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Gerodontology

Relationship of physical fitness to chewing in an 80-year-old population

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OBJECTIVE: Although tooth loss causes a decrease in masticatory ability, which may influence nutritional status, and impair an individual's general health including physical activity, little is known whether a decrease in chewing ability could result in deterioration in physical fitness in a very elderly population. Thus, the present study evaluated the relationship of chewing ability or teeth number with measures of physical fitness in a sample of 80-years-old in Japan.

DESIGN: Cross-sectional survey.

SUBJECTS AND METHODS: A total of 1282 people who were 80-years old and resided in the Fukuoka Prefecture were approached. A total of 697 individuals (277 male, 420 female) agreed to participate.

RESULTS: Chewing food number and teeth number were related positively with physical fitness measurements of hand grip strength, leg extensor strength, leg extensor power, stepping rate, and one-leg standing time. However, the significant relationship between the number of teeth and physical ability disappeared after adjustment for various confounders, using multiple regression analysis or logistic regression analysis. On the other hand, the relationship of chewing ability with physical fitness measurements of leg extensor strength, one-leg standing time, or isokinetic leg extensor power remained significant even after adjustment for these confounders.

CONCLUSION: There is a relationship between perceived chewing ability (number of foods considered chewable) and physical fitness in this 80-year-old population. Chewing ability may be an independent predictor of physical fitness, thus preventative dental care aimed at preserving chewing ability may be able to enhance activities of daily life and quality of life in very elderly individuals.

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Introduction

Tooth loss commonly occurs in association with aging, resulting in compromised mastication of food by elderly people (Carlsson, 1984; Slade, Spencer and Roberts-Thomson, 1996; Warren *et al*, 2002). Thus, impaired chewing may negatively influence nutritional status (Osterberg and Steen, 1982; Chauncey *et al*, 1984; Krall, Hayes and Garcia, 1998; Papas *et al*, 1998; Walls *et al*, 2000; Nordenram, Ljunggren and Cederholm, 2001; Sheiham *et al*, 2001; Nowjack-Raymer and Sheiham, 2003) and undermine general well-being (Walls *et al*, 2000; Nordenram *et al*, 2001; Shimazaki *et al*, 2001; Yoshida *et al*, 2001; Warren *et al*, 2002) including physical activity (Shimazaki *et al*, 2001; Yoshida *et al*, 2001). We have reported previously a positive relationship between number of teeth and physical activity in an 80-year-old Japanese population (Ansai *et al*, 2000). In this group, decreased physical capacity associated with tooth loss was improved by use of dentures (Ansai *et al*, 2000). Nagai *et al* (1990) evaluated the relationship of chewing ability to physical capacity in subjects at least 65-years old, finding a positive correlation between chewing ability and the time for which subjects could stand on one leg, using multiple regression analysis with adjustment for age and gender. Recently, Yamaga *et al* (2002) examined the relationship between physical fitness and occlusal condition according to the Eichner index in a population of 70 and 80-year-olds, concluding that dental occlusion is positively associated with dynamic strength, agility, and balance functions in the

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lower extremities. Questionnaires concerning food intake also have been valuable in epidemiologic surveys of masticatory function in the elderly (Leake, 1990; Nagai *et al*, 1990; Slade *et al*, 1996; Miura *et al*, 1998). We therefore hypothesized that good physical fitness may be the consequence of good chewing ability, and examined relationships of physical fitness in 80-year-olds to both chewing as assessed by questionnaire and tooth number.

Subjects and methods

In 1998, a total of 1282 individuals who were 80-years old resided in three cities (Buzen, Yukuhashi, and Munakata), four towns (Katsuyama, Tikujo, Toyotsu, and Kanda), one village (Shinyoshitomi), and one ward (Tobata of Kikakyushu City) in the Fukuoka Prefecture of Japan. All of these individuals were invited to participate in the study. Of these 1282 individuals, 697 (277 male, 420 female) agreed. The study was approved in terms of the rights and treatment of subjects by the Human Investigations Committee of Kyushu Dental College, and informed consent was obtained from all participants. The authors performed a dental examination in each subject in the manner recommended by the World Health Organization (WHO, 1997).

