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ORIGINAL ARTICLE

Category of functional tooth units in relation to the number of teeth and masticatory ability in Japanese adults

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Abstract The purposes of this study were (1) to examine differences in dental status among various age groups, particularly, focusing on whether subjects retained 20 or more natural teeth, and (2) to investigate the relationship among dental status, the number and categories of functional tooth units (FTUs), and masticatory ability. A dental examination and self-administered questionnaire were conducted in a total of 2,164 residents aged 40 to 75 years who dwelt in Japan. The percentage of subjects with 20 and more natural teeth and their number of posterior teeth decreased with age. There was not much difference in the mean number of FTUs in subjects with and without 20 or more natural teeth, but those with 20 natural teeth had fewer numbers of FTUs than those with more than 20 natural teeth. The categories of the FTUs were extremely different. Subjects with 20 or more natural teeth had FTUs consisting mostly of natural to natural teeth. Subjects with 19 or fewer natural teeth had many FTUs consisting of removable prosthetic teeth. The subjective chewing ability test was significantly correlated with the number of natural teeth. Subjects could chew the higher number of test foods as the number of natural teeth increased. Not only the number of natural teeth but the categories of FTUs appear to be key factors of chewing ability. It is important to keep as many natural teeth as possible so that the person's categories of FTUs are mainly composed of natural to natural teeth to maintain better oral function.

Keywords Functional tooth units · Masticatory ability · Tooth loss · Shortened dental arch · Prostheses

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Introduction

Dental status can be evaluated with a variety of indexes. One important index representing oral health is the number of natural teeth [1–4]. Tooth loss can occur either from loss due to progressive dental disease (e.g., dental caries and periodontal disease) or trauma. Our preceding study has reported that loss of natural teeth will decrease masticatory function [5].

Another significant index is a functional tooth units (FTUs) that is defined as pairs of opposing teeth. It has been used to evaluate oral function and masticatory performance [6–17]. Our previous study also demonstrated that the number of FTUs is an important determinant of masticatory performance [5]. A lower number of FTUs is not only associated with chewing difficulties but an association also exists between a reduced number of FTUs and physical disabilities [12].

Internationally, the World Health Organization set "the retention, throughout life, of a functional, esthetic, natural dentition of not less than 20 teeth and not requiring recourse to prostheses" as a goal for oral health in 1982 [18]. The Federation Dentaire Internationale also recommended a goal of 50% of individuals 65 years and older having 20 and more natural teeth [19].

In Japan, the Ministry of Health and Welfare and the Japan Dental Association jointly began the 8020 Campaign in 1989 to encourage the Japanese to keep at least 20 or more natural teeth until the age of 80, the approximate Japanese life expectancy. In 2000, the national "Healthy Japan 21" plan was initiated, focusing on health promotion and increased life expectancy. The plan included the promotion of better oral health to achieve its goals, which were to help people prevent tooth loss so that they could retain at least 20 teeth throughout their lifetimes.

Although the goal of maintaining 20 and more natural teeth has been announced worldwide, no study has investigated in detail the importance and significance of keeping one's own natural teeth using an index like FTUs. Thus, the purposes of this study were (1) to examine the dental condition in Japanese adults, particularly focusing on whether they retain 20 or more natural teeth, and (2) to investigate the relationship among natural teeth, FTUs, and masticatory ability.

Materials and methods

Details of the sampling method, examination procedure, and indexes used have been described in a preceding paper [5].

Subjects

Subjects were community residents aged 40 to 75 years, who dwelt in Yokote Health Center Jurisdiction, Akita Prefecture, Japan. Invitation letters informing about the purposes and the design of the study and seeking participation in the research were mailed to all subjects. Convenience sample consisted of 2,177 subjects who agreed to participate and signed the informed consent form. Investigation was carried out from July, 2005 through December, 2006. After excluding subjects who had incomplete data, a total of 2,164 people (916 men, mean age=61.7, SD=8.8 years old; 1,248 women: mean age=59.8, SD=9.2 years old) were used for the analysis.

