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Relationship between masticatory performance and heart rate variability: A pilot study

NORIKO TAKEUCHI, DAISUKE EKUNI, TAKAAKI TOMOFUJI & MANABU MORITA

Department of Preventive Dentistry, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama, Japan

Abstract

Objective. Little information is available on how impaired masticatory performance relates to heart-rate variability (HRV). The aim of this study was to investigate the relationship between HRV indices and masticatory performance. ***Materials and methods.*** Sixty-five subjects (19 men and 46 women, 66.1 ± 9.9 years old) who had received periodontal maintenance care at the Clinic of Preventive Dentistry of Okayama University Hospital were selected for the study. All subjects completed written questionnaires, a chewing (colour-changing gum) test for masticatory performance and measurement of occlusal force and HRV as well as oral examination. ***Results.*** The high sympathetic activity (LF ≥ 49.6) group showed a significantly lower level of masticatory performance (a* value) than the low sympathetic activity group (p < 0.05). There were also significant correlations of masticatory performance with LF and LF/HF (p < 0.05). ***Conclusion.*** These findings suggest that there is relationship between masticatory performance and HRV indices and impaired masticatory performance may be a risk factor for inducing high sympathetic activity.

Key Words: *mastication, heart rate variability, stress, chewing, sympathetic activity*

Introduction

Beyond its primary functions of food intake and digestion, mastication has related to general health [1,2]. For example, in a case-control study, a negative correlation was found between chewing ability and depressive status in elderly people (mean age ± SD, 76.6 ± 7.1 years) [3]. In animal studies, nitric oxide levels in the rat brain are increased by restraint stress and this increase is prevented by biting behaviour [4]. In rats, biting produces an anti-stress effect and parafunctional masticatory activity plays an important role in coping with stressful events [5]. Furthermore, immobilization stress induces activation of the sympathetic nervous system and chewing can ameliorate sympathetic hyperactivity during the stress in rats [6]. The sympathetic hyperactivity is a potent stimulus for ventricular tachyarrhythmias and sudden cardiac death, especially in patients with cardiovascular diseases [6]. These studies suggest a possible relationship between masticatory performance and activation of the autonomic nervous system (ANS).

Measurement of heart rate variability (HRV) can be used to investigate ANS function [7]. Measurement of HRV provides information on the systems that influence heart rate, especially the sympathetic and vagal divisions of the ANS, and includes a time domain, such as the standard deviation of the mean R-R interval (SDRR) [8] or root mean square of successive differences (RMSSD) [9], and a frequency domain, such as low frequency band power (LF, 0.04–0.15 Hz), high frequency band power (HF, 0.15–0.4 Hz) and their ratio (LF/HF) [7]. Vagal activity is a major contributor to the HF component. The LF component represents either sympathetic modulation or a combination of sympathetic and vagal influences. The LF/HF ratio is considered a measure of sympathovagal balance.

Normal masticatory performance modulates HRV indices, such as LF, HF or LF/HF [6,10-12]. However, there is little information on how impaired masticatory performance relates to HRV indices. Therefore, we hypothesized that impairment of masticatory performance would lead to reduced

Correspondence: Daisuke Ekuni, Department of Preventive Dentistry, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, 2-5-1 Shikata-cho, Kita-ku, Okayama 700-8558, Japan. Tel: +81 86 235 6712. Fax: +81 86 235 6714. E-mail: dekuni7@md.okayama-u.ac.jp

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HRV and be a possible risk factor for reduced HRV. The aim of this study was to investigate the relationship between HRV indices and masticatory performance. Among the various objective assessments, colour-changing chewing gum has been reported to be a useful test material for evaluating chewing ability and masticatory performance [13–16]. Thus, we used the chewing test to evaluate masticatory performance.

Materials and methods

Study sample

We enrolled 65 patients (19 males and 46 females; 66.0 years [median], [60.5, 72.5] [25%, 75%]) who had received periodontal maintenance care at the Clinic of Preventive Dentistry of Okayama University Hospital. The study was conducted from September 2010 to February 2011 and was approved by the Ethics Committee of Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences. After obtaining written informed consent, subjects completed written questionnaires regarding personal health and the State-Trait Anxiety Inventory (STAI) and then underwent an examination of masticatory performance, an oral examination and HRV indices.

