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The analysis of oral air using selected ion flow tube mass spectrometry in persons with and without a history of oral malodour

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Abstract: *Objectives:* Oral malodour is a common disorder predominantly caused by bacterial metabolism of food stuffs in the mouth. It is routinely diagnosed and monitored by either the subjective rating or the measurement of oral volatile sulphur compound (VSC) levels. Non-sulphur compounds are also believed to contribute significantly to the condition although there is currently no direct means to assess their levels. In this study, we utilized selective flow tube mass spectrometry (SIFT-MS) to measure, in real time, a range of sulphur and non-sulphur containing compounds in oral air to determine whether the technique can be used to objectively monitor oral malodour. *Methods:* Oral malodour was assessed using organoleptic scores in subjects with and without a history of oral malodour (n = 18) by a trained rater, while the chemical composition of oral air was analysed by both VSC sensor and SIFT-MS. *Results:* Total VSC levels were significantly correlated with levels of hydrogen sulphide and methylmercaptan measured by SIFT-MS, but not with organoleptic scores. In subjects with elevated organoleptic score, only levels of methylmercaptan were significantly elevated. In three subjects with elevated tongue organoleptic scores but normal total VSC levels, SIFT-MS suggested that one subject possessed high levels of oral acetone while another had high oral levels of acetic acid. *Conclusions:* Our data suggest that SIFT-MS can be used to assess a wide range of compounds in oral air in addition to VSC to provide a clearer picture of the chemical nature of malodour. This may assist in the diagnosis and monitoring of the condition.

Key words: halitosis; mass spectrometry; oral malodour; volatile sulphur compounds

Introduction

Oral malodour is a common cause of visits to the dentist's and dental hygienist's office. The disorder is a form of halitosis in which malodour is formed exclusively in the mouth as opposed to the lungs or nasal passages (1). The condition can cause considerable embarrassment and distress and may lead to social withdrawal and depression (2, 3). Malodour is believed to occur consequent to bacterial action upon food stuffs, being primarily associated with the degradation of protein and lipids to produce a variety of malodorous byproducts (4).

The decision to seek treatment for oral malodour occurs either when a person believes they have bad breath or someone tells them about the unpleasant smell. Self-reported oral malodour is, however, an unreliable determinant of the severity or even presence of the condition (1, 5). Semi-quantitative rating of the severity of oral malodour by the use of organoleptic scoring can, however, be accomplished by a trained rater. This has become the 'gold standard' for assessment even though such indices are necessarily subjective (4). Objective quantitative measures are available to clinicians although none have so far replaced the organoleptic scoring method for reasons of cost, time and complexity. For example, gas chromatography mass spectrometry (GCMS), while possessing high accuracy, sensitivity and chemical resolution is slow, expensive and technically demanding and therefore not suitable for routine use (4). Alternatively, devices are available which exploit the fact that the major group of chemicals involved in oral malodour are the volatile sulphur compounds (VSC). VSC, such as hydrogen sulphide and methylmercaptan, are formed during the catabolism of sulphur containing amino acids (4). Solid state sensors measuring total oral VSC levels in real time can therefore provide an objective and simple measure of oral malodour even though they lack the ability to resolve individual compounds. While useful, the VSC levels recorded by such devices generally correlate poorly with organoleptic scores produced by human raters. A possible explanation for this discrepancy is the presence of non-VSC malodour causing chemicals which contribute to organoleptic scores but not to the VSC sensor readings (4). For example, fatty acids can be catabolized to produce odiferous short chain organic acids such as butyric acid, while the decarboxylation of amino acids containing amino side leads to the formation of the polyamines (6). Furthermore, systemic production of gases such as acetone and ammonia or those derived from odiferous food stuffs such as garlic and onions, can also contribute to malodour, all of which must be considered by the clinician as potential causes of the condition (6).