Clinical dental examination

Clinical dental examinations of tooth status (third molars were excluded) were performed by trained and calibrated dentists. Standardized clinical dental criteria [20] were instructed beforehand at the meeting, and a handbook describing the detailed criteria was also distributed to all participating dentists. The dentists examined caries status as well as types of prosthetic restoration.

Functional tooth units

The number of FTUs was defined as pairs of opposing posterior natural (i.e., sound, restored and D_1–D_4 scale carious teeth) and artificial teeth on implant-supported, fixed (bridge pontics), and removable prostheses. D_4 scale carious teeth with extensive coronal destruction and missing teeth were regarded as non-functional. Two opposing premolars were defined as one FTU and two opposing molars were defined as two FTUs with 12 FTUs of a complete dentition (third molars were excluded). The total number of FTUs, divided into six categories (natural to natural teeth, fixed prosthetic to natural teeth, fixed to fixed prosthetic teeth, removable prosthetic to natural teeth, removable to fixed prosthetic teeth, and removable to removable prosthetic teeth), was evaluated at the subject level and at the opposing tooth pair level (i.e., 17/47, 16/46, 15/45, 14/44, 24/34, 25/35, 26/36, and 27/37).

Questionnaire

Self-administered questionnaire items consisted of demographic information (age and sex) and Yamamoto's chewing ability test questions that asked if the subject was able to chew the 15 test foods [5, 21, 22].

Statistical analysis

The number of subjects with or without 20 and more natural teeth by age group (40–49, 50–59, 60–69, and 70–75 years) was calculated, and the distributional differences of frequency were analyzed with chi-square tests. The mean numbers of posterior teeth and FTUs by age group were examined in subjects with and without 20 or more natural teeth. Age and sex adjustment was done by specifying these variables as covariates in the ANCOVA, after which the differences of the adjusted mean number of each FTU category between the two groups were analyzed with the *t* test. The proportion of each FTU category by opposing tooth pair was also investigated. The relationship between Yamamoto's chewing ability test and the number of natural teeth was assessed with Pearson's correlation. The statistical analysis was performed with the SPSS15.0J software.

Ethics

This study protocol was approved by the Tokyo Medical and Dental University Ethical Committee.

Results

Proportion of subjects with and without 20 or more natural teeth

Almost all subjects in the 40–49 age group had 20 or more natural teeth, but fewer than half of subjects in the 70–75

Table 1 Frequency and mean number of posterior teeth and FTUs in subjects with and without 20 or more natural teeth by age group

Age group	Number of natural teeth					
	20 and more	19 and less	20 and more	19 and less	20 and more	19 and less
	Number (%) of subjects		Number (95% CI) of posterior teeth		Number (95% CI) of FTUs	
40–49	294 (98.0)	6 (2.0)	14.3 (14.1, 14.5)	7.3 (3.9, 10.8)	10.5 (10.2, 10.7)	8.3 (3.9, 12.8)
50–59	544 (83.7)	106 (16.3)	13.7 (13.5, 13.9)	5.6 (5.1, 6.2)	10.1 (9.9, 10.3)	8.4 (7.6, 9.2)
60–69	499 (66.1)	256 (33.9)	13.2 (13.0, 13.4)	4.2 (3.8, 4.5)	10.0 (9.8, 10.3)	10.4 (10.0, 10.7)
70–75	181 (39.4)	278 (60.6)	12.9 (12.6, 13.2)	3.5 (3.1, 3.8)	9.8 (9.4, 10.2)	10.6 (10.3, 11.0)
Total	1518 (70.0)	646 (30.0)	13.5 (13.4, 13.7)	4.1 (3.9, 4.4)	10.1 (10.0, 10.2)	10.1 (9.9, 10.4)

age group had 20 or more natural teeth (Table 1). The percentage of subjects with 20 or more natural teeth decreased with age, and a significant distributional difference was observed ($p<0.001$).

