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Intra-oral temperature variation over 24 hours

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SUMMARY This study aimed to investigate temperature variation at archwire sites adjacent to the maxillary right central incisor and first premolar, its correlation with ambient temperature, and the influence of inter-racial variation. Twenty young adult male subjects were randomly selected (13 Asian, seven Caucasian). Thermocouples were attached to the labial archwire component of custom-made orthodontic retainers at the two intra-oral sites. A third thermocouple measured ambient temperature. A data-logger recorded temperatures at 5-second intervals over a 24-hour period. Temperatures ranged from 5.6 to 58.5°C at the incisor and from 7.9 to 54°C at the premolar, with medians of 34.9°C and 35.6°C, respectively. Ambient temperature correlated poorly with the intra-oral temperatures. The Asian and Caucasian groups had significantly different temperature distributions. On average during the 24-hour period, temperatures at the incisor site were in the range of 33–37°C for 79 per cent of the time, below it for 20 per cent, and above it for only 1 per cent of the time. Corresponding figures for the premolar site were 92, 6, and 2 per cent. At both archwire sites the most frequent temperatures were in the range of 35–36°C. The data presented demonstrate that the temperature at sites on an archwire *in situ* varies considerably over a 24-hour period and that racial differences may exist. This information should be considered during the manufacture and use of temperature-sensitive orthodontic materials, in particular nickel-titanium archwires and springs.

Introduction

The measurement of the temperature at specific sites within the human oral cavity has been reported for well over a century (Horvath *et al*., 1950). Sublingual temperature is routinely used as an indicator of oral temperature and when measured under specific conditions it approximates 37°C for most individuals. It cannot, however, be assumed that this represents the true resting temperature for all sites within the oral cavity (Horvath *et al*., 1950; Erickson, 1980; Mackowiak *et al*., 1992). Although the extremes of temperature produced at various sites resulting from the ingestion of hot and cold substances have been documented (Longman and Pearson, 1987; Terndrup *et al*., 1989; Michailesco *et al*., 1995; Airoldi *et al*., 1997) little is known about the variations in intra-oral temperature that occur during routine daily activities.

Many factors have been shown to affect oral cavity temperature. These include variation in body core temperature (Barnes, 1967), ambient temperature and humidity (Boehm, 1972; Sloan and Keatinge, 1975; Zehner and Terndrup, 1991), mouth-breathing (Boehm, 1972), intake of food and fluids (Longman and Pearson, 1987; Terndrup *et al*., 1989; Michailesco *et al*., 1995), smoking (Graham *et al*., 1983), and whether the mouth is open or closed (Sloan and Keatinge, 1975; Mairiaux *et al*., 1983; Cooper and Abrams, 1984; Volchansky and Cleaton-Jones, 1994). The variability of temperature at sites in the oral cavity and its effect on temperature-sensitive orthodontic wires has, until recently, been largely ignored.

The initial attraction of the nickel-titanium alloy archwires for orthodontic use was their unique properties of shape-memory and super-elasticity (Burstone *et al*., 1985; Miura *et al*., 1986). The clinical application of these properties has been based largely on *in vitro* testing at 37°C. At this temperature nickel-titanium alloy archwires and coil springs can generate relatively constant and predictable forces over extended periods of deactivation (Burstone *et al*., 1985; Miura *et al*., 1986, 1988; Han and Quick, 1993; Barwart, 1996).

However, recent research has shown that with a change in the ambient temperature, the forces generated during the deactivation of these wires vary widely, even approaching zero at temperatures likely to be experienced in the oral cavity (Tonner and Waters, 1994; Barwart, 1996). It would appear, therefore, that in order to predict more accurately the forces generated by nickel-titanium orthodontic wires during clinical use, a knowledge of the temperatures experienced at oral sites where they are usually positioned is essential.

The primary aim of this study was to record intra-orally the variation in temperature over a 24-hour period at two sites on a maxillary orthodontic archwire, adjacent to the right central incisor and first premolar. Secondary aims were to determine the level of correlation between temperatures at these sites and ambient temperature, and to investigate the temperature variation in two racial groups.

Subjects and methods

This study, which was approved by the Southern Regional Health Authority Ethics Committee, Otago, New Zealand, was undertaken during March and April (Autumn) 1997 in the city of Dunedin. Criteria for exclusion of subjects included a history of tactile over-sensitivity of the palate initiating gagging, epilepsy, depressive illness, febrile illness within 2 weeks prior to the study (including colds), and use of antipyretic drugs within 24 hours of participation in the study. From the 35 male students at the University of Otago School of Dentistry who volunteered to participate in the study, 20 were randomly selected as subjects. This group consisted of 13 Asians aged 18.4–26.1 years and seven Caucasians aged 17.8–23.1 years. To confirm the absence of febrile illness during the study period each subject's sublingual temperature was measured with an oral thermometer (Terumo digital clinical thermometer C402, Tokyo, Japan) before and immediately after his data-logging session.

A removable retainer with full palatal coverage was made for the maxillary arch of each subject. It incorporated a 0.7-mm stainless steel circumferential archwire which contacted the labial and buccal surfaces of the upper teeth. Small adjustment-loops were placed in the regions of the upper right central incisor, upper right first premolar and upper left canine (Figure 1). In order to accommodate to its presence, each subject was asked to wear his retainer full-time for at least 24 hours prior to the start of data collection.

