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Decreased chewing activity during mouth breathing

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SUMMARY This study examined the effect of mouth breathing on the strength and duration of vertical effect on the posterior teeth using related functional parameters during 3 min of gum chewing in 39 nasal breathers. A CO_2 sensor was placed over the mouth to detect expiratory airflow. When no airflow was detected from the mouth throughout the recording period, the subject was considered a nasal breather and enrolled in the study. Electromyographic (EMG) activity was recorded during 3 min of gum chewing. The protocol was repeated with the nostrils occluded. The strength of the vertical effect was obtained as integrated masseter muscle EMG activity, and the duration of vertical effect was also obtained as chewing stroke count, chewing cycle variation and EMG activity duration above baseline. Baseline activity was obtained from the isotonic EMG activity during jaw movement at 1·6 Hz without making tooth contact. The duration represented the percentage of the active period above baseline relative to the 3-min chewing period. Paired t-test and repeated analysis of variance were used to compare variables between nasal and mouth breathing. The integrated EMG activity and the duration of EMG activity above baseline, chewing stroke count and chewing cycle significantly decreased during mouth breathing compared with nasal breathing ($P < 0{\cdot}05$). Chewing cycle variance during mouth breathing was significantly greater than nasal breathing ($P < 0{\cdot}05$). Mouth breathing reduces the vertical effect on the posterior teeth, which can affect the vertical position of posterior teeth negatively, leading to malocclusion.

KEYWORDS: degree of vertical force, duration of vertical force, electromyographic activity, mouth breathing, isotonic contraction, chewing gum

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Introduction

Genetically determined intrinsic factors are, of course, a major factor in the morphogenesis of the face. However, extrinsic factors, including masticatory function, are also responsible for inducing malocclusion with vertical problems. Skeletal anterior open bite results in vertical problems and is classified as two types; one is open bite with downward and backward (clockwise) rotation of the mandible and the other is deformation of the jaws. Clockwise rotation of the mandible is caused by extruded posterior teeth, excessive vertical maxillary growth and vertical height deficiency of the mandibular ramus (1–3). In the former type, the magnitude of the masticatory muscular activity and occlusal bite force are less than those with standard values because of more tipping of the occlusal plane relative to the orientation of the masseter muscle (4–6).

The vertical position of the posterior teeth is decided by vertical effects like the magnitude and duration of vertical force on the posterior teeth relative to eruptive force (7). From the collaborative evidence of equilibrium theory, the increased vertical force on the posterior teeth will result in intrusion of the molars. Several research groups have addressed this importance of element on tooth position (8–10), concluding that any increase in the degree and duration of vertical force could have an intrusive effect on the posterior teeth and cause an upward rotation of the mandible. Based on this evidence, it is possible that continuous shortening of the duration and decreasing degree of occlusal force throughout the 24-h day could have an extrusive

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effect on the posterior teeth and cause downward and backward rotation of the mandible.

The aetiology of malocclusion is considered to involve nasal obstruction or mouth breathing. Animal studies have demonstrated that habitual mouth breathing is associated with various malocclusions, such as anterior reversed occlusion and open bite (11–13). In clinical observations, children with mouth breathing may have a dolichofacial appearance, narrow maxillary arch, increase in the anterior facial height and greater inclination of the mandibular plane angle (14). However, the notion of a complex relationship between mouth breathing and altered dentofacial growth remains controversial because the mouth breathing of study participants throughout the entire measurement period cannot be confirmed (15–17). With nasal breathing, it is possible to continue masticatory motion without stopping the chewing motion. When nasal breathing is switched to mouth breathing, the position of the lips, tongue and the mandible should change to provide an airway through the mouth (11–13, 18, 19). Accordingly, masticatory motion must be stopped or at least impeded while breathing through the mouth (20, 21).

The main hypothesis tested in this study was that mouth breathing reduces the vertical effect on the posterior teeth. For this purpose, vertical effect was regarded as the vertical force, exerted by chewing activity on the posterior teeth. Therefore, we examined the effect of mouth breathing on chewing activity while the subject chewed the gum.

Material and methods

Subjects and classification of breathing pattern

Volunteers were at randomly recruited from our Dental College, and 39 subjects who were confirmed to be nasal breathers participated in this study. The mean age was 24·23 ± 3·27 years. Subjects known to be partial or complete mouth breathers, who had the common cold, severe malocclusion or temporomandibular dysfunction, were excluded from the study. The study protocol was approved by the Human Ethics Review Committee of our Dental College, and informed consent was obtained from each of our subjects.

