cotton gauze and comminuted pieces were then rinsed under running water for 30 s in order to remove as much of the saliva and glucose as possible adhering to their surfaces. The comminuted jelly alone was subsequently placed in a plastic container, water (35°C, 15 ml) was injected into this container, and the contents were agitated for 10 s with a magnetic stirrer (PC-410D Digital Stirrer, Corning Incorporated, Tewksbury, Massachusetts, USA) (400 rpm). Immediately after this agitation, a small amount of the supernatant was collected on the tip of a set of forceps and placed in contact with the tip of a sensor fitted to a commercially available instrument for self-monitoring of blood glucose (Glutest Every, Sanwa chemical Laboratory Co., Nagoya, Japan), and the glucose concentration (mg/dl) displayed after 15 s was recorded. The increase in surface area of the comminuted jelly (in units of $mm^2$) was calculated from the glucose concentration using a regression formula ($y = 15x - 250$), and this was regarded as masticatory performance. For subjects who wore dentures, masticatory performance was measured while the dentures were in place.

4. Analytical methods

In this study, the subjects of the analysis were classified into those of Eichner A1–3 ($n$ = 1094, 452 men, 642 women, mean age 65.0 ± 8.0 years) and Eichner B1–4 ($n$ = 529, 249 men, 280 women, mean age 69.6 ± 6.9 years). For each group, periodontal status was classified in two different ways, either with/without moderate periodontitis (CPI Code ≤2/≥3) or with/without severe periodontitis (CPI Code ≤3/4), and masticatory performance was compared between the various groups. A similar comparison was also carried out restricted to denture wearers and non-denture wearers. As previous studies have found that sex and age are not significant independent variables as factors related

to masticatory ability, no allowance for sex or age was made during the analysis in this study (Ikebe et al. 2012).

In terms of statistical procedures, masticatory performance between the groups with different periodontal status was compared using a t-test, with the level of significance set at 5%. PASW Statistics 18 (SPSS Japan Inc., IBM Japan) was used for statistical analysis.

## Results

After excluding 13 subjects for whom masticatory performance could not be accurately measured, masticatory performance was measured in a total of 1610 individuals (699 men, 911 women, mean age 66.5 ± 8.0 years). With respect to occlusal support, the largest number of patients were classified as Eichner A1, and the largest number of subjects in all Eichner groups were of CPI Code 0–2. In the different Eichner groups, the proportion of teeth with CPI Code ≥3 increased in accordance with decreasing occlusal support. Only 30% of the relevant teeth had poor periodontal status in subjects who were Eichner A1, the lowest grade, but nearly 70% of them had poor periodontal status in subjects who were Eichner B3, the highest grade. The comparison of denture wearers ranged from 8% in subjects who were Eichner A2 to 95% in subjects who were Eichner B4 with a dramatic increase as occlusal support decreased (Table 1).

In subjects who were Eichner A1, masticatory performance was significantly lower in subjects with moderate periodontitis compared with those without them, and in subjects with severe periodontitis compared with those without severe periodontitis. In subjects who were Eichner B3, masticatory performance was significantly lower in subjects with

moderate periodontitis compared with those without them, and in subjects with severe periodontitis compared with those without severe periodontitis. In groups other than these, no significant difference in masticatory performance with respect to periodontal status was evident (Table 2).

In an analysis limited to denture wearers, in subjects who were Eichner B2, masticatory performance was significantly lower in subjects with moderate periodontitis compared with those without them. In subjects who were Eichner B3, masticatory performance was significantly lower in subjects with moderate periodontitis compared with those without them, and in subjects with severe periodontitis compared with those without severe periodontitis (Table 3).

In an analysis limited to non-denture wearers, excluding subjects who were Eichner 1, who were all non-denture wearers, there was no significant difference between any of the other groups in masticatory performance as a result of the health of periodontal tissue (Table 4).

## Discussion

To our knowledge, this is the first large-scale study of a random sample of the general public to have shown that the state of health of periodontal tissue affects masticatory ability. The study had a number of limitations. First is the use of the CPI by means of the partial examination method for evaluating periodontal disease, which meant that not all remaining teeth were evaluated. Previous studies, however, have found that the partial examination method identified approximately 85% of individuals with periodontal disease compared with those identified by the CPI by means of full mouth

recording (Shirone et al. 2007), and in the context of mass screenings, where time is limited, its use may be regarded as valid. In this study, we also used two different methods of categorizing periodontal status, with the aim of compensating for the deficiencies of the CPI partial examination method. The second limitation is that because occlusal support was classified using the Eichner Index, and the effect of periodontal status on masticatory ability was investigated within groups with the same level of occlusal support, the sample size of some of the groups was necessarily small, meaning that their statistical power was low.