To record the intra-oral and ambient temperatures, thermocouples of 1.5 m length were formed from 0.2-mm diameter K-type thermocouple wire. For each subject, the measuring junctions of two of these thermocouples were spot-welded to the retainer archwire, the first adjacent to the mid-labial surface of the upper right central incisor, and the second adjacent to the mid-buccal surface of the upper right first premolar. After firm ligation to the archwire, the Teflon-coated thermocouple leads were positioned to exit at the right-side corner of the mouth. A third thermocouple measuring ambient temperature was positioned at approximately 10–15 cm from the mouth (Figure 2). The three thermocouple leads were encased together in protective silicone tubing, the end of which was sealed just below the measuring junction of the third thermocouple (Figure 2). The thermocouples were connected to a data-logger (CR10 Measurement and Control Module, Campbell Scientific Inc., Logan, Utah, USA) which was secured within a small carry-bag.

Two self-calibrating data-loggers, each with an attached set of thermocouples, were used in the study. The precision of both thermocouple/data-logger assemblies (± 0.2°C) was determined at 0, 37, and 50°C against a mercury thermometer certified accurate to 0.02°C (S. Brannan & Sons Ltd, Cumbria, UK).

The retainer/thermocouple/data-logger assemblies were worn continuously throughout a 24-hour period, starting at 09.00 hours. Real-time and temperature (°C) were logged simultaneously

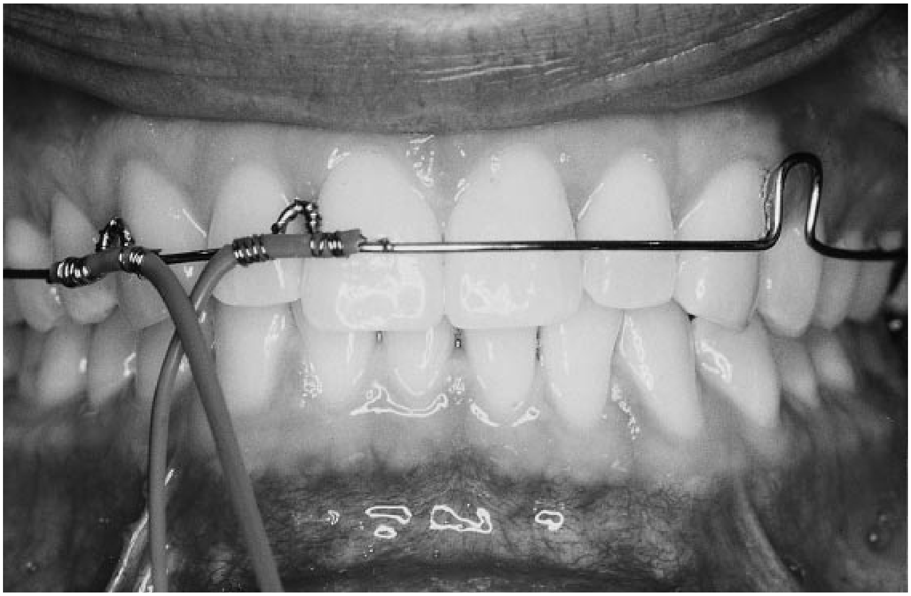

Figure 1 Retainer with thermocouples attached adjacent to the maxillary right central incisor and first premolar.

at 5-second intervals. Each subject kept a diary during this period detailing his activities, and all foods and drinks consumed. At the end of each session the data were downloaded to a computer (PC 486 with PC208 software, Campbell Scientific Inc., Logan, Utah, USA). The data were then transferred to an Apple MacIntosh Powerbook 150 for analysis and construction of: (i) line graphs using the full 24-hour data (17 280 readings from each thermocouple); (ii) graphs of the median temperature values for each subject calculated at 30-minute intervals; and (iii) frequency distributions of temperature (StatView SE + Graphics, Abacus Concepts Inc., Berkeley, CA, USA; Cricket Graph Version 1.3.2, Malvern, PA, USA). Temperature fluctuations in the data were manually compared with events recorded in each subject's diary.

Statistical analysis

The means, medians, and ranges of temperature at the incisor, premolar, and ambient sites were calculated for the individuals as well as the groups: Asian, Caucasian, and total subjects.

The strength of correlations between the temperatures recorded at the various sites was obtained by calculation of within-subject correlation coefficients. These were calculated for (a) the incisor and premolar sites, (b) the incisor and ambient sites, and (c) the premolar and ambient sites. Multiple regression analysis utilizing ANOVA was used, with subject as a class variable. Each correlation coefficient was calculated from the sum of squares and the residual after the method of Bland and Altman (1995).

The frequency distributions of temperatures recorded by the Asian and Caucasian groups were compared by Kolmogorov–Smirnov two-sample tests. These tests were applied to temperatures recorded at the incisor, premolar, and ambient sites.

Results

Outdoor ambient temperatures in the city of Dunedin over the period of the study ranged from 5.2 to 24.6°C (Meteorological Service data). The maximal ambient temperature recorded for

Figure 2 Subject wearing the data-logging equipment.

the subjects was 38.9°C, with an overall median temperature reading of 21.3°C.