To confirm the breathing pattern, each subject was fitted with a CO_2 sensor* placed over the mouth to detect expiratory airflow through the mouth, as described by Fujimoto *et al.* (22). This sensor was originally designed to detect both nasal and mouth breathing through two tubes inserted into the nostrils and a small adaptor over the mouth. We occluded the two nostril tubes so that the sensor could only detect the expiratory airflow through the mouth. The expiratory CO_2 airflow was recorded over a 15-min period while the subject was at rest during the day. When no airflow was detected from the mouth throughout the recording period, the subject was confirmed to be a nasal breather and enrolled in this study.

Chewing

Under normal nasal breathing conditions, the subject was asked to chew the gum continuously for 3 min while watching a movie on a TV screen. This was repeated three times for 3-min intervals. Then, the same protocol was repeated with the nose occluded using a nose clip (similar to the type used during synchronised swimming) to induce breathing through the mouth.

Electromyographic (EMG) recording of the masseter muscle during chewing

Bipolar surface electrodes (8 mm in diameter) were placed over the right and left masseter muscles with an interelectrode distance of 30 mm along the main direction of the muscle fibres, which was ascertained by palpation of the muscles. The skin was scrubbed using alcohol-soaked gauze to reduce the impedance between the skin and the electrode. The electrodes were connected to the EMG equipment (MyoTrac Infiniti†), with a ground surface electrode connected to the neck. The amplifier was connected directly to the ground electrodes to eliminate any electrical disturbance caused by unexpected movement of the electrodes. The EMG signal from the habitual side of mastication was recognised as the working side in the qualitative and quantitative evaluation of chewing stroke. The raw EMG signal was incorporated into the device at a sampling rate of 1 kHz and converted into the root mean square (RMS) signal every 0·1 s (Fig. 1). Thus, the chewing stroke while the subject chewed the gum was recorded as EMG activity.

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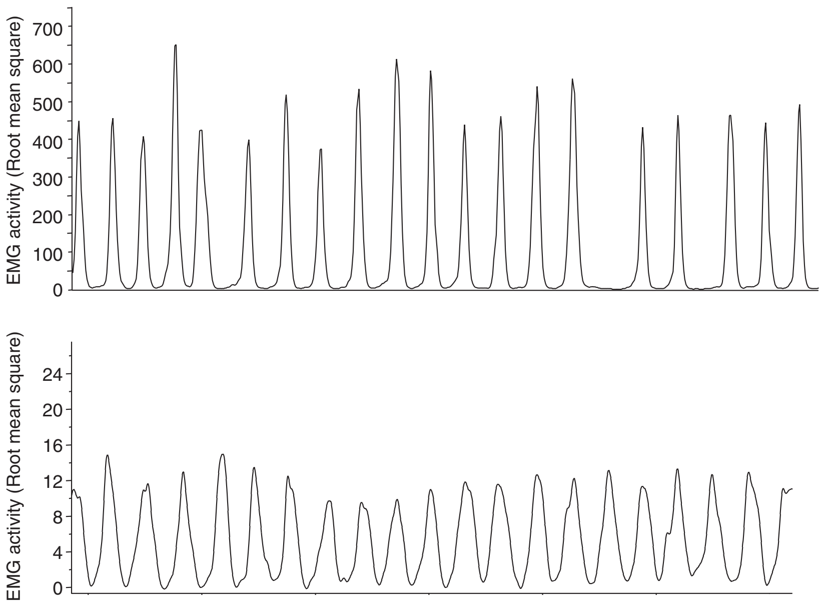

Fig. 1. Electromyographic (EMG) activity of the masseter muscle. Upper: EMG activity while the subject chewed gum (isometric and isotonic contractions). Lower: The EMG activity associated with mandibular movement not causing tooth contact shows low intensity (isotonic contraction against gravity).

Strength of chewing activity

While chewing the gum, the isometric contraction of the masseter muscle can exert vertical forces on the posterior teeth through direct tooth contact or indirect tooth contact intermediated by the gum. The magnitude of EMG activity of the masseter muscle while chewing food is highly correlated with the degree of occlusal forces (23–25). Therefore, to evaluate the magnitude of the vertical effect on the posterior teeth, the integrated EMG activity of the masseter muscle was obtained during the 3-min chewing period.