STAI

Subjects completed the Japanese version of the STAI consisting of 20 items each for state and trait of anxiety [17]. The items on the sub-scale are answered on a 4-point Likert scale from 1 (not at all) to 4 (very much so). The state sub-scale is a widely used instrument for measuring fluctuating levels of anxiety.

Oral examination

Three dentists examined participants' teeth. Clinical measurements included probing pocket depth (PPD), clinical attachment level (CAL), bleeding on probing (BOP), tooth mobility, the presence of a prosthesis, number of teeth and occluding pairs of teeth using Eichner's index [3,18,19]. PPD and CAL, rounded to the nearest 1 mm, were measured at six sites in each tooth (mesio-buccal, mid-buccal, disto-buccal, mesio-lingual, mid-lingual and disto-lingual) using a colour-coded probe (CP-8; Hu-Friedy, Chicago, IL) [19]. The CAL was determined as the distance from the cemento-enamel junction to the bottom of the periodontal pocket. BOP was defined as the presence of bleeding after gentle probing with 25 g of probing force. The intra- and inter-examiner agreement, evaluated with kappa statistics, of the PPD and CAL was more than 0.8. Eichner's index is based on the existence of occlusal contacts of the premolars and the molars, called the 'supporting zones' [3,18]. A maximum of four supporting zones can exist where at least one tooth must be in contact with an antagonist in both the molar and premolar areas.

Colour-changing chewing gum test

To evaluate masticatory performance, we used Masticatory Performance Evaluating Gum (Xylitol®; 70 mm × 20 mm × 1 mm, 3.0 g, Lotte Co., Ltd., Saitama, Japan). The gum base contains red, yellow and blue dyes, citric acid and xylitol [16]. The chewing gum is originally yellowish-green because of the presence of yellow and blue pigments. When the chewing gum is mixed with saliva during the mastication process, the pH inside the chewing gum increases because of the excretion of the citric acid into the saliva. Simultaneously, elution of the yellow and blue pigments changes the colour of the chewing gum from yellowish-green to red. There is a strong correlation between the colour change and masticatory performance, suggesting that the colour-changing chewing gum is useful for assessing masticatory performance [3]. Subjects were asked to normally chew the colour-changing chewing gum for 2 min. After chewing, the colour of the gum samples were photographed on a slide glass using a specially constructed device to keep a standardized distance between the digital camera (Canon Inc, Tokyo, Japan) and the specimen. The images were imported and evaluated in an $L^\star$ $a^\star$ $b^\star$ colour system using Adobe Photoshop CS2® (Adobe Systems Inc., San Jose, CA). The $L^\star$ $a^\star$ $b^\star$ colour system was developed by the Commission Internationale de l'Eclairage for measuring perceived colour and colour differences. The three basic co-ordinates represent the lightness of the colour ($L^\star$), its position between red/magenta and green ($a^\star$) and its position between yellow and blue ($b^\star$). In this study, $a^\star$ values were used to represent masticatory ability, because higher $a^\star$ values have been shown to be well-correlated with chewing performance [3].

Measurement of biting ability

Biting ability, including occlusal force, occlusal contact area and occlusal pressure was measured using a pressure-sensitive sheet (Dental Prescale, Type-R 50H, Fuji Film, Tokyo, Japan) and analysed by an image scanner (Occluzer, FPD-707, Fuji Film) [19]. The microcapsules in the pressure-sensitive sheet are broken to react with a colour-developing material when the sheet is bitten. Different colour densities are formed according to the magnitude of the pressure applied. The occlusal force and occlusal contact area were calculated after scanning the sheet with an image scanner (Occluzer). The occlusal force (N) was automatically determined as the sum of the degree of colouration and the area at each contact point. The area discoloured by biting was recorded as the occlusal contact area (mm^2). The occlusal pressure (N/mm^2) is the occlusal force per 1 mm^2 of occlusal contact area [19].

