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ORIGINAL ARTICLE

# Relationship between remaining teeth and self-rated chewing ability among population aged 45 years or older in Kaohsiung City, Taiwan

**Kun-Jung Hsu [a,b], Yea-Yin Yen [c], Shou-Jen Lan [d], Yi-Min Wu [e,f], Chun-Min Chen [e,g], Huey-Er Lee [e,h,*]**

[a] *School of Dentistry, College of Dental medicine, Kaohsiung Medical University, Kaohsiung, Taiwan*
[b] *Department of Family Dentistry, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan*
[c] *Department of Dental Hygiene, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan*
[d] *Department of Healthcare Administration, College of Health Science, Asia University, Taichung, Taiwan*
[e] *Department of Dentistry, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan*
[f] *Department of Periodontics, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan*
[g] *Department of Oral and Maxillofacial Surgery, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan*
[h] *Department of Prosthodontics, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan*

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**KEYWORDS**
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Remaining tooth

**Abstract** The purposes of this study were to (1) examine the relationship between the number of various types of healthy remaining natural teeth at different sites and self-rated chewing ability and (2) evaluate the relationship between the number of functional tooth units (FTUs), comprising functional natural teeth (FNT) or fixed prostheses, and self-rated chewing ability. A sample of 296 adults (122 men and 174 women), aged 45 years or older (average age, 56.6 ± 9.7), were recruited from seven dental clinics in Kaohsiung City. Dental information on the number and status of remaining teeth was obtained through examination by trained and calibrated dentists. Self-assessment of chewing ability (masticatory score) was evaluated with a self-administered questionnaire. Results showed that increased age is associated with a greater likelihood of difficulty in chewing. To avoid chewing difficulty, at least 24.7 FNT, 13.3 posterior-FNT, 8.1 units of natural tooth-FTUs, or 9.6 units of fixed tooth-FTUs must remain. Age and the number of healthy remaining teeth, including natural teeth and fixed prostheses, are key factors in chewing ability. Given that aging is unavoidable, the preservation of healthy remaining teeth plays a relatively important role in the maintenance of chewing ability among middle-aged and elderly people.


* Corresponding author. Department of Prosthodontics, Kaohsiung Medical University Hospital, No. 100, Tzyou 1st Road, San Ming District, Kaohsiung 807, Taiwan.
*E-mail address:* kjhsu@cc.kmu.edu.tw (H.-E. Lee).

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## Introduction

Research [1,2] has indicated that a decrease in the number of teeth threatens good health, particularly in people older than 55 years. Probable reasons [3,4] include the impact of tooth loss on digestive function because of food not being chewed adequately; people suffering from tooth loss may also alter their diet or eating efficiency and, thereby, fail to provide the body with adequate nutrition. Studies have also pointed out that chewing ability directly impinges on the quality of life [5,6], life expectancy [7], and the mortality rate [8] among the elderly. Reducing the number of missing teeth in people older than 65 years was the main goal of a World Health Organization initiative in 2000 [9]. In addition, Japan's 8020 Campaign [10] of 1987 and the Healthy Japan 21 in 2000 [11] encouraged people to preserve at least 20 natural teeth until the age of 80 years. The purpose was to maintain chewing ability in the elderly. All of these are evidence of the widespread recognition that chewing problems resulting from tooth loss have a significant impact on the health and quality of life of middle-aged and elderly people.

One previous study [12] showed that chewing difficulty was 2.7 times more likely to occur among people suffering from tooth loss compared with those with intact teeth. Factors believed to influence chewing ability include tooth loss, the number of remaining teeth [13,14], and whether the remaining teeth comprise 20 or more natural teeth [15—19]. Some studies have indicated that the following are key factors impacting chewing ability: number of posterior teeth [17—19]; pairs of occluding natural teeth [20]; functional units (defined as any opposing natural or prosthetic tooth pair) [7,21]; and occlusal units or functional tooth units (FTUs) (defined as pairs of occluding posterior natural teeth or fixed prostheses where an occluding molar pair was counted as 2 units and an occluding premolar pair was counted as 1 unit) [17,18,22—24].