Measurements of physical fitness included hand-grip strength, isometric leg extensor strength, isokinetic leg extensor power, stepping rate, and one-leg standing time. The numbers of subjects who participated in these tests were 644, 558, 549, 569, and 697 respectively. All our subjects participated in the test of one-leg standing time. However there was a reduction in the numbers participating in some of the other tests (hand-grip strength 644, isometric leg extensor strength 558, leg extensor power 549 and stepping rate 569). Only those subjects who participated in a specific test were included in the analysis for that test. Maximal hand-grip strength was measured in each hand using a Smedley hand dynamometer (DM-100s; Yagami, Nagoya, Japan). The best value in two trials for each hand was taken as the score for the test. Leg extensor strength was measured by a portable chair incorporating a strain gauge connected to a load cell. The subject sat on a seat in a vertical position with the legs hanging vertically and the knee initially bent at 90°. The trial was performed twice each for right and left legs. The values for both sides in this test were summed as their subject's score. Isokinetic leg extensor power was determined using a dynamometer (Aneropress 3500; Combi, Tokyo, Japan). The subject sat on the seat of the instrument and was instructed to press his or her feet forward on the plate as rapidly as possible until the legs were fully extended. The body mass of the subject was applied as resistance. The best score from five trials was used for statistical analysis. Stepping rate was measured using an industrial stepping rate counter (Stepping Counter; Yagami, Nagoya, Japan); while sitting, the subject was instructed to step with each leg as rapidly as possible for 10 s. The stepping rate for both legs was summed as the subject's score. One-leg standing time was measured with the eyes open. This time represented the number of seconds until the subject had to hop, until the raised foot was lowered to the floor, or until 2 min had elapsed. One trial was performed on the right and one on the left leg; the better score was used for statistical analysis.

Each subject was asked about ability to chew the following 15 foods; peanuts, yellow pickled radish, hard rice cracker, French bread, beefsteak, vinegared octopus, pickled shallots, dried scallops, dried cuttlefish, squid sashimi, konnyaku, tubular roll of boiled fish paste, boiled rice, sashimi of tuna, and grilled eel. The response was a simple dichotomous variable (yes/no). The number of foods that the subjects reported being able to chew was used as an independent variable for multiple regression analysis or logistic regression analysis.

In addition to the numbers of teeth and number of foods reported to be chewable, the following factors considered to influence physical fitness were characterized in each subjects: height (cm), body weight (kg), gender (male/female), systolic blood pressure (SBP; mmHg), serum albumin concentration (g dl^{-1}), fasting serum glucose concentration (FSG; mg dl^{-1}), low back pain (present *vs* absent), smoking (smoker *vs* non-smoker), alcohol drinking (yes *vs* no), marital status with a spouse (living *vs* not living), regular outpatient medical treatment (yes *vs* no), and regular exercise (yes *vs* no). The following cutoff values were used to convert continuous variables to categorical ones: hypertension, SBP $\geq$ 140 mmHg; diabetes, FSG $\geq$ 126 mg dl^{-1}; small status, height $<$ 150 cm; lean build, $<$ 50 kg; low albumin concentration, $\leq$ 4.2 g dl^{-1}. These categorical factors were used as independent variables for adjustment. SBP and FSG were chosen, because these are well-known risk factors for stroke, which is a significant cause of deterioration in quality of life in an older cohort. Similarly, short stature has also been associated with stroke (Parker *et al*, 1998; Goldbourt and Tanne, 2002). As socio-economic factors seem to be related to oral health status, medical care was included as a confounding variable.

All data are reported as the mean $\pm$ s.d. Differences in mean values between groups were assessed by analysis of variance. Categorical variables were compared using the chi-squared test. Multiple regression analysis was carried out to evaluate which factors were related to physical fitness after adjustment for confounding variables. Logistic regression also was used to determine which categorical factors were independent predictors of physical fitness. All statistical analyses were performed using StatView 5.0 (SAS Institute, Cary, NC, USA). Results were considered statistically significant when $P < 0.05$.

