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Original Article

Association between tongue pressure, masticatory function, and salivary bacterial load in older adults requiring long-term care

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KEYWORDS
Aspiration pneumonia;
Functional tooth unit;
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Tongue pressure

Abstract *Background/purpose:* Aspiration pneumonia is a major cause of mortality among older adults, with salivary bacterial load being a key contributing factor. The aim of this study was to clarify whether oral functions—including occlusal force and masticatory function—were associated with salivary bacterial counts in older individuals requiring long-term care, and to explore the relationship between tongue pressure and other oral functions to inform strategies for maintaining tongue pressure.
Materials and methods: A cross-sectional study was conducted in 80 residents (mean age: 85.4 years) of long-term care facilities in Japan. Participants underwent assessments of tongue pressure, occlusal force, masticatory ability, oral hygiene, and salivary bacterial counts. Multiple regression analysis was used to identify factors associated with increased bacterial load and decreased tongue pressure.
Results: Decreased tongue pressure was significantly associated with increased salivary bacterial counts ($P = 0.011$). In turn, reduced masticatory ability was the only factor significantly associated with decreased tongue pressure ($P = 0.002$). Participants with fewer than 20 teeth exhibited significantly reduced occlusal force and masticatory ability, and tended to have lower tongue pressure.
Conclusion: Tongue pressure plays a pivotal role in controlling salivary bacterial load, and is closely linked to masticatory function. Maintaining oral functions, especially tongue pressure, may help suppress the proliferation of oral bacteria and potentially reduce the risk of

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aspiration pneumonia in frail older adults. Preservation of natural and functional teeth appears critical for supporting these oral functions. Longitudinal studies are warranted to evaluate whether interventions targeting oral function can reduce bacterial load and aspiration pneumonia incidence.

Introduction

Pneumonia is one of the leading causes of death among older adults, and a significant proportion of these cases are aspiration pneumonia. The risk of developing aspiration pneumonia increases when three factors overlap: the presence of pathogenic microorganisms in saliva, the occurrence of aspiration, and a decline in immune function. Therefore, key preventive strategies include suppressing the proliferation of bacteria in saliva, preventing aspiration, and improving nutritional status. Among these, oral care methods focusing on plaque removal have been extensively investigated to reduce pathogenic microorganisms in saliva.[1–5] However, because aspiration pneumonia also occurs in edentulous individuals and patients with percutaneous endoscopic gastrostomy who are not taking food orally, it is suggested that factors other than dental plaque may influence the bacterial load in saliva.

We have previously investigated factors associated with bacterial counts in saliva. In older individuals requiring nursing care, we reported that poor oral hygiene, reduced tongue pressure, a lower level of food consistency, and difficulty in performing oral rinses were associated with increased bacterial counts in saliva.[6,7] The tongue plays a central role in transporting food to the esophagus during swallowing, and sufficient tongue pressure is essential for maintaining both masticatory and swallowing functions.[8,9] While it has been suggested that decreased tongue pressure increases the risk of aspiration of food or saliva into the airway and contributes to the development of aspiration pneumonia,[10] we have also shown that reduced tongue pressure itself is associated with increased bacterial counts in saliva.[6] Therefore, maintaining tongue pressure is important not only for preserving swallowing function but also for suppressing the proliferation of bacteria in saliva. To test our hypothesis that salivary bacterial counts are more strongly associated with oral function than with oral hygiene status, we designed the present study.

Tashiro et al. have reported that a decrease in the number of functional molars is associated with reduced tongue pressure, and that fixed prostheses such as bridges and implants may help maintain tongue pressure.[11] However, no studies to date have examined the relationship between tongue pressure and other oral functions such as occlusal force or masticatory function. We believe that identifying factors associated with tongue pressure will lead to the development of strategies for its maintenance.

The aim of this study was to clarify whether oral functions—including occlusal force and masticatory function—were associated with salivary bacterial counts in older individuals requiring long-term care, and to explore the relationship between tongue pressure and other oral functions to inform strategies for maintaining tongue pressure. These findings are expected to contribute to the development of effective oral health interventions for preventing aspiration pneumonia in frail older individuals requiring nursing care.