The results of those studies postulated that the number of various types of remaining teeth has a significant impact on chewing ability. However, in addition to quantity of teeth, quality is important. It was hypothesized that the key factor influencing chewing ability is the number of healthy remaining teeth; the concept of health here includes the integrity of tooth structures and the presence of any symptoms of discomfort (e.g. pain). In this study, an advanced definition of health was proposed to evaluate the impact of the number of healthy remaining teeth, including healthy natural teeth and fixed prostheses, on chewing ability.

The objectives of this study were to (1) examine the relationship between the number of various types of healthy remaining natural teeth at different sites and self-rated chewing ability and (2) evaluate the relationship between FTUs comprising healthy remaining natural teeth or fixed prostheses and self-rated chewing ability.

## Methods

### Participants

The study population comprised patients aged 45 years or older, who visited dental clinics in Kaohsiung City. Through the Kaohsiung Dental Association, we invited dental clinics to participate in our study. After we gave an overview of the study and its purposes, seven clinics in various administrative regions chose to participate. Patients in these dental clinics were provided with simple, structured self-administered questionnaires to collect sociodemographic data and self-rated food-chewing ability. Patients who were vegetarians and did not eat the foods listed in the questionnaire or those who were unable to fill/complete the questionnaire were excluded. Thus, 296 valid participants were finally obtained.

Patients were recruited between March 2006 and October 2006 in accordance with the population structure in Kaohsiung City in 2005. All participants signed an informed consent form before information collection. Dentists completed an oral examination and provided information on tooth loss and the health status of every tooth (including fixed and removable prostheses).

### Questionnaire

The questionnaire included questions to obtain basic sociodemographics (gender, age, and education level). Other questions collected information on self-rated food-chewing ability. These were adopted from Hirai et al. [13]. For food-chewing ability, we selected 33 daily foods that are available in Taiwan, including fruits, vegetables, seafood, and meat. Five experts ranked these foods according to how difficult they were to chew. A food ranking based on average scores was devised. On the basis of the opinion of the five experts, foods with similar chewing difficulties were grouped, and this process yielded 20 food groups.

A food intake questionnaire about the 20 food groups was developed to calculate the masticatory score of each subject. A ranking of these food groups from the most chewable to the least chewable is shown in Table 1. The Cronbach's $\alpha$ of the food intake questionnaire was 0.934.

### Masticatory score

Calculation of the masticatory score (Table 1) was based on methods from Hirai et al. [13]. A participant with an index lesser than 80% was regarded as having chewing difficulty. In this study, three choices were associated with each food group: "2: able to eat," "1: difficult to eat," and "0: unable to eat," where the number indicated the score for each answer. To obtain the masticatory score, we first calculated the percentage of "able to eat" for every food group. These food groups were further divided into four categories based on the rank of their chewability, and the average chewability of each category was calculated. Later, using the inverse relationship between relative difficulty in chewing and chewability of the food item with the chewability of Category IV as the base, the relative difficulty values for other food categories were generated. Finally, to calculate the masticatory score index for participants, we multiplied the score of each food category by its relative difficulty.

### Dental examination

All participants underwent clinical dental examinations by trained and calibrated dentists in dental clinics. Each