Results

The mean number of teeth in the whole sample was 8.0 $\pm$ 8.9; 241 subjects were edentate, the mean number of teeth within the dentate group was 12.3 $\pm$ 8.6. The mean height was 149.8 $\pm$ 9.0 cm; weight, 51.1 $\pm$ 9.4 kg; SBP, 150.5 $\pm$ 23.1 mmHg; FSB, 122.0 $\pm$ 51.4 mg dl^{-1}; and serum albumin concentration, 4.2 $\pm$ 0.3 g dl^{-1}. The mean number of foods that subjects could chew was 11.4 ± 3.7. Mean values for hand-grip strength, leg extensor strength, isokinetic leg extensor power, stepping rate, and one-leg standing time were 25.1 ± 7.4 kg, 38.0 ± 15.1 kg, 355.4 ± 184.5 W, 61.0 ± 15.0 per 10 s, and 13.3 ± 21.4 s, respectively. Chewing ability estimated by number of chewable foods was related significantly with number of teeth (10.9 ± 4.0 for edentate, 11.1 ± 3.6 for subjects with teeth one to nine, 11.5 ± 3.7 for those with teeth 10–19, 13.2 ± 2.8 for those with teeth >20, $F = 11.1$, $P < 0.0001$).

A gender difference was apparent for physical fitness results: hand-grip strength was 31.5 ± 6.4 kg for men and 20.8 ± 4.1 kg for women, $F = 670.5$, $P < 0.0001$; leg extensor strength, 48.8 ± 13.5 kg for men and 30.3 ± 11.0 kg for women, $F = 318.0$, $P < 0.0001$; isokinetic leg extensor power, 492.5 ± 180.9 W for men and 255.1 ± 105.7 W for women, $F = 372.3$, $P < 0.0001$; stepping rate, 66.0 ± 15.6 per 10 s for men and 57.5 ± 13.5 per 10 s for women, $F = 48.0$, $P < 0.0001$; and one-leg standing time, 18.8 ± 28.5 s for men and 9.7 ± 13.9 s for women, $F = 31.3$, $P < 0.0001$. There was no gender difference in edentulism (32.0% for men, 36.4% for women, $\chi^2 = 1.4$, $P = 0.2375$), while number of chewable foods was more in men than in women (12.0 ± 3.4 for men, 11.1 ± 3.9 for women, $F = 11.4$, $P = 0.0008$).

The number of foods that a subject felt able to chew correlated positively with all physical fitness test results by simple regression analysis (for hand grip, $F = 14.6$, $r = 0.149$, $P = 0.0001$; leg extensor strength, $F = 14.7$, $r = 0.161$, $P = 0.0001$; isokinetic leg extensor power, $F = 10.5$, $r = 0.138$, $P = 0.0012$; stepping rate, $F = 6.5$, $r = 0.107$, $P = 0.0108$; and one-leg standing time, $F = 12.8$, $r = 0.135$, $P = 0.0004$). Similarly, a significant positive correlation was seen between number of teeth and physical fitness test results (for hand grip, $F = 14.5$, $r = 0.149$, $P = 0.0002$; leg extensor strength, $F = 11.4$, $r = 0.142$, $P = 0.0008$; isokinetic leg extensor power, $F = 16.1$, $r = 0.169$, $P < 0.0001$; stepping rate, $F = 5.6$, $r = 0.099$, $P = 0.0187$; and one-leg standing time, $F = 5.6$, $r = 0.089$, $P = 0.0185$). When subjects were divided into four groups according to number of foods that could be chewed, or the number of teeth (0–4, 5–9, 10–14, or 15 foods; 0, 1–9, 10–19, and >20 teeth), hand-grip strength, leg extensor strength, isokinetic leg extensor power, and one-leg standing time each was increased significantly in groups with more foods chewed or more teeth (Table 1).

We adjusted for various confounding factors such as height, body weight, gender, SBP, serum albumin concentration, FSG, back pain, smoking, alcohol drinking, marital status, regular medical treatment, and regular exercise using a multiple-regression model. Multiple regression analysis showed that number of foods chewed still was positively related to leg extensor strength and to one-leg standing time. On the other hand, no relationships remained between number of teeth and any physical fitness test result (Table 2). The associations between physical variables and height or weight also were corrected for gender differences using multiple regression analysis, finding significant relationships with gender (hand-grip strength with height or weight, leg extensor strength with weight, isokinetic leg extensor power with weight, stepping rate with height and one-leg standing time with height or weight; Table 2).

