Intraoral pH and temperature during sleep with and without mouth breathing

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SUMMARY To measure and compare the intraoral pH and temperature of individuals during sleep with and without mouth breathing. Ten healthy participants [mean age = 25.8 (± 4.3)] wore a custom-made appliance fitted with a pH probe and thermocouple for two sets of 48 h. Continuous pH and temperature measurements were taken from the palatal aspect of the upper central incisors. To simulate mouth breathing during sleep, participants wore a nose clip for two nights of the four, with the first group (n = 5) wearing the nose clip during the first night and the rest (n = 5) wearing the nose clip during the second night of sleep to balance any potential bias from the wearing sequence. Both qualitative and quantitative analyses were conducted. The mean intraoral pH during daytime was 7.3 (± 0.4) and during sleep was 7.0 (± 0.5). The mean intraoral pH during sleep with mouth breathing was 6.6 (± 0.5), which was statistically significant compared with the normal sleep condition (P < 0.01). The intraoral pH decreased slowly over the hours of sleep in all participants. When sleeping with forced mouth breathing, intraoral pH showed a greater fall over a longer period of time. The mean intraoral temperature was 33.1 °C (± 5.2) during daytime and 33.3 °C (± 6.1) during sleep, with no statistical significance between sleep with and without mouth breathing (P > 0.05). The results suggest that mouth breathing during sleep is related to a decrease in intraoral pH compared with normal breathing during sleep, and this has been proposed as a causal factor for dental erosion and caries.

KEYWORDS: intraoral pH, salivary pH, intraoral temperature, mouth breathing, sleep

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Introduction

Mouth breathing brings adverse effects on one’s oral health (1, 2). Previous investigations reveal that patients who mouth breathe due to various reasons complain of dry mouth due to a reduction in the quantity and quality of saliva (3, 4). Dental practitioners are reporting an increasing number of patients who complain of dry mouth, especially during sleep or upon awakening. Those symptoms arise from ‘sleep-related xerostomia’, which can be defined as a sensation of dry mouth, associated with a report of throat discomfort, particularly during sleep and awakenings (3–5). The evidence suggests ‘sleep-related xerostomia’ has a link with sleep and respiratory disorders, for example obstructive sleep apnoea (OSA) and asthma, respectively (3–7). Such links come from a reduction in saliva production due to circadian rhythm and dehydration of the intraoral cavity, mainly caused by mouth breathing during sleep (8, 9).

When one sleeps, the activity of the central nervous system is at rest resulting in a loss of voluntary control. This in turn affects the control of the muscles and breathing, causing individuals to breathe through the mouth instead of nose (9). Previous studies report that healthy men who breathe through the nose spontaneously mouth breathe during 29 ± 8% of their total sleep time (lesser for women; 5%) (6, 9). Patients with OSA are found to spend greater time mouth breathing during sleep (5, 6, 9). Individuals with respiratory disorders, such as asthma, are also known to spend greater time mouth breathing during
daytime and sleep time, compared with healthy people (7, 10, 11).

Mouth breathing increases the chance of developing dental caries, gingival inflammation and dental erosion as it results in the saliva drying out, decelerating salivary flow rate resulting in a reduction in the antimicrobial function of saliva and less saliva to buffer the acid (1, 2, 7, 10–12). The imbalance of intraoral pH due to the reduced acid-neutralising ability leads to the destruction of the existing dental integuments as well as dental restorative materials present in the oral cavity (13, 14).

The relationship between mouth breathing during sleep and intraoral pH is yet to be directly proved, although there is considerable circumstantial evidence to indicate that such a link exists (3, 5, 15, 16). This is due to the difficulty in measuring the variables in the oral cavity of freely moving patients during sleep. There is a lack of techniques currently available to continuously measure the variables intraorally because most involve waking up the patients during sleep to collect saliva samples that may interfere with one’s circadian rhythms, possibly producing unreliable results (15). Intraoral temperature has been reported to have a close relationship with pH, and it can be a good indication of the existence of mouth breathing as it has been suggested that intraoral temperature drops when one breathes in and out through the mouth (17, 18). However, similar to the pH of saliva, the long-term measurement of intraoral temperature during sleep has been difficult resulting in only a few available studies (17, 18).