Duration of chewing activity

Count of chewing strokes. Although the upper and lower teeth may not make contact while the subject chewed the gum, the EMG activity of the masseter muscle will increase in proportion to the (similar) isometric contraction of the masseter muscle and decrease according to the opening phase of the chewing cycle. Therefore, chewing stroke was recorded by the EMG activity of the masseter muscle while the subject chewed the gum. The cycles of the converted EMG signals (RMS) were expressed as the chewing stroke during 3-min gum-chewing periods (Fig. 1).

Variation in the chewing cycle. The 3-min chewing period was divided into 10 segments (Fig. 2), and the coefficient of variation of the chewing cycle (rhythm of chewing) among the ten segments was calculated.

Estimate of the duration of EMG activity above baseline. The EMG activity of the masseter muscle while chewing

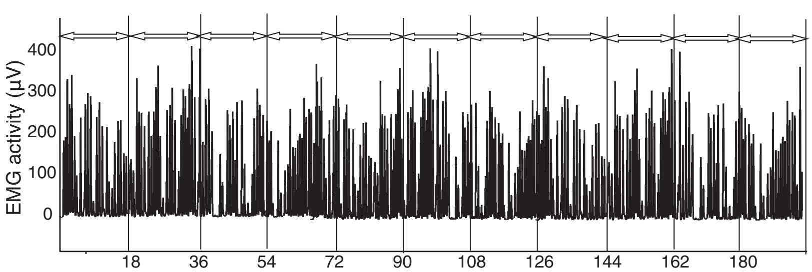

Fig. 2. Estimate of the variability of the chewing rhythm. The 3-min chewing period was divided into ten segments to estimate chewing frequency and rhythm.

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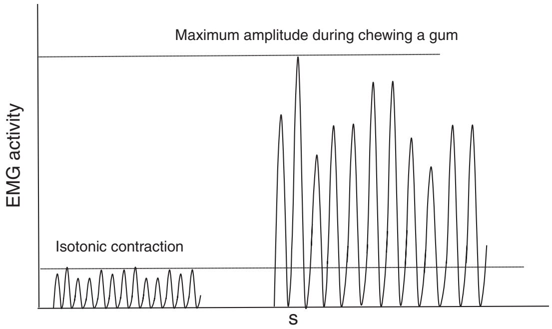

Fig. 3. Determination of the baseline. The electromyographic (EMG) activity of the masseter muscle while the subjects chewed gum is composed of the isometric contraction intermediating the gum between the teeth and the isotonic contractions owing to the mandibular movement against gravity. We recorded the isotonic EMG activity during mandibular movement at 1.6 Hz, which was obtained from 10 adult volunteers with normal occlusion and normal nasal breathing, without making tooth contact for 30 s. The mean isotonic EMG activity was 45.3 ± 5.6 μV, and the maximum EMG activity while chewing gum was 559.2 ± 90.9 μV.

the gum is composed of the isometric contraction intermediating the gum between the teeth and the isotonic contraction owing to the mandibular movement against gravity without making tooth contact (Fig. 3). The isometric EMG activity of the masseter muscle depends on how strongly the tooth makes contact, and the EMG activity during isotonic muscle contraction (isotonic EMG activity) depends on the rate of chewing (26, 27). The rate of chewing reported by many researchers (28–30) varies with the consistency of foods including chewing the gum and ranges from 0·9 to 2 Hz. In our pilot study, the procedure was followed by obtaining the standardised rate of isotonic EMG activity to the maximum EMG activity while chewing the gum for 3 min in five subjects with normal occlusion and normal nasal breathing. Initially, the mean chewing cycle was obtained for chewing the gum at a free rhythm for 3 min and was 1·6 Hz ± 0·3 (Table 1). Then, we recorded the isotonic EMG activity during mandibular movement (open-close) following the standard value (at 1·6 Hz) without making tooth contact for 30 s. The isotonic movement was controlled with a metronome. We obtained the isotonic EMG activity as the baseline and determined that the isometric EMG activity above the baseline is derived from the isometric contraction exerting vertical force on the posterior teeth, regardless of the force intermediating with gum or foods. The mean isotonic EMG activity was 45·3 ± 5·6 μV, and the maximum EMG activity while chewing the gum was 559·1 ± 90·9 μV (Table 2). The mean rate of isotonic EMG activity to the maximum EMG activity while chewing the gum for 3 min was 8·2 ± 1·5% in the pilot study (Table 2). Hence, we determined the standard point as 10% of the maximum EMG activity level of the masseter muscle while the subject chewed the gum (Fig. 4) and designated the duration of EMG activity above baseline as the duration of vertical force on the posterior teeth. The effective duration represented the percentage of the duration of vertical force to the 3-min chewing period.