Subjects were seated with their heads upright and in an unsupported natural head position and then the sheet was placed into the patient's mouth so that the midline of the arch coincided with the midline of the sheet [19]. Each subject was instructed to bite as forcefully as possible for ~ 3 s.

HRV indices

All assessments took place between 09:00 h and 11:00 h. The acquisition of HRV was done by a pulse frequency meter (Pulse Analyzer Plus; YKC Corporation, Tokyo, Japan) for 5 min before all other measurements [20]. The power spectrum of R-R intervals was obtained by means of fast Fourier transformation (Tas9; YKC Corporation, Tokyo, Japan). The area under the spectral peaks within the ranges 0.033–0.04, 0.04–0.15, 0.15–0.4 and 0.033–0.4 Hz were defined as very low frequency (VLF), LF, HF, and total power (TP), respectively. The normalized LF (normalized unit [n.u.]) and HF (n.u.) powers were calculated by 100 × LF/(TP VLF) and 100 × HF/(TP VLF), respectively. The LF/HF, considered an index of sympathovagal balance, was also calculated.

Evaluation of body mass index (BMI)

BMI was computed as weight in kilograms divided by square height in metres, as HRV decreases with augmented BMI [20].

Statistical analysis

All data were analysed using SPSS 15.0 J for Windows (SPSS Japan, Tokyo, Japan). Subjects with high sympathetic activity were diagnosed as those who showed an LF ≥ 49.6 in HRV indices. This cut-off value for sympathetic activity was based on the median of the present results, because the absolute cut-off value of LF for high sympathetic activity is still unclear. The Mann-Whitney U-test or chi-square est was used to compare parameters between high and low sympathetic activity groups. The statistical significance of associations among variables was determined using the Spearman's correlation coefficient. A p-value < 0.05 was considered significant.

Results

The age and gender distribution of subjects are shown in Table I. Almost all the variables examined did not differ significantly between the high (LF ≥49.6) and low (LF <49.6) sympathetic activity group, except for the masticatory performance. The masticatory performances (a* value) in the low sympathetic activity group were greater than those in the high sympathetic activity group ($p < 0.05$) (Table II).

The correlations between the HRV indices and each of the parameters are shown in Table III. Significant correlations were observed between LF, LF/HF and the masticatory performance (a* value) ($p < 0.05$).

Discussion

In the present study, subjects with high sympathetic activity showed a significantly lower level of masticatory performance than those with low sympathetic activity. A significantly negative correlation was also observed between LF and masticatory performance. These findings indicate that impaired masticatory performance could attenuate HRV and lead to sympathetic hyperactivity. Mastication produces an anti-stress effect and impaired masticatory performance plays an important role in coping with stressful events [5]. Stress induces activation of the sympathetic nervous system and chewing can ameliorate sympathetic hyperactivity during the stress in rats [6]. These findings support our hypothesis that impaired masticatory performance may be a possible risk factor for reduced HRV and decrease coping ability with stress thorough sympathetic hyperactivity.

Some studies have investigated the influence of chronic stress on HRV. Decreased HF and increased LF/HF have been associated with mental stress and a lack of ability to respond to physiological variability and complexity [21]. A reduced HF level is related to chronic stress [22]. LF and LF/HF increases in patients with symptoms of chronic psychological stress [22,23]. These trends in HRV shift were similar to our results.

However, there was no significant difference in STAI score between high and low sympathetic activity groups. The STAI is one of the most useful tools for specific measures of anxiety. However, some studies on chronic stress have reported that there is no relationship between chronic stress and state of anxiety in STAI or that the STAI score decreases to baseline levels during long-term follow-up [24,25]. It is possible that STAI may not be suitable for measuring chronic

Table I. Age and gender distribution of subjects.

Age group (years)	Males	Females	Total
30–39	1	0	1
40–49	1	3	4
50–59	1	7	8
60–69	7	23	30
70–79	4	12	16
80–89	5	1	6
Total	19	46	65

Table II. Comparison of parameters between high and low sympathetic activity groups.