Materials and methods

Study design and participants

This study included older adults aged 65 years or older who were residents of three long-term care facilities in Japan and provided informed consent to participate. Exclusion criteria were: individuals able to ambulate independently, those receiving enteral nutrition, individuals with insufficient cognitive ability to undergo tongue pressure measurements, and those diagnosed with neuromuscular diseases such as muscular dystrophy, Parkinson's disease, or amyotrophic lateral sclerosis.

Factors examined

The following parameters were assessed: sex, age, handgrip strength, number of remaining teeth, number of natural and fixed functional tooth units (nif-FTUs), oral hygiene status, presence of oral dryness, tongue coating score, tongue pressure, masticatory ability, occlusal force, and bacterial counts in saliva. Handgrip strength was measured twice on both hands using a digital hand dynamometer (T.K.K.5405; Takei Scientific Instruments Co., Ltd., Niigata, Japan), and the highest value was recorded.[12] Low grip strength was defined as $<$28 kg for men and $<$18 kg for women.

FTU scores were calculated based on the number of paired premolars and molars: one point was assigned for each pair of opposing premolars and two points for each pair of opposing molars.[13] We used nif-FTU, which includes natural teeth and fixed prostheses (bridges and implants). Oral hygiene was assessed using the debris index (DI) from the Oral Hygiene Index (OHI)[14] and the amount of denture plaque. Oral hygiene was defined as good when DI was $<$2 and denture plaque was minimal, and poor when DI was $\geq$2 or denture plaque was extensive. Tongue coating was evaluated according to Winkel's method.[15] The dorsal surface of the tongue was divided into six areas, and each area was scored from 0 to 2: 0 = no coating, 1 = thin coating with visible papillae, 2 = thick coating obscuring the papillae. A total score of $\geq$7 was defined as heavy tongue

coating. Oral dryness was assessed using the Challacombe Scale.[16] Absence of dryness was defined as no adherence of the dental mirror to the buccal mucosa. Presence of dryness was defined as adherence of the mirror to the mucosa or absence of pooled saliva in the floor of the mouth. Tongue pressure was measured using a JMS TPM tongue pressure measurement device (JMS Co., Ltd., Hiroshima, Japan), and values $<$ 20 kPa were considered decreased tongue pressure.[10] The device consists of a probe and a digital manometer with a balloon attached to the probe tip.[17] Masticatory ability was assessed using the Gluco Sensor GS-II (GC Corporation, Tokyo, Japan). Participants were instructed to chew a glucose-containing gummy for 20 s, rinse lightly with 5 mL of water, and expectorate. The glucose concentration in the expectorate was measured to determine masticatory ability. Values $\leq$ 100 indicated reduced masticatory ability.[18] For denture wearers, measurements were performed with dentures in place. Occlusal force was measured using the Dental Prescale II system (GC Corporation, Tokyo, Japan), which uses a pressure-sensitive film embedded with microcapsules and a developing agent. Upon biting, the microcapsules rupture, producing red coloration through a chemical reaction. The force exerted was quantified by analyzing the colored areas after scanning the film. Occlusal force $<$200 N was considered decreased.[19] Measurements for denture wearers were conducted with dentures in place. To ensure consistency in subjective evaluations, all assessments of plaque index, tongue coating score, and oral dryness were performed by the same dentist and the same dental hygienist. When differences in opinions occurred, the evaluators discussed and reached a consensus before finalizing the assessment.