To better characterize and monitor oral malodour, and to assist in the selection of appropriate treatments, the measurement of a greater range of compounds would be advantageous, ideally without the need for demanding techniques such as GCMS. The wide range of chemical classes and molecular sizes involved make such an analysis challenging. An emerging new technique used for the measurement of volatile chemical levels may offer a solution. Selected ion flow tube mass spectrometry (SIFT-MS) allows the measurement of trace volatiles in real time with a current sensitivity limit in the single digit parts per billion by volume (PPBV) range, performance as good as or better than that achieved by solid state sensors, but with the ability to measure a much greater range of compounds with good chemical resolution (7). SIFT-MS functions by reacting precursor ions (usually H_3O^+, O_2^+ or NO^+) with air samples containing the trace gases of interest and using mass spectrometry to analyse and quantify the resulting electrically charged products. The precursor ions, which take part in the reaction, are formed by a microwave/water vapour ion source with specific ions being selected using a quadrupole mass filter. Air samples containing the trace volatiles are then reacted with the precursor ions in fast moving stream of helium contained in a flow tube. The resulting product ions, characteristic of the trace gas being analysed, are produced at a rate dependent on the reaction kinetics. Once the rate constant of the reaction between the precursor and the trace gas is known, the absolute concentration of each trace gas present can be calculated without the need for calibration standards (7, 8). A wide range of compounds have already been characterized by SIFT-MS including those which may contribute to oral malodour including VSC, aldehydes, ketones, organic acids, ammonia and chemical markers of garlic (diallyl sulphide and diallyl disulphide) and onion (thiopropanal-S-oxide) (7, 9). In this study, we will determine, for the first time, whether SIFT-MS may be useful for the chemical analysis and clinical monitoring of oral malodour. To accomplish this we have used SIFT-MS to analyse oral air from subjects with and without a history of oral malodour and compared the data obtained with organoleptic scores generated by a human rater, and with total VSC levels measured using a solid state sensor.

Study population and methodology

Subjects

Subjects were recruited by invitation according to a protocol approved by the human research ethics committee of Lakehead University. The study group consisted of four male and

14 female participants whose age was 60 ± 15 (mean ± SD), range 21–85. Nine of the subjects had a history of oral malodour and had previously received treatment for the condition although none were undergoing treatment when recruited into this study.

Inclusion and exclusion criteria

To be included in the study, subjects had to be over 18 years of age. Exclusion criteria were chosen to minimize the effects of other variables which could alter the detection of oral malodour these being (i) currently: undergoing treatment for oral malodour or had a respiratory disease, (ii) within 3 h of testing: had ingested food, drink, mints or gum or had brushed or flossed their teeth, (iii) within 12 h of testing: had applied perfume or aftershave, (iv) within 24 h of testing: had used breath fresheners or mouth washes, smoked a cigarette, drank an alcoholic beverage, or eaten food containing garlic, onions or strong spices and (v) within 1 month of testing: had taken antibiotic medications.

Organoleptic scores

Subjective assessment was conducted by a trained rater (LM) with over 10 years of experience using the organoleptic rating scale: 0 – no malodour, 1 – barely noticeable malodour, 2 – slight malodour but evident, 3 – moderate malodour, 4 – strong malodour, 5 – extremely foul malodour (4). A value of 2 or greater indicates clinically significant oral malodour. The rater recorded malodour from the tongue, the mouth or from the nose. The latter is indicative of a systemic rather than oral malodour source. At the time of the assessment, the rater was blind to chemical level values for each subject.

Mouth air sampling procedure

A mouth air sample is taken using a short piece of clear PVC tubing (length 10 cm, OD 1/4″, ID 3/8″) connected to the inlet of the measurement device. The subject is asked to close their mouth and breathe through their nose for 3 min to concentrate volatile compounds in the mouth. A piece of tubing is then inserted 2.5–5 cm into a nearly closed mouth. The subject is asked to not touch any mouth surface with the tube, and must not blow or suck into the tubing. The air sampling method for the two devices used in the study differed only in the sampling flow rates, which were approximately 7 ml s^{-1} for the VSC sensor and 0.2 ml s^{-1} for the SIFT-MS. Lag time (time between sample introduction and change in recorded concentration) for the Halimeter is approximately 1 s and for SIFT-MS approximately 2 s.

Measurement of total volatile sulphur containing compound levels

Total VSC levels in the mouth were determined using a Halimeter solid state sensor based device (Interscan, Chatworth, CA, USA). The sensor in the device is sensitive to hydrogen sulphide, methylmercaptan and dimethylsulphide (10). The measured levels of VSC rapidly increase and reach a steady state after several seconds. VSC levels are recorded after 15 s of air sampling.

