THERMAL PROPERTIES DETERMINATION OF ESTHETIC RESTORATIVE MATERIALS

T. M. Cornacchia
Escola de Odontologia da UFMG, Av. Antônio Carlos 6627, Belo Horizonte.
cornacchia@uol.com.br

V. E. de Carvalho
Depto. de Física, ICEx, UFMG, Av. Antônio Carlos 6627, Belo Horizonte.
vagner@fisica.ufmg.br

E. B. de Las Casas, R. M. Andrade, C. A. Cimini Jr.
Escola de Engenharia da UFMG, Av. do Contorno 842, Belo Horizonte.
estevam@dees.ufmg.br, rma@ufmg.br, cimini@dedalus.lcc.ufmg.br

Abstract*. The purpose of this investigation was to determine the thermal conductivity of the esthetic materials used in restored teeth, as well as to verify the real temperature in the tooth-restoration interface when in contact with hot (73o.C) and cold water (4o.C), simulating the temperature changes in the act of drinking hot and cold liquids. The methodology of the experiments is detailed and the obtained results discussed and compared to the ones available in the literature. In the first part of experiment using the thermal comparator, the values obtained of thermal conductivity were 2,43x10-1, 0.8x10-1 and 1,29x10-1 W/m0C for porcelain (VITADUR ALPHA®), indirect composite resin (SINFONY®) and the resinous cement (BISFIL TM). In the second part of this study, the internal temperature for the tooth restored with porcelain was slightly higher than for the sane tooth. The resin provided an improved insulation when compared to ceramic and enamel.*

Keywords *Thermal conductivity, thermal shock, dental materials, thermal comparator.*

1. Introduction

There is an increasing demand for dental restorations that match tooth tissue and bond effectively to tissue. This demand is strongly influenced by esthetic considerations. A motivation for this paper is the fact that a number of thermo-mechanical properties for dental materials are not easily found in the technical literature or in specifications by the manufacturer, as the range of new and improved biomaterials for dentistry is always increasing. The simulation of the temperature distribution in teeth is obviously dependent on the quality of the available material data, and analysts are often forced to use data for "similar" material, with the risk of incurring in gross deviations from the correct response. An example is that of porcelain, a material often used in dental restorations for esthetic reasons. While traditional porcelain restorations were mounted on a metal reinforcing basis, which eventually became visible compromising its esthetic characteristics, newly developed techniques tend to eliminate this metal basis by improving the porcelain in its mechanical properties. These new types of porcelain are designed to have different mechanical properties than the ones more easily found in the literature.

Secondly, in order to gain confidence in a future model for numerical simulation of thermal cycling in the mouth, experimental results are necessary. The authors describe measurements obtained *in vitro* for teeth restored with the materials studied for thermal conductivity, and compared the results with measurements for a sane tooth. The experiment submitted the teeth to temperatures found in the human mouth during the act of drinking cold and hot liquids.

Although several methods have been developed to determine the thermal conductivity, the choice of the best method to be used is sometimes very challenging. Powell (1957, 1962), suggested a method to measure the thermal conductivity – called thermal comparator – that has the advantage of being non-destructive. The method is based on the observed thermal gradient that occurs when touching, with a finger, materials with different thermal conductivity, for example, a piece of wood and a piece of metal, both at room temperature. This is due to the fact that the temperature gradient established through the heat flux is higher for the finger-to-metal contact, as a consequence of its higher thermal conductivity, than that of the finger/wood contact. In order to use this fact to construct a reliable thermal conductivity meter, we may replace the finger by other object, a metal piece for example, and insert a temperature sensor at (or near to) the contact region. If the temperature of this metal-probe tip, initially higher than room temperature, is controlled at some constant value, the contact of the tip with materials of different thermal conductivities, but all of them at room temperature, will indicate different values of the temperature gradient established at the contact area, and these values can be recorder by the sensor. This method has shown to be very useful, as it is non-destructive, fast and easy to use. However, although the temperature difference developed between the probe tip and the sample surface depends on the sample thermal conductivity, the method does not give a direct measurement of the conductivity and the construction of a calibration curve, using well known values of thermal conductivity, is required. Also, some factors have to be carefully considered, such as the material of the probe tip and its shape, the dimensions of the contact area, the contact time, the intensity of the load applied on the specimen, the roughness, hardness and size of the sample. Several thermal comparator instruments have been constructed and used for measurements at different thermal conductivity ranges and shown good reliability (see, for example, Carvalho 1978; Henager and Pawlewics, 1993; Cheruparambil et all, 2000).