Parameter	High (LF ≥49.6) (n = 33)		Low (LF <49.6) (n = 32)		Total (n = 65)		p-value
General information							
Age (years)[b]	66.0	(61.5, 75.5)[a]	66.5	(60.3, 71.0)	66.0	(60.5, 72.5)	0.753
Body mass index (kg/m^2)[b]	22.6	(21.4, 23.9)	21.6	(20.5, 23.4)	22.1	(20.8, 23.9)	0.105
Gender (% of men)[c]	39.4		18.8		29.2		0.102
Take part in regular physical activity (%)[c]	54.5		65.3		60.0		0.568
Hypertension (%)[c]	33.3		21.9		27.7		0.408
Hyperlipidaemia (%)[c]	12.1		6.3		9.2		0.672
Diabetes mellitus (%)[c]	3.0		6.3		4.6		0.613
Heart disease (%)[c]	3.0		15.6		9.2		0.196
Habitual alcohol drinking (%)[c]	27.3		34.8		30.8		0.598
Tobacco exposure (%)[c]	24.2		9.4		16.9		0.277
Number of teeth[b]	24.0	(14.0, 26.5)	24.5	(18.0, 26.8)	24.0	(16.0, 26.5)	0.554
Mean probing pocket depth[b]	1.8	(1.7, 2.1)	1.8	(1.6, 2.2)	1.8	(1.7, 2.2)	0.839
Mean clinical attachment level[b]	2.3	(2.0, 2.9)	2.5	(1.9, 3.3)	2.5	(1.9, 3.2)	0.906
% of mobile teeth[b]	0.0	(0.0, 16.3)	0.0	(0.0, 8.2)	0.0	(0.0, 10.4)	0.893
% of sites with bleeding on probing[b]	2.2	(0.3, 7.4)	2.4	(1.4, 9.2)	2.2	(0.7, 9.2)	0.388
% of teeth with restorations on the occlusal surface of pre-molars and molars[b]	38.5	(24.8, 47.8)	36.2	(27.8, 44.3)	38.1	(27.4, 47.1)	0.880
Total occlusal contact area (mm^2)[b]	7.0	(4.8, 19.8)	9.6	(5.8, 17.2)	8.3	(5.6, 17.4)	0.351
Biting pressure (force per mm^2 occlusal contact area)[b]	32.0	(26.8, 35.1)	31.1	(27.0, 36.4)	31.7	(27.1, 35.7)	0.798
Total biting force (N)[b]	205.8	(146.4, 506.1)	294.8	(176.8, 532.4)	267.5	(156.7, 530.3)	0.332
Occluding pairs of teeth (Eichner's index)[b]	2.0	(1.0, 2.0)	1.5	(1.0, 2.0)	3.0	(0.0, 4.0)	0.316
Masticatory performance (a* value)	29.2	(20.5, 37.1)	37.8	(31.7, 43.7)			0.011
State-Trait Anxiety Inventory (STAI)							
State of anxiety in STAI[b]	35.0	(30.0, 42.5)	36.0	(27.0, 44.0)	35.0	(28.5, 42.5)	0.773
Trait of anxiety in STAI[b]	39.0	(30.5, 48.0)	40.0	(34.0, 47.8)	40.0	(34.0, 48.0)	0.793

[a]Median (25%, 75%).
[b]Mann-Whitney U-tests were performed.
[c]χ^2 tests were performed.

stress in this study, although the reason for this is unclear, or that subjects with sympathetic hyperactivity may be under stress at a sub-clinical level.

Chronic stress is associated with increased arterial pressure and impaired autonomic regulation of cardiovascular functions [22]. To understand the possible link, a two closed-loop model of the baroreflex system is proposed [26]. One loop involves heart rate and blood pressure control systems and the other involves vascular tone and blood pressure control systems. The blood pressure control system is a common link to both loops. For example, anxiety disorders involve dysfunctional reactions, which are related to the hypothesized domain of baroreflex modulation [26]. The current relationship between masticatory performance and HRV indices might be involved in the model of the baroreflex system. However, the mechanism of relationship between HRV indices and masticatory performance may be complex and further studies are required.