In this study, we first classified patients in each Eichner group as with/without moderate periodontitis (CPI Code ≤2/≥3). In order to investigate whether this difference in masticatory ability changes between individuals with more advanced periodontal disease and others, we then classified them as with/without severe periodontitis (CPI Code ≤3/4), and compared masticatory performance between the different types of periodontal status. We found that in both cases, in subjects who were Eichner A1 or B3, masticatory performance was significantly lower among those with poorer periodontal status. With the exception of subjects who were Eichner B4 and classified as with/without severe periodontitis, there was no significant difference between any of the other groups as a result of the presence of moderate or severe periodontitis, although the mean values of masticatory performance were lower. It is extremely interesting that periodontal status had a pronounced effect on masticatory ability only in subjects who were A1, with the best-established occlusal support, and B3, on the brink of tooth loss.

Alkan et al. measured maximum occlusal force in healthy individuals who still had all their teeth and individuals suffering from periodontal disease, and found that the latter exhibited significantly lower values than the former (Alkan et al. 2006). Okiyama

et al. measured maximum occlusal force and masticatory performance in healthy young individuals with natural dentition, and reported that there was a significant positive correlation between these two factors. Borges et al. used alveolar bone level and wobbling of remaining teeth as indices of the progress of periodontal disease, and investigated their association with masticatory performance. They found a significant positive correlation between alveolar bone level and masticatory performance, and a tendency toward a negative correlation between wobbling and masticatory performance. In this study, we did not measure either the alveolar bone level or the wobbling of remaining teeth, but as individuals with a CPI Code ≥3 had teeth with pockets more than 4 mm deep, meaning that there was a high possibility of both a lower alveolar bone level and of wobbling, and this probably had an effect on masticatory performance. These results of previous studies suggest the existence of a mechanism whereby in individuals with natural dentition, wobbling due to worsening periodontal status induces a decrease in occlusal force, further lowering masticatory performance. Our finding that worsening periodontal status resulted in significantly lower masticatory performance among subjects who were Eichner A1, with the best-established occlusion by natural dentition, also supports this mechanism. Although subjects who were Eichner A1 had a low proportion of teeth suffering from periodontal disease among those examined for the CPI, they may have had a high number of teeth suffering from periodontal disease (Table 1), with many of these teeth having been preserved rather than extracted, and it may be conjectured that they probably suffered from symptoms such as tooth wobbling and gingival pain that would hinder mastication. The situation of subjects who were Eichner B3 differed from that of those who were Eichner A1, with both the number of teeth and occlusal support reduced, and they were characterized by a high proportion of

teeth with periodontal disease. Denture wearers accounted for the vast majority, 84%, of subjects who were Eichner B3, and wobbling of the abutment tooth due to periodontal disease in such denture wearers would reduce the stability of the denture, making it easy to understand why the effect on masticatory performance was so obvious.

In this study, we also divided subjects into denture wearers and non-denture wearers to investigate the effect of wearing dentures on masticatory ability (Liedberq et al. 1995). Here, too, it is extremely interesting that from subjects who were Eichner A2 to Eichner B1, with 3 of 4 occlusal support points preserved, there was no reduction in masticatory performance due to periodontal disease irrespective of whether or not dentures were worn, but for subjects who were Eichner B2 or B3, with two or fewer occlusal support points, denture wearers exhibited a reduction in masticatory performance as a result of periodontal disease. The reason for the lack of effect of periodontal disease in subjects from Eichner A2 to B1 may have been that these subjects were capable of masticating with teeth other than those with poor periodontal status, while for denture wearers teeth with good periodontal status can be chosen as abutment teeth, meaning that dentures tend to be stable and there is less likelihood of a reduction in masticatory ability. If the occlusal supporting area becomes even smaller, however, mastication with the remaining teeth alone becomes difficult and there is less scope for choosing the abutment tooth, and when added to the fact that wobbling due to periodontal disease may make it difficult to obtain adequate maintenance stability for dentures, the generation of a significant effect on masticatory ability can be envisaged. Almost all of the subjects who were Eichner B4, who had lost all occlusal support in the molar region, were denture wearers, and rather than the periodontal status of the remaining teeth, it is possible that the state of the alveolar ridge, the quality of dentures,

and the ability to make the best use of dentures may have exerted a greater effect on masticatory ability. Among non-denture wearers, excluding subjects who were Eichner A1, who were all non-denture wearers, there was no significant difference between any of the other groups in masticatory performance as a result of the state of health of periodontal tissue. This may have been because of the existence of factors that had a greater effect on masticatory ability than periodontal disease, such as the fact they did not wear dentures despite tooth loss and comminuted jelly therefore became caught in the gaps between teeth, preventing the progression of mastication, as well as unstable masticatory jaw movement.