Methods of sample collection and bacterial counts

Saliva samples were collected using 5 mm-wide, 30 mm-long strip-type filter papers (Advantec Blood Collection Strip Type I; Toyobo Co., Ltd., Osaka, Japan) placed under the tongue for 10 s. The top 10 mm of the moistened filter paper was excised for analysis. Bacterial DNA was extracted from the saliva-absorbed filter paper, and the total bacterial count was quantified using real-time PCR targeting the 16S rRNA gene with universal primers. Detailed reaction conditions have been described in previous reports.[20,21]

Statistical analysis

All statistical analyses were performed using SPSS version 26 (IBM Japan, Tokyo, Japan). Factors associated with salivary bacterial count and tongue pressure were examined. Univariate analyses were conducted using the Mann–Whitney U test, and multivariate analyses were performed using multiple regression analysis. A two-tailed *P*-value $<$0.05 was considered statistically significant.

Ethics and registration

The study was conducted between June and July 2025. This study conformed to the ethical guidelines of the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects published by the Ministry of Health, Labour and Welfare of Japan. Ethical approval was obtained from the Institutional Review Board of The Japanese Society of Oral Care (No. E225001). The study was registered with the University Hospital Medical Information Network Clinical Trials Registry (UMIN-CTR) (June 27, 2025; UMIN000058300). Informed consent was obtained from all participants.

Results

Participants' characteristics

A total of 80 participants were enrolled in the study. The cohort included 23 men and 57 women, with a predominance of females. The mean age was 85.4 years. Decreased handgrip strength was observed in 77 participants (96.3 %), reduced masticatory ability in 57 participants (71.3 %), and decreased tongue pressure in 62 participants (77.5 %). In contrast, the reduced occlusal force was present in only 40 participants (50.0 %), indicating that occlusal force was relatively well preserved in many individuals (Table 1).

Table 1 Participants' characteristics.

Factors		Number of participants/ mean ± SD
Sex	Man	23
	Woman	57
Age		85.4 ± 11.6
Oral dryness	(−)	43
	(+)	37
Oral hygiene	Good	40
	Poor	40
Tongue coating index	6 or less	63
	7 or more	17
Hand grip		9.53 ± 7.19
	Normal	3
	Decreased	77
Masticatory ability		79.9 ± 63.4
	Normal	23
	Decreased	57
Occlusal force		278.4 ± 241.8
	Normal	40
	Decreased	40
Tongue pressure		15.0 ± 7.36
	Normal	18
	Decreased	62
nif-FTU		2.29 ± 3.72
Number of teeth		11.8 ± 10.0
Total		80

Abbreviation: SD: standard deviation; nif-FTU: natural teeth and artificial teeth from fixed prostheses or implant-supported functional tooth unit.

Number of total bacteria in saliva and related factors

The mean logarithmic value of the salivary bacterial count was 3.10 ± 3.29. Factors associated with bacterial count were examined. In univariate analysis, decreased tongue pressure was significantly associated with increased bacterial count ($P = 0.007$). Poor oral hygiene tended to be associated with increased bacterial count but did not reach statistical significance ($P = 0.056$) (Table 2).

Stepwise multiple regression analysis including all variables identified decreased tongue pressure as the only factor significantly associated with increased bacterial count in saliva ($P = 0.011$) (Table 3).

Tongue pressure and related factors

The mean tongue pressure was 15.0 ± 7.36 kPa. In univariate analysis, decreased tongue pressure was significantly associated with female sex ($P = 0.025$), poor oral hygiene ($P = 0.035$), reduced masticatory ability ($P = 0.003$), and decreased occlusal force ($P = 0.048$). A number of remaining teeth less than 20 showed a trend toward association with decreased tongue pressure, but this did not reach statistical significance ($P = 0.055$) (Table 4).

In stepwise multiple regression analysis including all variables, reduced masticatory ability was the only factor significantly associated with decreased tongue pressure ($P = 0.002$) (Table 5).

Number of teeth and oral function

Having fewer than 20 remaining teeth was significantly associated with decreased occlusal force ($P = 0.011$) and reduced masticatory ability ($P = 0.002$). It also showed a trend toward association with decreased tongue pressure, although this was not statistically significant ($P = 0.055$).

Table 2 Factors related to the bacterial count in saliva (Univariate analysis).