**Table 1** Expression of masticatory score

| Rank | Food item | Chewability of food item (%) | Food category | Chewability of food category (%) | Relative difficulty | Full score | Individual score[a] |
|---|---|---|---|---|---|---|---|
| 1 | Steamed sweet potato and taro | 98.25 | I | 97.28 | 0.66 | 5 kinds of food $\times$ 2 = 10 | A |
| 2 | Papaya and banana | 97.97 | | | | | |
| 3 | Sliced watermelon and pineapple | 97.30 | | | | | |
| 4 | Fish (steamed) | 96.62 | | | | | |
| 5 | Boiled turnip and carrot | 96.28 | | | | | |
| 6 | Sliced melon and tangerine | 95.27 | II | 93.85 | 0.68 | 5 kinds of food $\times$ 2 = 10 | B |
| 7 | Water spinach and cabbage | 93.92 | | | | | |
| 8 | Pickled lettuce in soy sauce and pickled cucumber in soy sauce (canned) | 93.92 | | | | | |
| 9 | Sliced star fruit and bell fruit | 93.24 | | | | | |
| 10 | Boiled asparagus and cucumber | 92.91 | | | | | |
| 11 | Sliced orange | 91.22 | III | 84.32 | 0.76 | 5 kinds of food $\times$ 2 = 10 | C |
| 12 | Sliced apple and pear | 87.50 | | | | | |
| 13 | Boiled sweet corn | 84.46 | | | | | |
| 14 | Fried chicken leg or chicken fillet | 80.74 | | | | | |
| 15 | Stir-fried peanut | 77.70 | | | | | |
| 16 | Sliced guava | 74.66 | IV | 63.72 | 1.00 | 5 kinds of food $\times$ 2 = 10 | D |
| 17 | Boiled squid and steak | 73.65 | | | | | |
| 18 | Soy sauce braised pork ears and pig bag | 66.89 | | | | | |
| 19 | Grilled calamari and soy sauce braised chicken gizzard | 58.45 | | | | | |
| 20 | Sugarcane (not juice) | 44.93 | | | | | |
| Total | | | | | 3.1 | 10 | 31 |

[a] Individual chewing index = $(0.66A + 0.68B + 0.76C + D) \times 100/31$.

study participant sat in a dental chair, and a dental operatory light, dental mouth mirror, and dental probe were used, but no X-ray image was taken. All participating dentists attended a workshop and they were requested to practice two case records to complete the designed research workshop before joining this study. Dentists with a kappa coefficient agreement of less than 0.70 were excluded from the study. Dental examinations were conducted in accordance with the World Health Organization format [25]. We also provided a dental examination manual describing the detailed criteria to every participating dentist.

A healthy tooth was defined as a tooth with the ability to chew; in other words, it was functional. Dentists counted the number of functional natural teeth (FNT), natural tooth-FTUs (nt-FTUs), fixed tooth-FTUs (ft-FTUs), and all-FTUs. None of the examinations included third molars.

## Functional natural teeth

For remaining natural teeth, teeth with missing crowns resulting from caries; Mobility III and percussion pain; or extensive coronal destruction, indicating that the tooth should be extracted (i.e. extensive subgingival caries), were regarded as non-FNT, and the rest were FNT. Among them, the premolars and molars were classified as posterior-FNT (P-FNT).

## Functional teeth

Functional teeth (FT) are FNT or fixed artificial teeth, including abutment teeth, pontics, and implant-supported prostheses. Fixed artificial teeth with Mobility III and percussion pain were excluded. Premolars or molars are posterior-FT.

## Removable FT

Removable artificial teeth comprise removable FT (RFT), but those with loss of retention and poor stability were excluded. Premolars or molars are posterior-RFT.

## Functional tooth units

FTUs consist of pairs of opposing posterior teeth. If opposing posterior teeth were restricted to P-FNT, they could be defined as nt-FTUs. Conversely, for posterior-FT, the definition changed to ft-FTUs. If FTUs include posterior-RFTs, they were defined as all-FTUs. The number of FTUs for premolars was 1 unit, and 2 units for molars; thus, 12 FTUs indicate an intact dentition.

## Statistical analysis

We performed $t$ tests and analysis of variance followed by Tukey's pairwise comparison to understand the different

