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Original article

Prosthodontic treatment can improve the ingestible food profile in Japanese adult outpatients

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Abstract

Purpose: To investigate the effect of prosthodontic treatment on the ingestible food profile in adult Japanese outpatients, and to identify the related risk factors that can deteriorate the profile.

Methods: The participants were 277 outpatients who visited university-based specialty clinics in Japan for prosthodontic treatment. The demographic data, number of present teeth assessed via intraoral examination, and oral health-related quality of life assessed by the total Oral Health Impact Profile (OHIP-J54) scores of all participants were recorded before treatment. Ingestible food profile score (IFS) was recorded using a validated food intake questionnaire. Eligible participants who answered the questionnaire before and after treatment were categorized into five groups based on the prosthodontic treatments they received (i.e., crowns, bridges, removable partial dentures, removable complete dentures, and removable complete and partial dentures).

Results: Multivariate analysis of covariance revealed a statistically significant main effect of prosthodontic intervention (time course: before and after treatment) on mean IFS (P=0.035, F=4.526), even after adjusting for covariates (age, number of present teeth, and treatment modality). Multiple linear regression analysis revealed that the low number of present teeth (r=0.427, P<0.001) and a high OHIP-J54 total score (r=-0.519, P<0.001) of the patients at the baseline were significantly associated with their baseline IFSs, even after adjusting for confounding variables.

Conclusions: The findings of this multicenter follow-up study indicate the importance of prosthodontic rehabilitation in improving patients' ingestible food profiles.

Keywords: Dietary diversity, Ingestible foods, Oral-health quality of life, Prosthodontic rehabilitation

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1. Introduction

Inappropriate dietary intake and low dietary diversity are widely known to cause various medical diseases, including malnutrition, sarcopenia, heart disease, stroke, and type 2 diabetes[1–4]. In addition to physical health, cognitive function can be affected by dietary diversity. For instance, higher dietary diversity decreases brain aging and the risk of cognitive decline in older adults[5] by preventing the decrease in hippocampal volume[6]. Therefore, high dietary diversity, which reflects a nutrient-rich diet, can maintain higher physical and cognitive functions and decrease the risk of all-cause mortality[7–10].

Dietary diversity, defined as the number of different foods or food groups consumed over a given reference period[11], can be affected by various factors such as nutritional knowledge, physical health, loss of appetite, and living circumstances[12]. Oral health status, such as the number of present teeth, can also affect the dietary diversity by influencing food choice and preference[13]. Nowjack-Raymer and Sheiham[14] reported that individuals with fewer than 28 teeth exhibited significantly lower carrot, tossed salad, and dietary fiber intake than did their fully dentate counterparts. Iwasaki *et al.*[15] demonstrated that older women with ≤ 9 and 10-19 teeth exhibited significantly lower food diversity than did those with ≥ 20 teeth after adjusting for confounders. These findings suggest that healthy masticatory organs can contribute to improving dietary diversity by maintaining favorable chewing ability. Since it is well-known that prosthodontic rehabilitation can improve the chewing ability of patients with tooth loss, it may also help improve dietary diversity. In fact, prosthodontic rehabilitation has been reported to improve the nutritional status in partially dentate older individuals, as evaluated using the Mini Nutritional Assessment[16–18]. However, the direct effect of prosthodontic treatment on dietary diversity has not yet been investigated in clinical epidemiological studies.

Moreover, several questionnaires have been developed to assess dietary diversity and overall nutritional quality by analyzing the number of foods and food groups (higher dietary diversity indicates a well-balanced diet)[19]. Nevertheless, these questionnaires assess the actual consumption of a specific food or food group and do not allow a more detailed analysis of ingestible food in relation to difficulty in chewing. To enable this analysis, the ingestible food profile score (IFS) system[20] was developed specifically among the Japanese population. The important feature of IFS is its self-estimating nature to assess the ability or inability to consume a specific food or food group with various textures without any additional nutritional estimation. Further, the results are less susceptible to different dietary content depending on the timing of the measurement. Above all, IFS is a simple and less burdensome measuring method for both subjects and measurers. Based on these advantages, IFS measurement was considered useful as the surrogate endpoint of dietary diversity.