Our research group has recently developed an intraoral pH and temperature device, which can measure the two parameters continuously and simultaneously for up to 48 h (19). The pilot study confirmed that there is a difference in intraoral pH and temperature while one is asleep compared with daytime values. Such variation is found to come from the functional activity of the jaw movement and breathing during eating and talking. On the basis of the evidence, we believe it is important to measure intraoral pH and temperature during sleep with and without mouth breathing to understand the real-time impact of mouth breathing on the oral environment. Investigations on intraoral physiology under carefully controlled conditions in normal subjects during sleep will contribute to the prevention of dental disease related to mouth breathing and sleep disorders.

Therefore, the objective of this study was to measure intraoral pH and temperature in healthy individuals during sleep with and without simulated mouth breathing. It was hypothesised that there will be a significant difference in the intraoral pH and temperature variance when one is asleep with and without mouth breathing.

Materials and methods

Ethical approval and recruitment of subjects

Ethical approval for this project was given by the University of Otago Human Ethics Committee (H14/051). Sample size was based on calculations from a preliminary study, which revealed that a sample size of 10 subjects completing a study was calculated to have 80% power to detect the differences in pH and temperature between sleep with and without mouth breathing. Volunteers of both genders were recruited from the student and staff body at the University of Otago, Dunedin, New Zealand. The exclusion criteria (allergies, medication intake, chronic mouth breathers, smokers, asthmatics and known (diagnosed) sleep disorders) were enforced based on a personal interview. Regarding the oral cavity, no participant reported any current dental procedures, xerostomia, pain or spontaneous gingival bleeding, erosion or active caries. Any participant with dental restorations in the upper anterior region where the measuring probes need to be located was excluded from the study. The research outline and the protocol leaflets were explained to 16 persons, of whom 10 satisfied the inclusion criteria and gave informed consent. All 10 subjects completed all study periods.

Testing protocols

The 10 participants were asked to be present at the clinic, and impressions of upper teeth were taken. With the impressions, custom-made appliances were made as described in the authors’ previous study (19). The vacuum-formed appliance covering the 1st quadrant of the maxilla was fitted with a pH-measurement probe* and a thermocouple†. The probe and the thermocouple were placed 3–5 mm behind the central incisors (Fig. 1), where drying of the saliva is the

*ResTech Corp, San Diego, CA, USA.
†K-Type; Lascar Electronics, Inc., Erie, PA, USA.
most pronounced and where prominent erosion is found (1, 20, 21).

Participants attended the University of Otago School of Dentistry, and their salivary flow rate was measured using the 5-min spit technique (22). The pre-custom-made appliance was calibrated and fitted intraorally, and the 1st set of experiments began (Fig. 1). To simulate mouth breathing during sleep, participants were asked to wear the intraoral appliance for 48 h while wearing a nose clip during sleep for one of the study days depending on allocated group; group 1 wore the nose clip during the 1st night of each experimental set, whereas the other group wore the nose clip on the 2nd night of their study. This was performed to detect any potential bias such as first-night effect. The wearing of the nose clip during sleep was to simulate mouth breathing (Fig. 1). The appliance was taken off when eating and washing to avoid water getting into the data transmitters. A minimum of 1 week after the first set of experiments, the participants were asked to wear a newly made and calibrated device again and repeat the experimental steps. They were advised to keep a detailed log of daily activities during their participation days. Once completed, the results stored in a SD card or USB were retrieved and analysed via computer software (View Lite; *Restech Corp) (Fig. 1).

**Data analysis**

The recording parts when the intraoral appliance was not worn (e.g. meal times and shower) were tracked
according to daily logs provided by volunteers and subsequently deleted. The study data were then categorised into groups, depending on different subjects (group 1 or 2, refer to Fig. 1) and measurement phases [awake, sleep NMB (non-mouth breathing), sleep MB (mouth breathing)]. The categorised data were summarised using descriptive statistics (mean, minimum and maximum). Estimation of the variance was investigated as the total standard deviation as well as a coefficient of variation. For comparison between the groups, paired t-test or nonparametric Wilcoxon signed rank test was conducted, depending on each groups’ data distribution. The relationship between the pH and temperature was investigated using a Spearman’s rho non-parametric correlation. All statistical analyses were performed using SPSS version 22,§ and P-values < 0.05 were regarded as being statistically significant.