## Conclusions

Our finding in this study that periodontal disease affects masticatory ability not only if occlusion is established by natural dentition with no tooth loss, but also if occlusal support has decreased and is now being established by dentures, suggesting that keeping periodontal tissue healthy is important in order to maintain masticatory ability. These findings may be valuable for the provision of dietary guidance to elderly people with tooth loss or periodontal disease.

## References

Ainamo, J., Barmes, D., Beagrie, G., Cutress, T., Martin, J. & Sardo-Infirri, J.(1982) Development of the World Health Organization (WHO) Community Periodontal Index of Treatment Needs (CPITN). *International Dental Journal* **32**, 281-291.

Alkan, A., Kesliner, I., Arici, S. & Sato, S. (2006) The effect of periodontitis on biting abilities. *Journal of Periodontology* **77**,1442-1445.

Borges T de F., Regalo, S. C., Taba, M. Jr., Siessere, S., Mestriner, W. Jr. & Semprini, M. (2013) Changes in masticatory Performance and quality of life in individuals with chronic periodontitis. *Journal of Periodontology* **84**, 325-331.

Hayakawa, I., Watanabe, I., Hirano, S., Nagao, M. & Seki, T. (1998) A simple method for evaluating masticatory performance using a color-changeable chewing gum. *The International Journal of Prosthodontics* **11**, 173-176.

Ikebe, K., Morii, K., Matsuda, K., Hazeyama, T. & Nokubi, T. (2005) Reproducibility and accuracy in measuring masticatory performance using test gummy jelly. *Prosthodontic Research and Practice* **4**, 9-15.

Ikebe, K., Hazeyama, T., Morii, K., Matsuda, K., Maeda, Y. & Nokubi, T. (2007) Impact of masticatory performance on oral health-related quality of life for elderly Japanese. *The International Journal of Prosthodontics* **20**, 478-485.

Ikebe, K., Matsuda, K., Murai, S., Maeda, Y. & Nokubi, T. (2010) Varidation of the Eichner index in relation to occlusal force and masticatory performance. *The International Journal of Prosthodontics* **23**, 521-524.

Ikebe, K., Matsuda, K., Kagawa, R., Enoki, K., Yoshida, M., Maeda, Y. & Nokubi, T. (2011) Association of masticatory performance with age, gender, number of teeth, occlusal force and salivary flow in Japanese older adults: is ageing a risk factor for masticatory dysfunction? *Archives of Oral Biology* **56**, 991-996.

Ikebe, K., Matsuda, K., Kagawa, R., Enoki, K., Okada, T., Yoshida, M., Maeda, Y. (2012) Masticatory performance in older subjects with varying degrees of tooth loss. *Journal of Dentistry* **40**, 71-76.

Joshipura, K. J., Willett, W. C. & Douglass, C. W. (1996) The impact of edentulousness on food and nutrient intake. *The Journal of the American Dental Association* **127**, 459-467.

Johansson, A. S., Svensson, K. G. & Trulsson, M. (2006) Impaired masticatory behavior in subjects with reduced periodontal tissue support. *Journal of Periodontology* **77**, 1491-1497.

Kanmori, H., Yoshihara, A., Ando, Y. & Miyazaki, H. (2003) The effect of chewing ability on the dietary intake of healthy elderly people. *Journal of Dental Health* **53**, 13-22.

Kapur, K. K., Soman, S. D. & Yurkstas, A. A. (1964) Test foods for measuring masticatory performance of denture wearers. *The Journal of Prosthetic Dentistry* **14**, 483-491.

Kokubo Y (2011) The association of cardiovascular disease with metabolic syndrome and its risk factors in Japanese urban cohort : the Suita study. *Japanese Journal of Clinical Medicine* **69**, 68-76.

Krall, E., Hayes, C. & Garcia, R. (1998) How dentition status and masticatory function affect nutrient intake. *The Journal of the American Dental Association* **129**, 1261-1269.