For logistic regression analysis, subjects were grouped as above; foods chewed, 0–4, 5–9, 10–14, or 15; tooth number, 0, 1–9, 10–19, or >20; BP, ≥ 140 mmHg or <140 mmHg; FSG, ≥ 126 mg dl^{-1} or <126 mg dl^{-1}; height, >150 cm or <150 cm; weight, >50 kg or <50 kg; and albumin concentration, >4.2 g dl^{-1} or ≤ 4.2 g dl^{-1}. For each physical fitness measurement, we divided subjects into groups with better or poorer scores. Physical fitness measurements were divided using median value to have a similar number of subjects in two groups (hand-grip strength >24.0 kg, $n = 322$ *vs* <24.0 kg, $n = 322$; leg extensor strength >37.0 kg, $n = 279$ *vs* <37.0 kg, $n = 279$; isokinetic leg extensor power >319 W, $n = 274$ *vs* <319 W, $n = 275$; stepping rate >62, $n = 284$ *vs* <62, $n = 285$; one-leg standing time >6.2 s, $n = 348$ *vs* <6.2 s, $n = 349$). After the data were adjusted for various confounding factors, we

Table 1 Physical fitness measurement in four elderly groups differing by number of food types considered chewable or by tooth number

Chewable foods	*Hand-grip strength (kg)*	*Leg extensor strength (kg)*	*Isokinetic leg extensor power (W)*	*Stepping rate (times)*	*One-leg standing time (s)*
0–4	22.3 ± 7.3 (44)	33.6 ± 14.6 (30)	288.8 ± 161.4 (28)	58.8 ± 14.8 (31)	5.5 ± 6.4 (48)
5–9	23.5 ± 7.2 (124)	33.9 ± 15.2 (104)	313.3 ± 177.2 (101)	58.6 ± 15.1 (108)	10.7 ± 15.5 (134)
10–14	25.3 ± 6.9 (289)	38.2 ± 14.9 (253)	355.1 ± 171.7 (248)	61.1 ± 15.2 (259)	12.9 ± 20.4 (307)
15	26.4 ± 7.9 (185)	41.0 ± 14.9 (169)	391.6 ± 202.9 (170)	62.8 ± 14.5 (169)	17.7 ± 27.2 (204)
F-value	6.1	5.7	5.3	2.0	5.7
P-value	0.0005	0.0008	0.0014	0.1200	0.0008
Tooth number					
0	24.0 ± 7.2 (229)	36.4 ± 15.5 (194)	331.0 ± 172.8 (191)	59.7 ± 13.8 (199)	10.3 ± 16.7 (241)
1–9	24.7 ± 7.2 (184)	36.5 ± 14.3 (166)	337.0 ± 171.0 (162)	60.3 ± 16.2 (167)	14.6 ± 22.6 (199)
10–19	25.8 ± 7.6 (132)	39.8 ± 14.8 (112)	372.6 ± 195.4 (113)	62.0 ± 15.4 (116)	13.8 ± 22.3 (148)
20	27.2 ± 7.3 (99)	42.0 ± 15.4 (86)	424.3 ± 203.3 (83)	63.8 ± 14.3 (87)	17.0 ± 26.5 (108)
F-value	5.0	3.9	6.0	1.8	2.9
P-value	0.0019	0.0089	0.0005	0.1501	0.0343

Comparison was made by analysis of variance. Numbers in parentheses indicate numbers of subjects participating in each test.