**Table 2** Number of remaining teeth in middle-aged and elderly people in terms of sociodemographic features and presence of chewing difficulty ($n = 296$)

| | *n* | % | FNT | P-FNT | Nt-FTUs | Ft-FTUs | All-FTUs |
|---|---|---|---|---|---|---|---|
| | | | Mean ± SD | Mean ± SD | Mean ± SD | Mean ± SD | Mean ± SD |
| Total | 296 | 100 | 22.4 ± 7.0 | 11.9 ± 4.4 | 6.9 ± 4.2 | 8.3 ± 4.2 | |
| Age (y) | | | | | | | |
| (1) 45–54 | 158 | 53.4 | 25.0 ± 3.7 | 13.5 ± 2.8 | 8.3 ± 3.5 | 9.5 ± 3.2 | 10.0 ± 2.8 |
| (2) 55–64 | 76 | 25.7 | 22.5 ± 6.1 | 11.6 ± 4.2 | 6.4 ± 4.2 | 8.7 ± 3.9 | 9.2 ± 0.4 |
| (3) 65+ | 62 | 20.9 | 15.7 ± 9.5 | 8.0 ± 5.5 | 3.6 ± 4.0 | 4.6 ± 4.6 | 6.3 ± 0.5 |
| *p** | | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Tukey's pairwise comparison | | | (1) > (3); (2) > (3) | (1) > (3); (2) > (3) | (1) > (3); (2) > (3) | (1) > (3); (2) > (3) | (1) > (3); (2) > (3) |
| Gender | | | | | | | |
| Male | 122 | 41.2 | 22.0 ± 6.8 | 11.5 ± 4.4 | 6.4 ± 4.3 | 7.8 ± 4.2 | 8.7 ± 3.7 |
| Female | 174 | 58.8 | 22.7 ± 7.1 | 12.1 ± 4.4 | 7.2 ± 4.2 | 8.6 ± 4.2 | 9.3 ± 3.8 |
| *p*** | | | 0.4104 | 0.2264 | 0.1485 | 0.1079 | 0.1913 |
| Education (y) | | | | | | | |
| ≤9 | 122 | 41.2 | 20.4 ± 8.5 | 10.8 ± 5.2 | 6.2 ± 4.5 | 7.4 ± 4.7 | 8.2 ± 4.4 |
| >9 | 174 | 58.8 | 23.8 ± 5.2 | 12.7 ± 3.6 | 7.3 ± 3.9 | 8.9 ± 3.6 | 9.6 ± 3.2 |
| *p*** | | | 0.0001 | 0.0006 | 0.0221 | 0.0049 | 0.0026 |
| Chewing difficulty | | | | | | | |
| Yes | 90 | 30.4 | 17.1 ± 8.7 | 8.6 ± 5.2 | 4.0 ± 4.1 | 5.1 ± 4.4 | 6.7 ± 4.5 |
| No | 206 | 69.6 | 24.7 ± 4.4 | 13.3 ± 3.1 | 8.1 ± 3.6 | 9.6 ± 3.2 | 10.0 ± 2.9 |
| *p*** | | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

*The *p* value is calculated from one-way analysis of variance.
**The *p* value is calculated from two-sample *t* test.
FNT = functional natural tooth; ft-FTU = fixed teeth-functional tooth unit; nt-FTU = natural teeth-functional tooth unit; P-FNT = posterior-functional natural tooth; SD = standard deviation.

distributions of mean with regard to age, gender, education level, and chewing difficulty, as they pertained to FNT, P-FNT, nt-FTUs, ft-FTUs, and all-FTUs. Chi-square tests were conducted to understand the distribution of chewing difficulty with respect to age, gender, and education level. Finally, the five kinds of teeth were further adjusted according to age, gender, and educational level within multiple logistic analyses to determine the predicted variables of chewing difficulty. A *p* value less than or equal to 0.05 was considered significant. All statistical analyses