Number of posterior teeth and FTUs

The mean number of posterior teeth declined with age regardless of the fact that subjects had 20 or more natural teeth or not. The mean number of FTUs in subjects with 20 or more natural teeth had a decreasing trend with age, while among those with 19 or fewer natural teeth, there was an increasing trend with age. In the 40–49 and 50–59 age groups, the mean numbers of FTUs in subjects with 20 or more natural teeth were slightly higher than those with 19 or fewer natural teeth, but the mean numbers of FTUs were almost the same in the 60–69 and 70–75 age groups.

Number of FTU categories by subject level

As displayed in Table 2, the mean numbers of total FTUs were 10.14 in subjects with 20 or more natural teeth and 10.11 in those without, and no significant difference was detected. However, the mean number of each FTU category differed significantly between the two groups at $p<0.05$. Among subjects with 20 or more natural teeth, FTUs with natural to natural teeth was predominant (8.02), followed by fixed prosthetic to natural teeth (1.05). The other FTU categories were all less than 1.00. In contrast, among those with 19 or fewer natural teeth the mean number of FTUs based on natural to natural teeth was very small (1.12), and removable to removable prosthetic teeth (5.04) and removable prosthetic to natural teeth (3.33) were the two main categories. All other FTU categories were less than 0.50.

Subjects with 20 or more natural teeth were further divided into two groups: subjects with more than 20 natural teeth including first molars ($N=1,427$) and those with 20 natural teeth ($N=70$). Subjects with more than 20 natural teeth had similar numbers of each FTU category to those with 20 or more natural teeth (Table 3). Among subjects with 20 natural teeth, the mean number of total FTUs was slightly low (8.10), and FTUs with natural to natural teeth (3.58) and removable prosthetic to natural teeth (2.96) were the two major categories.

Table 2 Adjusted mean number (adjusted for sex and age; 95% CI) of FTUs categories in subjects with and without 20 or more natural teeth

FTUs	Number of natural teeth		*p* value
	20 and more teeth	19 and less teeth	
n–n	8.02 (7.88, 8.16)	1.12 (0.89, 1.35)	<0.001
f–n	1.05 (0.99, 1.12)	0.17 (0.06, 0.28)	<0.001
f–f	0.08 (0.06, 0.10)	0.04 (0.01, 0.07)	<0.05
r–n	0.81 (0.68, 0.93)	3.33 (3.13, 3.53)	<0.001
r–f	0.06 (0.03, 0.09)	0.41 (0.36, 0.46)	<0.001
r–r	0.12 (0.00, 0.26)	5.04 (4.82, 5.27)	<0.001
Total	10.14 (10.00, 10.28)	10.11 (9.89, 10.33)	n.s.

n.s. not significant, *n–n* natural to natural teeth, *f–n* fixed prosthetic to natural teeth, *f–f* fixed to fixed prosthetic teeth, *r–n* removable prosthetic to natural teeth, *r–f* removable to fixed prosthetic teeth, *r–r* removable to removable prosthetic teeth

Table 3 Adjusted mean number (adjusted for sex and age; 95% CI) of FTUs categories in subjects with more than 20 natural teeth including first molars and 20 natural teeth

FTUs	Number of natural teeth		*p* value
	More than 20 teeth	20 teeth	
n–n	8.52 (8.37, 8.68)	3.58 (2.89, 4.26)	<0.001
f–n	1.04 (0.96, 1.12)	0.85 (0.50, 1.20)	n.s.
f–f	0.07 (0.05, 0.09)	0.06 (0.00, 0.14)	n.s.
r–n	0.60 (0.51, 0.70)	2.96 (2.52, 3.39)	<0.001
r–f	0.04 (0.02, 0.06)	0.34 (0.26, 0.42)	<0.001
r–r	0.01 (0.00, 0.02)	0.31 (0.24, 0.38)	<0.001
Total	10.28 (10.16, 10.40)	8.10 (7.53, 8.64)	<0.001

n.s. not significant, *n–n* natural to natural teeth, *f–n* fixed prosthetic to natural teeth, *f–f* fixed to fixed prosthetic teeth, *r–n* removable prosthetic to natural teeth, *r–f* removable to fixed prosthetic teeth, *r–r* removable to removable prosthetic teeth

