Ethical approval was secured from the ethical committee of the Hokkaido University Graduate School of Dental Medicine and written informed consent was obtained from each participant. Questionnaires on background factors and the self-assessed masticatory ability were sent via mail prior to the survey and the responses confirmed by the examiners on the day of the examination.

The questions about background factors included age, gender, current employment (working or not working), type of household (alone or with other family members), educational background (<10 years or ≥10 years of school education), social interaction (participating or not) including participation in groups gathering for social service, sports and hobbies, further about chronic systemic diseases (presence or absence of one or more chronic complaints such as hypertension, cardiac complaints, diabetes, cerebrovascular complaints, respiratory tract complaints, renal complaints, articular rheumatism, hepatic diseases and history of malignant tumour). The self-assessed masticatory ability was assessed by the question "Can you chew all kinds of food?" and the four alternative responses: "Yes, all kinds of food" (Good); "Yes, fairly hard food" (Fair), and "Only soft food" or "Only pureed food" (Poor) (Moriya *et al.*, 2009).

Data collected by intraoral examination included the pattern of POPs, periodontal status and denture related factors. Intraoral examinations were performed by four dentists of the Graduate School of Dental Medicine, Hokkaido University and calibration was conducted to get close agreement in the assessments of dental status, periodontal status and the quality of dentures prior to the survey. The pattern of POPs was classified according to the presence or absence of POPs in the bilateral premolar and molar regions: 1, tooth contact in all of the bilateral premolar and molar regions; 2, tooth contact at least in one region except 1; or, 3, an absence of tooth contact (lost POPs). Periodontal status was evaluated by using the WHO Community Periodontal Index of Treatment Needs (CPI) and it was examined for all participants with at least one recordable sextant. Each participant was classified according to the maximum CPI code: code 0-2; code 3; or, code 4. Denture-related factors were evaluated based on use of dentures when eating and pain when using dentures for the participants with lost POPs and denture base fit for those using full upper and lower dentures. According to Kapur (1967) denture base fit of the totally edentulous was scored separately for its stability and retention, respectively, on 3- (0-2) and 4- (0-3) point-scales then summed for upper and lower dentures to range from 0 to 10. A sum >8 was characterised as clinically good dentures, 6-8 as fair dentures and <6 as poor dentures (Kapur, 1967). The assessment of denture base fit was not applied to the participants using partial dentures, because any standardised assessment tool for partial dentures suitable for an epidemiological survey was not available to our limited knowledge.

The chi-squared test was used to examine the relationships between the self-assessed masticatory ability and the background factors and oral conditions. Further, ordinal regression models were constructed with the self-assessed masticatory ability as the dependent variable; the background factors and oral conditions as the independent variables. These models present the estimated coefficient of ordinal regression (β) which reflects how changes in the independent variables affect the dependent variables and its 95% confidence interval (95% CI) for the self-assessed masticatory ability. The concordance of measurements between the examiners was evaluated according to the Kappa statistic. Only p-values <0.05 were considered significant. Analyses were performed using SPSS PASW® Statistics Base v18.0.

Results

After excluding participants with missing data from the 843 participants, there were 736 participants in the study (411 females, mean age 73.0 (sd 5.3) years, 325 males, 73.1 (sd 5.0) years). The relationships between the self-assessed masticatory ability and the background factors are shown in Table 1. The distributions of the participants by the self-assessed masticatory ability were related to age, gender, type of household, employment status, degree of social interaction and hypertension. Renal diseases and articular rheumatism were not included in the analysis because too few participants (6 and 5 respectively) had these diseases. The relationships between the self-assessed masticatory ability and oral conditions are shown in Table 2. The CPI could be assessed for 540 persons and use of dentures when eating was assessed for 428 persons who had no POPs. Of the 428 participants, 270 were partially edentulous and 158 were totally edentulous. After exclusion of 32 participants who did not use any dentures when eating from the 428 participants having no POPs, 396 participants using dentures could be included in the assessment of pain when using dentures. Of the 158 totally edentulous participants, 8 participants using no dentures were excluded and finally 150 could be evaluated for stability and retention of dentures. The distributions of the participants by the self-assessed masticatory ability were significantly related to the pattern of POPs (p<0.001), CPI (p=0.025), use of dentures (p<0.001), pain when using dentures (p<0.001) and stability and retention of dentures (p=0.049) (Table 2). Kappa values of each item were more than 0.80 for inter assessor agreement.