Lepley, C. R., Throckmorton, G. S., Ceen, R. F. & Buschang, P. H. (2011) Relative contributions of occlusion, maximum bite force, and chewing cycle kinematics to masticatory performance. *American Journal of Orthodontics and Dentofacial Orthopedics* **139**, 606-613.

Liedberq, B., Spiechowicz, E. & Owall, B. (1995) Mastication with and without removable partial dentures : an intraindividual study. *Dysphagia* **10**, 107-112.

Manly, R. S. & Braley, L. C. (1950) Masticatory performance and efficiency. *Journal of Dental Research* **29**, 448-462.

Marshall, T. A., Warren, J. J., Hand, J. S., Xie, X. J. & Stumbo, P. J. (2002) Oral health, nutrient intake and dietary quality in the very old. *The Journal of the American Dental Association* **133**, 1369-1379.

Miura, H., Arai, Y., Sakano, S., Hamada, A., Umenai, T. & Isogai, E. (1998) Subjective evaluation of chewing ability and self-rated general health status in elderly residents of

Japan. *Asia-Pacific Journal of Public Health* **10**, 43-45.

Morita, M., Kimura, T., Kanegae, M., Ishikawa, A. & Watanabe, T. (1994) Reasons for extraction of permanent teeth in Japan. *Community Dentistry and Oral Epidemiology* **22**, 303-306.

Nakashima, A., Higashi, K. & Ichinose, M. (1989) A new, simple and accurate method for evaluating masticatory ability. *Journal of Oral Rehabilitation* **16**, 373-380.

Nowjack-Raymer, R. E. & Sheiham, A. (2003) Association of edentulism and diet and nutrition in US adults. *Journal of Dental Research* **82**, 123-126.

Ohara, A., Tsukiyama, Y., Ogawa, T. & Koyano, K. (2003) A simplified sieve method for determining masticatory performance using hydrocolloid material. *Journal of Oral Rehabilitation* **30**, 927-935.

Okiyama,S.,Ikebe, K. & Nokubi, T. (2003) Association between masticatory performance and maximal occlusal force in young men. *Journal of Oral Rehabilitation* **30**, 278-282.

Papas, A. S., Joshi, A., Giunta, J. L. & Palmer, C. A. (1998) Relationships among education, dentate status, and diet in adults. *Special Care in Dentistry* **18**, 26-32.

Pereira, L. J., Gazolla, C. M., Magalhaes, I. B., Dominguete, M. H., Vilela, G. R., Castelo, P. M., Marques, L. S. & van der Bilt, A. (2012) Influence of periodontal

treatment on objective measurement of masticatory performance. *Journal of Oral Science* **54**, 151-157.

Sahyoun, N. R., Lin, C. L. & Krall, E. (2003) Nutritional status of the older adult is associated with dentition status. *Journal of the American Dieteric Association* **103**, 61-66.

Sato, H., Fueki, K., Sueda, S., Sato, S., Shiozaki, T., Kato, M. & Ohyama, T. (2003) A new and simple method for evaluating masticatory function using newly developed artificial test food. *Journal of Oral Rehabilitation* **30**, 68-73.

Sato, Y., Minagi, S., Akagawa, Y. & Nagasawa, T. (1989) An evaluation of chewing function of complete denture wearers. *The Journal of Prosthetic Dentistry* **62**, 50-53.

Sheiham, A., Steele, J. G., Marcenes, W., Lowe, C., Finch, S., Bates, C. J., Prentice, A. & Walls, A. W. (2001) The relationship among dental status, nutrient intake, and nutritional status in older people. *Journal of Dental Research* **80**, 408-413.

Shirone, K., Ogawa, H., Hirotomi, T., Takano, N., Yamaga, T., Kaneko, N., Sakuma, S., Yoshihara, A. & Miyazaki, H. (2007) Evaluation of CPI and loss of attachment scoring methods (WHO) and longitudinal study on periodontal conditions in Japanese elderly cohort. *Journal of Dental Health* **57**, 28-35.

Slagter, A. P., Olthoff, L. W., Bosman, F. & Steen, W. H. A. (1992) Masticatory ability,

denture quality, and oral conditions in edentulous subjects. *The Journal of Prosthetic Dentistry* **68**, 299-307.

Slaqter, A. P., Bosman, F. & van der Bilt, A. (1993) Comminution of two artificial test foods by dentate and edentulous subjects. *Journal of Oral Rehabilitation* **20**, 159-176.

Takata, Y., Ansai, T.,Awano, S., Sonoki, K., Fukuhara, M., Wakisaka, M. & Takehara, T. (2004) Activities of daily living and chewing ability in an 80-year-old population. *Oral Diseases* **10**, 365-368.