Factors		Median of number of bacteria [25, 75 percentile]	*P*-value
Sex	Man	1.83 [1.64, 3.86]	0.220
	Woman	2.54 [1.99, 3.67]	
Age	<85	2.11 [1.69, 4.07]	0.392
	≥85	2.72 [1.95, 3.54]	
Oral dryness	(−)	2.48 [1.75, 3.25]	0.858
	(+)	2.51 [1.81, 3.91]	
Oral hygiene	Good	2.23 [1.69, 3.11]	0.056
	Poor	2.88 [1.84, 4.02]	
Tongue coating index	6 or less	2.43 [1.74, 3.48]	0.256
	7 or more	2.88 [2.03, 4.45]	
Hand grip	Normal	1.42 [1.00, 1.42]	0.452
	Decreased	2.51 [1.78, 3.71]	
Masticatory ability	Normal	2.16 [1.65, 3.35]	0.172
	Decreased	2.59 [1.84, 3.85]	
Occlusal force	Normal	2.47 [1.69, 3.97]	0.822
	Decreased	2.51 [1.84, 3.17]	
Tongue pressure	Normal	1.85 [1.40, 2.68]	0.007*
	Decreased	2.72 [1.93, 3.96]	
nif-FTU	≥1	2.51 [1.76, 4.31]	0.255
	0	2.50 [1.75, 3.16]	
Number of teeth	≥20	2.95 [1.73, 4.33]	0.281
	<20	2.47 [1.76, 3.30]	

Abbreviation SD: standard deviation nif-FTU: natural teeth and artificial teeth from fixed prostheses or implant-supported functional tooth unit Statistical significance at $P < 0.05$ is indicated by an asterisk (*).

Table 3 Multiple regression analysis for relationship between bacterial count and each variable.

	Unstandardized coefficients		Standardized coefficients	95 % confidence interval		*P*-value
	B	SE	β	Lower	Upper	
Tongue pressure (decreased/Normal)	0.842	0.325	0.283	0.195	1.490	0.011*

Adj. R2 = 0.068. Stepwise selection.
Statistical significance at $P < 0.05$ is indicated by an asterisk (*).

Table 4 Factors related to the tongue pressure.

Factors		Median of tongue pressure [25, 75 percentile]	*P*-value
Sex	Man	17.5 [12.4, 23.6]	0.025*
	Woman	13.3 [8.55, 17.8]	
Age	<85	15.3 [10.1, 24.0]	0.215
	≥85	14.5 [8.7, 17.5]	
Oral dryness	(−)	15.0 [10.3, 19.5]	0.390
	(+)	14.2 [8.3, 19.1]	
Oral hygiene	Good	15.6 [10.9, 23.2]	0.035*
	Poor	12.0 [8.7, 17.5]	
Tongue coating index	6 or less	15.0 [8.9, 21.6]	0.338
	7 or more	12.0 [9.6, 16.4]	
Hand grip	Normal	26.5 [0, 26.5]	0.452
	Decreased	14.7 [9.48, 18.9]	
Masticatory ability	Normal	18.2 [14.0, 24.9]	0.003*
	Decreased	12.9 [8.3, 17.5]	
Occlusal force	Normal	16.3 [10.5, 21.9]	0.048*
	Decreased	12.0 [8.7, 17.4]	
nif-FTU	≥1	15.1 [11.0, 20.2]	0.348
	0	13.5 [8.5, 18.5]	
Number of teeth	≥20	18.9 [11.1, 23.6]	0.055
	<20	14.1 [8.6, 17.5]	

Abbreviation: SD: standard deviation.
nif-FTU: natural teeth and artificial teeth from fixed prostheses or implant-supported functional tooth unit.
Statistical significance at $P < 0.05$ is indicated by an asterisk (*).

Table 5 Multiple regression analysis for relationship between tongue pressure and each variable.