Table 1. Chewing cycle while each subject chews a gum

Subject	Trial 1	Trial 2	Trial 3	Mean (times)	Cycle (Hz)
Cont-1	221	215	213	216·3	1·2
Cont-2	283	290	274	282·3	1·6
Cont-3	302	328	325	318·3	1·8
Cont-4	253	269	275	265·7	1·5
Cont-5	311	322	340	324·3	1·8
Mean				280·9 ± 43·8	1·6 ± 0·3

Reproducibility and reliability of the measurements

The chewing activity was recorded in the same five subjects in the pilot study on two separate days using the same time course as in the study protocol (Table 3). The reproducibility and reliability of the measurements were examined by evaluating the variability of the inter-trial and inter-day recordings of the RMS EMG activity during the 3-min gum-chewing period using repeated analysis of variance (ANOVA; *F*-test). There were no significant differences between the inter-trial and inter-day recordings for integrated EMG activity and chewing stroke counts (Table 3). The recordings for each subject were completed in one afternoon with the same sequence. Variables were compared by paired t-test and by repeated ANOVA for nose and mouth-breathing modes. The significance level was set at 5% ($P < 0·05$).

Results

Tables 4 and 5 show the results of the study.

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Table 2. Rate of isotonic activity for the maximum activity

Subject	Isotonic (μV)			Mean	Maximum (μV)			Mean	Rate (%)
Cont-1	38	54	41	44·2	349	404	487	413·3	10·7
Cont-2	39	52	26	38·9	602	572	530	568·0	6·8
Cont-3	56	46	59	53·9	680	559	631	623·3	8·6
Cont-4	42	48	38	42·6	517	524	596	545·7	7·8
Cont-5	50	47	43	46·8	668	638	630	645·2	7·3
Mean				45·3 ± 5·6				559·1 ± 90·9	8·2 ± 1·5

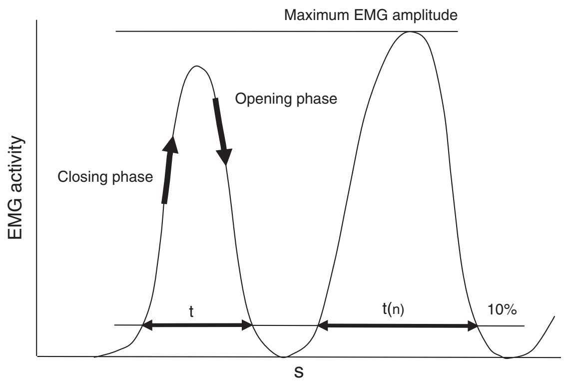

Fig. 4. Determining the duration of electromyographic (EMG) activity above baseline while chewing a gum. We determined the standard point as 10% of the maximum EMG activity level of the masseter muscle while the subjects chewed gum and designated the duration of EMG activity above baseline as the effective duration of the vertical force on the posterior teeth. This duration represented the period of percentage of the tooth contact relative to the 3-min chewing period.

Table 3. Reliability and reproducibility of the chewing stroke (times)

	Day 1			Day 2		
Subject	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Cont-1	221	215	213	190	202	207
Cont-2	249	255	252	296	283	282
Cont-3	140	156	154	135	132	132
Cont-4	240	260	154	253	240	275
Cont-5	302	328	325	311	322	340

No significant difference was noted among the inter-trial and inter-day recordings.

Magnitude of vertical effect on the posterior teeth

Integrated EMG activity of masseter muscle. The integrated activity was 12 887·7 ± 6149·8 and 11 444·0 ± 6086·2 μV·s for nasal and mouth breathing. The integrated activity was significantly ($P < 0{\cdot}05$) less for mouth breathing than for nasal breathing, and it decreased to 88·8% upon switching from nasal to mouth breathing.