Volatile chemical level measurement using SIFT-MS

A Profile 3 SIFT-MS instrument (Instrument Science, Crewe, UK) was set to measure a range of compounds by measuring the generation of product ions generated in the reaction between H_3O^+, which are used to determine absolute gas concentration using the following product ions and kinetic constants (in units of cm^3 s^{-1}): water *m/z* 37, 53, 73, $k = 1.3 \times 10^{-11}$ (calculated water concentration is corrected for temperature and pressure); acetaldehyde *m/z* 45, 81, $k = 3.7 \times 10^{-9}$; acetone *m/z* 58, 77, $k = 3.9 \times 10^{-9}$; ammonia *m/z* 18, 36, 54, $k = 2.6 \times 10^{-9}$; propanol plus acetic acid *m/z* 43, 61, 79, 97, $k = 2.7 \times 10^{-9}$; acetic acid *m/z* 61, 79, 97, $k = 2.6 \times 10^{-9}$; butyric acid *m/z* 89, 107, 125, $k = 2.9 \times 10^{-9}$; hydrogen sulphide *m/z* 35, $k = 2.0 \times 10^{-9}$; methylmercaptan *m/z* 49, $k = 2.5 \times 10^{-9}$; diallyl disulphide *m/z* 147, $k = 3 \times 10^{-9}$; thiopropanal-S-oxide *m/z* 91, 109, $k = 2.5 \times 10^{-9}$ (9, 11–16). The mass spectrometer was set to sequentially monitor precursor ions for 0.1 s and product ions for 0.2 s. The diffusion constants required in the concentration calculation was determined using an approximation as described (8). The precursor ions count for the sum of H_3O^+ plus hydrates $[H_3O^+.(H_2O)_n;\ n = 1–3]$ was approximately 1×10^6 counts per second. Oral air was sampled for a period of 1 min via a transfer line heated to 99°C. Environmental levels of each compounds were routinely monitored. Immediately following oral air measurements, the subject was asked to exhale through a breath sampling device which sampled a fraction of the air flow via the heated transfer line (7). For each exhalation the instrument measured trace gas levels in real time to determine the plateau levels corresponding to alveolar breath. The median level of three exhalations was recorded as the alveolar gas concentration for each compound.

Statistical analysis

Breath trace gas levels were not found to be normally distributed within the subject group. As such, we utilized non-parametric statistical methods throughout this study specifically Spearman correlations and, when comparing medians, the Mann–Whitney *U*-test.

Results

Eighteen subjects were investigated using a combination of subjective appraisal (organoleptic scores), total oral VSC level measurements and SIFT-MS analysis of static oral air. We observed that mouth malodour organoleptic scores were either 0 (12 subjects), 1 (5 subjects) or 2 (1 subject), nose organoleptic scores were either 0 (5 subjects), 1 (5 subjects), 2 (5 subjects) or 3 (3 subjects) and tongue organoleptic scores were 0 (4 subjects), 1 (3 subjects), 2 (4 subjects), 4 (6 subjects) or 5 (1 subject). Subjects with a history of malodour had significantly higher tongue organoleptic scores than those with no history ($P < 0.05$; Mann–Whitney *U*-test; median scores were 1 in subjects without history and 3 in subjects with history); tongue and nose scores did not significantly differ between the two groups ($P > 0.05$; Mann–Whitney *U*-test). Nose, mouth and tongue scores were not significantly correlated to each other (Spearman correlation; $P > 0.05$).

Oral levels of total VSC and levels of the compounds measured by SIFT-MS did not differ significantly ($P > 0.05$; Mann–Whitney *U*-test) between subjects with and without a history of oral malodour (data not shown). As illustrated in Fig. 1, total VSC levels in static mouth air were not significantly ($P > 0.05$) correlated with tongue organoleptic scores (Spearman rank correlation coefficient = 0.47) and with mouth or nose scores (Spearman correlation coefficients were 0.30 and 0.29 respectively; $P > 0.05$). Total VSC levels measured using the solid state sensor were significantly ($P < 0.05$) correlated with SIFT-MS measurements of hydrogen sulphide and methylmercaptan in static oral air (Fig. 2; Spearman rank correlation coefficients were 0.93 and 0.53 respectively). We next compared the levels of a number of volatile compounds in static oral air of those with tongue organoleptic scores of 2 or less ($n = 11$) to those with scores of 3 or higher ($n = 7$). Only methylmercaptan levels were significantly ($P < 0.05$; Mann–Whitney *U*-test) elevated in those with higher tongue organoleptic scores, while levels of water vapour, total VSC, hydrogen sulphide, ammonia, acetone, acetaldehyde, propanol/acetic acid, acetic acid, butyric acid, diallyl disulphide and propanol-s-oxide did not significantly differ between the two groups (Fig. 3 and Table 1). Within the group of subjects who had