Temperatures recorded over the 24-hour periods for the total subject group (Asians and Caucasians combined) ranged from 5.6 to 58.5°C at the incisor site and from 7.9 to 54°C at the premolar site (Table 1). Separate analysis of the Asian group gave temperature ranges of 5.6–58.3°C at the incisor site and 7.9–54°C at the premolar site. Corresponding figures for the Caucasian group were 8.3–58.5°C and 13.4–52.1°C.

The total group median temperature at the incisor site was 34.9°C with individual median temperatures at this site ranging from 33.2 to 35.8°C. At the premolar site it was 35.6°C, with individual medians ranging from 34.6 to 36.2°C. Figures for the separate Asian and Caucasian groups were very similar, the Asian group median being 0.5°C higher than the Caucasian group at the incisor, and 0.2°C higher at the premolar. For the total subject group, temperature at the premolar site was 0.7°C higher than at the incisor site. For the Caucasian group this figure was 0.9°C and for the Asian group 0.6°C.

The frequencies of temperatures recorded within 1 degree intervals are shown in Table 2. The most frequent temperatures were in the range of 35–36°C for the total group, at both intra-oral sites. Over 24 hours, 33.8 per cent of temperatures recorded at the incisor site and 44.6 per cent at the premolar site fell within this range. Over the wider range of 33–37°C, temperatures at the incisor site were within this range for 79 per cent of the time, below it for 20 per cent, and above it for only 1 per cent of the time. Corresponding figures for the premolar site were 92, 6, and 2 per cent. High individual variation was evident in the temperature frequency distributions over the 24-hour period (frequency ranges shown in Table 2).

The frequencies of the temperature readings over the 24-hour study period are given in Figure 3 and Table 2. Figure 3 shows that intra-oral temperature recorded most frequently at the two sites was between 35 and 36°C. Although the frequency readings gradually increased to 36°C, there were a few instances when intra-oral temperature exceeded 40°C. However, for some individuals the maximum temperature range over the 24-hour period was between 5.6 and 58.5°C (Table 1). Incisor site temperature frequencies were spread over a lower range than those recorded at the premolar site in both the Asian and Caucasian groups (Figure 4), even though the actual measured temperature ranges were greater at the incisor site (Table 2). As a group, the Asians had a distribution of temperatures which was higher than that of the Caucasians, at both the incisor and the premolar

Table 1 Individual medians and ranges of temperature (°C) recorded at the incisor and premolar sites over 24 hours.

Subject no.	Incisor			Premolar		
	Minimum	Maximum	Median	Minimum	Maximum	Median
Asian						
1	17.1	45.4	35.3	16.6	43.5	35.7
2	13.1	42.8	35.2	7.9	43.0	35.5
3	21.6	38.3	35.7	18.7	41.3	36.1
5	17.7	45.4	35.8	18.4	46.7	35.9
6	12.2	49.9	34.0	11.7	48.5	34.6
7	11.2	43.7	34.4	23.9	38.9	35.9
9	18.4	42.9	35.2	20.4	50.3	35.8
11	5.6	58.3	34.9	22.8	40.0	35.7
12	12.1	46.7	34.4	13.1	54.0	35.4
16	21.7	46.3	35.4	19.3	42.5	35.9
17	17.2	44.7	35.4	16.2	39.8	36.2
19	10.5	37.3	35.6	20.4	40.6	35.8
20	13.3	38.3	35.2	13.9	39.2	35.8
Caucasian						
4	15.9	38.8	34.3	16.2	44.3	35.1
8	8.3	38.5	33.6	23.0	54.0	35.6
10	11.5	58.5	35.8	26.1	39.4	35.9
13	13.9	52.2	35.3	22.2	52.1	35.7
14	9.1	47.2	35.1	13.4	42.1	35.7
15	15.4	40.2	33.2	17.6	37.5	35.3
18	15.6	47.3	35.1	18.0	38.2	35.3

sites (Figure 4). Kolmogorov–Smirnov two-sample tests indicated that the frequency distributions for the Asian and Caucasian groups were significantly different (incisor site: $P < 0.0005$; premolar site $P < 0.0005$; ambient site $P < 0.0005$).

Within-subject correlation of temperatures at the incisor and premolar sites was high (Table 3, Figure 5). A general trend, seen in Figure 5, was that as intra-oral temperature lowered incisor temperature was increasingly below premolar temperature. As the intra-oral recorded temperature approached 36.8°C, the core body temperature (Mackowiak *et al.*, 1992), the difference in temperature between the two oral sites diminished.

Regression analysis of ambient temperature with that at the incisor site gave a low correlation coefficient, as did ambient temperature with temperature at the premolar site. These findings were similar whether the Asian and Caucasian groups were analysed separately or together (Table 3). The weak relationship between ambient temperature and temperature at the oral sites can be seen when the individual 24-hour data are plotted as median values calculated at 30-minute intervals (Figure 6).

