older Japanese: a nationwide cohort study of 1987-2006. J Gerontol B Psychol Sci Soc Sci 2016;71:378-88.
24. Berlin KS, Parra GR, Williams NA. An introduction to latent variable mixture modeling (part 2): longitudinal latent class growth analysis and growth mixture models. J Pediatr Psychol 2014;39:188-203.
25. Jones BL, Nagin DS. Advances in group-based trajectory modeling and an SAS procedure for estimating them. Sociol Methods Res 2007;35:542-71.
26. Jones BL, Nagin DS, Roeder K. A SAS procedure based on mixture models for estimating developmental trajectories. Sociol Methods Res 2001;29:374-93.
27. Nagin DS. Group-based modeling of development. Cambridge, MA: Harvard University Press; 2005.
28. Nagin DS, Odgers CL. Group-based trajectory modeling in clinical research. Annu Rev Clin Psychol 2010;6:109-38.
29. Zheng H, Tumin D, Qian Z. Obesity and mortality risk: new findings from body mass index trajectories. Am J Epidemiol 2013;178:1591-9.
30. Zajacova A, Ailshire J. Body mass trajectories and mortality among older adults: a joint growth mixture-discrete-time survival analysis. Gerontologist 2014;54:221-31.
31. Murayama H, Liang J, Bennett JM, Shaw BA, Botoseneanu A, Kobayashi E, et al. Trajectories of body mass index and their associations with mortality among older Japanese: do they differ from those of western populations? Am J Epidemiol 2015;182:597-605.
32. Twisk J, Hoekstra T. Classifying developmental trajectories over time should be done with great caution: a comparison between methods. J Clin Epidemiol 2012;65:1078-87.
33. Winter JE, MacInnis RJ, Wattanapenpaiboon N, Nowson CA. BMI and all-cause mortality in older adults: a meta-analysis. Am J Clin Nutr 2014;99:875-90.
34. Chung WS, Ho FM, Cheng NC, Lee MC, Yeh CJ. BMI and all-cause mortality among middle-aged and older adults in Taiwan: a population-based cohort study. Public Health Nutr 2015;18:1839-46.
35. Gu D, He J, Duan X, Reynolds K, Wu X, Chen J, et al. Body weight and mortality among men and women in China. JAMA 2006;295:776-83.
36. Inoue K, Shono T, Toyokawa S, Kawakami M. Body mass index as a predictor of mortality in community-dwelling seniors. Aging Clin Exp Res 2006;18:205-10.
37. Chandra RK. Nutrition and the immune system: an introduction. Am J Clin Nutr 1997;66:460S-3S.
38. Abe T, Sakamaki M, Yasuda T, Bemben MG, Kondo M, Kawakami Y, et al. Age-related, site-specific muscle loss in 1,507 Japanese men and women aged 20 to 95 years. J Sports Sci Med 2011;10:145-50.
39. Visser M. Epidemiology of muscle mass loss with age. In: Cruz-Jentoft AJ, Morley JE, editors. Sarcopenia. Oxford: John Wiley & Sons; 2012. p. 1-7.
40. Schwartz MW, Seeley RJ. Seminars in medicine of the Beth Israel Deaconess Medical Center. Neuroendocrine responses to starvation and weight loss. N Engl J Med 1997;336:1802-11.