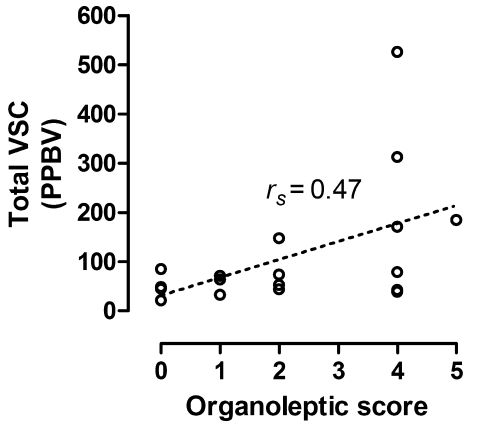

Fig. 1. Lack of correlation between organoleptic scores and total volatile sulphur compound levels in mouth air. Tongue organoleptic scores were not significantly correlated ($P < 0.05$) with total volatile sulphur compounds (VSC). The best fit linear regression line is shown along with the Spearman correlation coefficient.

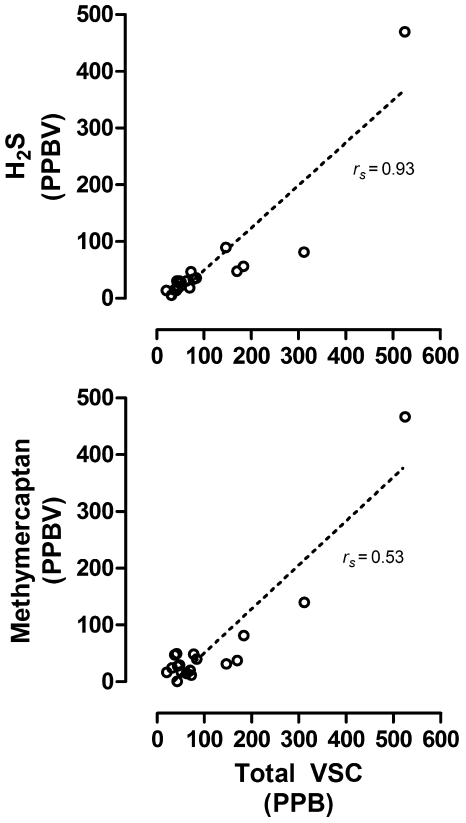

Fig. 2. Correlation between total sulphur containing compound levels and hydrogen sulphide or methylmercaptan in mouth air. Oral levels of total volatile sulphur compounds (VSC), measured using a solid state sensor, were compared with levels of hydrogen sulphide (H_2S) and methylmercaptan, measured using SIFT-MS. Best fit linear regression lines are shown along with the Spearman correlation coefficient. A statistically significant correlation ($P < 0.05$) was observed to occur between hydrogen sulphide or methylmercaptan and total VSC levels.

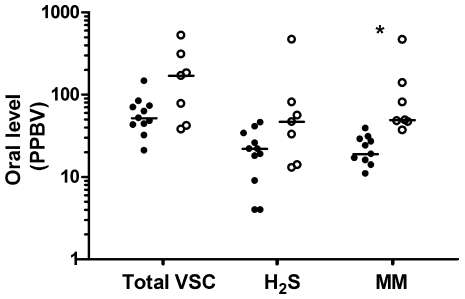

Fig. 3. Volatile compound levels in mouth air. Levels of oral total volatile sulphur compounds (VSC), measured using a solid state sensor, hydrogen sulphide (H_2S) and methylmercaptan, measured using SIFT-MS, are shown for subjects with tongue organoleptic scores ≤ 2 (filled dots) and those with scores ≥3 (open dots). Bars indicate the median value. Note that concentrations are plotted on a log scale. $^*P < 0.05$ by Mann–Whitney *U*-test.