We previously conducted a multicenter prospective cohort study to investigate the validity of the multi-axis assessment protocol for classifying the level of difficulty in prosthodontic treatment[21]. As an unreported treatment outcome, IFS was also recorded to measure chewing ability before and after prosthodontic treatment. Therefore, this study aimed to analyze the effect of prosthodontic treatment on the IFS-based assessment of dietary diversity by reanalyzing part of the database of a multicenter prospective cohort study.

2. Materials and Methods

2.1. Study sample

Consecutive sampling was used to select patients from among new outpatients requesting prosthodontic treatment for tooth problems or partial/complete edentulism at nine university-based specialty clinics for prosthodontics in Japan from 2007 to 2009. This study used the database of a multicenter clinical cohort study previously conducted to investigate the validity of the multi-axis assessment protocol for classifying the level of difficulty in prosthodontic treatment[21]. All participants completed the treatment before August 2012. Detailed information of each clinic and the selection process of the study participants have been previously described[21]. The final study participants (n=321) were asked to respond to a questionnaire on ingestible food before and after prosthodontic treatment. However, 34 participants with incomplete IFS questionnaires and 10 who received implant-supported dentures were excluded. Finally, 277 participants were included in this study (**Fig. 1**). This study was approved by the ethics committee of the Okayama University Hospital (approval number: KEN1904-016).

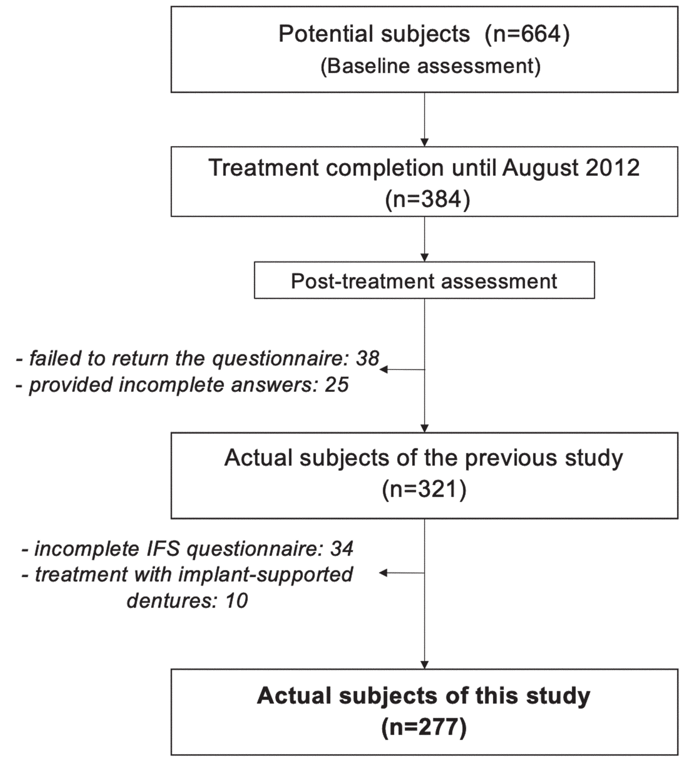

Fig. 1. Sampling process in this study

2.2. Oral examination and oral health-related quality of life measurement

All participants underwent a multi-axis assessment comprising a clinical examination and questionnaire. Evaluations included the following four axes: oral physiological conditions, including the number of present teeth, general health and sociological conditions; oral health-related quality of life (OHRQoL) assessed via the Oral Health Impact Profile (OHIP-J54)[22]; and psychological health. The detailed assessment methods have been described in a previous study[21]. In this study, data on the number of present teeth and the OHRQoL score of each participant were used in the statistical analyses.

2.3. Ingestible food questionnaire

The ingestible food profiles were assessed using a validated questionnaire developed by Koshino *et al.*[20]. The questionnaire required the participants to self-assess their ability to eat each of the 25