**Table 3** Number of people with chewing difficulty among middle-aged and elderly people by selected demographic characteristics ($n = 296$)

| | Chewing difficulty | | Non-chewing difficulty | | Total | | *p** |
|---|---|---|---|---|---|---|---|
| | *n* | % | *n* | % | *n* | % | |
| Total | 90 | 30.4 | 206 | 69.6 | 296 | 100.0 | |
| Age (y) | | | | | | | |
| 45–54 | 27 | 17.1 | 131 | 82.9 | 158 | 53.4 | <0.0001 |
| 55–64 | 26 | 34.2 | 50 | 65.8 | 76 | 25.7 | |
| 65+ | 37 | 59.7 | 25 | 40.3 | 62 | 20.9 | |
| Gender | | | | | | | |
| Male | 41 | 33.6 | 81 | 66.4 | 122 | 41.2 | 0.3161 |
| Female | 49 | 28.2 | 125 | 71.8 | 174 | 58.8 | |
| Education (y) | | | | | | | |
| ≤9 | 45 | 36.9 | 77 | 63.1 | 122 | 41.2 | 0.0424 |
| >9 | 45 | 25.9 | 129 | 74.1 | 174 | 58.8 | |

*The *p* value is calculated using Chi-square test.

**Table 4** OR with 95% CI for chewing difficulty by a logistic regression analysis

| | Crude OR[a] (95% CI) | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|---|---|---|---|---|---|---|---|
| | | Adjusted OR[b] (95% CI) | Adjusted OR[b] (95% CI) | Adjusted OR[b] (95% CI) | Adjusted OR[b] (95% CI) | Adjusted OR[b] (95% CI) | Adjusted OR[b] (95% CI) |
| Age (y) | | | | | | | |
| 45–54 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 55–64 | 2.52 (1.34–4.75)* | 2.54 (1.33–4.86)* | 1.73 (0.84–3.54) | 1.91 (0.94–3.86) | 1.87 (0.92–3.79) | 2.44 (1.21–4.97)* | 2.39 (1.21–4.74)* |
| 65+ | 7.18 (3.77–14.02)* | 7.29 (3.59–15.24)* | 2.88 (1.25–6.63)* | 3.47 (1.55–7.81)* | 3.49 (1.56–7.85)* | 3.57 (1.57–8.21)* | 5.30 (2.48–11.58)* |
| Gender | | | | | | | |
| Male | 1.29 (0.78–2.13) | 1.06 (0.60–1.84) | 1.10 (0.59–2.03) | 1.04 (0.56–1.90) | 1.04 (0.57–1.91) | 0.96 (0.52–1.76) | 0.96 (0.53–1.73) |
| Female | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Education (y) | | | | | 0.97 (0.51–1.84) | 0.96 (0.50–1.83) | 0.88 (0.46–1.63) |
| ≤9 | 1.68 (1.02–2.77)* | 0.95 (0.52–1.71) | 0.81 (0.41–1.55) | 0.84 (0.44–1.60) | 1.00 | 1.00 | 1.00 |
| >9 | 1.00 | 1.00 | 1.00 | 1.00 | | | |
| FNT | | | | | | | |
| 0–17 | 20.50 (9.77–45.75)* | | 13.70 (6.09–32.60)* | | | | |
| 18–24 | 3.51 (1.84–6.77)* | | 3.04 (1.56–5.95)* | | | | |
| 25–28 | 1.00 | | 1.00 | | | | |
| P-FNT | | | | | | | |
| 0–9 | 13.17 (6.91–26.04)* | | | 9.00 (4.50–18.53)* | | | |
| 11–12 | 3.13 (1.51–6.41)* | | | 2.50 (1.17–5.26)* | | | |
| 13–16 | 1.00 | | | 1.00 | | | |
| Nt-FTUs | | | | | | | |
| 0–4 | 9.09 (5.00–17.03)* | | | | 6.28 (3.32–12.15)* | | |
| 5–7 | 0.92 (0.36–2.12) | | | | 0.85 (0.33–1.99) | | |
| 8–12 | 1.00 | | | | 1.00 | | |
| Ft-FTUs | | | | | | | |
| 0–5 | 13.82 (7.19–27.65)* | | | | | 9.69 (4.78–20.30)* | |
| 6–9 | 3.70 (1.83–7.55)* | | | | | 3.89 (1.88–8.12)* | |
| 10–12 | 1.00 | | | | | 1.00 | |
| All-FTUs | | | | | | | |
| 0–7 | 6.64 (3.73–12.08)* | | | | | | 5.05 (2.73–9.48)* |
| 8–9 | 1.52 (0.62–3.44) | | | | | | 1.59 (0.63–3.74) |
| 10–12 | 1.00 | | | | | | 1.00 |

