doi: 10.1111/j.0904-2512.2006.00484.x

J Oral Pathol Med (2007) 36: 127–31

www.blackwellmunksgaard.com/jopm

The feasibility of using infrared thermography to evaluate minor salivary gland function in euhydrated, dehydrated and rehydrated subjects

P-J. Lamey[1], P. A. Biagioni[1], I. Al-Hashimi[2]

[1]*Oral Science Research Centre, School of Dentistry, Queen's University Belfast, BT12 6BP, UK;* [2]*Salivary Dysfunction Clinic, Baylor College of Dentistry, Dallas TX, USA*

BACKGROUND: Infrared thermography technique (IRT) is utilized by a growing number of disciplines within medicine and dentistry. However, IRT has not been employed in the evaluation of salivary gland dysfunction. The purpose of this study was to examine the feasibility of using thermographic imaging in the evaluation of minor labial salivary gland function in subjects during euhydration, dehydration, and rehydration states.
METHODS: Ten subjects were studied. Upper labial minor salivary gland secretion was quantified whilst simultaneously visualizing lower minor salivary gland output thermographically during each state.
RESULTS: A significant difference was observed in the minor labial salivary flow among euhydrated, dehydrated and rehydrated, states. Despite the lack of statistical difference in the thermographic findings, IRT images reflected noticeable differences among the three hydration states.
CONCLUSION: The overall results of this study suggest that IRT could potentially provide a valuable non-invasive tool for evaluating the relationship between minor labial salivary gland function and hydration status.
J Oral Pathol Med (2007) **36**: 127–31

Keywords: hydration; infrared thermography; saliva function

Introduction

Infrared thermography technique (IRT) is utilized by a growing number of disciplines within medicine (1–4). IRT is considered as a non-invasive scanning thermometer. Crandell and Hill were the first to publish data using IRT in dental research. (5–8). Since its first application IRT has shown considerable potential within a number of dental disciplines including periodontology (9, 10), implantology (11, 12), restorative dentistry (13–15), oral surgery (16, 17) and oral medicine (18–20). However, the most widely studied application of thermography to the orofacial region has been in the characterization of craniomandibular disorders and principally temporomandibular joint dysfunction. Although its use had been applied to diagnosis of salivary gland disease (21, 22), IRT has not been used for evaluation of the functional disorders of the salivary glands. Relative estimates of minor salivary flow can be obtained by blotting techniques; however, such technique has the potential of introducing error due to the requirement of surface contact. IRT has the advantage of not introducing recording error due to contact with the surface of interest. Considering the difficulty of measuring minor gland flow (23), the purpose of this study was to examine the potential application of electronic infrared thermography (IRT) (24) technology as a non-invasive tool for the evaluation of minor labial salivary gland function. The study also employed techniques involving depletion and repletion of total body water as an indicator of whether IRT could identify differences in minor salivary gland function under these conditions.

Correspondence: Prof. P-J Lamey, Oral Science Research Centre, School of Dentistry, Queen's University Belfast, The Royal Group of Hospitals and Dental Hospital HSS Trust, Grosvenor Road, Belfast BT12 6BP, UK. Tel: +44 28 9063 4240. Fax: +44 28 9043 8861. E-mail: p.lamey@qub.ac.uk
Accepted for publication June 27, 2006

Material and methods

Subjects

A total of ten healthy subjects gave written consent to participate in this study. All subjects were non-smokers on no systemic medication and all had a body mass index (BMI) between 18.5 and 24.9, i.e. in the healthy range. The sample was divided equally between males and females with a mean age of 24.6 years (SEM = 1.09). Subjects were required to drink 2 l of water before going to bed on the night before each study. Subjects were also required to rest the night before the trial and to abstain from consuming any alcohol. It was assumed that the subjects were honest and indeed they gave their word that they had actually taken the fluid as requested and had undertaken no heavy exercise the evening before or on the morning of the experiment.

Equipment
All weight measurements were recorded using a Sartorius Ba110s (Sartorius Ltd, Epsom, UK) analytic balance. The readability of this balance is 0.0001 g and a reproducibility of 0.0001 g.