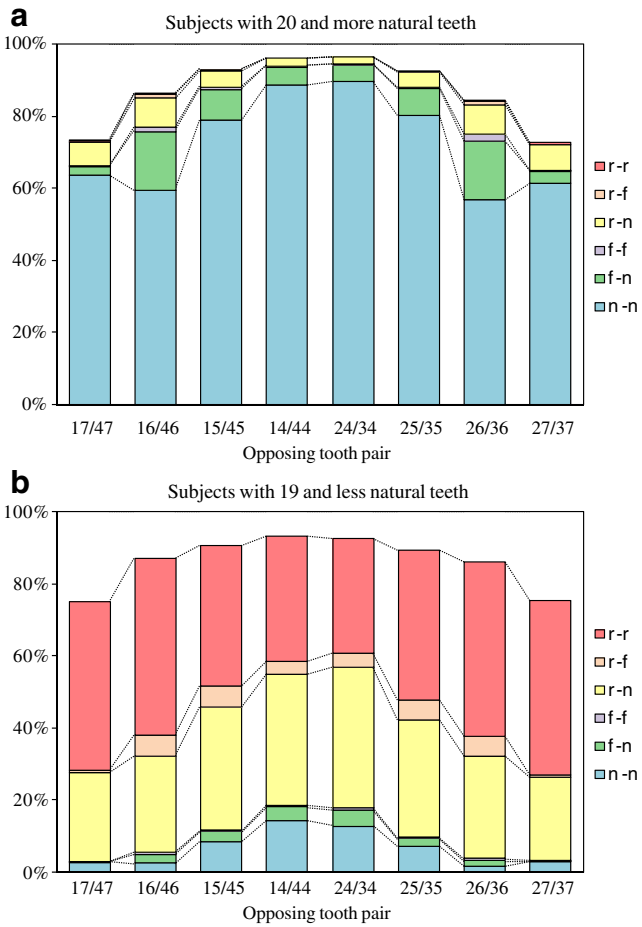

Fig. 1 Percentage of FTU categories at opposing tooth pair level in subjects with (**a**) and without (**b**) 20 or more natural teeth (*n–n* natural to natural teeth, *f–n* fixed prosthetic to natural teeth, *f–f* fixed to fixed prosthetic teeth, *r–n* removable prosthetic to natural teeth, *r–f* removable to fixed prosthetic teeth, *r–r* removable to removable prosthetic teeth)

Percentage of FTU categories by opposing tooth pair level

There was no apparent difference in the percentage of total FTUs at each opposing tooth pair between subjects with and without 20 natural teeth (Fig. 1). The percentage of total FTUs was highest in first premolars and gradually decreased toward second molars in both groups: approximately 95% in first premolars, 90% in second premolars, 85% in first molars, and 75% in second molars.

FTUs with natural to natural teeth were dominant in subjects with 20 or more natural teeth, while FTUs composed of removable prostheses (i.e., removable to removable prosthetic teeth, removable prosthetic to natural teeth, and removable to fixed prosthetic teeth) were 70% to 80% in subjects with 19 or fewer natural teeth. Among subjects with 20 or more natural teeth, approximately 60% for molars and 80% to 90% for premolars were FTUs with natural to natural teeth, and the percentage was higher for second molars than for first molars. Among subjects with 19 or fewer natural teeth, only 2% to 3% for molars and 10% to 15% for premolars were FTUs with natural to natural teeth. The FTUs with removable to removable prosthetic teeth were slightly higher for molars (around 50%) than for premolars (30% to 40%). In contrast, FTUs from removable prosthetic to natural teeth were slightly higher for premolars (30% to 40%) compared to molars (25% to 30%).

The percentage of each FTU category in subjects with more than 20 natural teeth was very similar to that in those with 20 or more natural teeth (Fig. 2). On the other hand, the percentage of total FTUs was lower, especially in molars, among subjects with 20 natural teeth. The percentages of FTUs with natural to natural teeth were around 60% in premolars and less than 20% in molars, and higher percentages of FTUs with removable prosthetic to natural teeth were observed in second premolars and molars.