	Unstandardized coefficients		Standardized coefficients	95 % confidence interval		*P*-value
	B	SE	β	Lower	Upper	
Masticatory ability (decreased/Normal)	−5.602	1.757	−0.341	−9.101	−2.103	0.002*

Adj. R2 = 0.105. Stepwise selection.
Statistical significance at $P < 0.05$ is indicated by an asterisk (*).

Table 6 Relationship between number of teeth and oral function.

Variable		Median of tongue pressure [25, 75 percentile]	*P*-value
Number of teeth	≥20	18.2 [11.3, 23.1]	0.055
	<20	14.1 [8.6, 17.5]	
nif-FTU	>1	14.9 [11.0, 20.1]	0.348
	0	13.5 [8.5, 18.5]	
Variable		Median of occlusal force [25, 75 percentile]	*P*-value
Number of teeth	≥20	327.4 [161.1, 594.6]	0.011*
	<20	182.4 [113.2, 294.4]	
nif-FTU	>1	314.7 [161.1, 553.0]	0.001*
	0	174.0 [105.3, 262.0]	
Variable		Median of masticatory ability [25, 75 percentile]	*P*-value
Number of teeth	≥20	105.0 [59.0. 136.0]	0.002*
	<20	61.0 [25.5, 93.8]	
nif-FTU	>1	99.0 [47.0, 131.3]	0.001*
	0	52.0 [24.0, 81.5]	

Abbreviation: nif-FTU: natural teeth and artificial teeth from fixed prostheses or implant-supported functional tooth unit.
Statistical significance at $P < 0.05$ is indicated by an asterisk (*).

Participants with no functional molar occlusion (nifFTU = 0) had significantly lower occlusal force ($P = 0.001$) and masticatory ability ($P = 0.001$), but there was no significant association with tongue pressure (Table 6).

Summary of findings

These results indicate that increased bacterial counts in saliva were significantly associated with decreased tongue pressure. Furthermore, reduced tongue pressure was significantly associated with reduced masticatory ability. Preservation of natural teeth was found to be beneficial for maintaining occlusal force and masticatory function.

Discussion

This study demonstrated that, among older adults requiring long-term care who consume food orally, decreased tongue pressure was significantly associated with increased bacterial counts in saliva.

In recent years, the relationship between oral hygiene and the prevention of aspiration pneumonia has been increasingly reported.[22] Yoneyama et al. showed that oral care interventions—including toothbrushing after every meal, oral swabbing with povidone-iodine by nursing staff, and weekly professional oral care—significantly reduced the incidence of pneumonia in older adult care facilities.[1] A closer examination of their study reveals that among edentulous individuals (i.e., without dental plaque), the incidence of pneumonia was 20 % in the control group and 9 % in the oral care group, similar to the results for dentate individuals (21 % vs. 9 %). This suggests that the presence of dental plaque alone may not be directly related to the development of pneumonia. While the importance of oral care in preventing aspiration pneumonia is widely recognized, the precise mechanisms of pneumonia development and the most effective oral care strategies remain topics for further investigation.

Pneumonia is a multifactorial disease involving more than just oral bacteria. Manabe et al. identified the need for suctioning, dysphagia, dehydration, and dementia as risk factors for aspiration pneumonia.[23] van der Maarel-Wierink et al. also listed advanced age, male sex, pulmonary disease, swallowing dysfunction, diabetes, severe dementia, ACE genotype, poor oral hygiene, malnutrition, Parkinson's disease, and certain medications as risk factors, noting that oral hygiene contributed only modestly among them.[24] Therefore, a comprehensive risk assessment for aspiration pneumonia must consider multiple factors beyond oral hygiene, particularly dysphagia.