The results of ordinary regression analysis for the self-assessed impairment of masticatory ability are shown in Tables 3 and 4. Educational background and systemic diseases other than hypertension were not included in these models because no significant relationship was established in the univariate analysis. Five ordinal regression models were constructed for all participants (model 1), for those of CPI (model 2), for those who had no POPs (model 3), for those who had no POPs but used dentures when eating (model 4) and for the totally edentulous participants using both upper and lower dentures when eating (model 5). In model 1, self-assessed impairment of masticatory ability was associated with living alone status (p=0.020), non-working status (p=0.040), low social activity status (p=0.012) and lost POPs (p<0.001). In model 2, an association was established with code 4 of CPI (p=0.012). In model 3, self-assessed impairment of masticatory ability was associated with not using dentures when eating (p<0.001). In model 4, an association was established with pain when using dentures (p<0.001). In model 5 for the totally edentulous participants us-

Table 1. Relationships between the self-assessed masticatory ability and background factors

Background factors		*n*	*Self-assessed masticatory ability (%)*			*p-value*
			Good	*Fair*	*Poor*	
Age	65-74 years	447	68.9	25.3	5.8	
	75-84 years	289	58.5	35.6	5.9	0.009
Gender	Female	411	59.9	32.1	8.0	
	Male	325	71.1	25.8	3.1	0.001
Household	Living with others	561	68.3	27.1	4.6	
	Living alone	175	53.7	36.6	9.7	0.001
Employment	Working	561	62.0	31.0	7.0	
	Not working	175	73.7	24.0	2.3	0.007
Social interaction	Yes	324	70.1	26.5	3.4	
	No	412	60.7	31.6	7.7	0.007
Educational background	≥10 years	207	67.2	28.0	4.8	
	<10 years	529	63.9	29.9	6.2	0.631
Hypertension	Absence	382	68.8	26.7	4.5	
	Presence	354	60.5	32.2	7.3	0.038
Diabetes	Absence	650	63.7	30.0	6.3	
	Presence	86	73.3	24.4	2.3	0.139
Cardiac disease	Absence	618	66.0	28.3	5.7	
	Presence	118	58.5	34.7	6.8	0.290
Cerebrovascular disease	Absence	699	64.9	29.5	5.6	
	Presence	37	62.2	27.0	10.8	0.415
Liver disease	Absence	713	65.4	28.7	5.9	
	Presence	23	47.8	47.8	4.4	0.142
Respiratory tract disease	Absence	714	64.6	29.4	6.0	
	Presence	22	72.7	27.3	0.0	0.454
Malignant tumour	Absence	716	64.7	29.4	5.9	
	Presence	20	70.0	25.0	5.0	0.886

Table 2. Relationships between the self-assessed masticatory ability and oral conditions

Oral conditions		*n*	*Self-assessed masticatory ability (%)*			*p-value*
			Good	*Fair*	*Poor*	
The pattern of POPs	All regions	139	90.6	8.6	0.8	
n=736	At least one region	169	82.2	15.4	2.4	<0.001
	Absence	428	49.5	41.6	8.9	
CPI	Code 0-2	116	79.3	17.3	3.4	
n=540	Code 3	239	72.4	24.3	3.3	0.025
	Code 4	185	62.2	32.4	5.4	
Dentures use	Yes	396	51.3	42.2	6.5	
n=428	No	32	28.1	34.4	37.5	<0.001
Pain when using dentures	No	278	59.7	37.1	3.2	
n=396	Yes	118	30.5	55.1	14.4	<0.001
Stability/retention of dentures	Good/Fair	76	64.5	28.9	6.6	
n=150	Poor	74	44.6	45.9	9.5	0.049

POPs: Posterior occluding pairs of natural teeth, CPI: The maximum WHO Community Periodontal Index of Treatment Needs of each participant. Use of dentures was evaluated for the participants having no POPs. Pain when using dentures was evaluated for the participants having no POPs but using dentures (partial dentures: 246 persons, full upper and lower dentures: 150 persons). Stability and retention of dentures were evaluated for the totally edentulous participants wearing both upper and lower dentures.
All regions: tooth contact in all of the bilateral premolar and molar regions
At least one regions: tooth contact at least in one region, except the participants of all regions
Absence: an absence of tooth contact in premolar and molar regions (lost POPs)

Table 3. Results of the ordinal regression analysis for the self-assessed impairment of masticatory ability (1)

Independent variables		Self-assessed masticatory ability (dependent variable) *			
		Model 1 (n=736)		Model 2 (n=540)	
		β (95%CI)	p-value	β (95%CI)	p-value
Age	65-74 years	0.00		0.00	
	75-84 years	-0.15 (-0.49,0.20)	0.409	-0.12 (-0.56,0.32)	0.592
Gender	Female	-0.20 (-0.54,0.14)	0.245	-0.06 (-0.49,0.37)	0.799
	Male	0.00		0.00	
Household	With others	0.00		0.00	
	Alone	-0.60 (-0.98,-0.22)	**0.020**	-0.37 (-0.83,0.89)	0.113
Employment	Working	0.00		0.00	
	Not working	-0.44 (-0.86,-0.02)	**0.040**	-0.25 (-0.78,0.27)	0.344
Social interaction	Yes	0.00		0.00	
	No	-0.43 (-0.76,-0.09)	**0.012**	-0.60 (-1.02,-0.18)	0.012
Hypertension	Absence	0.00		0.00	
	Presence	-0.31 (-0.64,-0.02)	0.068	-0.32 (-0.73,0.09)	0.125
Pattern of POPs	All regions	0.00		0.00	
	At least one region	-0.56 (-1.27,0.14)	0.116	-0.52 (-1.23,0.19)	0.154
	Absence	-2.24 (-2.85,-1.62)	**<0.001**	-2.16 (-2.81,-1.52)	**<0.001**
CPI	Code 0-2			0.00	
	Code 3			-0.20 (-0.78,3.80)	0.499
	Code 4			-0.76 (-1.35,-0.16)	**0.012**

Model 1 was constructed for all participants and Model 2 was constructed for the participants of CPI.
β: coefficient of ordinal logistic regression, CI: confidence interval
* Dummy variables of the self-assessed masticatory ability were created as: Good=2, Fair=1 and Poor=0.