Table 1. **Levels of volatile chemicals in oral and ambient air measured by SIFT-MS**

	Organoleptic score		
Compound	≤2 (n = 11)	≥3 (n = 7)	Ambient
Water vapour	5.7 ± 0.2	5.8 ± 0.2	1.2 ± 0.1
Acetone	210 ± 150	289 ± 190	12 ± 3
Ammonia	580 ± 530	792 ± 712	22 ± 12
Acetaldehyde	19 ± 84	25 ± 87	4 ± 2
Propanol plus acetic acid	180 ± 48	275 ± 69	17 ± 6
Acetic acid	97 ± 25	152 ± 71	11 ± 5
Butyric acid	19 ± 13	13 ± 19	0 ± 2
Diallyl disulphide	1 ± 3	0 ± 4	0 ± 1
Thiopropanal-S-oxide	12 ± 22	5 ± 4	3 ± 4

Oral air was sampled from 18 subjects and volatile chemical levels assessed using SIFT-MS. Subjects were divided into two groups on the basis of each subjects tongue organoleptic score. Ambient air was measured for a period of 2 min and the average value recorded. Values shown are median levels in PPBV ± quartile range except for water vapour which is given as percent of total air volume. There were no statistically significant differences between the two groups ($P < 0.05$) as determined using a Mann–Whitney *U*-test. Acetic acid concentrations should be considered approximate because of the contribution of propanol while water vapour may have contributed to apparent thiopropanal-S-oxide levels (please see text for details).
SIFT-MS, selective flow tube mass spectrometry; PPBV, parts per billion by volume.

the higher tongue organoleptic scores, three out of seven subjects possessed total VSC levels within the normal range (<150 PPBV) (17). Levels of each volatile compound measured by SIFT-MS were assessed for the possible cause of the high organoleptic scores (Fig. 4). In the first subject static mouth levels of acetone were the highest of all 18 subjects. In the second subject, levels of propanol and acetic acid, and acetic acid alone were the highest of all 18 subjects. Examination of the individual ion counts strongly suggested that this elevation was because of acetic acid rather than propanol given that

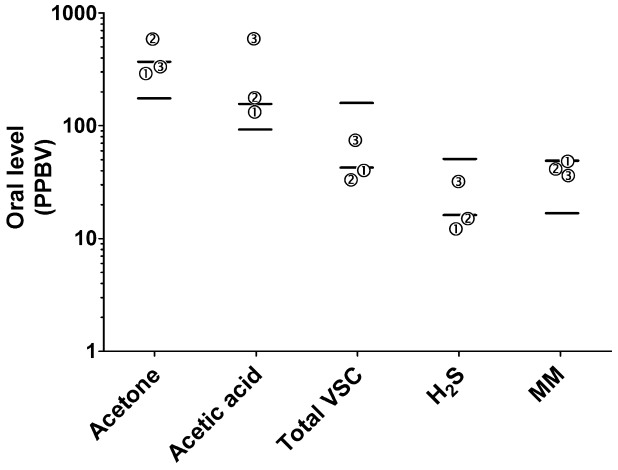

Fig. 4. Volatile compound levels in mouth air of subjects having a high organoleptic score but low total volatile sulphur compound levels. Levels of acetone, acetic acid, total volatile sulphur compounds (VSC), hydrogen sulphide (H_2S) and methylmercaptan were determined in oral air. For each compound the two bars show the extent of the median ± interquartile range for the entire subject group (n = 18) along with individual values of three numbered subjects plotted on a log scale. Note that subject 2 has relatively high acetone levels whereas subject 3 has relatively high acetic acid levels. Acetic acid concentrations should be considered approximate because of the contribution of propanol (please see the text for further consideration of this issue).

while m/z 43 counts, a propanol specific product ion, were unremarkable (76 ± 3 counts per second averaged over 60 s), while m/z 61 counts, a product ion common to both propanol and acetic acid, were high (423 ± 12 counts per second). In the third subject, none of the *a priori* selected compounds exhibited remarkable oral abundance. Finally, alveolar trace gas levels were compared with the oral levels in each subject. Only acetone exhibited a statistically significant ($P < 0.05$) correlation between oral and lung levels (Spearman correlation coefficient = 0.72).