Duration of vertical effect on the posterior teeth

Effective duration of vertical effect and chewing stroke count. The effective percentage duration of the vertical force while chewing the gum for 3 min was 41·3 ± 5·4% and 36·5 ± 5·9% during nasal and mouth breathing, respectively. The effective duration was significantly ($P < 0{\cdot}05$) lower after switching to mouth breathing. The mean chewing stroke count was 221·7 ± 25·5 and 199·5 ± 29·8 times during the entire 3-min period while breathing through the nose and mouth, respectively. The chewing stroke count was significantly decreased to 88·4% after switching to mouth breathing ($P < 0{\cdot}05$).

Variation in the chewing cycle. The coefficient of variation in the chewing cycle was significantly higher during mouth breathing (0·092 ± 0·052) compared with nasal breathing (0·069 ± 0·040) ($P < 0{\cdot}05$). Visual observations of the chewing cycle showed that in one subject (Fig. 5, left), chewing stopped to allow for breathing, but regular chewing rhythm commenced immediately thereafter. In another subject (Fig. 5: right), the entire chewing cycle was completely impeded. In these subjects, the coefficient of variation in the chewing cycle increased after switching to mouth breathing.

Discussion

In general, respiration and mastication are performed through different routes and controlled through different mechanisms. When nasal breathing is switched to mouth breathing, the position of the lips, tongue and the mandible should change to provide an airway through the mouth (11–13, 18, 19). Accordingly, masticatory function must be stopped or at least interrupted during mouth breathing (20, 21). Masticatory function may be an environmental factor controlling the morphogenesis of the face (31, 32). In this study, we tested the hypothesis

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Table 4. Various parameters while chewing a gum with nasal (NB) and mouth (MB) breathings

	Integrated electromyo-graphic		Chewing count		Duration		Variation	
Subjects	NB	MB	NB	MB	NB	MB	NB	MB
1	12643·3	12340·0	185·7	150·3	29·8	24·6	0·0291	0·0896
2	12173·3	10984·0	240·0	179·0	34·9	26·9	0·0499	0·0708
3	7048·3	6252·0	250·0	238·0	49·6	43·9	0·0788	0·0696
4	9205·5	6545·3	255·3	211·0	38·6	32·9	0·1719	0·1357
5	14026·7	12783·3	258·7	239·3	39·4	32·6	0·1864	0·2011
6	14026·7	7929·7	229·0	212·7	46·9	43·9	0·1566	0·1347
7	9889·0	9417·7	217·3	193·7	49·0	46·0	0·0962	0·1179
8	16160·0	15990·0	213·0	202·3	41·6	35·0	0·1110	0·0659
9	6049·0	5267·7	246·0	216·7	48·6	43·7	0·0766	0·1140
10	17656·7	16143·3	241·0	213·0	39·7	34·1	0·0569	0·0410
11	25866·7	24666·7	248·0	238·7	38·7	36·4	0·0725	0·0929
12	10473·3	9976·3	222·7	213·0	30·9	29·3	0·0749	0·0763
13	10062·3	9415·3	221·7	198·0	41·2	37·2	0·0292	0·0431
14	7684·7	8423·0	221·3	186·3	33·1	30·9	0·0444	0·0379
15	12048·0	10766·0	227·3	211·3	48·9	44·2	0·0331	0·0455
16	7174·7	6064·0	186·0	131·0	34·8	21·0	0·0518	0·0631
17	8624·7	7280·3	220·7	215·0	37·3	35·1	0·0596	0·1037
18	9428·7	8272·0	187·3	141·7	42·6	39·5	0·0727	0·0873
19	15123·3	14990·0	202·7	178·7	39·1	36·2	0·0376	0·0381
20	10747·7	7747·7	241·0	208·3	36·3	28·9	0·0272	0·0675
21	8893·3	7690·3	247·7	203·3	45·3	37·2	0·0543	0·0564
22	25126·6	24593·3	248·7	235·3	44·1	41·1	0·0551	0·1101
23	13108·7	9171·7	176·7	162·0	51·5	46·4	0·0737	0·2173
24	37834·5	35513·3	198·3	195·7	39·8	37·1	0·0594	0·0635
25	11960·0	10804·3	215·0	211·0	45·0	37·8	0·0760	0·0997
26	13186·7	11642·0	191·0	171·0	42·2	39·8	0·0618	0·0697
27	12456·5	11062·3	246·3	234·0	37·0	32·0	0·0576	0·0575
28	13376·7	12083·3	233·7	230·0	45·3	41·6	0·0280	0·0465
29	6975·0	5259·3	218·0	203·0	43·3	39·3	0·0298	0·0582
30	7790·7	6916·3	207·0	180·3	38·1	35·2	0·1125	0·2507
31	8964·3	7937·0	224·0	230·0	35·3	28·9	0·0280	0·0465
32	8422·7	6804·3	167·7	135·3	43·3	36·1	0·0438	0·0732
33	13859·7	10950·3	174·0	150·7	44·1	40·1	0·0406	0·1064
34	18623·3	17340·0	228·3	217·0	51·1	44·4	0·0492	0·0989
35	14770·0	13183·3	229·7	223·3	39·8	36·1	0·1364	0·1380
36	8326·0	7282·3	253·7	232·7	43·5	37·8	0·0845	0·1892
37	7784·7	6096·3	229·7	208·0	40·2	37·8	0·1228	0·1203
38	16594·4	14058·2	254·7	205·7	36·4	32·0	0·0436	0·0338
39	18454·7	16673·6	186·3	175·0	45·0	41·6	0·0456	0·0457
Mean	12887·7	11444·0	221·7	199·5	41·3	36·5	0·0697	0·0917