Table 4. Results of the ordinal regression analysis for the self-assessed impairment of masticatory ability (2)

Independent variables		Self-assessed masticatory ability (dependent variable) *			
		Model 3 (n=428)		Model 4 (n=396)	
		β (95%CI)	p-value	β (95%CI)	p-value
Age	65-74 years	0.00		0.00	
	75-84 years	-0.15 (-0.54,0.24)	0.409	-0.21 (-0.63,0.21)	0.335
Gender	Female	-0.41 (-0.81,-0.11)	**0.044**	-0.31 (-0.74,0.12)	0.156
	Male	0.00		0.00	
Household	With others	0.00		0.00	
	Alone	-0.61 (-1.06,-0.17)	**0.007**	-0.59 (-1.07,0.10)	**0.017**
Employment	Working	0.00		0.00	
	Not working	-0.64 (-1.13,-0.14)	**0.012**	-0.72 (-1.24,-0.19)	**0.008**
Social interaction	Yes	0.00		0.00	
	No	-0.36 (-0.75,-0.03)	0.067	-0.19 (-0.61,0.22)	0.353
Hypertension	Absence	0.00		0.00	
	Presence	-0.17 (-0.56,0.22)	0.387	-0.25 (-0.66,0.16)	0.238
Denture use when eating	Yes	0.00			
	No	-1.55 (-2.28,-0.82)	**<0.001**		
Pain when using dentures	No			0.00	
	Yes			-1.28 (-1.73,-0.84)	**<0.001**

Model 3 was constructed for the participants having no POPs and Model 4 was constructed for the participants having no POPs but using dentures (partial dentures: 246 persons, full upper and lower dentures: 150 persons).
β: coefficient of ordinal logistic regression, CI: confidence interval
*: Dummy variables of the self-assessed masticatory ability were created as follows: Good=2, Fair=1 and Poor =0.

ing dentures (n=150), there were also associations with pain when using dentures (β=-1.33, 95% CI -2.06,-0.60, p<0.001), but not with stability and retention of dentures (β=-0.64, 95% CI -1.33, 0.51, p=0.070) (data not shown).

Discussion

We have shown previously that the self-assessed masticatory ability was significantly related to physical performance among community-dwelling elderly persons (Moriya *et al.*, 2009). The findings here identified factors associated with the self-assessed masticatory ability. Our study has several limitations that should be recognised. The study population was considered to be representative of a rural elderly population in Japan but not a nationally representative sample and the study was cross-sectional in design (Moriya *et al.*, 2009). Nevertheless, the findings here added data for the detailed relationships between the self-assessed masticatory ability and oral conditions such as dental status, periodontal status and denture-related factors, to prior studies in this area (Nakanishi *et al.*, 2005; Österberg *et al.*, 1996).

The self-assessed masticatory ability was associated with the type of household, employment and social interaction in model 1 and these findings are consistent with those of earlier studies (Nakanishi *et al.*, 2005; Österberg *et al.*, 1996). It is not possible to show any causation of these relationships here, but a theoretical mechanism of the relationships can be explained by a number of hypotheses. First, living with others, working and reporting high social activity may have a positive effect on oral hygiene and consequently contribute to the preservation of the self-assessed masticatory ability. Elsewhere, life style related factors have been significantly related to oral hygiene in a rural population in Japan (Harada *et al.*, 2005).

Second, a perception of masticatory ability may be influenced by psychosocial status, i.e., positive affect, defined as emotional contentment and happiness that has been associated with social activity (Kurland *et al.*, 2006). Finally, it has been shown that masticatory ability was associated with physical performance and higher level functioning capacity (Moriya *et al.*, 2009; Takata *et al*, 2008) and consequently the self-assessed masticatory ability may contribute to participating in work and the high social activity status.

A number of studies have found no clinical significant differences between subjects with shortened dental arches (SDA) of 3 to 5 occlusal units and complete dental arches regarding variables such as masticatory ability, signs and symptoms of temporomandibular disorders and oral comfort (Witter *et al.*, 1994a, 1994b). Partially lost POPs (at least one region) was not related to the self-assessed impairment of masticatory ability in the present study. These findings suggest that occluding pairs of natural teeth may play an important role in oral functions, especially masticatory ability.