Our previous study in healthy adults without dysphagia showed no association between dental plaque and bacterial counts in saliva. This may be explained by the fact that when oral and swallowing functions—including adequate tongue pressure—are intact, saliva is secreted in sufficient quantity and frequently swallowed, allowing the oral cavity to be constantly rinsed. As a result, even in the presence of abundant dental plaque, bacteria are swallowed along with the saliva before multiplying to high levels. In contrast, when oral function declines, the frequency of swallowing may decrease, leading to the retention and accumulation of bacteria in the saliva. Even in healthy individuals, salivary bacterial counts are highest in the morning, possibly due to a decrease in swallowing during sleep and a consequent reduction in the self-cleansing effect of saliva. These observations suggest a strong relationship between oral function and salivary bacterial load. In particular, the close relationship between swallowing and tongue pressure has been demonstrated in many studies.[25–28] Our findings also suggest that decreased tongue pressure may contribute to increased pneumonia-related mortality via impaired swallowing function.[10] However, methods for preventing or improving tongue pressure remain unclear.[29,30]

Tongue pressure is closely associated with systemic frailty,[10,31,32] and conversely, reduced tongue pressure may exacerbate nutritional and feeding difficulties, thereby promoting further frailty.[33,34] Thus, preventing frailty is critical to preserving tongue pressure. Nonetheless, some frail older adults are able to maintain adequate tongue pressure. In our previous work, we reported that a lower number of functional tooth units (FTUs) was associated with reduced tongue pressure, and that fixed prostheses such as bridges and implants may help preserve tongue pressure.[11] This suggests that the act of mastication may serve as a form of tongue muscle training, potentially preventing a decline in tongue pressure.

Given our findings that reduced tongue pressure was associated with increased salivary bacterial counts, we further explored which oral functions are related to tongue pressure in order to identify possible strategies for its maintenance. Our analysis revealed that older adults with reduced masticatory ability were more likely to have decreased tongue pressure. Various oral function training programs—such as swallowing exercises, tongue training, and speech-based exercises—have been implemented to maintain or improve tongue pressure. However, these interventions often require active cooperation from the individual, which is difficult to obtain in older adults with cognitive decline. Therefore, there is a need for alternative strategies to maintain or improve tongue pressure without relying on patient cooperation. Additionally, a higher number of posterior FTUs was associated with better maintenance of occlusal force and masticatory function. These findings suggest that maintaining oral function is essential for suppressing the increase in salivary bacteria, and that preserving natural and functional teeth plays a key role in maintaining oral function.

However, it should be noted that all of these findings are based on cross-sectional studies. The possibility of unknown confounding factors between tooth retention, oral function, and salivary bacterial load cannot be excluded. Therefore, longitudinal studies are needed to determine whether restoring functional dentition through prosthetic treatment improves oral function and reduces salivary bacterial counts.

This study has several limitations. First, it was a cross-sectional study with a relatively small sample size, which may limit the generalizability of the findings. Second, although the ultimate aim of our research is to contribute to the prevention of aspiration pneumonia in older adults, the current study focused on salivary bacterial count as the endpoint rather than pneumonia incidence itself. Whether an increase in salivary bacterial count directly elevates the

risk of aspiration pneumonia remains uncertain. Third, our bacterial measurements assessed total bacterial counts; specific pathogens and microbiota composition were not analyzed.

Nonetheless, this study suggests that maintaining oral functions such as tongue pressure may help prevent aspiration pneumonia, and that the preservation of functional teeth may play a vital role in this process. Future studies with larger cohorts and longitudinal designs are warranted to further clarify these relationships.

In conclusion, this study demonstrated that among older adults requiring long-term care, decreased tongue pressure is significantly associated with increased bacterial counts in saliva, and that reduced masticatory ability is a key factor related to decreased tongue pressure. Furthermore, the preservation of natural and functional teeth contributes to maintaining occlusal force and masticatory function, which may indirectly support tongue pressure. These findings suggest that comprehensive strategies aimed at maintaining oral functions—particularly tongue pressure—could help suppress the proliferation of oral bacteria and potentially contribute to the prevention of aspiration pneumonia in frail older adults.

Given the cross-sectional nature of this study, causal relationships cannot be definitively established. Future longitudinal studies are needed to determine whether interventions that improve or preserve oral functions—such as prosthetic rehabilitation—can effectively reduce salivary bacterial loads and ultimately lower the risk of aspiration pneumonia.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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