Takata, Y., Ansai, T.,Awano, S., Fukuhara, M., Sonoki, K., Wakisaka, M., Fujisawa, K., Akifusa, S. & Takehara, T. (2006) Chewing ability and quality of life in an 80-year-old population. *Journal of Oral Rehabilitation* **33**, 330-334.

Tatematsu, M., Mori, T., Kawaguchi, T., Takeuchi, K., Hattori, M., Morita, I., Nakagaki, H., Kato, K., Murakami, T., Tuboi, S., Hayashizaki, J., Murakami, H., Yamamoto, M. & Ito, Y. (2004) Masticatory performance in 80-year-old individuals. *Gerodontology* **21**, 112-119.

Tumrasvin, W., Fueki, K. & Ohyama, T. (2006) Factors associated with masticatory performance in unilateral distal extension removable partial denture patients. *Journal of Prosthodontics* **15**, 25-31.

Wayler, A. H., Kapur, K. K., Feldman, R. S. & Chauncey, H. H. (1982) Effects of age

and dentition status on measures of food acceptability. *Gerodontology* **37,** 294-299.

Yamashita, S., Sakai, S., Hatsh, J.P. & Rugh, J.D. (2000) Relationship between oral function and occlusal support in denture wearers. *Journal of Oral Rehabilitation* **27,** 881-886.

Table 1

Age, gender, clinical parameter and denture wearers distribution of each Eichner Index

| | Eichner Index | | | | | | |
|---|---|---|---|---|---|---|---|
| | A1 | A2 | A3 | B1 | B2 | B3 | B4 |
| N | 653 | 326 | 107 | 201 | 130 | 117 | 76 |
| Age* | 63.9 ± 8.1 | 66.3 ± 7.7 | 67.2 ± 6.9 | 68.0 ± 7.3 | 69.8 ± 7.2 | 70.4 ± 6.5 | 72.4 ± 4.7 |
| Male(%) | 270(41.3) | 147(45.1) | 34(31.8) | 91(45.0) | 57(43.8) | 59(49.2) | 42(43.4) |
| Number of present teeth* | 27.0 ± 1.6 | 25.6 ± 1.8 | 23.4 ± 2.3 | 22.9 ± 2.3 | 20.0 ± 2.9 | 15.6 ± 3.9 | 13.9 ± 3.8 |
| Number of CPI target teeth* | 9.5 ± 1.0 | 8.7 ± 1.1 | 7.5 ± 1.4 | 6.4 ± 1.3 | 5.3 ± 1.4 | 4.1 ± 1.5 | 3.5 ± 1.9 |
| Number of CPI 3 or 4 teeth* | 3.6 ± 2.4 | 3.1 ± 2.0 | 3.4 ± 1.8 | 2.8 ± 1.6 | 2.5 ± 1.6 | 2.3 ± 1.4 | 2.0 ± 1.2 |
| Prevalence of subjects with, % | | | | | | | |
| CPI 0-2 | 54.1 | 47.2 | 49.5 | 38.8 | 50.0 | 41.9 | 51.3 |
| CPI 3 | 33.7 | 40.5 | 32.7 | 35.8 | 30.8 | 35.9 | 30.3 |
| CPI 4 | 12.3 | 12.3 | 17.8 | 25.4 | 19.2 | 22.2 | 18.4 |
| Median percentage of CPI 3 or 4 teeth / target teeth, % | 30.0 | 33.3 | 43.6 | 41.4 | 50.0 | 66.7 | 60.0 |
| Denture wearers, % | 0.0 | 8.3 | 14.0 | 48.5 | 72.3 | 84.2 | 93.4 |

* Mean±SD.

Table 2

Comparison of masticatory performance ($mm^2$) between different periodontal status of each Eichner Index