Lost POPs was significantly and closely related to the self-assessed impairment of masticatory ability here. These findings are in agreement with earlier studies, which have suggested that fewer functional tooth units and extremely shortened dental arches are associated with the perceived impairment of chewing ability (Sarita *et al.*, 2003). The pattern of POPs has been significantly associated also with an objective masticatory performance based on particle size measures of a test food (Yamashita *et al.*, 2000). Therefore, POPs may influence subjective and objective assessments of masticatory ability. These relationships may be accounted for through the stability of jaw relation, degree of support of dentures due to lost POPs and afferent signals arising from dentoalveolar ligaments, which have been shown to modulate masticatory behaviour in the laboratory (Inoue *et al.*, 1989).

The findings of the present study showed that the advanced periodontal status (code 4 of CPI) was associated with self-assessed impairment of masticatory ability (p=0.012). It is thought that advanced periodontal conditions would cause biting pain, mobile teeth and a decline in biting force during mastication and consequently lead to an impairment of masticatory ability. Mobile teeth have been associated with eating difficulties in an old Chinese population (Zeng *et al.*, 2008). No correlation has been found between periodontal status and biting force in persons with slightly reduced periodontal tissue support (Morita *et al.*, 2003), but significant correlations have been established in persons with moderately to severely reduced periodontal tissue support (Takeuchi *et al.*, 2008). It has been suggested that maximal occlusal force positively correlates with the masticatory performance (Okiyama *et al.*, 2003).

The results of the data for dentures suggest that the masticatory ability may be impaired by not using dentures and pain when using dentures. Pain when using dentures is thought to be dependent chiefly on discordance of occlusal relationships of dentures and ill-fitting dentures. The absence of relationships between the self-assessed masticatory ability and denture adhesion (p=0.070) could be explained by several mechanisms; psychological factors may also influence the acceptance of dentures (Ozdemir *et al.*, 2006), individuals wearing ill-fitting dentures may modify their chewing habits to optimise masticatory performance with such dentures (Demers *et al.*, 1996), masticatory ability with dentures is thought to be influenced by factors other than denture adhesion such as occlusal relationships, the motion of the soft tissues and denture-supporting tissues.

The present study suggests that self-assessed masticatory ability may be influenced by dentition status, periodontal status and denture-related factors, providing a possibility that masticatory ability could be improved by dental interventions among community-dwelling elderly persons.

Acknowledgements

The present study was supported in part by funds from Hokkaido University. We are grateful to the public offices in Iwanai and Tomamae of Hokkaido of Japan for their considerate cooperation.

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Gerodontology

Original article

Influence of dental treatment on physical performance in community-dwelling elderly persons

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doi: 10.1111/j.1741-2358.2011.00563.x

Influence of dental treatment on physical performance in community-dwelling elderly persons

Objective: The aim of the study was to investigate the influence of dental treatment on physical performance (muscle strength and balance function) among the elderly.
Background: Oral conditions have been associated with physical performance. We hypothesised that improved oral conditions by dental treatment would lead to improved physical performance.
Methods: A total of 154 persons aged 65 years or over were judged to be in need of dental treatment as a result of dental examination; of these, 121 persons underwent dental treatment. After 1 year, differences in each parameter of physical performance before and after the intervention were evaluated using the Wilcoxon signed rank sum test. The Spearman rank correlation coefficient was calculated to examine correlations between changes in self-assessed masticatory ability (masticatory ability) and each parameter of physical performance, and multivariate logistic regression analysis was performed using changes in each parameter of physical performance as the dependent variable and changes in masticatory ability as the principal independent variable.
Results: Improved physical performance was not observed for the total study population with dental treatment; however, in subjects with improved masticatory ability, one-leg standing times with eyes open increased significantly. A significant correlation was established between changes in masticatory ability and each parameter of physical performance. These relationships were not found in those without dental treatment. A significant relationship was also established for one-leg standing time after adjusting for age, gender, dentition status and needs of dental treatments.
Conclusion: Chewing ability may be a positive contributing factor to balance function among the elderly.

Keywords: the elderly, oral conditions, chewing ability, physical performance.

Accepted 17 July 2011

Introduction

Prolonged life expectancy in Japan has led to an increase in the number of elderly persons. In 2009, 22.7% of the total Japanese population was over the age of 65 years, and this proportion continues to grow[1]. Such growth stresses the importance of preventing decline in functioning in activities of daily living (ADLs) among the elderly, as this is considered to be a major component of quality of life. It has been shown that decline in functioning in ADLs is induced by functional impairment, frailty, the risk of falls and gait disturbances and that these factors are significantly influenced by parameters of physical performance such as muscle strength and balance function[2–7].

A number of epidemiological studies have shown that physical performance is significantly associated with dental status, periodontal status and chewing ability among elderly persons[8–11]. Dental treatment has been shown to improve functioning in ADLs and prevent falls among the elderly[12,13]. These findings suggest that improvement in some oral conditions by dental treatment may positively influence physical performance parameters and subsequently lead to improvement in functioning in ADLs and prevention of falls.