Table 1. Demographic data of participants at baseline

Variables	All subjects	Crowns (Cr)	Bridges (Br)	Removable partial dentures (RPD)	Complete dentures (CD)	Removable partial and complete dentures (RPD/CD)
Number of subjects (n)	277	51	24	127	52	23
Mean age (years)***	63.2 ± 13.5	52.4 ± 14.8 ***vs RPD, CD, RPD/CD*	55.8 ± 16.0 ***vs CD, RPD/CD*	64.1 ± 11.1 ***vs CD, RPD/CD*	71.3 ± 8.4	71.6 ± 9.8
Sex (Male/female, n)	124/153	20/31	14/10	55/72	27/25	8/15
Number of present teeth***	15,7 ± 10.4	26.0 ± 4.0 ***vs Br,RPD, CD, RPD/CD*	25.1 ± 2.0 ***vs RPD, CD, RPD/CD*	18.5 ± 5.9 ***vs CD, RPD/CD*	1.0 ± 3.3	6.5 ± 4.6
Number of restored teeth***	11.7 ± 10.4	1.8 ± 1.4 ***vs RPD, CD, RPD/CD*	2.1 ± 1.6 ***vs RPD, CD, RPD/CD*	8.7 ± 5.8 ***vs CD, RPD/CD*	27.0 ± 3.2 ***vs RPD/CD*	21.6 ± 3.0
OHIP-J54 score****	48.0 [44.0 to 54.0]	32.0 [20.0 to 46.0]	42.0 [21.0 to 60.0]	54.0 [47.0 to 61.0] ***vs Cr*	51.5 [38.0 to 74.0]	48.0 [22.0 to 77.0]
Duration of treatment (months)	5.2 ± 5.4	3.3 ± 3.1 ***vs RPD, CD, RPD/CD*	4.7 ± 6.4 ***vs RPD/CD*	6.7 ± 6.3	5.3 ± 3.6	7.7 ± 5.1
Ingestible food prolife score ****	85.1 [61.9 to 96.8]	96.8 [93.4 to 100.0] ***vs RPD, CD, RPD/CD*	98.4 [91.5 to 100] ***vs RPD, CD, RPD/CD*	79.5 [74.7 to 86.3]	52.0 [44.0 to 74.0]	62.5 [48.8 to 91.9]

*: P<0.05, **: P<0.01. ***: Mean ± Standard deviation, ****: Median [95% confidence interval]. Steel-Dwass test: mean age, number of present teeth, number of treatment teeth, OHIP score, duration of treatment, and ingestible food score. Chi-square test: gender. OHIP: Oral Health Impact Profile.

food items according to the following five categories: can eat easily, can eat with difficulty, cannot eat, cannot eat because of taste aversion or dislike, and have not been able to eat since starting to wear dentures. The score of the items in each grade was multiplied by the weighted value to obtain a final IFS in the range of 0 to 100. A higher IFS indicated a higher ingestible food profile of the participant.

2.4. Statistical analyses

The participants were categorized into five groups based on the prosthodontic treatment received: crowns (Cr), bridges (Br), removable partial dentures (RPD), removable complete dentures (CD), and both removable CD and RPD (CD/RPD). Baseline characteristics of the groups were compared using the Steel-Dwass test (age, number of present teeth, number of restored teeth, OHIP-J54 score, duration of treatment, and IFS). The chi-square test was used to compare sex differences among the groups. The relationship between the baseline IFS and the demographic data (age, number of present and restored teeth, and OHIP-J54 score), except for sex differences, was analyzed using the Spearman's rank correlation coefficient. The Wilcoxon signed-rank test was used to compare the baseline IFS between the male and female participants.

Multivariate analysis of covariance (MANCOVA) was used to clarify whether prosthodontic treatment affected the IFS after adjusting for the following independent variables: age, number of present teeth, and treatment modality. The dependent variables were the IFSs both before and after treatment. The difference in the median IFSs of each treatment group before and after treatment was analyzed using the Wilcoxon signed-rank test.

Multiple linear regression analysis was performed to examine the relationship between the baseline IFS and baseline predictors. Two analytical models were employed: in model 1, the predictors were age, sex, and the number of present teeth, whereas in model 2, the OHIP-J54 scores were included as an additional predictor to those used in model 1.

Another multiple linear regression analysis was performed to examine the predictability of IFS change among the predictors at the baseline and after treatment. Two analytical models were also employed: in model 1, the predictors were age, sex, treatment modality, the number of teeth present, and the duration of treatment; in model 2, the OHIP-J54 scores were included as an additional predictor to those used in model 1.

The significance level was set at P<0.05. All statistical analyses were performed using JMP version 14.2.0 (SAS Institute, Inc., Tokyo, Japan).