Thermography
The imaging system used was the Agema thermovision 900 series (AGEMA Infrared Systems AB, Danderyd, Sweden). The scanner is a longwave, cryogenically cooled system utilizing a mercury cadmium telluride detector with a spectral response of 8–12 μ and a sensitivity of 0.1°C at 30°C. This window of 8–12 μ coincides with the region of maximal skin emission of 8–10 μ. The scanner is controlled by a dedicated system controller, which runs software specifically for thermal image analysis.

Experimental design
Upon arrival at the thermographic suite, subjects changed into sports clothes and were weighed on standard bathroom scales, disrobed. The subjects were then asked to complete a medical history and were then given time to relax prior to the fluid balance studies. Medical history was checked by the clinician in charge of the study (PJL).

The output of the upper labial minor salivary gland was quantified on the inner aspect of the upper lip using two filter discs placed approximately 1 cm to the left and the right of the midline. Each respective area was dried using sterilized gauze prior to insertion of each disc. Each disc remained in place for 1 min during which time function of the lower labial minor glands was monitored simultaneously using IRT. The weight of saliva was calculated by weighing the discs before insertion and then weighing after removal from the mouth. In order to facilitate the weighing of each disc, they were kept in a sealed container so that drying out would not affect results. The weight of the disc and container was therefore taken before each session. The difference in the weight of the disc and the container before the session and the disc-absorbed saliva and the container after the session were assumed to represent the net saliva collected after 1 min.

A specially designed mouth guard was placed in the lower lip and adjusted so that the lower labial mucosa surface was exposed to the thermal imaging camera. This did not displace or interfere with the filter discs placed beneath the upper lip. Subjects were positioned so as to obtain a sharp thermal image of the lower labial mucosa, saliva was removed from the labial surface by wiping with sterilized gauze. Immediately prior to thermographic imaging 1 ml of 10% citric acid was introduced to the back of the subject's throat via a syringe in order to stimulate salivary flow. Thermal images of the lower labial minor salivary glands were recorded once every second for 15 s and were stored in 12 bit format on the thermal imaging system for later analysis. This completed the euhydrated state assessment.

Subjects were then required to exercise for approximately 50 min or until they lost 1–2% of their body weight. This was achieved through the use of a cross country skier. They were then allowed to rest for a period long enough to allow their breathing to normalize which took approximately 10 min. Thermographic imaging of the lower labial salivary glands was repeated as for the subjects in the euhydrated state.

Subjects were then given 500 ml of water to drink over a 5 min period. Upper minor labial gland output was again measured via the filter paper absorption method and thermographic imaging of saliva production was recorded as before for the rehydrated state. All trials were repeated on three separate occasions over a 2 week period to ensure consistency of the results.

Thermographic measurements
The thermographic flow of saliva from the minor labial glands was recorded and the mucosal surface area affected was shown by a change in temperature, measured in square millimetre (samples of images obtained during each state at the times T = 1, T = 8 and T = 16 are presented in Figure 1).

Thermographic results were then entered into Excel Version 7.0 for Windows 95' and the area under the graph (representing fluctuations in area of effect for each subject) during each phase was calculated. The

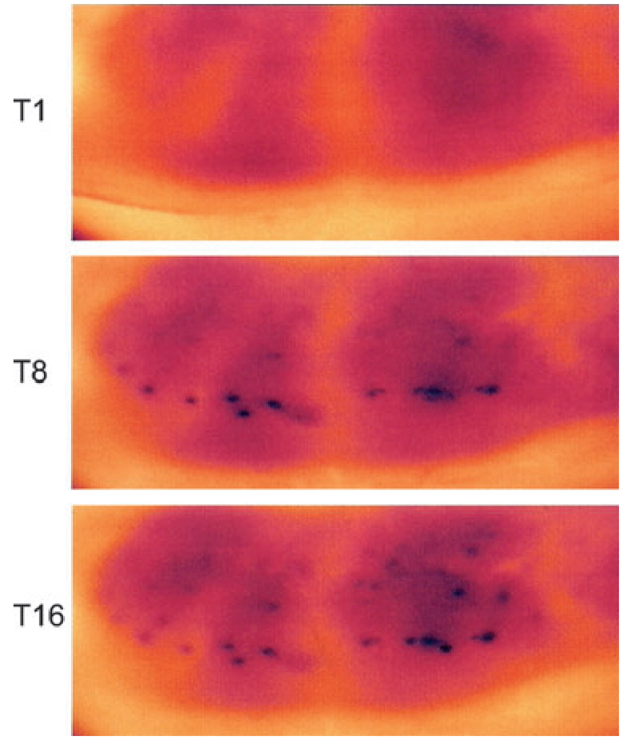

Figure 1 Thermographic image of labial surface at various stages of hydration. T1, prior to the application of salivary stimulant; T8, 8 s following stimulation with 10% citric acid; T16, 16 s following citric acid stimulation.

subsequent values were entered into SPSS version 6.0 for the purposes of statistical analysis.