Therefore, we investigated the causal relationships between oral conditions and physical performance among the elderly. We hypothesised that improvement in oral conditions by dental treatment would positively affect muscle strength and balance function among the elderly, thereby applying a community-based intervention strategy for dental treatment.

Materials and methods

A total of 294 individuals aged 65 years or over and living independently underwent a dental health examination sponsored by the public authority in a rural community (Iwanai) in Hokkaido, the northernmost prefecture of Japan. The examination was performed over 10 days from August to September 2006. Of these 294 persons, 174 (59.2%) were judged to be in need of dental treatment and were advised to undergo treatment as a result of the oral examination (the baseline survey). Consequently, 154 (88.5%) of these 174 persons participated in the follow-up survey, which was performed 1 year after the baseline survey. Of these 154 persons, 121 (78.6%) underwent dental treatment during the last year as advised, but the other 33 persons (21.4%) did not undergo any dental treatment. These 154 individuals were enrolled in this study. All persons were informed of the purpose and methods of the study and the routine that they informed us of significant changes in general health status during the follow-up period, and then they provided written informed consent to participate. Ethical approval for the study was obtained from the ethics committee of the Graduate School of Dental Medicine, Hokkaido University.

Subjects were interviewed based on questionnaires about self-assessed masticatory ability (masticatory ability), demographic factors such as gender and age, and general health status such as hypertension, diabetes, cardiac, cerebrovascular, respiratory, hepatic, renal and mental diseases (absence vs. presence). Information about whether the participants could live independently or dependently was obtained from the Long-Term Care Insurance System of Japan (LTCI)[14], which was under control of the public authority.

Masticatory ability was assessed using the following question: 'How do you rate your masticatory ability?' Answers were classified into one of the following: 'I can chew all kinds of food' (good); 'I can chew only slightly hard food' (fair); or 'I can chew only soft or pureed food' (poor)[10].

Intra-oral examination was performed by two dentists. The intra-examiner reliability of the two dentists was considered to be good, as they had worked together at the same dental hospital for more than 5 years and calibration was conducted to obtain close agreement in the assessment of dental status, periodontal status, crown and bridge prostheses and dentures prior to the survey. Periodontal status was evaluated using the WHO Community Periodontal Index of Treatment Needs (CPITN), and a person in need of periodontal treatment was defined as a person with a CPITN code 2 or above. Need for treatment with dentures was defined as the presence of pain when using dentures, poor retention and stability of dentures clinically and not using dentures regardless of having missing teeth in the pre-molar or molar regions. A person with ill-fitting crown and bridge prostheses was also defined as a person in need of treatment. The pattern of occluding pairs of natural teeth was classified into one of the three classes based on the presence or absence of occluding pairs of natural teeth, that is, (1) tooth contact in all of the bilateral pre-molar and molar regions (total support), (2) tooth contact at least in one region except (1) (partial support) or (3) an absence of tooth contact (lost support).

Handgrip strength (kg) and one-leg standing time with eyes open (s) were measured for the evaluation of muscle strength and static balance function, respectively. The single greatest value of handgrip strength was measured with the subject standing upright holding a hand dynamometer (Tanita, Ltd., Tokyo, Japan) in both hands. The maximum measurement of the right or the left hand was used for each subject. For one-leg standing time with eyes open, subjects were asked to stand on one leg with their eyes open and with arms stretched out, once on each foot until balance was lost, and the maximum measurement of the right or the left was used as the value for each subject.

The chi-squared test was used to compare distribution of participants according to each characteristic between those with and without dental treatment. The Wilcoxon signed rank test was used to examine changes in handgrip strength and one-leg standing time with eyes open between before and after the intervention. The Spearman rank correlation coefficients were used to examine correlations between changes in handgrip strength and one-leg standing time with eyes open, and those in masticatory ability. After significant correlations were identified, multivariate logistic regression analysis was performed with handgrip strength and one-leg standing time with eyes open (improved vs. unchanged or impaired) as dependent variables and changes in masticatory ability as the principal independent variable. These models presented the odds ratio (OR) and 95% confidence interval (CI) for the impairment and improvement in masticatory ability as compared with the unchanged status. Only p values smaller than 0.05 were defined as statistically significant. Statistical analysis was performed using the IBM SPSS statistical package (IBM SPSS PASW® Statistics Base 18.0, IBM Japan, Tokyo, Japan).

Results

Characteristics of the subject at the baseline survey are shown in Table 1. Although the participants had some chronic medical diseases, all of them were kept under good medical control and none of them were certificated for care-needs in the LTCI during the follow-up period. The percentage distribution by masticatory ability before and after the intervention is shown in Table 2. In the participants with dental treatment, the number of subjects with good masticatory ability did not change, but the number with fair masticatory ability increased, and the number with poor masticatory ability decreased. Percentage distributions by the type of changes in masticatory ability before and after the intervention are shown in Table 3. In the participants with dental treatment, 12 (9.9%), 91 (75.2%) and 18 (14.9%) subjects had impaired, unchanged and improved masticatory ability, respectively. In those individuals without dental treatment, 3 (9.1%), 28 (84.8%) and 2 (6.1%) subjects had impaired, unchanged and improved masticatory ability, respectively.