3. Results

3.1. Baseline properties of the participants

The baseline data of all participants and groups categorized according to their treatment modalities are shown in **Table 1**. Significant differences among the treatment groups were observed when comparing the patients' in terms of age, number of present teeth, number of restored teeth, OHIP-J54 score, duration of treatment, and IFS. The number of subjects who had been certified as requiring support and requiring long-term care by the Long-Term Care Insurance Act in Japan were 16 and one, respectively.

3.2. Correlation between IFS and variables at the baseline

Spearman's rank correlation coefficient between the baseline IFS and number of present teeth showed a significant positive correlation (ρ=0.427, P<0.001). Significant negative correlations were observed between the baseline IFS and the number of restored teeth (ρ=-0.445, P<0.001) and OHIP-J54 scores (ρ=-0.519, P<0.001). However, the correlation between the baseline IFS and age was not significant (ρ=-0.029, P=0.626). Additionally, no significant difference was observed in the IFS between the male and female participants (P=0.120).

3.3. Effect of prosthodontic treatment on IFS in each treatment group

MANCOVA revealed a significant main effect (P=0.035, F=4.526) of prosthodontic treatment (time course: before and after treatment) on the mean IFS of all participants (**Table 2**) by adjusting the covariates: age, number of present teeth, and treatment modality. Moreover, the number of present teeth at the baseline was a significant covariate for prosthodontic treatment. **Figure 2** shows the comparison of median (with 95% confidential interval) IFSs before and after treatment in all groups categorized by their treatment modalities and revealed a significantly greater median IFS after treatment in all treatment groups and in all participants (P<0.001).

Table 2. Multivariate analysis of covariance for ingestible food score according to prosthodontic treatment

Variable	dF	P-value	F
Main effect			
Before *vs.* after treatment (Intervention)	1	**0.035**	**4.526**
Covariate			
Age	1	0.954	0.003
Number of present teeth	1	**<0.001**	**11.745**
Treatment modality	5	0.086	1.959
Interaction			
Intervention × Treatment modarity	5	0.394	1.041
Intervention × Age	1	0.93	0.008
Intervention × Number of present teeth	1	0.127	2.341

Dependent variable: Ingestible food score before and after treatment. dF: degrees of freedom

3.4. Predictors of the baseline IFS

Table 3 shows the results of the multiple linear regression analysis to identify the significant predictors of baseline IFS. In model 1, a higher number of present teeth (P<0.001) significantly correlated with a higher baseline IFS. In model 2, a higher number of present teeth (P<0.001) and a higher OHIP-J54 score (P<0.001) significantly correlated with a higher baseline IFS.

3.5. Predictors of IFS-change among baseline and follow-up variables

Multiple regression analysis revealed that a longer duration of treatment (SRC=−0.193) was a significant predictor of the extent of the IFS change in model 1. Meanwhile, when the OHIP-J54 score was added to a set of the predictors of model 1, the duration of treatment was no longer a significant predictor of the IFS change, but a higher number of present teeth (SRC=0.810) and lower OHIP-J54 score (SRC=-0.251) at the baseline significantly correlated with a lower IFS change in model 2 (**Table 4**).

4. Discussion

The validated questionnaire used in this study was developed to clarify the ingestible food profiles commonly consumed in Japan[20]. The findings observed on using this questionnaire showed that prosthodontic treatment could significantly increase the IFS. It should be noted that IFS does not directly measure nutrients or the daily food intake. However, an increase in IFS could indicate improvement of food intake ability with regard to foods with tougher textures[20]. Thus we advocate that IFS could be used as a self-estimated, surrogate endpoint for dietary diversity. To supplement these findings, we calculated the average nutrient composition for each food item employed in this study (**Appendix 1**) according to the Standard Tables of Food Composition in Japan (2020) published by the Ministry of Education, Culture, Sports, Science and Technology[23]. In the IFS questionnaire, each food item was classified into five grades (I-V) according to its mechanical and physical properties, including stiffness and difficulty of mastication. Interestingly, the higher the classification grade of a food item, the higher the amount (g) of protein and potassium per 100 g of the food item (**Appendix 1**). Furthermore, an individual who self-assesses as being able to consume food classified in a higher grade (e.g., grade IV items) could most probably consume those in the lower grades (i.e., grades I, II, and III items). Thus, IFS improvement might reflect much wider nutritional improvement in terms of dietary diversity than the estimated intake of protein and potassium. In other words, individuals with a higher IFS might be able to ingest a wider variety of nutrients in the foods contained in the grades lower than itself. On the other hand, several previous studies demonstrated that recovery of masticatory function by prosthodontic treatment did not always change the status of nutritional intake[24,25]. Meanwhile, most recently, studies have indicated a positive relationship between the two. For example, the combination of prosthodontic treatment and dietary counselling was effective in improving the nutritional intake status[26–29]. Considering these recent findings and the results of this study, prosthodontic treatment can improve the IFS (increase in ability to chew foods with tougher textures). Educating and motivating patients regarding good nutrition when IFS is improved can lead to higher dietary diversity. Additional future research is needed to examine the impact of improved IFS on genuine nutrient intake.