2. Materials and Experimental Methods.

2.1 The thermal comparator apparatus and measurements

The Thermal Comparator used in this work, was constructed in the Surface Laboratory at the Physics Department-UFMG (Carvalho, 1978). Fig. (1) shows the unit that contains the tip and the temperature sensor. The tip temperature is electronically controlled and it takes about 30 minutes to stabilize at 63^{o}C. The changes in the contact temperature gradient ($\Delta V=V_c-V_s$) and the changes in the sample temperature (ΔV_F) are measured using copper-constantan differential thermocouples. The Comparator output that is used to determine the thermal conductivity is the ratio L= $\Delta V/\Delta V_{F.}$ As it was pointed out above, the measurement with the Thermal Comparator requires the construction of a calibration curve using the conductivity data well described in the literature. For the present work the instrument was calibrated in the low thermal conductivity range using the following samples: balsa wood, plastic PVC, Teflon, acrylic, pine wood, cesium iodide (CsI) mono-crystal, mica, porcelain, glass, window glass, quartz glass, potassium iodide (KI) and lithium fluoride (LiF) mono-crystals, quartz, titanium (Ti), and stainless steel. In order to get the calibration curve, the reported values of the thermal conductivity for these samples were used, according to CRC Handbook (1996) and the web page MatWeb Materials Property Database, www.matweb.com.

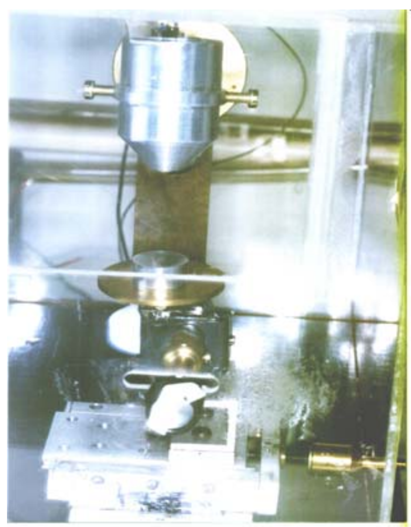

Figure 1. View of the Thermal Comparator tip and the sample holder

In all of the samples at least one flat surface was polished up to sandpaper-600 or better. The samples were fit to the sample holder and adjusted via a laser beam, in a way such as to get the tip normal to the surface during the contact. For each sample a number of six measurements were carried out, and a simple average was taken as the Comparator output. The data were plotted (see Fig. (2)) and a curve fitting procedure was performed in order to get the relation between the thermal conductivity (λ) and the Comparator output L. As can be seen in the Fig. (2), the best obtained fit function is

$$\lambda = -0.0218 + 0.0265\, e^{100.297\,L} + 1356.593/((-316.555/L) - 1) \qquad (1)$$

The samples of the dental restoration materials, that is, porcelain (VITADUR ALPHA-VITA), indirect composites (SINFONY-ESPE) and resin cement (BISFIL BISCO) and a natural human tooth, were prepared and fit to the sample holder in the same way as the calibration samples and the measurements were performed. The first three materials were selected due to the fact of forming a representative sample of the white indirect restorative dental materials used in clinical practice.

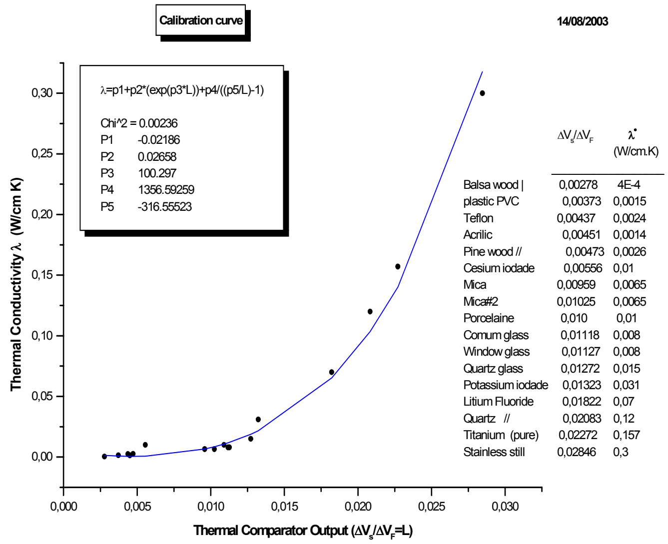

Figure 2. Thermal Comparator calibration curve.
λ values from CRC Handbook (1996) and MatWeb Materials Property Database.