Comparisons of handgrip strength and one-leg standing time with eyes open between before and after the intervention are shown in Table 4. Handgrip strength decreased significantly in the total subjects and those with impaired masticatory ability, but no significant changes were observed in those with unchanged and improved masticatory ability. The one-leg standing time with eyes open did not change significantly in the total subjects and those with impaired masticatory ability; it decreased significantly in subjects with unchanged masticatory ability, but increased significantly in those with improved masticatory ability. No statistically significant changes in physical performance were observed in those without dental treatment.

There were significant correlations between changes in masticatory ability and each parameter of physical performance before and after the

Table 1 Characteristics of the subjects.

	Participants with dental treatment n = 121		*Participants without dental treatment n = 33*		
	n	%	*n*	%	*p-values*[a]
Gender					
Female	60	49.6	19	57.6	0.416
Male	61	50.4	14	42.4	
Age (years)					
65–69	41	33.9	11	33.3	0.119
70–74	37	30.6	4	12.1	
80–84	29	24.0	13	39.4	
>85	14	11.6	5	15.2	
The pattern of occluding pairs of natural teeth					
Lost support	44	36.4	19	57.6	0.038
Partial support	44	36.4	5	15.2	
Full support	33	27.3	9	27.3	
Self-assessed masticatory ability					
Good	81	66.9	24	72.7	0.729
Fair	30	24.8	6	18.2	
Poor	10	8.3	3	9.1	
Need for dental treatment					
Periodontal disease					
Needed	93	76.9	22	66.7	0.233
Needless	28	30.1	11	33.3	
Dentures					
Needed	44	36.4	17	51.5	0.115
Needless	77	63.6	16	48.5	
Others[b]					
Needed	5	4.1	1	3.0	0.772
Needless	116	95.9	32	97.0	
Chronic medical diseases					
Hypertension					
Absence	72	59.5	20	60.6	0.909
Presence	49	40.5	13	39.4	
Diabetes					
Absence	109	90.1	31	93.9	0.495
Presence	12	9.9	2	6.1	
Cardiac diseases					
Absence	103	85.1	30	90.9	0.391
Presence	18	14.9	3	9.1	
Cerebrovascular disease					
Absence	114	94.2	32	97.0	0.527
Presence	7	5.8	1	3.0	
Respiratory diseases					
Absence	119	98.3	33	100.0	0.457
Presence	2	1.7	0	0.0	
Hepatic disease					
Absence	119	98.3	32	97.0	0.612
Presence	2	1.7	1	3.0	
Renal disease					
Absence	121	99.2	33	100.0	0.600
Presence	1	0.8	0	0.0	
Mental disease					
Absence	119	98.3	32	97.0	0.612
Presence	2	1.7	1	3.0	

[a]chi-squared test.
[b]Dental caries or impairment of crown prosthesis.

Table 2 Percentage distribution of the participants by masticatory ability before and after intervention.

	Before		After	
Masticatory ability	n	%	n	%
Participants with dental treatment (n = 121)				
Good	81	66.9	81	66.9
Fair	30	24.8	38	31.4
Poor	10	8.3	2	1.7
Participants without dental treatment (n = 33)				
Good	24	72.7	23	69.7
Fair	6	18.2	6	18.2
Poor	3	9.1	4	12.1

Table 3 Percentage distribution by the type of changes in masticatory ability before and after intervention.

Type of changes in masticatory ability	Before	After	n	%
Participants with dental treatment (n = 121)				
Impaired[a]	Good	Fair	11	9.1
n = 12 (9.9%)	Fair	Poor	1	0.8
Unchanged[b]	Good	Good	70	57.9
n = 91 (75.2%)	Fair	Fair	20	16.5
	Poor	Poor	1	0.8
Improved[c]	Fair	Good	9	7.4
n = 18 (14.9%)	Poor	Good	3	2.5
	Poor	Fair	6	5.0
Participants without dental treatment (n = 33)				
Impaired[d]	Good	Fair	1	3.0
n = 3 (9.1%)	Good	Poor	1	3.0
	Fair	Poor	1	3.0
Unchanged[e]	Good	Good	22	66.7
n = 28 (84.8%)	Fair	Fair	4	12.1
	Poor	Poor	2	6.1
Improved[f]	Fair	Good	1	3.0
n = 2 (6.1%)	Poor	Fair	1	3.0

The ratios of participants with needs of each dental treatment are shown as follows:
[a]Periodontal diseases (58.3%), dentures (58.3%) and others (8.1%).
[b]Periodontal diseases (84.6%), dentures (29.7%) and others (3.3%).
[c]Periodontal diseases (55.6%), dentures (66.7%) and others (5.6%).
[d]Periodontal diseases (66.7%), dentures (66.7%) and others (33.3%).
[e]Periodontal diseases (71.4%), dentures (46.3%) and others (0.0%).
[f]Periodontal diseases (0.0%), dentures (100.0%) and others (0.0%).

intervention in those with dental treatment, but not in those without dental treatment (Table 5). Further multivariate logistic regression models were performed to examine the independent relationships between changes in masticatory ability and improvement in each parameter of physical performance in those with dental treatment (Table 6). In these models, improved masticatory ability was significantly related to improvement in one-leg standing time with eyes open (OR = 4.05, 95% CI = 1.25–13.16, $p = 0.020$), but these relationships were not established for handgrip strength.