Regarding the baseline characteristics of the study participants, the results indicated that the mean age and number of restored teeth in the CD and CD/RPD groups were significantly higher than those in the other groups. As it is well-known that the number of missing teeth increases with age[30], this difference is not surprising. Regarding the ingestible food profile, the baseline median IFSs (range: 0-100) in the Cr (96.8) and Br (98.4) groups were significantly greater than those in the other groups (RPD: 79.5; CD: 52.0; CD/RPD: 62.5). The significantly higher number of present teeth in the Cr and Br groups contributed to the baseline IFS difference. Judging from the IFS values, it is clear that the ingestible food profile was severely compromised in RPD and CD patients. If this compromised condition continues without appropriate prosthodontic rehabilitation, the deteriorating effect on nutrition, physiological health, and cognitive function could accumulate for years, potentially leading to malnutrition, loss of independence, cognitive impairment, and even mortality[31]. Therefore, prosthodontic rehabilitation plays a critical role in maintaining general health, and the potential decline in masticatory function and nutritional status in non-rehabilitated individuals should not be ignored.

The results of the multiple linear regression analysis showed that the number of present teeth was a significant predictor of IFS at the baseline. These results are consistent with those of several previous studies[14,15,32], indicating high external validity. Further, the baseline OHIP-J54 scores significantly correlated with the IFS at the baseline. Statistical significance was evident, even after adjusting for the number of present teeth. Interestingly, Nanri *et al.*[33] reported that a higher frequency of fruit and/or vegetable consumption was related to higher OHRQoL, even after adjustment for subjective masticatory ability and denture use in Japanese community-dwelling people.

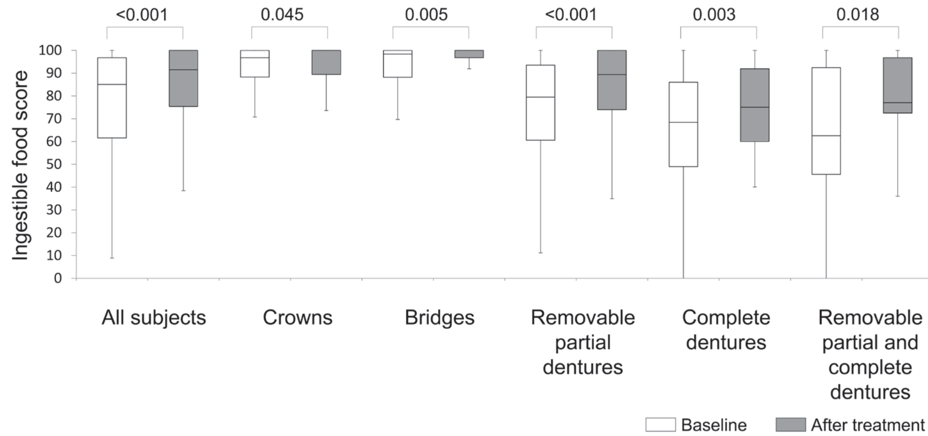

Fig. 2. Comparison of ingestible food score before and after treatment (Wilcoxon signed-rank test)

Table 3. Predictors of ingestible food score at baseline

Variable	Model 1		Model 2	
	P-value	SRC	*P*-value	SRC
Age	0.915	0.019	0.343	0.086
Sex	0.107	2.561	0.652	0.625
Number of present teeth	**<0.001**	**1.015**	**<0.001**	**0.815**
OHIP-J54 score at baseline	-		**<0.001**	**-0.360**
R^2	0.177		0.413	