2.2 Teeth temperature measurements.

The second objective of this work was to estimate the temperature that occurs at the restoration-tooth interface in the cement line. Those teeth had two different types of restorations: porcelain (VITADUR ALPHA-VITA) and indirect resin (SINFONY-ESPE). The restorations were cemented using resin cement (BISFIL SELF CURED-BISCO). The measurements were performed for the tooth crown in contact first with hot (73°C) and then cold water (4°C). Three teeth were used in the experiment, two restored and one sane tooth used for control. Contact with liquid occurred only in occlusal surface. The objective of this experiment was to simulate the temperature changes while imbibing hot and cold liquids.

The three teeth were sectioned at apical portion to obtain uniform depth and position of the thermocouple (Baik et al, 2001). In order to insert the thermocouples and control the exact position where temperature was measured, the intraradicular channel was widened using a drill. The hole was then filled with a wax stick to avoid cement penetration during the fixation of the restoration, shown in the first part of Fig. (3) After finishing the restoration, the end of the hole coincided exactly with the cement-restoration interface. The control of the thickness of the layer between the external tooth surface and the point of data acquisition was made with X-ray seen in the second part of Fig. (3). A sane tooth of approximately the same dimensions was prepared with the same hole depth.

A device (coffee machine) was used to assure that the experiment was performed at the same temperature, kept constant during the measurements. The measurement system used thermocouples type K, with 1.5 mm diameter, time constant of 0.3 sec in air. Data acquisition system consisted of a Lynx data acquisition board model CAD 12/32 (16 channels), a signal conditioner Lynx, 12-bit resolution, up to 20,000 am/s and ± 5 V, model MCS1000 (16 channels, being one for reference temperature), connected to a standard dedicated PC. The thermocouples were previously calibrated using three reference points: ice melting point, water boiling point at pressure of 0.95 bar, and room temperature. Expanded uncertainty evaluated was ± 1,1ºC (with 95% probability level).

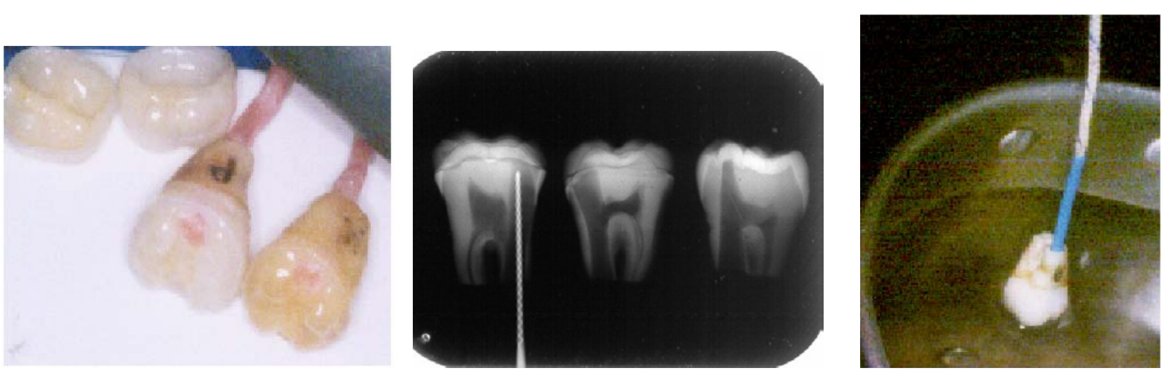

Figure 3. Specimen preparation and temperature measurement for hot water.

3. Results

3.1 Thermal Conductivity

The thermal conductivity of composite resin (Adaptic) has been reported by the authors Civjan et al, 1972; O'Brien, 1997 and Fenner, 1998 to be 1,09x10^{-1}, 1,36x10^{-1} and 1,1x10^{-1} W/m^{0}C, respectively. The thermal conductivity of porcelain (feldspathic) has been reported by McLean and Hughes (1965) to be 9,99x10^{-1} W/m^{0}C.