Data analysis
Data analysis was conducted using SPSS Version 6.0 for Windows. For comparisons between states and trials and after obtaining statistical advice it was decided that a repeated measures multivariate analysis of variance would be used and specifically the bonferroni statistic. This allowed intra-subject variation to be taken into consideration. Ninety-five per cent confidence intervals were used to examine differences against baseline levels for each parameter. A significance level of 5% was set.

Results

All 10 subjects successfully completed the trials, and all upper labial salivary gland outputs and quantified and IRT images simultaneously achieved of the lower labial minor salivary glands. The cumulative mean weight of subjects before commencing each trial was 70.11 ± 3.86 kg. Following exercise all subjects lost in excess of 1% of their body weight and eight subjects lost over 2% of their body weight.

The mean weights of saliva, collected from the inner aspect of the upper lip for 1 min during the euhydrated, dehydrated and rehydrated states are expressed in mg ± SEM. The consistency of thermography results between trials was also verified with bonferroni analyses and there was no significant difference between trials (data not shown).

Inter state comparisons
Comparison of the thermographic area evaluated and upper minor labial salivary gland output are shown in Table 1. Analyses were conducted on the overall data as a whole and consistency across trials was excellent. The average temperature changes over the minor labial salivary glands over the 15 s period during the euhydrated state was 31.53°C (SEM = 0.059), 31.69°C (SEM = 0.059) during the dehydrated state and 30.76°C (SEM = 29.9) during the rehydrated state. A clear difference was observed in the thermographic images obtained at various time points during various states of hydration, (Figure 1).

Comparisons of minor upper labial salivary gland output between various hydration states showed a significant difference in the mean weight of saliva collected from that site. Figure 2 demonstrates the mean volume of saliva collected from euhydrated, dehydrated and rehydrated states. The mean weight of saliva collected from the labial surface indicates a change between euhydrated and dehydrated stated such that a significantly lower weight of saliva than that collected during the dehydrated than euhydrated state (coefficient = −0.0087, $t = -3.94$, $P < 0.05$). There was no significant difference between dehydrated and rehydrated states (coefficient = 0.003, $t = 1, 14$, $P > 0.05$).

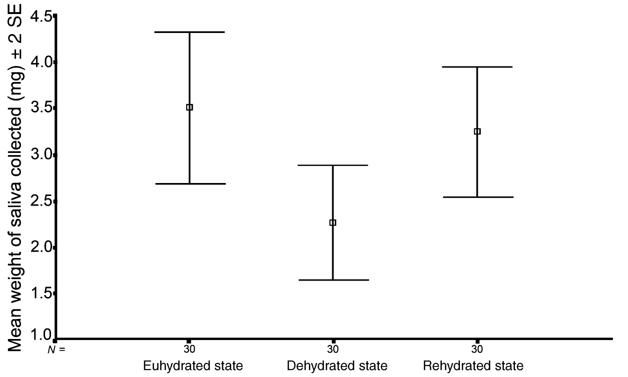

Figure 2 Salivary flow at various hydration states (data represent cumulative mean of three trials).

Discussion

Thermography is a generic title for various methods of quantifying the temperature distribution from body surfaces. The three forms of thermography used are liquid crystal thermography (LCT), IRT and microwave thermography (MWT). LCT makes use of cholesterol compounds which are anisotropic, i.e. they show a colour change with changes in temperature. MWT and IRT are both modalities that allow for the detection of thermal emissions from a surface in the microwave and infrared regions of the electromagnetic spectrum respectively. However, of the three methods only IRT involves no contact with the surface being analysed. This therefore immediately has the advantage of not introducing recording error due to contact with the surface of interest.