Results

The mean age of the participants was 25.8 ± 4.3 years old, and their mean salivary flow rate was 0.85 ± 0.4 mL min⁻¹, confirming that they were all healthy saliva secretors.

The graphs in Fig. 2 show the total mean and the standard deviation of pH and temperature of 10 subjects over 24 h of 4 days in total. The pH recordings over 24 h clearly show the circadian rhythm; it is stable during the daytime; however it starts to decrease at night, the early morning being the lowest and rises when the participants wake up from their sleep. The mean temperature variation pattern was different from that of pH, with minor fluctuation throughout the 24-h period, including during sleep. The detailed values are presented in Table 1. The mean pH during daytime (awake) was 7.3 (±0.4). During sleep, a slight drop in mean pH (-0.46; 95% CI = -0.58, -0.34) was observed for all subjects. The mean pH during sleep with mouth breathing was 6.6 (-0.40; 95% CI = -0.65; -0.16). The differences between the three groups were all statistically significant (P < 0.01, indicated in Table 2).

The opposite trend was observed for intraoral temperature, as reflected in the mean and P-values presented in Table 2. The intraoral temperature was slightly but insignificantly higher during sleep than during daytime (+1.2 °C; 95% CI = -0.29, 0.54). The

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§SPSS Inc., Chicago, IL, USA.
Table 1. Mean, standard deviation, maximum, minimum and coefficient of variation values of pH and temperature measured by continuous collection on 10 subjects, over the 4 days

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Temperature °C</th>
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<tbody>
<tr>
<td></td>
<td>Awake</td>
<td>Sleep NMB</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>7.3 ± 0.4</td>
<td>7.0 ± 0.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>8.1</td>
<td>7.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>7.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Coefficient of variance (%)</td>
<td>5.5</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Table 2. Significance of the pH and temperature difference between groups and measurement phases as indicated by P-values

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awake vs. Sleep</td>
<td>0.000**</td>
<td>0.073</td>
</tr>
<tr>
<td>Sleep NMB vs. Sleep MB</td>
<td>0.002**</td>
<td>0.248</td>
</tr>
<tr>
<td>Group 1 vs. Group 2</td>
<td>0.04*</td>
<td>0.017*</td>
</tr>
</tbody>
</table>

*Significant P < 0.05; **very significant P < 0.01.

The present study showed that there is a change in intraoral pH and temperature during sleep, especially with mouth breathing. This is in agreement with the previous report on the association with dental diseases, intraoral pH and mouth breathing; mouth-breathers are found to be at a higher risk of developing erosion (1, 13, 15) and caries (2, 10, 11). It was suggested that mouth breathing might promote the development of dental erosion because the effect of saliva, as a modifying factor, will be reduced even under normal salivary conditions. The current study is the first to investigate the continuous intraoral pH variation in healthy individuals for long-term, including sleep and with simulated mouth breathing.

The decline in intraoral pH during sleep, especially with mouth breathing, supports the argument of mouth breathing, reducing the protective effect of saliva even in healthy saliva secretors (1). The minimum pH of 3.6 was detected during all study days, and this is well below the critical pH of 5.5 when the enamel starts to demineralise (1, 13, 14). The fact that this drop of pH was recorded during sleep with mouth breathing, the possible association between the sleep, mouth breathing, intraoral pH variation and dental diseases is clear. This nocturnal decline in intraoral pH and its range is consistent with the previous findings (15). However, in the previous study, the pH was measured only three times during night-time, including waking up the participants at midnight to collect their saliva (15). Therefore, the current findings from the continuous measurement of pH provide a more detailed picture of the intraoral pH fluctuation during sleep.
reliable result as the disturbance to subjects’ sleep has
been minimised.

The intraoral temperature results are also found to
be in the range of earlier studies. The current finding
is not as dramatic as previous reports; the minimum
intraoral temperature was 9.2 and 39.5 °C as the
maximum, compared with 0–70 °C (23, 24). This may
be due to the participants not having too hot or cold
drinks during the study periods.