[a] Crude OR is calculated from univariate logistic regression model.
[b] Adjusted OR is calculated from multiple logistic regression model.
*$p < 0.05$.
CI = confidence interval; FNT = functional natural tooth; ft-FTU = fixed teeth-functional tooth unit; nt-FTU = natural teeth-functional tooth unit; OR = odds ratio; P-FNT = posterior-functional natural tooth.

were performed using SAS (Jump7) statistical software (SAS Institute Inc., Cary, NC, USA).

## Results

Descriptive statistics on sociodemographics, chewing difficulty, and healthy remaining teeth are displayed in Table 2. A total of 296 patients were included in this study. They were aged at least 45 years; the mean age was $56.6 \pm 9.7$ years. Most patients were aged 45—54 years ($n = 158$, 53.4%), with the lowest number of patients in the age group of 65 years or older (20.9%). Women were dominant ($n = 174$, 58.8%) in the study sample, and most of the patients ($n = 174$, 58.8%) had completed more than 9 years of education. The average number of the five types of healthy remaining teeth was lowest in patients aged at least 65 years. Gender was not statistically significant here. In terms of education level, more than 9 years of education was associated with a higher number of healthy remaining teeth. Patients with chewing difficulty had, on average, 17.1 FNT, 8.6 P-FNT, 4.0 units of nt-FTUs, 5.1 units of ft-FTUs, and 6.7 units of all-FTUs. Among patients without chewing difficulty, these figures were 24.7, 13.3, 8.1, 9.6, and 10.0, respectively. Patients with chewing difficulty had fewer healthy remaining teeth, regardless of the five kinds of teeth.

Among the 296 patients in the study, 90 (30.4%) had difficulty chewing. Significant differences in chewing difficulty occurred between age groups and education levels; this suggests that elderly patients and those having 9 or less years of education were more likely to have chewing difficulty. The trend for chewing difficulty increased with age (Table 3).

To examine the true impact of the number of various types of healthy remaining teeth on chewing difficulty, the patients were subgrouped into three categories according to the mean number of five kinds of healthy teeth in those with chewing difficulty or non-difficulty. This categorized variable was adjusted for age, gender, and education level within multiple logistic analyses to determine the true predicting variables of chewing difficulty (Table 4).

Because the numbers of the five kinds of healthy remaining teeth were highly correlated in the Pearson's correlation analyses (correlation coefficient $> 0.7261$, $p < 0.0001$), we adjusted the number of these five kinds of healthy remaining teeth with age, gender, and education level in different multiple logistic models. Results from our multiple logistic analyses revealed that before controlling for covariates, age, education level, and number of five kinds of healthy remaining teeth were factors influencing chewing difficulty.

After adjusting for age, gender, and education level (Model 1), the odds ratio (OR) of chewing difficulty in the 55-year to 64-year age group increased from 2.52 to 2.54 [95% confidence interval (CI), 1.33—4.86], and the OR for the 65 years or older age group rose from 7.18 to 7.29 (95% CI, 3.59—15.24). Education level ceased to be significant.

After controlling for age, gender, education level, and FNT (Model 2), the OR for chewing difficulty in the 55-year to 64-year age group became nonsignificant. Furthermore, the figure decreased from 7.18 to 2.88 (95% CI, 1.25—6.63) for the age group of 65 years or older. The OR for chewing difficulty in patients with 17 or less FNT fell from 20.50 to 13.70 (95% CI, 6.09—32.60), and for subjects having 18—24 FNT, the OR dropped from 3.51 to 3.04 (95% CI, 1.56—5.95). These results indicated that identical numbers of FNT meant no difference in chewing difficulties between subjects in the age groups of 45—54 years and 55—64 years. In addition, chewing difficulty had an approximately 50% decrease in subjects aged 65 years or older. This could also be seen for P-FNT (Model 3), nt-FTUs (Model 4), and ft-FTUs (Model 5).