| Eichner Index | CPI0~2 vs CPI3~4 | | | | | CPI 0~3 vs CPI 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CPI0~2 | | CPI3~4 | | | CPI 0~3 | | CPI 4 | | |
| | N | Mean±SD | N | Mean±SD | *p*-value | N | Mean±SD | N | Mean±SD | *p*-value |
| A1 | 353 | 5674±1544 | 300 | 5234±1624 | < 0.001* | 573 | 5534±1556 | 80 | 5027±1798 | 0.008* |
| A2 | 154 | 5149±1785 | 172 | 5101±1574 | 0.797 | 286 | 5161±1674 | 40 | 4855±1677 | 0.279 |
| A3 | 53 | 4735±1514 | 54 | 4537±1718 | 0.528 | 88 | 4700±1598 | 19 | 4336±1706 | 0.376 |
| B1 | 78 | 4712±1503 | 123 | 4350±1575 | 0.108 | 150 | 4554±1547 | 51 | 4305±1573 | 0.325 |
| B2 | 65 | 4097±1629 | 65 | 3666±1489 | 0.118 | 105 | 4000±1596 | 25 | 3387±1372 | 0.079 |
| B3 | 49 | 3794±1658 | 68 | 3024±1504 | 0.010* | 91 | 3555±1578 | 26 | 2617±1527 | 0.008* |
| B4 | 39 | 3156±1679 | 37 | 2833±1640 | 0.399 | 62 | 2886±1653 | 14 | 3498±1639 | 0.214 |

* $p<0.05$ for Student's *t*-test comparing CPI 0~2 with CPI 3~4 and CPI 0~3 with CPI 4.

Table 3

Comparison of masticatory performance ($mm^2$) between different periodontal status of each Eichner Index in denture wearers

| Eichner Index | CPI0~2 vs CPI3~4 | | | | | CPI 0~3 vs CPI 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CPI0~2 | | CPI3~4 | | | CPI 0~3 | | CPI 4 | | |
| | N | Mean±SD | N | Mean±SD | *p*-value | N | Mean±SD | N | Mean±SD | *p*-value |
| B1 | 43 | 4929±1518 | 55 | 4478±1538 | 0.150 | 77 | 4769±1580 | 21 | 4335±1352 | 0.254 |
| B2 | 49 | 4208±1661 | 45 | 3533±1410 | 0.037* | 74 | 4008±1660 | 20 | 3429±1125 | 0.074 |
| B3 | 41 | 3818±1674 | 58 | 2921±1511 | 0.007* | 75 | 3539±1606 | 24 | 2519±1503 | 0.007* |
| B4 | 37 | 3080±1664 | 34 | 2815±1707 | 0.511 | 58 | 2813±1661 | 13 | 3579±1677 | 0.138 |

* $p<0.05$ for Student's *t*-test comparing CPI 0~2 with CPI 3~4 and CPI 0~3 with CPI 4.

Table 4

Comparison of masticatory performance ($mm^2$) between different periodontal status of each Eichner Index in non-denture wearers.

| | CPI 0~2 vs CPI 3~4 | | | | | CPI 0~3 vs CPI 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Eichner | CPI 0~2 | | CPI 3~4 | | | CPI 0~3 | | CPI 4 | | |
| Index | N | Mean±SD | N | Mean±SD | *p*-value | N | Mean±SD | N | Mean±SD | *p*-value |
| A1 | 353 | 5674±1624 | 300 | 5234±1624 | < 0.001* | 573 | 5534±1556 | 80 | 5027±1798 | 0.008* |
| A2 | 141 | 5164±1762 | 158 | 5129±1536 | 0.854 | 264 | 5162±1646 | 35 | 5026±1647 | 0.646 |
| A3 | 43 | 4642±1439 | 49 | 4679±1679 | 0.908 | 74 | 4734±1516 | 18 | 4349±1755 | 0.347 |
| B1 | 35 | 4445±1462 | 68 | 4247±1609 | 0.543 | 73 | 4327±1490 | 30 | 4285±1734 | 0.901 |
| B2 | 16 | 3758±1526 | 20 | 3967±1650 | 0.699 | 31 | 3980±1456 | 5 | 3218±2290 | 0.323 |
| B3 | 8 | 3674±1677 | 10 | 3623±1377 | 0.944 | 16 | 3628±1491 | 2 | 3793±1835 | 0.886 |
| B4 | 2 | | 3 | | | 4 | | 1 | | |

* $p<0.05$ for Student's *t*-test comparing CPI 0~2 with CPI 3~4 and CPI 0~3 with CPI 4.

There were few subjects who were Eichner B4, so they were excluded from analysis.

ORIGINAL ARTICLE

# Additive Interaction of Oral Health Disorders on Risk of Hypertension in a Japanese Urban Population: The Suita Study

Yoshio Iwashima,[1] Yoshihiro Kokubo,[2] Takahiro Ono,[3] Yoko Yoshimuta,[3] Momoyo Kida,[3] Takayuki Kosaka,[3] Yoshinobu Maeda,[3] Yuhei Kawano,[1] and Yoshihiro Miyamoto[2]

**BACKGROUND**
This study assessed the relationship between different oral health markers—periodontitis, gingival bleeding, tooth number, and occlusal status—and hypertension in a Japanese urban population.