Discussion

Our major finding is that SIFT-MS is capable of detecting a range of VSC and non-VSC compounds present in oral air that are thought to play a role in oral malodour. Our subject group comprised individuals possessing predominantly low mouth organoleptic scores, which did not differ between those with and without a history or oral malodour. Tongue organoleptic scores were higher, however, in those with a history of the disorder suggesting that although prior treatment had reduced the severity of the condition in most subjects, the underlying metabolic processes responsible for the generation of malodour were still occurring on the surface of the tongue.

In agreement with other researchers (4) both the total VSC levels as well as the individual sulphur compounds measured using SIFT-MS correlated poorly with rater generated organoleptic scores. This indicates that in some subjects the major cause of oral malodour is most likely not the elevated bacterial VSC synthesis. As expected the VSC levels determined using the solid state sensor were significantly correlated with both hydrogen sulphide and methylmercaptan quantified using SIFT-MS. Comparison of chemical levels in those with low and high tongue organoleptic scores suggested that methylmercaptan, but not hydrogen sulphide, was elevated in the latter, a finding in agreement with data suggesting the methylmercaptan is the predominant oral malodour producing VSC (3). A proportion of the methylmercaptan concentration may be due to the reaction of H_3O^+ with an isotopologue of ethanol containing the oxygen isotope ^{18}O (which comprises approximately 0.2% of total oxygen), as both the compounds give rise to a product possessing an *m/z* of 49. This may be of importance in clinical environments given that there is frequently a moderate to high abundance of ethanol in the ambient air because of, for example, the presence of hand washing stations. In our laboratory the ambient ethanol concentration is approximately 300 PPBV, which would result in approximately 0.6 PPB of the methylmercaptan concentration being due to ethanol, a negligible amount. Higher ambient ethanol concentrations, however, could result in significant interference with the measurement of methylmercaptan which would have to be accounted for. We also observed that the ammonia content of oral air did not differ between those with high and low organoleptic scores, or did oral ammonia levels correlate with levels of VSCs. As systemic ammonia production in individuals who do not have kidney failure is low while production of ammonia by oral bacteria is high (18), this finding is supportive of the concept that different bacteria are responsible for the generation of different types of volatile compounds (4).

Ambient levels of the volatile chemicals monitored were not subtracted from oral air levels. As the oral levels of compounds are monitored after allowing trace gas levels to accumulate by means of nose breathing, it is unclear as to how ambient gases will contribute to the total measured oral gas levels because of the effects of mucous membrane absorbance. Further, subtraction of ambient volatile gas levels often creates misleading and incorrect measurements for many gases as the proportion of inspired gas which is subsequently expired is neither 100% nor predictable (e.g. exhaled O_2 levels are less than inhaled levels while exhaled CO_2 levels are independent of the inhaled concentration of CO_2 over a wide range of concentrations) (19). As such while ambient levels may have an effect on oral gas levels, we have opted to report total levels in this study [it is worth noting that median breath levels exceeded ambient levels for the compounds measured (see Table 1)]. Furthermore, as all breath measurements were taken in the same location in which ambient gas levels varied little over time, it is likely that the ambient levels had a minimal impact on between group comparisons. The question of how to account for the variable ambient levels likely to be encountered in clinical settings is an important one, however, and further investigation of how to minimize the effects of this potential confound in the assessment of oral air is required.

Our data suggest that SIFT-MS may be of utility in the analysis of oral malodour which is not caused by elevated VSC production. Specifically, three subjects with elevated tongue organoleptic scores had normal oral levels total VSC, hydrogen sulphide and methylmercaptan. None of these subjects had remarkable levels of markers associated with onion (thiopropanal-S-oxide) or garlic (diallyl disulphide) consumption (9) and hence it is unlikely that either foodstuff is responsible for the malodour. It is worth noting that the apparent levels of thiopropanal-S-oxide were higher than diallyl disulphide. This is most likely because of the fourth hydrate of H_3O^+ $[H_3O^+.(H_2O)_4]$ which also possesses an *m/z* of 91. While such interference does not rule out the utility of such a method for the detection of thiopropanol-S-oxide vapour in the breath, further investigation of the reaction of odiferous food derived compounds with the alternative precursor ions NO^+ or O_2^+ may result in methodology for their detection which possesses increased specificity.