The perception that the oral mucosa feels dry is thought to be linked to thirst and desire to drink (25). Minor salivary gland output could reasonably be considered to influence the perception of oral wetness but this is unproven. The relationship is however

Table 1 Comparison of the thermographic area evaluated and upper minor labial salivary gland during various hydration states[a]

	Euhydration	*Dehydration*	*Rehydration*	*Index*[b]
Thermography (mm^2 ± SEM)[c]	89.47 ± 32.76	49.03 ± 16.80	61.50 ± 31.75	1.82
Oral wetness (mg ± SEM) labial salivary gland	1.16 ± 0.3	0.50 ± 0.2	0.90 ± 0.2	2.3

[a]Cumulative mean of three separate trials.
[b]Area under the graph.
[c]Index represents the ratio between the cumulative means of euhydration vs. dehydration states.

complex and it would appear that there is more to thirst than just dehydration of the oral cavity (26). Thirst is important as part of the body's homeostatic mechanisms of fluid control which is, in normal circumstances, highly integrated with higher central control mechanisms such that fluid balance is normally within $\pm 0.2\%$ of total body weight (27).

Under normal circumstances the integration between hypothalmic osmoreceptors and vascular baroreceptors maintains fluid intake in balance with fluid loss both via body secretions and respiration and via the skin. Deliberately altering this balance by forced exercise would compromise normal physiological functions and would be expected to increase thirst (28). Thirst is probably linked among other factors to the subject's perception of a reduction in oral wetness.

As IRT depends on the measurement of short wave infrared radiation from the surface, and because water is opaque to infrared radiation, a wet area produces darker (more opaque) thermal images than dry areas, as seen in Figure 1.

From the data presented in this report, it appears that infrared thermography is an effective technique for examining minor salivary gland function of saliva glands and should be investigated further. Results of this study suggest that more minor labial gland saliva was produced during the euhydrated and rehydrated states than in the dehydrated state. Despite the lack of statistical significance, the IRT images appear to reflect clinically important changes that warrant further investigation of the application of IRT for the evaluation of minor salivary gland function and dysfunction.

Because of the dynamic nature of the process under scrutiny and the fact that minor salivary glands secretion appeared at different intervals, then the action of each gland appears to be a complex process. For example, the average temperature of the area affected by glandular action displayed little variation over time, whereas minimum and maximum temperatures appeared to show greater variation. Typically what would occur is that the minor gland output of saliva would appear, then remain stable in terms of area and temperature for approximately 2–4 s. The temperature would then either drop or rise and this change in temperature would be reflected in a thermographically smaller or larger area respectively.

That there were observed changes in the area affected by glandular action, which were associated with a drop or increase in minimum/maximum temperatures, indicates that the thermal imaging system is detecting underlying physiological changes associated with the production of saliva from the minor glands under scrutiny. Therefore, as saliva is produced, the minimum temperature will typically drop and there will be an associated decrease in the area affected by the gland. We suggest that this decrease in temperature is directly related to the production of saliva and the subsequent formation of a droplet of saliva above the gland. This will occlude more of the underlying mucosal temperature and therefore be observed thermographically as a reduction in temperature.

In terms of the site to be studied in relation to minor salivary gland secretion it appears that the labial surface is suitable for any further research. This is in part due to the accessibility of the glands but also because infrared radiation needs to travel in straight lines to be detected by IRT.