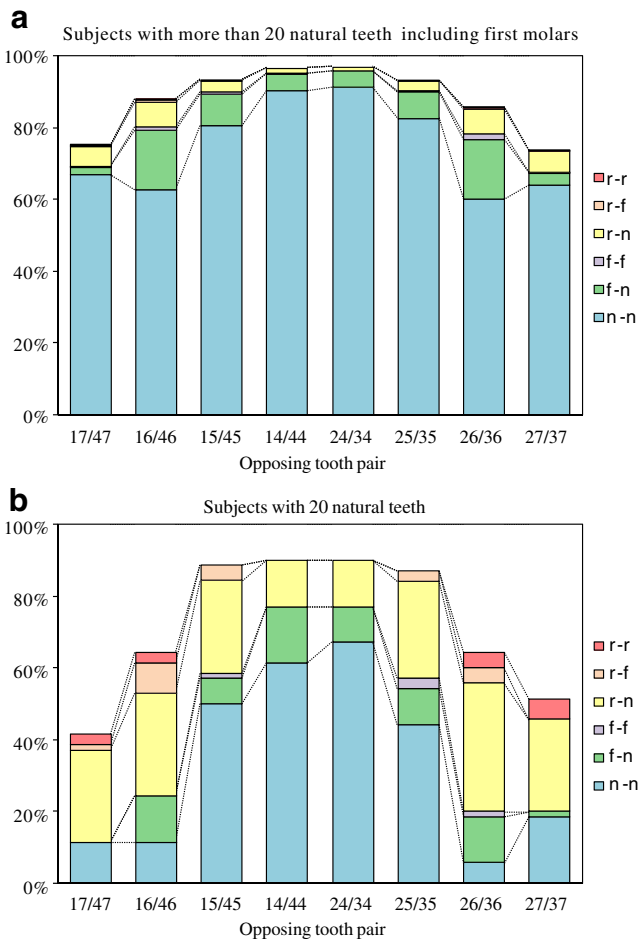

Fig. 2 Percentage of FTU categories at opposing tooth pair level in subjects with (**a**) more than 20 natural teeth including first molars and with (**b**) 20 natural teeth (*n–n* natural to natural teeth, *f–n* fixed prosthetic to natural teeth, *f–f* fixed to fixed prosthetic teeth, *r–n* removable prosthetic to natural teeth, *r–f* removable to fixed prosthetic teeth, *r–r* removable to removable prosthetic teeth)

Masticatory ability and number of teeth

There was a significant correlation between the number of Yamamoto's 15 chewing ability test foods which subjects reported they could chew and the number of natural teeth (r= 0.55, p<0.001). Subjects could chew the higher number of foods as the number of natural teeth increased. A higher proportion of subjects with 20 or more natural teeth could chew all 15 foods (70.6%) compared to those with 19 or fewer natural teeth (19.2%). Among subjects with 20 or more natural teeth, 72.9% of subjects with more than 20 natural teeth could chew all 15 foods and 28.6% of those with 20 natural teeth.

Discussion

This study of the relationship among dental status, the number and categories of FTUs, and masticatory ability indicated that retaining as many natural teeth as possible is preferable to maintain appropriate oral function. Käyser [23–25] reported that at least 12 anterior teeth and eight premolars are necessary for satisfactory biting and chewing. Witter [26] also suggested that, as long as people maintained 20 well-distributed teeth, there was an adaptive mechanism to maintain adequate oral function. On the other hand, an impairment of masticatory ability is thought to occur when fewer than 20 teeth are present [27–29]. Similar conclusions were also drawn in Japan. It is stated that maintaining more than 20 teeth was necessary for mastication [30] and people with 20 or more teeth could eat most types of Japanese foods [31–33]. People who have 20 or more remaining teeth also show better oral condition and health status than those who have less than 20 teeth [34, 35]. According to the Japanese dental survey [36] conducted in 2005, the mean number of retained teeth in the Japanese elderly (65 years and older) was less than 20. Thus, there is much room for improvement in dental status of the Japanese elderly.