Discussion

The present study revealed the influence of changes in masticatory ability following dental treatment on parameters of physical performance among community-dwelling elderly persons as follows. First, balance function improved significantly in subjects with improved masticatory ability. Second, there was a significant correlation between changes in masticatory ability and balance function. Finally, improvement in masticatory ability was significantly related to that of balance function after adjusting for age, gender, dentition status and the need for dental treatment. In regard to muscle strength, a significant correlation was observed between changes in masticatory ability and handgrip strength, but no significant improvement in muscle strength was seen in subjects with improved masticatory ability.

Subjects with unchanged masticatory ability accounted for about three-quarters (75.2%) of the total participants, because in this group, the number of subjects with good masticatory ability was large (76.9%) and the number of those in need of treatment with dentures was small (29.7%) at baseline (before intervention). The impairment in masticatory ability of 9.9% of the subjects may be explained by the possibility that the subjects in need of treatment with dentures (58.3%) were not satisfied with the results of the dental treatment they received. The subjectivity of evaluation for mastication can influence the results obtained. Since self-assessed masticatory ability has been shown to reflect dental status, periodontal status and denture-related factors in community-dwelling elderly persons[15], the self-assessed masticatory ability to evaluate change in mastication was used.

Handgrip strength decreased significantly in the total study population and those with impaired masticatory ability, and it tended to decrease in those with unchanged masticatory ability. This decline was thought to be mainly an age-related change. In those with improved masticatory ability, handgrip strength did not tend to decrease,

Table 4 Comparisons of handgrip strength and one-leg standing time with eyes open between before and after intervention.

		Handgrip strength (kg)			One-leg standing time with eyes open (s)		
		Mean ± SD			Mean ± SD		
Masticatory ability	*n*	*Before*	*After*	*p-values*[a]	*Before*	*After*	*p-values*[a]
Participants with dental treatment (n = 121)							
Total	121	28.0 ± 7.5	27.4 ± 7.7	0.047	33.0 ± 33.3	29.9 ± 34.4	0.106
Impaired	12	24.7 ± 6.8	22.6 ± 6.9	0.005	21.0 ± 27.4	15.7 ± 20.6	0.182
Unchanged	91	29.3 ± 7.3	28.7 ± 7.7	0.066	37.8 ± 34.6	32.1 ± 34.8	0.029
Improved	18	23.4 ± 6.8	24.2 ± 5.9	0.117	16.5 ± 21.2	28.1 ± 38.9	0.029
Participants without dental treatment (n = 33)							
Total	33	26.9 ± 7.7	26.4 ± 6.7	0.734	30.7 ± 30.0	23.0 ± 27.4	0.088
Impaired	3	21.0 ± 8.5	23.8 ± 6.3	0.109	14.9 ± 5.3	30.0 ± 32.4	0.285
Unchanged	28	27.6 ± 7.6	26.6 ± 6.8	0.205	29.8 ± 27.1	22.1 ± 28.4	0.066
Improved	2	26.0 ± 8.8	28.0 ± 8.5	0.157	68.0 ± 73.5	25.0 ± 0.0	0.655

[a]p-values were evaluated with the Wilcoxon signed rank sum test.

Table 5 Correlations between changes in handgrip strength and one-leg standing time with eyes open, and those in masticatory ability.

	Changes in handgrip strength between before and after – intervention (kg)[a]		Changes in one-leg standing time with eyes open between before and after intervention (S)[b]	
	r	*p-value*	*r*	*p-value*
Participants with dental treatment (n = 121)				
Changes in masticatory ability[c]	0.30	0.001	0.21	0.020
Participants without dental treatment (n = 33)				
Changes in masticatory ability[c]	−0.09	0.635	−0.26	0.146

r: Spearman rank correlation coefficient.
[a]Q–P; P = handgrip strength (kg) before intervention, Q = those after intervention.
[b]*S–R*; *R*= one-leg standing time with eyes open (s) before intervention, *S*=those after intervention
[c]Y–X; X = Categories of masticatory ability before intervention, Y = categories of masticatory ability after intervention., Categories of masticatory ability were created as follows: Poor = 0, Fair = 1, Good = 2.

and there was a significant positive correlation between changes in masticatory ability and handgrip strength. Therefore, it is possible that the improvement in masticatory ability may contribute to controlling the age-related decline in muscle strength. These findings are supported by previous studies that reported a significant positive relationship between perceived chewing ability and muscle strength of the body among the elderly[10,11].