We did observe that one subject had high oral levels of acetone. Acetone is a relatively abundant compound in alveolar air being derived from the systemic catabolism of fatty acids. Bacteria also produce acetone and hence an oral source is also likely (20). Notably, acetone was the only compound assessed which exhibited a significant correlation between alveolar and oral sources. The reason for such a correlation is unclear but does suggest the possibility that significant amounts of acetone present in the bloodstream are released via the tongue. The possibility must be considered, therefore, that an elevated level of systemic acetone is the source of the malodour in this subject, a possibility supported by the observation that this subject had a nasal organoleptic score of 3 along with a tongue score of 5. Significantly elevated acetone levels are a known cause of malodour occurring both in type 1 diabetes and after fasting (21, 22). Although our exclusion criteria were designed to reduce the effects of prolonged fasting, it remains a possibility that ketosis was occurring in this subject at the time of testing. Such a finding achieved using SIFT-MS is of likely

clinical utility as it would assist in determining the most appropriate treatment choice or advice to be given to the patient.

In another subject with a high tongue organoleptic score but low total oral VSC levels, elevated levels of propanol and/or acetic acid were observed. Differentiating between these two compounds using the H_3O^+ precursor is made difficult due to both compounds producing overlapping, thought not identical, ionized products (see Study Population and Methodology). Analysis of the actual ions being produced, however, strongly indicates that the compound present in relatively high amounts is acetic acid rather than propanol although accurate quantification of acetic acid separate from propanol is not possible using the H_3O^+ precursor. Future investigations would usefully utilize the NO^+ precursor which does allow quantification of acetic acid apart from propanol. Despite these limitations, it is worth noting that acetic acid has long been known to be produced in the mouth by bacterial action (23, 24). The compound has not previously been associated with oral malodour although it is a volatile acid with a distinctive odour (6). Further investigation is required to determine whether the malodour is caused by acetic acid *per se* or by another as yet unknown compound, the levels of which are also raised in this subject. It is notable, however, that butyric acid levels were unremarkable in this subject although levels of other odiferous acids such as propionic and valeric acid were not measured. In the third subject possessing low oral VSC levels but high tongue organoleptic scores, we did not observe elevated oral levels of any of the compounds measured using SIFT-MS. The source of the malodour in this subject therefore remains unknown. Other compounds not measured in this study may be responsible however. For example, the polyamines putrescine and cadaverine have been suggested to cause malodour in some patients (4). Given that monoamines are amenable to SIFT-MS analysis (25, 26), it is likely that their diamine counterparts will also be quantifiable using this technique. It is unclear whether the levels of polyamines in the gas phase within the mouth will be sufficient to allow quantification by SIFT-MS, however they are detectable in saliva in the tens of μg/ml range in healthy subjects (27). Work to answer this question is currently underway in our laboratory.

Our finding that oral levels of all compounds (with the exception of acetone) correlates poorly with alveolar levels is likely because of a combination of differing gas sources (systemic versus oral) and our specific methodology which allowed orally derived compounds to accumulate by means of asking the subject to nose breath for 3 min prior to testing. The general lack of correlation between oral and alveolar air indicates that cross contamination between the two compartments is minimal. Nevertheless, our data do indicate that the oral cavity is a rich source of volatile compounds and it is likely that factors such as oral hygiene will change oral levels with the potential for varying degrees of contamination of alveolar air. While monitoring air exhaled from the nose rather than the mouth may offer a solution to this problem (18); it may be important to prevent inhalation via the mouth for some time before taking any sample via the nose, as inhaled oral compounds will also be present in exhaled alveolar air to some extent.

In conclusion, our data support the use of SIFT-MS as an investigational and monitoring tool for oral malodour. The technique has the advantage of allowing the determination of oral levels of a wide range of volatile chemicals over and above the total VSC levels measurements currently in common use. The ability to routinely measure the levels of odiferous chemical in addition to VSC may allow a fuller understanding of the nature and, potentially, the cause of oral malodour in each subject. Although not investigated in this study it is also likely that SIFT-MS could find use in determining the effectiveness of various treatments upon the oral production of a wide range of malodorous compounds. A limitation of our study is that the subject group as a whole possessed a low to moderate severity of malodour, this being mainly detectable on the tongue. Future investigations employing larger number of subjects and which include subjects with untreated moderate to severe oral malodour will be required to fully explore the use of SIFT-MS as an investigational tool for the disorder.

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