There are researches that examine the total number of FTUs [11, 12, 37], but no study investigates the categories of the FTUs or FTUs at the opposing tooth pair level. Comparison of the number of FTUs in subjects with and without 20 or more natural teeth indicated that the mean number of FTUs did not differ, although those with 20 natural teeth had fewer numbers of FTUs than those with more than 20 natural teeth by approximately two.

The categories of the FTUs were extremely different depending on the number of natural teeth. Not only did subjects with 20 or more natural teeth have natural to natural teeth as the dominant category of FTUs, but they had fewer FTUs with removable prosthetic teeth compared to those with 19 or fewer natural teeth. The latter had very few FTUs with natural to natural teeth and many FTUs with removable prosthetic teeth. Subjects with 20 or more natural teeth had more than 9.1 FTUs based on natural or fixed prosthetic teeth out of 10.1 total FTUs. On the other hand, those with 19 or fewer natural teeth had more than 8.7 FTUs based on removable prosthetic teeth out of 10.1 total FTUs. Even among subjects with 20 or more natural teeth, those with 20 natural teeth had fewer number of FTUs with natural to natural teeth and higher number of FTUs with removable prosthetic to natural teeth compared to those with more than 20 natural teeth. In other words, people with fewer natural teeth tended to have their missing teeth restored with dentures. Consequently, they had a higher number of FTUs with removable prosthetic teeth.

An analysis of FTU categories at the opposing tooth pair level revealed that the overall distribution of total FTUs was similar, whether or not subjects had 20 or more natural teeth. The percentage of FTUs was higher in the premolars than in the molars. The proportion of FTUs with natural to natural teeth was also higher in the premolars than in the molars in subjects with 20 or more natural teeth, while FTUs with natural to natural teeth had been replaced with removable prosthetic to natural teeth or removable to removable prosthetic teeth in those with 19 or fewer natural teeth. The investigation of subjects with 20 or more natural teeth also showed that those with 20 natural teeth had very low percentages of FTUs with natural to natural teeth, particularly in molars, compared to those with more than 20 natural teeth.

Subjective masticatory function, as determined from Yamamoto's chewing ability test suggested that ease of eating was clearly influenced by the number of natural teeth, with chewing becoming easier with a greater number of natural teeth. More than 70% of subjects with 20 or more natural teeth reported they could chew all 15 foods, thus having many natural teeth was considered important for people to eat and enjoy meals with a wide range of foods. In contrast, less than 20% of subjects with 19 or fewer natural teeth could chew all foods. Therefore, people are more likely to experience chewing difficulty if they lose their natural teeth. Those results suggested that the shortened dental arch (SDA) [29, 38], which was defined as having an intact anterior region but a reduced number of posterior teeth, was not sufficient for appropriate mastication.

The masticatory ability also depends on the number of FTUs, and a loss of FTUs is reported to be a key variable in the decrease of masticatory performance [13–16]. In this study, however, the findings from FTUs category imply that even if the total number of FTUs increases as a result of removable prosthodontic treatment, it may not yield a significantly improved masticatory function. Thus, when FTUs are recovered with dentures, they appear to be poor substitutes for natural teeth in chewing foods, possibly due

to various factors, including a lack of retention, poor adaptation, poor stability, and reduced bite force as suggested in previous studies [39–41]. Maintaining as many occluding pairs of natural teeth as possible is essential in reducing the likelihood of chewing difficulty [9, 11, 17] and masticatory function is not improved with removable dentures [42–44]. Hence, we suggest that not only the number of FTUs but also the category of the FTUs are relevant factors affecting masticatory function.

As shown in this study, the number of retained natural teeth and categories of the FTUs are key factors of chewing ability. These results add evidence that maintenance of these factors may be of primary importance for promoting a healthy oral condition. It is reported that the SDA influences not only on mastication, oral function, and temporomandibular joint but on the oral health-related quality of life [23, 45]. Therefore, it is important to maintain as many natural teeth as possible and to avoid replacing lost posterior teeth with removable prostheses. Keeping the FTUs with natural to natural teeth better maintains good oral function.

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Conflict of interest statement We have no conflict of interest.

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