Multiple linear regression,dependent variable: Ingestible food score at baseline. SRC: standard regression coefficient; OHIP: Oral Health Impact Profile

Table 4. Predictors of ingestible food score change between before and after-treatment scores

Variable	Model 1		Model 2	
	P-value	SRC	*P*-value	SRC
Age	0.786	0.021	0.094	0.090
Sex	0.209	0.082	0.966	0.630
Treatment modality	0.746	-0.107	0.358	-0.061
Number of present teeth	0.208	-0.320	**0.015**	**-0.810**
Duration of treatment (months)	**0.006**	**-0.193**	0.680	-0.317
OHIP-J54 score at baseline	-	-	**<0.001**	**0.251**
R^2	0.210		0.410	

Multiple linear regression,dependent variable: Ingestible food score at baseline. SRC: standard regression coefficient; OHIP: Oral Health Impact Profile

Their findings suggest that being able to eat various foods can be associated with personal pleasure and can improve their quality of life. Further studies are needed to investigate dietary diversity and eating pleasure.

The overall data in this study indicated that all types of prosthodontic treatment improved the IFS. For example, a significant median IFS increase was observed not only in the RPD and FD groups but also in the Cr and Br groups. Since this is the first study to directly investigate the effect of prosthodontic treatment on the ingestible food profile in an epidemiological study setting, the results demonstrating clear IFS improvement in all treatment groups are important. The IFS questionnaire was originally developed for and validated among edentulous older patients, and so the treatment efficacy of the Cr and Br groups might have been underestimated. Neverthless, it is particularly interesting that even a single tooth crown restoration can improve the IFS. Since the average time required to finish prosthodontic rehabilitation was approximately five months and patients were blinded to the pre-treatment IFS, it is unlikely that most participants could remember their pre-treatment assessments after their treatment. Therefore, it can be considered that the improved IFS is a real phenomenon promoted by prosthodontic treatment. Nevertheless, since this study was based on a reanalysis of a previous study's dataset[21], it was not possible to evaluate the correlation between IFS and general health and the socioeconomic environment. Future prospective studies considering the possible confounding factors that affect the ingestible food profile, such as loss of appetite[27], solitary meal situation, and economic status[34], are also required.

Interestingly, the IFS improvement induced by prosthodontic rehabilitation (**Table 4**) was not related to the treatment modality, but to the total treatment time in statistical model 1. However, this significance disappeared when the baseline OHRQoL score was added to the explanatory variables of statistical model 2. Since the baseline OHRQoL score correlated with the total treatment time (a surrogate endpoint of treatment difficulty indices used in a previous study[21]), these two factors could reasonably be considered confounders. Additionally, since the baseline OHRQoL score more weakly correlated with the number of present teeth than to the duration of treatment, the statistical significance of the number of present teeth was recovered by adding the OHRQoL score at baseline in model 2. Consequently, patients with a higher number of present teeth and higher OHRQoL levels (lower OHIP-J54 scores) before treatment had difficulties in improving IFS in this study. This phenomenon can be partially explained by the ceiling effect on the IFS when the number of present teeth in a patient was 28 (no missing) or 27 (one missing). These conditions can be observed for the Cr and Br groups in **Figure 2**. The IFSs after treatment in the Cr and Br groups were almost the highest (100). Conversely, the IFS after treatment in the RPD, CD, and CD/RPD groups was not as high as that of the Cr and Br groups. This indirectly indicates that the masticatory functional improvement by wearing RPDs and CDs is not sufficiently compatible with the Cr and Br groups. Recently, bone-anchored dentures have frequently been used to recover masticatory function in patients with large edentulous areas. Unfortunately, we excluded patients treated with bone-anchored dentures from this study because of the small sample size. Future studies should include such patients to overcome the difficulty of improving the IFS in patients with large edentulous areas.

5. Conclusions

The findings of this multicenter follow-up study indicated that prosthodontic treatment improved the IFS of outpatients in university-based prosthodontic specialty clinics in Japan. Moreover, a lower number of present teeth and poorer OHRQoL at the baseline were related to a lower IFS even after adjusting for confounders at the baseline.

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Conflict of interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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