The results for the thermal conductivity determination are presented in Tab. (1). The lowest conductivity determined is that of the indirect composite resin (SINFONY-ESPE) and resin cement (BISFIL BISCO) and the highest is that of porcelain (VITADUR ALPHA-VITA). The magnitude of these results is in reasonable agreement with the results of similar materials reported in the literature.

In fact, it is difficult to do any comparison with good confidence, since different types of materials serve as basis for the results in the available literature data. For example, in the reference www.lib.umich.edu/dentlib/Dental_tables, a value of 0,010 W/cm^{0}C for the feldspathic porcelain is reported, about four times of the value measured in this work (0,00243 W/cm^{0}C). Also, for the human tooth, values of 0,0057 W/cm^{0}C and of 0,0093 W/cm^{0}C has been reported in the same reference for the dentin and enamel, respectively. We have found a result of 0,00262 W/cm^{0}C from a measurement of all of the tooth structure. Comparing our result to the average (0,0075 W/cm^{0}C) of the reported values, we can see that our value is about three times lower. It may be asked if the differences detected could come from some systematic error in the measurement, producing lower values. We may discard this possibility, considering that the porcelain sample used in the calibration procedure gave a comparator output L = 0,0109 and using this values in the equation of the calibration curve results in λ = 0,0107 W/cm^{0}C, a value that agree very well with that reported for the feldspathic porcelain. Therefore, we believe that the low values obtained via Thermal Comparator measurement, for the samples shown in the Tab. (1), are realistic for the thermal conductivity of the samples.

Table 1. Comparator output and Thermal conductivity measurements for different materials.

Material	Comparator output (L)	Thermal conductivity λ (W/cm^{0}C)
Porcelain Vidatur Alpha	0,007524	0,00243
Resin (SINFONY-ESPE)	0,005520	0,00080
Cement (BISFIL BISCO)	0,006486	0,00129
Human tooth	0,007658	0,00262

3.2 Teeth temperatures

A photograph of the tooth in hot water can be seen in Fig. (3). The results obtained for the teeth are given in Tabs. (2) and (3) for selected time intervals and in graphical form in Figs. (4) and (5).

Table 2. Temperature measurement (room temperature 28°C, water at 73°C)

Time	Tooth restored Indirect Resin (Temp ºC)	Tooth restored Porcelain (Temp. ºC)	Sane tooth (Temp. ºC)
1"	30,85	28,44	29,66
10"	30,21	30,22	30,23
17"	30,25	30,83	30,85
30"	33,83	38,42	38,5
2'	47,78	56,84	50,05

Table 3. Temperature measurement (room temperature 25°C, water at 4°C)

Time	Tooth restored Indirect Resin (Temp ºC)	Tooth restored Porcelain (Temp. ºC)	Sane tooth (Temp. ºC)
1"	25,58	24,39	24,98
10"	25,58	25,56	23,73
17"	23,8	24,39	22,52
30"	24,4	21,96	20,15
2'	18,35	14,7	15,32