**METHODS**
A total of 1,643 participants with no prior cardiovascular disease (mean age = 66.6 years; 43.4% women) underwent comprehensive health checkups, including a lifestyle questionnaire and dental examination in the Suita Study.

**RESULTS**
In the multivariable-adjusted logistic model, none of the individual oral health markers, namely severe periodontitis, gingival bleeding, lowest quartile of tooth number, and malocclusion, were significantly associated with increased odds of hypertension. The additive effects of oral health markers on hypertension were examined and showed that, compared with subjects with no component of the oral health markers, the multivariale-adjusted odds ratio of hypertension in those with ≥3 components was 1.82 (95% confidence interval (CI) = 1.23–2.72; $P = 0.003$). In the subpopulation without antihypertensive medication (n = 1,148; 59.8% women), a significant graded relationship between multivariable-adjusted systolic blood pressure and the number of components was found ($P_{trend} = 0.03$), and, compared with subjects with no component of the oral health markers, having ≥3 components was related to a higher systolic blood pressure ($\beta = 5.41$; 95% CI = 1.16–9.66; $P = 0.01$).

**CONCLUSIONS**
There is an additive relationship between oral health disorders and risk of hypertension. Our results suggest that the existence of moderate or severe oral health disorders—that is, several concomitant oral health disorders—is associated with risk of hypertension.

*Keywords:* blood pressure; hypertension; life style; oral health disorder; risk factor.

doi:10.1093/ajh/hpt227

Several epidemiological surveys have suggested the existence of a positive relationship between oral health disorders and hypertension.[1–5] Among such disorders, periodontitis is a common chronic infectious disease of the adult population, characterized by an exaggerated gingival inflammatory response against pathogenic bacterial microflora. If left untreated, it leads to deterioration of the supportive tissue of the teeth and eventually to tooth loss.[6] Periodontal disease, gingival bleeding, and tooth loss have been reported to be associated with hypertension,[1–5,7,8] and the systemic inflammatory response that may accompany these conditions has been implicated as a mechanism in the development of hypertension.[9] Periodontal disease and subsequent tooth loss may lead to poor dietary habits, or vice versa, and patients with these conditions may be likely to favor soft carbohydrate foods[10] and restrict fruit intake,[11] which influences blood pressure.[12] The modification of diet that occurs with these conditions has been speculated to be another possible mechanism in the development of hypertension;[9,13] however, the clinical implication of lifestyle variables such as eating habits or physical activity in the association between oral health disorders and hypertension remains to be elucidated. Further, tooth loss could contribute to worse occlusal status or masticatory performance, which is also an important pathological condition in oral health disorders; however, the influence of worse occlusal status on hypertension is also unknown.

In an effort to enrich understanding in the emerging area of the association between oral health and hypertension, we investigated the potential interrelationship between different markers of oral health, lifestyle variables, and risk of hypertension in a Japanese urban population.

Correspondence: Yoshio Iwashima (iwashima@hsp.ncvc.go.jp).

Initially submitted May 20, 2013; date of first revision June 21, 2013; accepted for publication November 10, 2013.

**Divisions of [1]Hypertension and Nephrology, and [2]Preventive Cardiology, Department of Medicine, National Cerebral and Cardiovascular Center, 5-7-1, Fujishirodai, Suita City, Osaka, Japan; [3]Department of Prosthodontics, Gerodontology and Oral Rehabilitation, Osaka University Graduate School of Dentistry, 1-8, Yamada-oka, Suita City, Osaka, Japan.**

## METHODS

### Study subjects

The data used in this research derive from the Suita Study, which consisted of a random sample of Japanese urban residents. The details of this study are described elsewhere.[14–16] Briefly, 6,485 men and women aged 30–79 years had a baseline survey at the National Cardiovascular Center (now the National Cerebral and Cardiovascular Center) between September 1989 and March 1994 and underwent a medical examination every 2 years. Of these, 1,797 underwent comprehensive regular health checkups and dental examinations between June 2008 and March 2012. Participants in the study population were excluded from these analyses if they had a past or present history of cardiovascular disease, including ischemic heart disease, acute coronary syndrome, congestive heart failure requiring hospitalization, valvular heart disease requiring medication, stroke, history of transient ischemic attack (n = 88), or atrial fibrillation (n = 35), or had not undergone baseline dental examination (n = 31). After applying these exclusions, a total of 1,643 participants aged 30–79 years were available for this analysis. Physicians or nurses administered the questionnaire on individual personal habits and present illnesses. Informed consent was obtained from all participants. All participants were Japanese, and this study was approved by the Institutional Review Board of the National Cerebral and Cardiovascular Center (M19-062-3).