Figure 7 shows the temperatures recorded at 5-second intervals over a 24-hour period for subject 13. This is a good representation of the general pattern for all subjects. The incisor and premolar temperatures closely follow each other, with temperatures at the premolar site being generally higher than those at the incisor site (see also Figure 6). The temperature pattern during sleep was relatively smooth, with only minor fluctuations occurring for the majority of subjects. As expected, temperature extremes were associated with the consumption of hot and cold foods and drinks (Figure 7). In general, where subjects indicated that they were walking outside, especially uphill, the number and size of the temperature fluctuations increased. A magnified view of a temperature peak associated

Table 2 Frequency of intra-oral temperatures recorded at two maxillary sites over a 24-hour period in all Asian and Caucasian subjects. Mean and range (%).

Intra-oral temperature range (°C)	Frequency (%)											
	Asians (n = 13)				Caucasians (n = 7)				Total subjects (n = 20)			
	Incisor		Premolar		Incisor		Premolar		Incisor		Premolar	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
18–19	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.1)	0.0	(0.0–0.1)
19–20	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.0)
20–21	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.2)	0.0	(0.0–0.1)	0.0	(0.0–0.2)	0.0	(0.0–0.1)
21–22	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.1	(0.0–0.4)	0.0	(0.0–0.1)	0.0	(0.0–0.4)	0.0	(0.0–0.1)
22–23	0.0	(0.0–0.1)	0.0	(0.0–0.1)	0.2	(0.0–0.7)	0.0	(0.0–0.1)	0.1	(0.0–0.7)	0.0	(0.0–0.1)
23–24	0.0	(0.0–0.3)	0.0	(0.0–0.1)	0.4	(0.0–1.7)	0.2	(0.0–0.2)	0.2	(0.0–0.3)	0.0	(0.0–0.2)
24–25	0.2	(0.0–0.6)	0.0	(0.0–0.2)	0.6	(0.0–2.8)	0.1	(0.0–0.3)	0.3	(0.0–2.8)	0.0	(0.0–0.3)
25–26	0.4	(0.0–2.0)	0.1	(0.0–0.2)	0.9	(0.0–4.3)	0.1	(0.0–0.4)	0.6	(0.0–4.3)	0.1	(0.0–0.4)
26–27	0.6	(0.0–2.8)	0.1	(0.0–0.3)	1.2	(0.1–5.4)	0.2	(0.0–0.5)	0.8	(0.0–5.4)	0.1	(0.0–0.5)
27–28	0.8	(0.1–3.2)	0.2	(0.0–0.5)	1.5	(0.2–5.9)	0.2	(0.0–0.9)	1.1	(0.1–5.9)	0.2	(0.0–0.9)
28–29	1.1	(0.2–3.5)	0.3	(0.1–2.0)	1.9	(0.3–6.5)	0.4	(0.0–1.1)	1.4	(0.2–6.5)	0.3	(0.0–2.0)
29–30	1.6	(0.4–4.4)	0.6	(0.1–3.0)	2.0	(0.9–4.6)	0.5	(0.1–1.3)	1.8	(0.4–4.6)	0.6	(0.1–3.0)
30–31	2.3	(0.5–5.0)	0.9	(0.2–4.3)	2.9	(1.7–4.7)	0.8	(0.2–2.1)	2.5	(0.5–5.0)	0.9	(0.2–4.3)
31–32	3.9	(0.9–7.9)	1.3	(0.2–6.5)	4.9	(1.7–10.4)	1.3	(0.4–2.7)	4.3	(0.9–10.4)	1.3	(0.2–6.5)
32–33	5.9	(2.0–11.1)	2.1	(0.4–9.6)	8.3	(4.7–18.6)	2.4	(0.9–3.8)	6.7	(2.0–18.6)	2.2	(0.4–9.6)
33–34	8.3	(4.1–12.2)	3.8	(0.8–13.6)	14.4	(7.3–27.9)	5.8	(4.0–8.2)	10.4	(4.1–27.9)	4.5	(0.8–13.6)
34–35	18.2	(4.5–26.7)	9.2	(2.1–19.2)	18.3	(13.1–36.4)	16.4	(10.1–25.5)	18.2	(4.5–36.4)	11.7	(2.1–25.5)
35–36	36.5	(22.0–53.8)	42.3	(23.4–61.8)	28.8	(10.7–44.6)	48.9	(39.8–57.8)	33.8	(10.7–53.8)	44.6	(23.4–61.8)
36–37	18.4	(4.3–35.2)	36.3	(14.6–68.5)	12.8	(1.5–32.5)	21.9	(3.1–35.2)	16.4	(1.5–35.2)	31.2	(3.1–68.5)
37–38	1.1	(0.1–5.9)	1.9	(0.4–4.9)	0.2	(0.0–0.9)	0.5	(0.1–1.9)	0.8	(0.0–5.9)	1.4	(0.1–4.9)
38–39	0.2	(0.0–0.9)	0.4	(0.0–1.3)	0.1	(0.0–0.5)	0.1	(0.0–0.7)	0.2	(0.0–0.9)	0.4	(0.0–1.3)
39–40	0.1	(0.0–0.4)	0.2	(0.0–0.5)	0.1	(0.0–0.4)	0.1	(0.0–0.2)	0.1	(0.0–0.4)	0.2	(0.0–0.5)
40–41	0.1	(0.0–0.3)	0.1	(0.0–0.4)	0.0	(0.0–0.3)	0.0	(0.0–0.1)	0.1	(0.0–0.3)	0.1	(0.0–0.4)
41–42	0.0	(0.0–0.1)	0.1	(0.0–0.3)	0.0	(0.0–0.2)	0.0	(0.0–0.1)	0.0	(0.0–0.2)	0.0	(0.0–0.3)
42–43	0.0	(0.0–0.1)	0.0	(0.0–0.1)	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.1)
43–44	0.0	(0.0–0.1)	0.0	(0.0–0.1)	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.1)
44–45	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.0)
45–46	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.0)
46–47	0.0	(0.0–0.1)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.0)	0.0	(0.0–0.1)	0.0	(0.0–0.0)
33–37	81.3	(60.7–97.9)	91.5	(72.0–97.9)	74.3	(54.5–87.6)	92.9	(86.2–96.5)	78.8	(54.5–97.9)	92.0	(72.0–97.9)
35–37	54.8	(33.2–77.4)	78.5	(41.7–91.9)	45.9	(12.3–82.1)	70.8	(57.3–82.1)	48.7	(12.3–82.1)	75.8	(41.7–91.9)
<33	17.0	(5.0–38.3)	5.5	(1.2–25.7)	25.0	(9.8–45.3)	6.1	(1.6–13.4)	19.4	(5.0–45.3)	5.7	(1.2–25.7)
≥37	1.6	0.2–5.9	2.8	(0.6–6.3)	0.5	(0.0–2.5)	0.9	(0.1–2.6)	1.2	(0.0–5.9)	2.1	(0.1–6.3)