One-leg standing time with eyes open decreased significantly in subjects with unchanged masticatory ability after the intervention. Subjects with impaired masticatory ability only showed a decreasing tendency in one-leg standing time, probably because the number of participants (n = 12) was too small to reach significance. This decline was thought to be mainly an age-related change. The significant increase in one-leg standing time with eyes open among those with improved masticatory ability suggested that improvement in balance function was accompanied by improvement in masticatory ability. This suggestion was further confirmed by the findings in terms of the significant positive correlation and independent relationships between changes in masticatory ability and one-leg standing time with eyes open. The present findings are consistent with those of epidemiological studies on the relationships between

Table 6 Multivariate logistic regression models for improvement in each parameter of physical performance in the participants with dental treatment (n = 121).

	Dependent variables					
	Improvement in handgrip strength[a]			*Improvement in one-leg standing time*[b]		
	OR	*95% CI*	*p-values*	*OR*	*95% CI*	*p-values*
Gender						
Female	1.00 (reference)			1.00 (reference)		
Male	0.87	0.36–2.10	0.759	1.90	0.79–4.56	0.153
Age						
65–74	1.00 (reference)			1.00 (reference)		
75–84	0.87	0.35–2.20	0.779	0.78	0.33–1.88	0.587
Occluding pairs of natural teeth						
Lost support	1.00 (reference)			1.00 (reference)		
Partial support	2.90	0.84–10.10	0.093	1.71	0.53–5.48	0.368
Full support	5.02	1.15–21.90	0.032	3.13	0.79–12.39	0.104
Need for dental treatment						
Periodontal disease						
Needless	1.00 (reference)			1.00 (reference)		
Needed	0.84	0.23–3.00	0.784	0.37	0.11–1.25	0.109
Dentures						
Needless	1.00 (reference)			1.00 (reference)		
Needed	3.26	0.98–10.75	0.053	1.33	0.42–4.17	0.624
Changes in masticatory ability						
Impaired	0.00[c]			0.63	0.14–2.77	0.541
Unchanged	1.00 (reference)			1.00 (reference)		
Improved	2.44	0.75–7.93	0.139	4.05	1.25–13.16	0.020

OR, odds ratio; CI, confidence interval.
[a]Improved (n = 43, 35.5%) vs. unchanged (n = 15, 12.4%) or impaired (n = 63, 52.1%).
[b]Improved (n = 45, 37.2%) vs. unchanged (n = 5, 4.1%) or impaired (n = 71, 58.7%).
[c]There were no persons with impaired masticatory ability among those with improved handgrip strength.

chewing ability and balance function, as well as a clinical trial on the influence of improved dental functional occlusion on the occurrence of falls in elderly with dementia[10,11,13].

According to the related literature, physical performance such as muscle strength and balance function can be influenced by a variety of factors including ageing, the presence of physical diseases (including neurological) and psychological status in older adults[16–19]. Although the participants enrolled had some chronic medical disease, all of them were kept under good medical control. They had no difficulties in activities of daily living and could live independently, as none of them were certificated for care-needs in the LTCI[14] during the follow-up period. It has been shown that masticatory ability was significantly associated with physical performance such as muscle strength and balance function after adjusting for some demographic and general health status[9–11]. Therefore, improved masticatory ability may influence physical performance positively as shown in the present study.

The relationships between chewing ability and physical performance can be explained by several possible underlying mechanisms. First, it has been shown that chewing ability is significantly related to nutritional intake and nutritional status[20–22] and that nutritional status is a significant contributing factor to physical performance, especially muscle strength[23–25], thereby suggesting that chewing ability may positively influence physical performance. Second, muscle strength and balance function may be influenced by orofacial sensory inputs from the trigeminal nerve, that is, epithelial mechanoreceptors and periodontal mechanoreceptors, temporomandibular joint receptors, jaw-closing muscle spindles and Golgi tendon organs[26–32]. Therefore, it is possible that these peripheral orofacial sensory inputs influence motor-neural control of muscle strength in other parts of body as there may be associations between orofacial motor control mechanisms[33,34] and associations between changes in dental occlusion and postural stability[35,36].

In these experimental studies, modification of dental occlusion may influence physical performance in a short time[33–36]. In a clinical trial, elderly persons with dementia underwent denture treatment, and then they experienced decreased frequency of falls during the 1-year investigative period[13].

The present study had a limitation that it was not designed as a randomised controlled trial. Nevertheless, to the best of our knowledge, the present study is the first to elucidate the influence of changes in chewing ability on parameters of physical performance among community-dwelling elderly persons. Further sophisticated study designs such as a randomised controlled trial are required to confirm the findings reported.

Conclusions

Our hypothesis that dental treatment might improve physical performance among the elderly was not confirmed in the present study. Nevertheless, in the subjects where masticatory ability was improved by dental treatment, one-leg standing time with eyes open significantly improved, suggesting that chewing ability may positively contribute to enhancing balance function among the elderly.

Acknowledgement

The present study was supported by grants from the 8020 Foundation in Japan. We are grateful to the public authorities in Iwanai, Hokkaido, Japan, for their assistance.

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