### Measurement of blood pressure and covariables

Well-trained physicians measured blood pressure twice in a seated position with an automated sphygmomanometer (Colin BP-I03ill; Omron, Kyoto, Japan) and an appropriately sized cuff according to a standard protocol after at least 5 minutes of rest before the initial blood pressure reading was obtained. Systolic (SBP) and diastolic (DBP) blood pressure were considered the average of 2 measurements recorded >1 minute apart. Hypertension was defined as SBP ≥140 mm Hg and/or DBP ≥90 mm Hg or use of antihypertensive medication.

At the baseline examination, routine blood tests were performed, including triglycerides, high-density lipoprotein cholesterol, glucose, and hemoglobin A1c. Height and body weight were measured, and body mass index was calculated as weight (kg) divided by the square of height ($m^2$). Dyslipidemia was defined according to the guidelines of the National Cholesterol Education Program Third Adult Treatment Panel.[17] Diabetes mellitus was defined according to the American Diabetes Association criteria.[18] Estimated glomerular filtration rate was calculated using the Japanese coefficient-modified Chronic Kidney Disease Epidemiology Collaboration equation in milliliters per minute per 1.73 $m^2$, as previously described.[19–21]

### Oral examination

All participants received a complete oral examination by trained, certificated dentists. The periodontal condition was assessed using a modified Community Periodontal Index of Treatment Needs (CPITN)[22] in 8 designated molars (first and second molars) and 2 incisors (upper right and left central incisors) by applying the following scores: 0 indicates healthy periodontal tissue; 1 indicates gingival bleeding; 2 indicates calculus and/or overhanging restorations; 3 indicates pocket depth of 4–5 mm; and 4 indicates pocket depth of ≥6 mm. All periodontal examinations were performed by 4 experienced dentists, and the interobserver Cohen's kappa coefficient for grading was 0.78. The periodontal condition of every patient was reported as the worst CPITN condition. The presence or absence of gingival bleeding was also assessed by salivary occult blood test using a paper test strip (Salivaster; Showa Yakuhin, Tokyo, Japan).

The number of remaining teeth was counted in the full mouth with the exception of the third molars, which tend to be impacted, congenitally missing, or surgically removed because of anticipated pericoronitis.[23] Therefore, the maximum number of teeth was 28.

The status of occlusal support or masticatory performance was recorded by means of the Eichner index,[24] which is based on occlusal contact areas for the natural dentition in antagonist jaws, including fixed dentures. Class A contains 4 support zones; this means there is a minimum of 1 tooth in contact between the maxilla and the mandible in both the premolar and molar regions on each side. Class B contains 3, 2, or 1 support zone or support in the anterior area only. In class C, there are no antagonist contacts in the dentition.

Maximal bite force was measured by using the Dental Prescale System (GC, Tokyo, Japan), which consists of a horseshoe-shaped bite foil of pressure-sensitive film (50H, type R) and a computerized scanning system for analysis of the load.[25,26]

### Lifestyle variables

Information on lifestyle was collected with a standardized questionnaire by physicians or nurses through face-to-face interviews, including demographic information such as smoking habit, dietary practices and usual frequency of food intake, exercise/sports and walking hours a day, and sleeping hours. Smoking status was defined as never smoker, former smoker, or current smoker. Alcohol consumption was categorized as none, social, or daily. Consumption of fruit and sugar-sweetened soft drinks was ascertained by questions as "fruit (citrus fruit, other fruit, and fresh fruit juice) intake ≥1 /day" and "sugar-sweetened soft drink intake ≥3 times /day," respectively. Sugar-sweetened soft drinks included all types of non-low-calorie, concentrated, carbonated, and ready-to-drink soft drinks. All low-calorie, no-added-sugar, and sugar-free types of concentrated, carbonated, and ready-to-drink soft drinks were not classified as sugar-sweetened soft drinks in this study. Physical activity was ascertained by question as"">1 hour walking or equivalent physical activity on average a day." Average sleep duration was classified into 8 categories: <4, 4–5, 5–6, 6–7, 7–8, 8–9, 9–10, and ≥10 hours per day.

### Statistical analysis

Summary statistics are presented as mean (±SD) for continuous variables and as percentage for categorical