Temperature intervals with <0.1% frequency have been excluded.

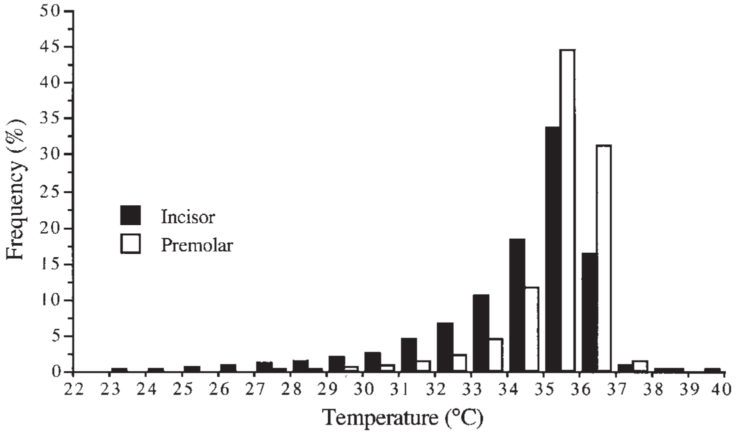

Figure 3 Frequency distribution of temperatures at the incisor and premolar sites for the total subject group.

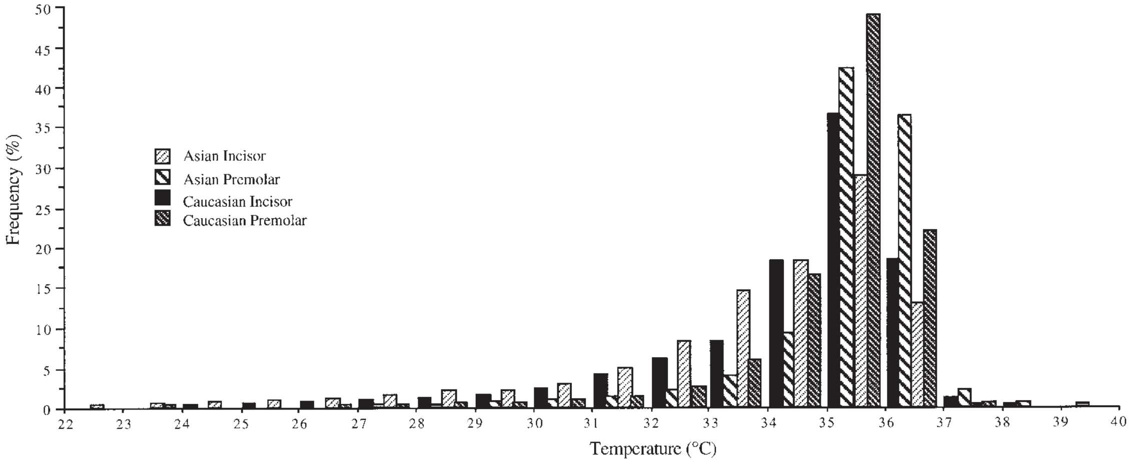

Figure 4 Histogram showing temperature frequency distributions at the incisor and premolar sites for the Asian and Caucasian groups.

Table 3 Correlation coefficients (*r* values) for within-subject comparisons between temperatures at ambient (A), incisor (I), and premolar (P) sites.

	A *versus* I	A *versus* P	I *versus* P
Asians	0.15	0.08	0.82
Caucasians	0.14	0.09	0.81
Total subjects	0.03	0.01	0.81

with the consumption of a hot drink by subject 16 is shown in Figure 8. This typifies the common pattern of a rapid peaking of temperature followed by a slower return towards a baseline temperature. In this instance, temperature at the premolar site was relatively unaffected.