To sum up, increased age was associated with a greater likelihood of chewing difficulty, as was a smaller number of healthy remaining teeth.

## Discussion

In this cross-sectional study of subjects recruited from dental clinics, we noticed a trend toward a reduced number of FNT, P-FNT, nt-FTUs, ft-FTUs, and all-FTUs with increased age. In addition, with respect to each of these five types of healthy remaining teeth, subjects having chewing difficulty had fewer healthy remaining teeth than those without chewing difficulty. The occurrence of chewing difficulty increased with age, and subjects with higher education level were less likely to have this problem. However, after controlling for sociodemographic factors and for the number of healthy remaining teeth, we found that the true factors influencing self-rated chewing ability were age and number of healthy remaining teeth.

As the results of our multiple logistic analyses show, after controlling for the number of healthy remaining teeth, the impact of age on chewing difficulty decreased significantly, especially for patients 65 years or older. This finding indicates that an adequate number of healthy remaining teeth could reduce the impact of age on chewing difficulty. This is in agreement with the findings of another study that pointed out that the increase in age was not intrinsically associated with a loss of chewing ability [26]. Rather, one probable reason was the degradation in oral function. Damage to the oral and maxillofacial structure gradually develops with increased age; for instance, the number of teeth or healthy natural teeth gradually decreases. Thus, preserving an adequate number of healthy teeth with associated improved masticatory muscle function would diminish the impact of age on chewing ability. This approach is also far more feasible than attempting to maintain the strength of masticatory muscles. Therefore, the preservation of healthy remaining teeth is essential to assure adequate chewing ability in the elderly.

For healthy remaining teeth, after adjustment for sociodemographic factors, patients with a masticatory score greater than 0.8 (those able to eat squid, steak, or sliced guava), needed at least 25 FNT or 13 P-FNT. This finding is consistent with the results of many other studies [10,20,24,27,28] that demonstrated that maintaining at least 20 natural teeth was important to avoid chewing difficulty. In addition, previous studies [27—30] pointed out that 12 anterior and 8 premolar teeth assured satisfactory eating and chewing functions. However, another study [24] suggested that preservation of 12.6 natural posterior teeth was necessary to maintain adequate chewing function. This is more consistent with the results from the present study.

Many studies have shown that having fewer FTUs is associated with an increased likelihood of chewing difficulty. Hildebrandt et al. [7] revealed that the number of FTUs were a superior predictive factor for chewing ability than the number of remaining natural teeth. Furthermore, FTUs that were restricted to natural teeth were the best predictors of chewing ability. In other words, compared with FTUs comprised mainly of natural teeth, when fixed prostheses were counted, more FTUs were required to avoid chewing difficulty. In the present study, a score of at least five nt-FTUs or 10 ft-FTUs was necessary to prevent chewing difficulty, and these findings are, therefore, consistent with the results of Hildebrandt et al.

Previous studies showed that treatment by a removable denture could improve chewing ability [31,32]. However, in this study, significantly improved chewing ability was not necessarily observed when the number of FTUs increased because of the presence of a removable denture. In addition, subjects with chewing difficulty had more FTUs comprising a removable denture (chewing difficulty group: $1.58 \pm 3.62$ units; non-chewing difficulty group: $0.40 \pm 1.64$ units; $p = 0.0039$). Some studies also suggested that removable prosthodontic treatments may not improve masticatory function significantly [33,34]; these findings were also consistent with those of the present study.

Haugejorden et al. [35] and Lin et al. [36] conducted investigations in adults aged 65—74 years and 20—79 years, respectively, and found that illiterate people, or people with less than 12 years of education, had fewer remaining teeth. In the present study, the number of healthy remaining teeth did not differ significantly according to the level of education, indicating that higher education level did not guarantee greater knowledge of oral health. Locker et al. [37] suggested that tooth loss was an outcome of a complicated mutually influential process among disease, socioeconomic status, and attitude toward dental services, and that it was deeply influenced by the decisions of patients and dentists. Thus, to improve the preservation of teeth among middle-aged and elderly people, the general population should have appropriate knowledge of oral health and alter their attitudes concerning dental services. Dentists should also be encouraging patients to improve their oral health and consider rescuing natural teeth rather than replacing them with dentures.