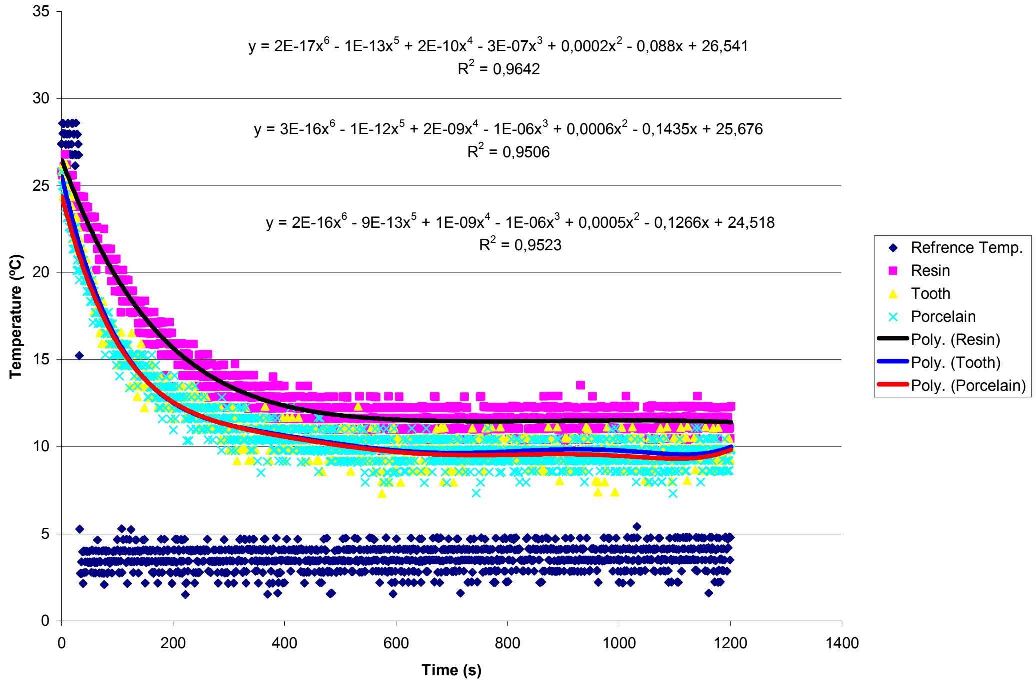

Figure 4. Temperature variations with time for contact with cold water

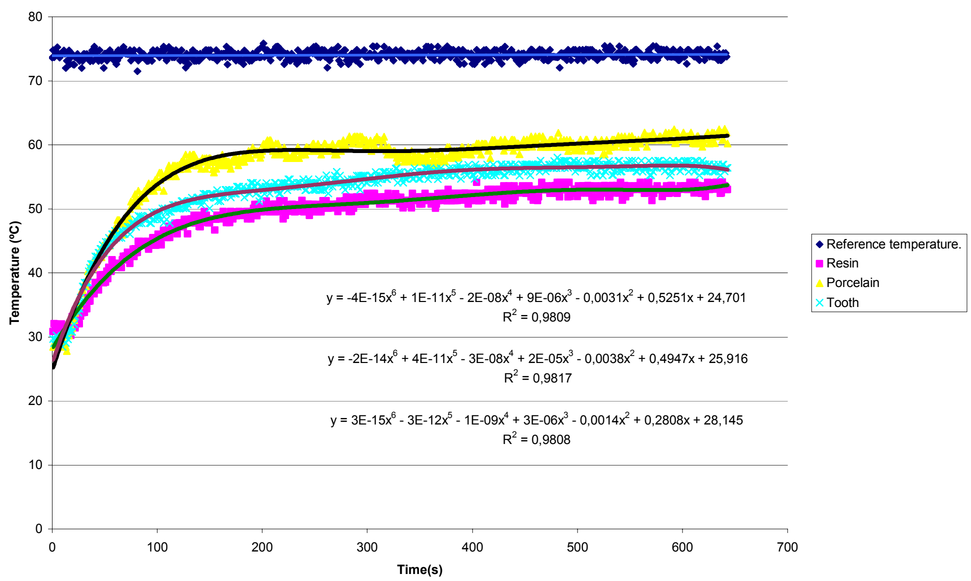

Figure 5. Temperature variations with time for contact with hot water

4. Conclusion

The study of temperature distribution in human mouth is a relevant topic, as this environment is subjected to constant variations in heat. The thermal comparator method made possible to obtain in a simple and efficient manner the conductivity of dental materials widely used in dental restorations. The obtained constants agree with expected values based on a survey of the literature. The correct evaluation of thermal constants allows more accurate simulation of restored teeth behavior under temperature changes, an objective to be attained in a later stage of this research project.

The results described in the previous items for conductivity of newly developed materials contribute to the simulation of their mechanical behavior under functional conditions. In the case of Vitadur Alpha, the lower conductivity when compared to other types of porcelain can lead to less severe conditions in the restored teeth when submitted to cyclic temperatures, improving its performance.

The internal temperature in the teeth restored with porcelain was very similar to the sane tooth, but the temperature for the porcelain-restored tooth was a little higher than for the sane specimen at dental enamel. Resin was more insulating than the other considered cases. These relative results confirm the correctness of the data obtained for thermal conductivity of the various materials.

5. Acknowledgements

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