No significant difference was found in the intraoral
thermal environment during the daytime and sleep
(17, 18). The interesting finding is that the intraoral
temperature during sleep with mouth breathing is
also not significantly different than normal sleep
breathing. This is noteworthy because it has been pro-
posed that on inhalation, the intraoral temperature is
lowered due to ‘evaporative effects’ during breathing,
and upon exhalation, the temperature is closer to
body temperature (17, 18, 23). However, the thermal
environment in the oral cavity is also largely affected
by the mode of breathing, such as the rapidity, deep-
ness and evenness rather than mouth breathing itself
(24). In addition, although the ambient environment
temperature is known not to affect the intraoral tem-
perature, the ambient humidity may have an effect
(17, 24), which is not measured in the current study.
As the experiments were home-based studies includ-
ing sleep, it was difficult to monitor the subject’s
mode of breathing, especially with a nose clip on.

It has been widely believed that open mouth
breathing lowers the intraoral temperature and accel-
erates the saliva dehydration, which is linked to a
decline in intraoral pH (17, 18). The current study
revealed that the relationship between pH and tem-
perature over a long-term period was in fact weak.
This indicates that the intraoral acidity and tempera-
ture do not necessarily correlate; however, other sali-
vary factors may play more significant roles in
determining the intraoral pH (12, 14, 16).

The current study has a number of limitations.
First, the data were collected from one intraoral site
only. The site was chosen due to the palatal aspect of
anterior teeth being the area where the most dental
erosion and salivary dehydration are found (17, 20,
It is also reported to show the maximum variation of intraoral temperature, due to the airflow during inhalation (17, 23). Other intraoral sites, for instance the buccal cervical area where caries and erosion are commonly found in individuals with xerostomia due to mouth breathing, should be considered for measurements in future studies (1, 2, 7, 10, 11). Moreover, various acidic drinks have been found to increase the risk of erosion. This is particularly so when coupled with mouth breathing and dehydration of the oral cavity, and further investigation on the impact of acidic drinks on tooth erosion in mouth breathers would be beneficial (1, 2, 13, 14). Studies considering these issues will further improve our knowledge of the continuous changes in intraoral pH and temperature over time.

The mouth breathing condition was simulated only during sleep and in healthy individuals in this study. The intraoral pH and temperature in actual mouth breathers during daytime or sleep may differ from the results of the current study, as the quantity and the quality of their saliva may be different from healthy individuals. However, there are only a few available studies, which have investigated the different saliva parameters in mouth breathers (10–12, 16). Although the current study was only conducted in healthy subjects with simulated mouth breathing, it had demonstrated the existence of intraoral pH and temperature change under two breathing conditions, which provides preliminary data and direction for future studies.

The tolerance level of wearing the nose clip during sleep was different in each individual. A few participants reported that it took longer time to fall asleep than usual and they slept fewer hours due to the nose clip. The result also revealed that there is a learning bias depending on the sequence of wearing the nose clip during sleep (Table 2; group 1 vs. 2 P < 0.05). This can be explained by the first night effect, in which the uncomfortable settings created from wearing an appliance decrease the sleep efficacy and duration of deep sleep. This effect is known to possibly impair the reliability of assessment in a single-night study (25). The current study consisted of multiple experiments (sleeps) per subject to minimise and balance this effect. Lastly, all participants reported a temporary dry mouth in the morning following sleep with a nose clip on, which may have contributed to a short-term alteration in the intraoral pH and temperature. All participants reported no other issues regarding discomfort or unusual symptoms while wearing the appliance and the nose clip.

The current investigation confirms that the continuous and simultaneous measurement of intraoral pH and temperature over 24 h provides valuable information, especially during sleep. Future research conducted in patients with dental diseases as well as sleep or respiratory diseases using the presented technique might shed light on new diagnostic criteria.

**Conclusion**

Within the limitations of this study, the following conclusions were drawn:

1. There is a decrease in intraoral pH during sleep and a noticeable difference in the pattern of variation of pH and temperature between day and night.
2. Mouth breathing during sleep is related to a decrease in intraoral pH compared with normal breathing during sleep, and this has been proposed as a causal factor for dental diseases such as dental erosion and caries.

**Acknowledgments**

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**Conflict of interest**

The authors declare no conflicts of interest.

**References**


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