Table 2 Multiple regression analysis for each physical fitness measurement

	Dependant variables									
	Hand-grip strength		*Leg extensor strength*		*Isokinetic leg extensor power*		*Stepping rate*		*One-leg standing time*	
Independent variables	*β-value*	*P-value*	*β-value*	*P-value*	*β-value*	*P-value*	*β-value*	*P-value*	*β-value*	*P-value*
Number of chewable foods	0.027	0.3449	0.075	0.0366	0.044	0.1962	0.078	0.0955	0.100	0.0248
Number of teeth	0.005	0.8659	0.003	0.9373	0.021	0.5354	0.002	0.9698	0.017	0.6996
Gender	−0.395	< 0.0001	−0.482	< 0.0001	−0.4440	< 0.0001	−0.107	0.1724	−0.103	0.1547
Height (cm)	0.285	< 0.0001	−0.061	0.3292	−0.011	0.8472	0.270	0.0009	0.271	0.0004
Weight (kg)	0.191	< 0.0001	0.302	< 0.0001	0.323	< 0.0001	−0.031	0.5957	−0.194	0.0004
SBP (mmHg)	0.032	0.2757	0.061	0.1015	−0.049	0.1644	−0.009	0.8574	−0.044	0.3324
FSG (mg dl^{-1})	−0.046	0.0977	−0.020	0.5715	−0.108	0.0014	0.050	0.2826	−0.034	0.4296
Albumin(g dl^{-1})	0.102	0.0005	0.062	0.0963	0.065	0.0639	0.095	0.0483	0.043	0.3485
Smoking	−0.007	0.8142	−0.010	0.7901	−0.001	0.9810	0.014	0.7607	−0.125	0.0052
Drinking	−0.001	0.9726	0.004	0.9133	−0.003	0.9287	−0.028	0.5708	0.035	0.4449
Spouse	0.061	0.0880	0.019	0.6586	0.075	0.738	−0.002	0.9768	−0.003	0.9603
Exercise	0.110	0.0001	0.086	0.0156	0.110	0.0011	0.050	0.2828	0.059	0.1740
Medical care	−0.025	0.3729	−0.019	0.5847	−0.030	0.3770	−0.040	0.3897	−0.015	0.7298
Back pain	0.037	0.1918	0.151	< 0.0001	0.148	< 0.0001	−0.016	0.7361	0.059	0.1855
Number of subjects	488		434		422		440		498	
Coefficient of determination (R^2)	0.641		0.478		0.558		0.129		0.121	

SBP, systolic blood pressure; FSG, fasting serum glucose.

Table 3 Logistic regression analysis of physical fitness measurements

	Hand-grip strength [OR (95% CI)]	*Leg extensor strength [OR (95% CI)]*	*Isokinetic leg extensor power [OR (95% CI)]*	*Stepping rate [OR (95% CI)]*	*One-leg standing time [OR (95% CI)]*
Number of chewable foods					
0–4	1	1	1	1	1
5–9	0.542 (0.172–1.714)	0.780 (0.233–2.610)	3.767 (1.005–14.123)*	1.189 (0.444–3.184)	2.333 (0.973–5.591)
10–14	0.687 (0.234–2.017)	1.796 (0.584–5.522)	5.396 (1.584–18.383)**	1.406 (0.559–3.532)	2.349 (1.036–5.327)*
15	1.001 (0.328–3.052)	1.093 (0.343–3.488)	4.885 (1.391–17.157)*	1.732 (0.669–4.483)	2.596 (1.108–6.082)*
Number of teeth					
0	1	1	1	1	1
1–9	1.236 (0.656–2.329)	1.100 (0.596–2.030)	1.219 (0.645–2.303)	1.131 (0.686–1.863)	1.341 (0.841–2.140)
10–19	1.158 (0.564–2.377)	1.365 (0.682–2.732)	0.964 (0.475–1.958)	1.299 (0.747–2.258)	1.191 (0.717–1.978)
≥20	0.795 (0.355–1.779)	1.817 (0.842–3.919)	0.859 (0.387–1.905)	0.833 (0.451–1.538)	1.380 (0.774–2.459)

*$P < 0.05$, **$P < 0.01$; OR, odds ratio; CI, cofidence interval.

calculated odds ratios (OR) and 95% confidence intervals (CI) for achievement of better physical fitness scores (Table 3). Among individuals able to chew five or more foods, achievement of better isokinetic leg extensor power scores was significantly more frequent than among individuals able to chew four or fewer foods. Similarly, longer one-leg standing time was achieved more often among individuals chewing 10 or more foods than among those chewing four or fewer foods. Classification based on tooth number, however, did not show significant correlation with any physical fitness test by logistic regression analysis.