References

1. Baillie AJ, Biagioni PA, Forsyth A, Garioch JJ, McPherson D. Thermographic assessment of patch-test responses. *Br J Dermatol* 1990; **122**: 351–60.
2. Seifalian AM, Stansby G, Jackson A, Howell K, Hamilton G. Comparison of laser Doppler perfusion imaging, laser Doppler flowmetry and thermographic imaging for assessment of blood flow in human skin. *Eur J Vasc Surg* 1994; **8**: 65–9.
3. McHugh NJ, Elvins DM, Ring EFJ. Elevated anticardiolipin antibodies in a patient with vibration – white finger, valvular heart disease and psoriatic arthritis. *Clin Rheumatol* 1993; **12**: 70–3.
4. Mohr FWJ, Grudfest W, et al. Thermal coronary angiography: a method of assessing graft patency and coronary anatomy in coronary by-pass surgery. *Ann Thorac Surg* 1989; **47**: 441–9.
5. Crandell CE, Hill RP. Thermography in dentistry: a pilot study. *Oral Surg Oral Med Oral Pathol* 1966; **21**: 316–20.
6. Irwin JW, Savara BS, Bartley MH, Rau JA. Intraoral thermography and oral inflammatory conditions. *Oral Surg* 1971; **32**: 724–30.
7. Soffin CB, Morse DR, Seltzer S, Lapayowker S. Thermography and oral inflammatory conditions. *Oral Surg* 1983; **56**: 256–62.
8. White BA, Lochart PB, Connolly SF, Sonis ST. The use of infrared thermography in the evaluation of oral lesions. *Int J Tissue React* 1987; **9**: 105–14.
9. Barnett ML, Gilman RM, Charles CH, Bartels LL. Computer based thermal imaging of human gingiva: preliminary investigation. *J Periodontol* 1989; **60**: 628–33.
10. Momann WH, Bosiger P, Grau P, Scaroni F. The thermodynamic behaviour of labial gingiva in patients with destructive periodontal disease. *J Clin Periodontol* 1985; **12**: 477–93.
11. Benington IC, Biagioni PA, Crossey P-J, Hussey DL, Sheridan S, Lamey P-J. Temperature changes in bovine mandibular bone during implant site preparation: An assessment using infrared thermography. *J Dent* 1996; **24**: 263–7.
12. Watanabe F, Tawada Y, Komatsu S, Hata Y. Heat distribution in bone during preparation of implant sites: Heat analysis by real time thermography. *Int J Oral Maxillofac Impants* 1992; **7**: 212–9.
13. Hussey DL, Biagioni PA, Lamey P-J. Thermographic measurement of temperature change during resin composite polymerisation *in-vivo*. *J Dent* 1995; **23**: 267–71.
14. Anic I, Dzubur A, Vidovic D, Tudja M. Temperature and surface changes of dentine and cementum induced by C02 laser exposure. *Int Endod J* 1993; **26**: 284–93.
15. Launay Y, Mordon S, Cornil A, Brunetaud JM, Moschetto Y. Thermal effects of lasers on dental tissues. *Lasers Surg. Med* 1987; **7**: 473–7.
16. Hartel J, Sonerburg M, Birr H, Mahnke K. Thermometric measurements of the course of mandibular fracture healing. *Beitr Orthop Traumatol* 1976; **23**: 280–4.

17. Nagasawa A. The application of thermography to oral surgery. In: Atsumi K, ed. *Medical Thermography*. Tokyo: Univ. of Tokyo press, 1973; 166–78.
18. Biagioni PA, Lamey P-J. Electronic infrared thermography as a method of assessing herpes labialis infection. *Acta Derm Venereol Suppl (Stockh)* 1995; **23**: 267–71.
19. Lamey P-J, Biagioni PA. Thermographic resolution of the prodromal phase of herpes labialis treated with acyclovir. *Dentomaxillofac Radiol* 1995; **24**: 201–3.
20. Mumford JM, Miles JB. Thermography and orofacial pain. *Acta Thermogr* 1977; **2**: 155–61.
21. Brands T. Diagnosis of salivary gland disease. *Z Laryngol Rhinol Otol* 1972; **51**: 639–59.
22. Brands T, Dinkloh H, Hagemier B. Thermographic studies of the parotid gland and submandibular gland. *Rontgenpraxis* 1972; **25**: 203–12.
23. Ferguson DB. The flow of unstimulated human labial gland saliva. *J Dent Res* 1996; **75**: 980–5.
24. Biagioni PA, McGimpsey JG, Lamey P-J. Electronic infrared thermography as a dental research technique. *Br Dent J* 1996; **180**: 226–30.
25. Adolph EF. *Physiology of man in the desert*. New York: Interscience, 1947; 42–58.
26. Maddison S, Woos RJ, Rolls BJ, Biggs J. Drinking in the rhesus monkey: peripheral factors. *J Comp Physiol* 1980; **945**: 365–74.
27. Greenleaf JE. Problem: thirst, drinking, behaviour and involuntary dehydration. *Med Sci Sports Exerc* 1992; **24**: 645–56.
28. Murray R. Fluid needs in hot and cold environments. *Int J Sport Nutr* 1995; **5**: 562–73.