that impeding chewing activity by breathing through the mouth reduces the vertical effect on the posterior teeth. The vertical position of the posterior teeth is an important factor determining the vertical dimension of the dentofacial complex as well as the vertical height of the maxilla and the mandibular ramus (1, 33, 34). The vertical position of the posterior teeth is determined by the degree and duration of occlusal forces on the posterior teeth, which is exerted by the masticatory activity (7). In this study, chewing movement or activity was recorded as the EMG activity of the masseter muscle. To eliminate the problems using surface electrodes to estimate the strength of EMG activity of the elevator muscle, only the intra-individual magnitudes of the EMG activity were compared.

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Table 5. Comparison of various parameters while chewing a gum with nasal and mouth breathings

	Nose breathing		Mouth breathing		
	Mean	SD	Mean	SD	*P value*
Integrated electromyographic activity (μV·s)	12887·7	6149·8	11444·0	6086·2	*
Duration S (%)	41·3	5·4	36·5	5·9	*
Count of chewing stroke (times)	221·7	25·5	199·5	29·8	*
Variation of chewing cycle	0·069	0·0403	0·092	0·052	*

*$P < 0{\cdot}05$.

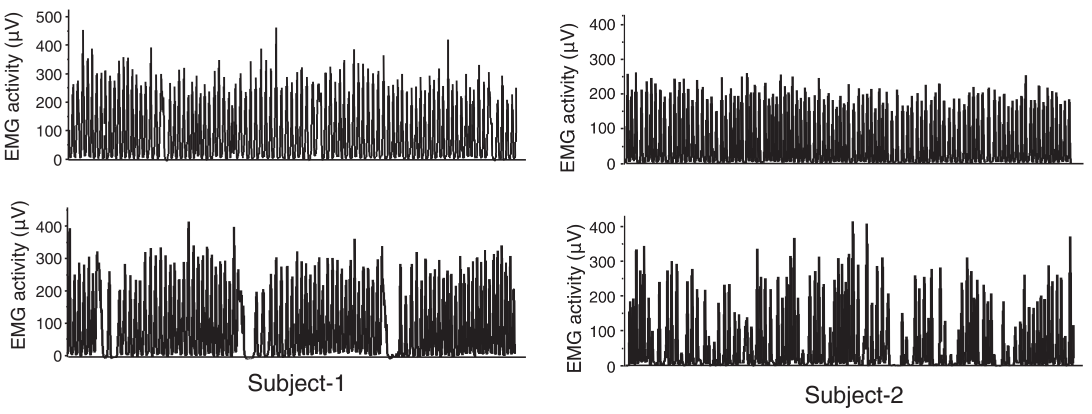

Fig. 5. Example of chewing variation in two subjects. Visual observations of the chewing cycle showed that in some subjects, chewing stopped to allow for breathing, but regular chewing rhythm commenced immediately thereafter (on the left). In another subjects (on the right), the entire chewing cycle was completely impeded. It is not clear when the subject takes a breath. These findings indicate that mouth breathing interfered with the chewing rhythm.