Discussion

There are numerous factors which may be implicated in explaining the intra- and inter-subject temperature variability which was

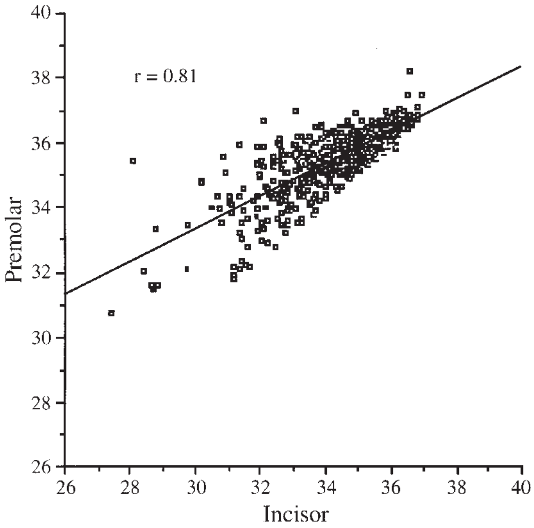

Figure 5 Scattergram and within-subject correlation of temperature (°C) at the incisor site with temperature at the premolar site, for the total subject group. (Median values at 30-minute intervals.)

recorded at the two archwire sites in this study. Over the 24-hour recording period, specific factors such as exercise (Du Bois, 1951; Mairiaux *et al.,* 1983; Guyton, 1991), digestion of food (Owen *et al.*, 1980), and the endogenous circadian rhythm of body temperature (Refinetti and Menaker, 1992) may have indirectly influenced the temperatures at the oral sites. Small individual differences in body core temperature (sublingual) were present, possibly influenced by factors such as differences in body mass (Adam, 1989), obesity (Zahorska-Markiewicz and Staszkiewicz, 1987), and the subjects' state of physical fitness (Atkinson *et al.*, 1993). A number of factors which affect core body temperature, namely variation in age (Fox *et al.*, 1973; Howell, 1975), intake of drugs (Mellerup *et al.*, 1978; Horne, 1989), depression (Pflug *et al.*, 1976, 1981), and febrile illness (Guyton, 1991), were eliminated from our subject groups by the selection criteria. The subjects were restricted to males since the cyclic hormonal variation seen in mature females could complicate intra- and inter-individual temperature comparisons (Zuspan and Zuspan, 1974).

Ambient temperature and humidity may also affect body core temperature (Kukkonen-Harjula *et al.*, 1989; Rastogi *et al.*, 1989; Guyton, 1991), while at the same time having a direct effect on temperatures recorded at sites in the oral cavity (Sloan and Keatinge, 1975; Zehner and Terndrup, 1991). However, in this study a

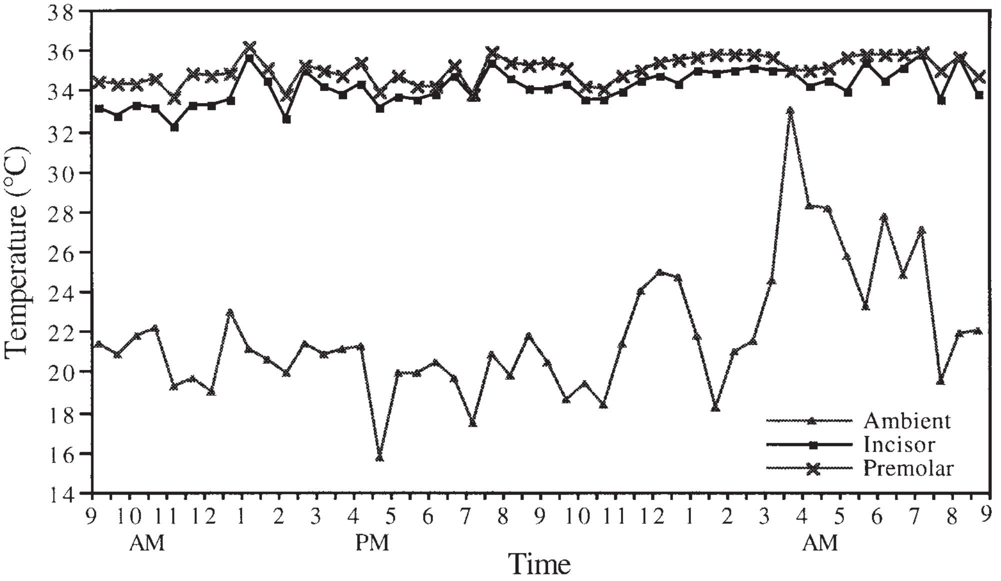

Figure 6 Median temperatures at 30-minute intervals (subject 4).