According to data from Taiwan's National Health Insurance (NHI), 2.75 million adults (35.9%) aged 45 years or older visited a dentist in 2006 [38]. A study of determinants of dental care utilization showed that people with lower income levels are less likely to visit their dentist regularly [39]. Another study [40] focusing on people older than 55 years in the United States pointed out that people with teeth were more likely to use dental services than those without teeth. Studies [40,41] also showed that the greatest barrier to dental services among people older than 55 years was the cost. In Taiwan, however, a single-payer NHI system has been available for years. The NHI system provides the people of Taiwan with more equitable access to health care, greater financial risk protection, and equity in health care financing [42]. Therefore, the costs of dental services are relatively low in Taiwan.

This study had a number of limitations. People who are less concerned about dental health or hold negative attitudes toward dental services are less likely to use these services, and this group tends to be comprised of people with poorer dental condition and chewing ability. As a result, studying subjects from dental clinics could lead to an overestimation of the number of healthy remaining teeth and chewing ability. Furthermore, a recent spate in fraudulent activity in Taiwan made random sampling by telephone or letter difficult, as people were on their guard and less likely to participate in studies conducted this way. However, the purpose of the present study was to examine the relationship between the number of healthy remaining teeth and chewing abilityand not the prevalence of tooth loss or chewing difficulty. In addition, the sampling method considered the demographic structure of Kaohsiung City. According to the test of goodness of fit, a marginally statistically significant difference between the results of the study sample and those of the population structure in Kaohsiung City ($X^2_{0.95(2)} = 6.1$, $p < 0.05$; $X^2_{0.95(2)} = 6.0$, $p = 0.05$, respectively) suggested that the age distribution of the study sample was close to that of the population in Kaohsiung City. This helped to reduce the bias caused by including subjects from dental clinics as the study sample.

Another limitation was the existence of objective and subjective measures involved in the evaluation of chewing ability. Objective measures are obviously more precise but require more time and specialized equipment, and they can be expensive and inconvenient when applied to epidemiological studies. Subjective measures are relatively simple and cheap, despite the misgivings of researchers, particularly when fewer remaining natural teeth are present [43]. Nevertheless, Hirai et al. [13] and Miura et al. [44] indicated that a masticatory ability index established by self-rated food-chewing ability showed higher validity and provided more consistent results than precision tools. Therefore, using the masticatory ability index established by self-rated food-chewing ability is practical and applicable to epidemiological investigations regarding chewing ability in middle-aged and elderly populations. On the other hand, to the best of our knowledge, the present study was the first in Taiwan to use food questionnaires for self-rated chewing ability. As a result, we needed to refer to related studies from Western countries and Japan. We chose a number of foods available in Taiwan with various textures and degrees of toughness, and conducted tests of expert validity as well as a pilot study to select 33 foods for use in the self-rated chewing ability. This method reduced the study bias by avoiding the possibility that subjects would express a preference for specific kinds of food.

To conclude, in the present study, patients aged at least 65 years had notably fewer healthy remaining natural teeth than people in other age groups. In addition, on an average, they had only 16 FNT and eight P-FNT. In other words, the rate of removable prosthesis use in such a population is unlikely to be low. Determining whether different kinds of remaining teeth or FTUs, including removable prosthesis, influence chewing ability, is a question that merits further study.

In the present study, we learned that age and healthy remaining teeth are predictive factors for chewing ability among middle-aged and elderly people. If at least 25 FNT or

10 units of FTUs (it is better if these are composed of healthy natural tooth) are preserved, chewing ability can be maintained, and the impact of age on chewing difficulty can be reduced. Although the present study was unable to provide results for the entire population, we have provided evidence regarding methods for the evaluation of chewing difficulty among middle-aged and elderly people.

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