We used the chewing test to evaluate masticatory performance because colour-changing chewing gum has been reported to be a useful test material for evaluating objective chewing ability and masticatory performance [13–16]. As described in a recent review [27], a wide variety of methods have been used to determine masticatory performance, for example, measuring colour changes in chewing gum [13–16], sugar loss from chewing gum [28], a colourimetric method to determine the release of dye when chewing raw carrots [29], photometric methods to quantify changes in colour [30,31], optical scanning of chewed particles [32,33], the degree of breakdown of a food determined by sieving the comminuted food [34,35] and the ability to mix and knead two-coloured chewing gum [36,37] or paraffin wax [38]. On the other

Table III. Spearman's correlation coefficients of parameters associated with HRV indices.

	Low frequency (LF) (n.u.)		High frequency (HF) (n.u.)		LF/HF	
Parameter	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
General information						
Age (years)	0.096	0.446	0.104	0.409	0.126	0.319
Body mass index (kg/m^2)	0.200	0.110	0.198	0.114	0.190	0.130
Oral information						
Number of teeth	0.016	0.898	0.022	0.862	0.032	0.800
Mean probing pocket depth	0.048	0.704	0.037	0.768	0.003	0.979
Mean clinical attachment level	0.068	0.593	0.062	0.624	0.056	0.656
% of mobile teeth	0.013	0.921	0.028	0.822	0.017	0.894
% of sites with bleeding on probing	0.063	0.062	0.052	0.684	0.020	0.873
% of teeth with restorations on the occlusal surface of pre-molars and molars	0.010	0.940	0.011	0.933	0.003	0.980
Total occlusal contact area (mm^2)	0.021	0.869	0.027	0.828	0.014	0.914
Biting pressure (force per mm^2 occlusal contact area)	0.046	0.718	0.045	0.722	0.047	0.711
Total biting force (N)	0.002	0.987	0.008	0.948	0.009	0.940
Occluding pairs of teeth (Eichner's index)	0.006	0.959	0.009	0.943	0.015	0.906
Masticatory performance (a* value)	0.247	0.048	0.240	0.055	0.252	0.043

hand, the number of occluding (pre) molar teeth and bite force could explain 70% of the variance in masticatory performance [27]. In this study, there were correlations between masticatory performance (a* value), and total biting force and occluding pairs of teeth (Eichner's index). These findings strongly support that masticatory performance assessed by the a* value using colour-changing chewing gum has reliability and validity.

Using a non-invasive approach based on spectral analysis of short-term cardiovascular variability, we showed that low masticatory performance in humans appears to be associated with impaired HRV indices or autonomic regulation of cardiovascular functions. Sympathetic predominance and vagal withdrawal might represent the autonomic counterpart of the complex psychophysiological changes underlying the increase in cardiovascular risk associated with chronic stress [22]. As preventing cardiovascular diseases at the sub-clinical level is important by controlling risk factors, monitoring of HRV indices might be useful. Moreover, optimizing the autonomic profile by improving masticatory performance might represent a new strategy to reduce not only chronic stress but also the future incidence of hypertension or cardiovascular diseases [39].

Our study has some limitations. First, all subjects were recruited from among patients at Okayama University and the number of subjects was small. This may limit the ability to extrapolate these findings to the general population. Second, this study was cross-sectional. It is therefore still uncertain as to whether low masticatory performance is the cause of reduced HRV. Intervention studies will be needed to examine the causal relationship between masticatory performance and HRV. Third, the role of other factors (e.g., diet and genetic factors) that have been shown to affect HRV indices were not considered in our study. To the best of our knowledge, this is the first study that showed the relationship between masticatory performance and HRV in humans in spite of these limitations.

In conclusion, there was a relationship between masticatory performance and HRV indices and impaired masticatory performance may be a risk factor for inducing high sympathetic activity.

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