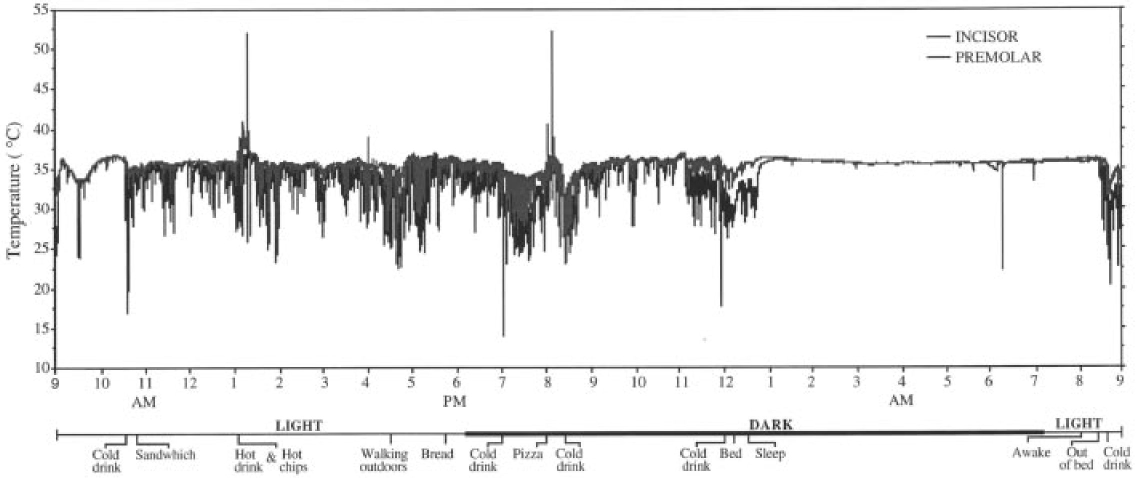

Figure 7 Graph of temperatures at the incisor and premolar sites for one subject over a 24-hour period (subject 13).

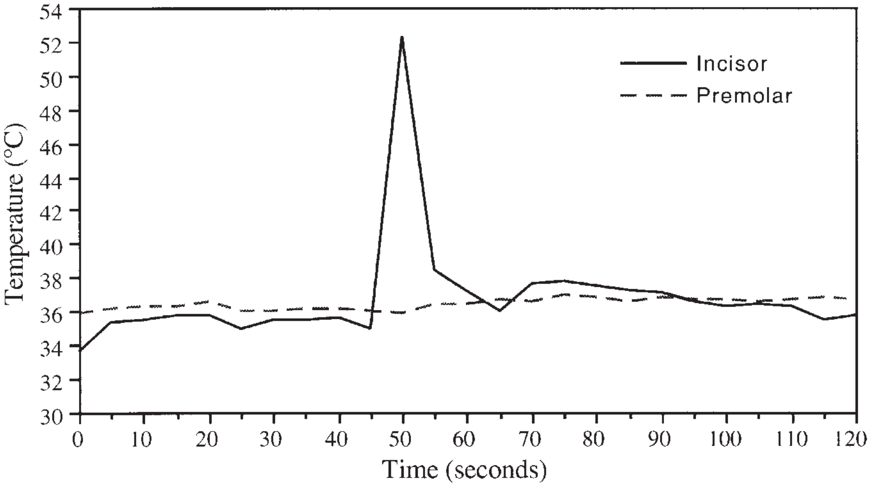

Figure 8 Temperature peak associated with the intake of a hot drink (subject 16).

low correlation between archwire site temperature and ambient temperature was found ($r < 0.15$), implying that the latter was only a minor factor in explaining temperature variability at the two sites. The unexpectedly high ambient temperatures, exceeding 30°C during night-time sleep by most subjects (Figure 6), were probably the result of bed-clothes covering the thermocouple junction. This situation may reflect the ambient temperature for the side of the face when it is covered by bed-clothes or lying against a pillow. However, as a precaution these apparently abnormal data were excluded from the statistical analysis.

Other factors which may have directly affected temperature at the measurement sites include mouth-breathing, and whether an individual's mouth was open or closed. These two factors may have been especially evident in those subjects who had low temperature distributions in our study. It has been shown that following mouth-opening for extended periods, temperatures do drop significantly, especially at anterior sites (Volchansky and Cleaton-Jones, 1994), and they remain lowered for varying lengths of time following mouth closure (Cooper and Abrams, 1984). During open-mouth breathing a widely varying thermal environment is produced in the region of the teeth. On inhalation temperatures lower, whereas on exhalation they approach body temperature (Boehm, 1972). It is difficult to ascertain the proportion of time spent mouth-breathing over a 24-hour period, especially as it may be at a subclinical level (Tandberg and Sklar, 1983; Durham *et al*., 1986) and will vary with activities such as conversation, sleeping, and exercise. It is, however, a factor which may be implicated in the temperature variability over the 24-hour period of our study.

Lip incompetency could be expected to have a significant effect on oral temperatures, especially at incisor sites. Subjects with incompetent lips would be likely to record a lower overall range of temperatures with more fluctuations in temperature than those whose lips are habitually together at rest. In our study, the one subject (subject 8) with habitually incompetent lips was also aware of habitually mouth-breathing. Over 45 per cent of his readings at the incisor site were less than 33°C compared with the group average of 19.4 per cent (Table 2). In contrast, his premolar site temperature distribution was very close to the group average. Lip incompetency is more often seen in children than adults (Gross *et al*., 1994) and, generally, the upper lip covers more of the upper incisors in adults compared with children (Jackson, 1962). Therefore, a group of young patients with incompetent lips would most likely record temperatures that are lower, especially at incisor sites, than the averages reported for our subject group.