Discussion

In the present study in an 80-year-old Japanese population, we found a significant relationship between certain physical fitness measurements and chewing ability as judged from number of foods considered chewable. The relationship persisted after adjustment for various confounding variables using either multiple-regression analysis or a logistic regression model. Physical fitness measurements related to chewing ability were isokinetic leg extensor power and one-leg standing time, suggesting that chewing ability in very elderly individuals may be related to lower extremity dynamic strength, and to equilibrium. This is essentially in agreement with the findings of Yamaga *et al* (2002), who correlated the Eichner index of occlusion with leg extensor power, stepping rate, and one-leg standing time. As reduced lower extremity muscle strength has been associated with reduction in gait speed (Brown, Sinacore and Host, 1995; Wolfson *et al*, 1995; Ferrucci *et al*, 1997), ability to maintain balance (Wolfson *et al*, 1995; Ferrucci *et al*, 1997), speed in arising from a seated position (Skelton *et al*, 1994; Brown *et al*, 1995; Ferrucci *et al*, 1997), chewing ability as estimated by counting food varieties considered chewable also may be associated with physical capacity in very elderly individuals. One-leg standing time (Haga *et al*, 1986) and lower extremity strength (Wolfson *et al*, 1995) both have been reported to be related to risk of falls, an important cause of bone fractures and a factor compromising activities of daily living in the elderly. Therefore, the present findings suggest that improving chewing ability could improve performance of activities of daily life, enhance quality of life, and prevent disability and bedridden states in many cases. As the deterioration of chewing ability may be related with malnutrition and poor general health situation, resulting in decreased physical activity. However, as the values of β for chewing ability were very small, the improvement of chewing ability may be partly contributory to improving general conditions.

In addition to numbers of foods chewed, a significant relationship of gender (male > female) and body weight (heavier > lighter) was seen for hand-grip strength, leg extensor strength, and isokinetic leg extensor power in multiple regression analysis. Similarly, height (taller > shorter) was significantly related to hand-grip strength, stepping rate, and one-leg standing time. These findings were essentially identical with those of Yamaga *et al* (2002), and were similar to those of other investigators (Ringsberg *et al*, 1999; Wang, Olson and Protas, 2002).

It is evident from the literature in western countries that chewing ability not only depends on number of teeth but also on edentulism compared with having some teeth (Sheiham *et al*, 2001; Nowjack-Raymer and Sheiham, 2003). Similarly, in the present study, chewing ability was improved with increasing teeth number as compared with that in edentate. The present study found a significant association between perceived chewing ability and strength, but did not find between tooth number and strength. The former finding was in agreement with the that of Yamaga *et al* (2002), in which dental occlusal condition judged by Eichner index was related with several physical fitness measurements. On the other hand, there was few report finding a relationship between tooth number and strength. Sakki *et al* (1994) found a lack of association of tooth number and lifestyle including physical activity. Thus, it seems likely that chewing ability, but not tooth number, is related with physical strength.

Increased values for all physical fitness measurements were related to increased tooth number when only simple regression analysis and analysis of variance were performed; the relationship disappeared after adjustment for confounding variables. Therefore, the relationship of tooth number to physical fitness measurements appears to reflect such confounding factors such as gender, height, and body weight rather than being a direct relationship. In our previous study, logistic regression analysis revealed that individuals with fewer than 20 teeth were more likely than other subjects to have ST segment depression and T wave abnormalities, after adjusting for various confounding factors, suggesting that tooth loss may be an independent predictor of abnormal electrocardiographic (ECG) findings in octogenarians (Takata *et al*, 2001). Moreover, use of dentures improved the ECG in these patients (Y. Takata, unpublished observation). Therefore, physical fitness ability may relate to dental status differently than ECG findings.

Conclusion

This study suggest that there is an association between chewing ability (number of foods considered chewable) and physical ability in 80-year-old subjects. Preventative dental care aimed at preserving chewing ability may be able to enhance activities of daily life and quality of life in very elderly individuals. Alternatively, however, it could also be possible that good physical and mental health and good quality of life are associated with successful ageing and good oral health.

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