The effect of mouth breathing was discussed from two points of view; the degree and the duration of vertical forces exerted on the posterior teeth, which is represented by the degree and duration of EMG activity of the masseter muscle.

Changes in EMG activity

Strength of occlusal force: Integrated EMG activity. Ono *et al.* (21) reported that oral respiration was associated with the inhibition of masseter muscle EMG activity in cats. The integrated EMG activity of the masseter muscle was significantly less during mouth breathing compared with that during nasal breathing, decreasing to 88·8% after switching from nasal to mouth breathing. The result suggests a decrease in the degree of vertical effect on the posterior teeth during mouth breathing.

Duration of the force on the posterior teeth: effective duration. In previous studies on chewing strokes using devices for recording the mandibular movement, the chewing stroke is divided into opening, closing and occlusal contact phases, and the duration of the occlusal contact phase ranges from 30% to 45% (35–37). In our study utilising isotonic and isometric EMG activity, the effective duration of vertical force was 41·3 ± 5·4% during nasal breathing. This result is supported by previous studies (35–37). It is surprising that the vertical force on the posterior teeth while chewing the gum for 3 min accounts for half of the chewing time, although the occlusal contact phase is a just small phase in the jaw movement during chewing. On the other hand, the effective duration of tooth contact was 36·5 ± 5·9% during mouth breathing, and decreased by approximately 10% compared with the duration during nasal breathing. The duration of vertical effect

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correlated with the count and cycle of the chewing stroke. This means that the reduced vertical effect on the posterior teeth could be ascribed to the low stroke count and chewing cycle during mouth breathing. The mean chewing stroke count was 221 times within the 3-min period, and decreased by approximately 10% during cycles with mouth breathing.

Chewing rhythm. Visual observation of the chewing cycle showed that chewing stopped or was impeded to allow for mouth breathing. The coefficient of variation in the chewing cycle increased after switching to mouth breathing. These subjective and objective findings indicate that mouth breathing interfered with the chewing rhythm and also resulted in decreased chewing strokes. These findings coincide with the decrease in the effective duration above the baseline defined by isotonic EMG activity of the masseter muscle.

Mouth breathing influences tooth contact and tooth vertical position. Postural changes in oro-facial soft tissues following the establishment of the oral cavity as an airway are thought to induce the anteroposterior and horizontal changes in dentofacial growth (11–13, 18, 19). On the other hand, there is little evidence explaining the aetiological relationship between mouth breathing and the vertical change in the face. Maintenance of the vertical position of the posterior teeth is controlled by elements of the applied force, such as degree and duration (8–10). Uchida *et al.* (8) noted daily clenching exercises increased the degree and duration of occlusal force on the posterior teeth because of the anterior shift of the anteroposterior balance of the occlusal contact area in response to an increase in the anterior occlusal contact area. Masumoto *et al.* (9) reported that chewing the gum 30 min per day was beneficial for increasing the duration of occlusal contact to preserve the vertical position of the posterior teeth. With nasal breathing, it is possible to continue the masticatory motion without stopping the chewing motion. When nasal breathing is switched to mouth breathing, masticatory motion must be stopped or at least interrupted during mouth breathing to preserve an airway through the mouth (11–13, 18, 19). Accordingly, we examined the effect of mouth breathing while chewing the gum on the degree and duration of vertical effects on the posterior teeth.

In this study, when nasal breathing was switched to mouth breathing, the magnitude of masseter muscle EMG activity was reduced by approximately 10%, and the effective duration of EMG activity above baseline was decreased by approximately 10% while chewing the gum, and the chewing pattern, including chewing stroke and rhythm, was interfered with. Hence, both the reduced degree and duration of vertical forces on the posterior teeth may result in extrusion of the posterior teeth and vertical deformity such as open bite.

Conclusion

Mouth breathing decreases the number of chewing cycles and reduces chewing activity such in terms of the degree and duration of EMG activity of the masseter muscle, resulting in decreased vertical effect on the posterior teeth. Therefore, these results support our hypothesis and suggest that mouth breathing may negatively influence the vertical position of the posterior teeth, which could be a contributing aetiological factor in the development of open bite.

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