The finding of significant differences in temperature distributions between the Asian and Caucasian groups was not expected, and we could not identify any one explanatory factor. On average, the Asian group had slightly higher temperature distributions than the Caucasians at both oral sites. The differences may be a reflection of the small size of the subject groups, especially as both groups had large individual variations within them (Tables 1 and 2).

For all subjects, temperatures at the incisor site were generally lower than those at the premolar site. This is consistent with reports that an increasing gradient in temperature exists from the anterior to the posterior regions of the oral cavity. This has been found in studies at the surface of the teeth (Brown and Goldberg, 1966; Longman and Pearson, 1987), the oral mucosa (Bergstrom and Varga, 1971; Erickson, 1980; Volchansky *et al*., 1985; Volchansky and Cleaton-Jones, 1994), and in subgingival areas (Haffajee *et al*., 1992). The temperatures at the two sites closely followed each other for much of the time (Figures 6 and 7) and were highly correlated (Table 3). This suggests that similar variables were affecting temperature at both sites.

As expected, the extremes in temperature for all subjects occurred when hot and cold foods and fluids were ingested. In agreement with other reports, our data also show that alterations in oral temperature occur rapidly (Figure 8), while the return to baseline temperature occurs more slowly (Nelsen *et al*., 1952; Longman and Pearson, 1984, 1987; Michailesco *et al.,* 1995; Airoldi *et al*., 1997). Temperature fluctuations during meals were frequent and variable (Figure 7).

The extreme ranges of temperature were 5.6–58.5°C at the incisor site and 7.9–54°C at the premolar site, although a large variation in the temperature ranges for individuals was evident. Other studies have investigated the extremes of temperature produced at the teeth when hot and cold substances are introduced into the mouth (Nelsen *et al*., 1952; Crabtree and Atkinson, 1955; Peterson *et al*., 1966; Plant *et al*., 1974; Longman and Pearson, 1987; Mair, 1989; Palmer *et al*., 1992; Michailesco *et al*., 1995; Airoldi *et al*., 1997). In these studies, the highest temperatures were recorded at the occlusal surface of a premolar when hot food was consumed (55°C; Mair, 1989), and at the palatal surface of upper incisors following the intake of hot drinks (58.5°C; Palmer *et al*., 1992). These figures closely approximate those recorded in our study. The lowest temperatures (0–4°C) were recorded when ice-cream was eaten or when ice was held against a tooth surface (Mair, 1989; Palmer *et al*., 1992;

Michailesco *et al.*, 1995). In contrast, the minimum temperatures experienced by our subjects, even on eating ice-cream, were above those reported in those studies.

From our data, an average young adult male's maxillary archwire on the labial of the central incisors could be expected, over a 24-hour period, to be in the temperature range of 33–37°C for 79 per cent of the time, below it for 20 per cent, and above it for only 1 per cent of the time. In the first premolar region corresponding figures would be 92, 6, and 2 per cent. At both archwire sites the most frequently recorded temperatures were in the range of 35–36°C. The overall group median temperature was 34.9°C at the incisor site and 35.6°C at the premolar site. These results lead us to conclude that 37°C should not be considered to represent mouth temperature. If an ambient temperature is to be chosen for *in vitro* testing of orthodontic wires, 35.5°C would be more appropriate.

The importance of even a small change in temperature on the performance of nickel-titanium wires for orthodontic tooth movement has recently been emphasized (Tonner and Waters, 1994; Barwart, 1996). The results of this investigation may aid in a more accurate prediction of the force values applied to a tooth over a 24-hour period *in vivo*. For instance, if thermodynamic nickel-titanium wires are used clinically, it can be concluded that a wire with a temperature transition range below 35°C would be fully active for a considerably longer period of time than those manufactured to be fully active at 37–40°C. Only a few of the subjects in our study reached 40°C at any time during the 24-hour period so that the amount of time recorded temperatures exceeded this value was very small (14.4 minutes). Of course, oral temperature can be raised by hot mouth rinses (Hurst *et al.*, 1990), but this then places reliance on a very frequent intake of hot fluids to ensure optimal activity of the archwire. Despite the observation that temperature within the oral cavity may be raised for up to 7 minutes following a hot drink (Terndrup *et al.,* 1989), our data suggest that this elevation of temperature would not be sustained at a sufficient level at the archwire sites to be clinically significant.

Conclusions

Temperatures at sites on a maxillary labial archwire vary considerably for an individual over a 24-hour period. Inter-individual variation in temperature frequency distributions was found to be high and small, but significant racial differences were found. The Asian group had an overall higher temperature distribution than the Caucasian group. The premolar site temperatures were generally higher than those at the incisor site and the temperatures at both sites demonstrated a high correlation between the two sites. Temperatures ranged from 5.6 to 58.5°C at the incisor and from 7.9 to 54°C at the premolar. The overall median temperatures at the incisor and premolar sites were 34.9 and 35.6°C, while the individual medians ranged from 33.2 to 35.8°C and 34.6 to 36.2°C, respectively. Ambient temperature was not an important factor in explaining intra-oral temperature variation.

The temperature data presented should be considered during the manufacture and clinical use of temperature-sensitive orthodontic materials, in particular nickel-titanium archwires and springs. If a single temperature is to be selected at which the properties of orthodontic wires are investigated *in vitro*, then 35.5°C would be more appropriate than 37°C.

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