Al-Rafidain Dental Journal
rden.mosuljournals.com

Thermal Conductivity of Polymethyl Methacrylate Denture Base Material Incorporated with Hydroxyapatite Nanoparticles

Saif Mohanad Al-Obaidy [1], Ammar Khalid Al-Noori [2]

[1] Ministry of Health/ Nineveh Health Directorate / Iraq.
[2] Department of Prosthodontics, College of Dentistry, Mosul University / Iraq.

Article information

Received: June 20, 2022
Accepted: August 27, 2022
Available online: March 1, 2024

Keywords

Thermal conductivity,
HA nanoparticles.

***Correspondence:**
E-mail: saifmohaned93@gmail.com

Abstract

Aims: To investigate the effects of the incorporation of hydroxyapatite nanoparticles (HA NPs) with size (20 nm) at two concentrations (0.5% and 1%) on the thermal conductivity of heat-cured acrylic resin. **Materials and methods**: The total number of specimens was thirty which was divided into ten specimens (control, 0.5 % HA NPs, and 1 % HA NPs), the thermal conductivity was performed using Lee's disc apparatus. The statistical analysis was done by using the SPSS program including descriptive statistics, ANOVA, and Duncan's test at $p \leq 0.05$. **Results**: The results demonstrated that there was a significant increase in the thermal conductivity for the PMMA-HA nanocomposite at HA nanoparticles (0.5%) and (1%) when compared to the control. **Conclusions:** the use of hydroxyapatite nanoparticles as dental fillers at 0.5% and 1% by weight increased the thermal conductivity of PMMA denture base material.

التوصـــيلية الحرارية لمادة البولى ميثايل ميثاكريليت المدمجة مع جســيمات الهايدروكسى ابتايت النانوية

الملخص

الأهداف: دراسة تأثير دمج جزيئات الهيدروكسي ابيتايت النانوية بحجم (20 نانومتر) بتركيزين (٠,٥٪ و ١٪) على التوصيلية الحرارية لراتنج الأكريليك المعالج بالحرارة. **المواد و طرائق العمل**: كان العدد الإجمالي للعينات ثلاثين مقسمة إلى عشر عينات (مجموعة السيطرة ، ٠,٥٪ ، ١٪) هيدروكسي ابيتايت النانوية ، تم إجراء فحص التوصيلية الحرارية باستخدام قرص لي . تم إجراء التحليل الإحصائي باستخدام برنامج الاحصاء بما في ذلك الإحصاء الوصفي ، اختبارانوفا ، واختبار دنكن عند $p \leq 0.05$. **النتائج**: أظهرت النتائج أن هناك زيادة ملحوظة في قابلية التوصيلية الحرارية لمركب النانوي المتولد في جزيئات الهايدروكسي ابيتايت النانوية (٠,٥٪) و (١٪) ، عند مقارنتها بمجموعة السيطرة. **الاستنتاجات**: أن إضافة هيدروكسي ابيتايت إلى البولي ميثيل ميثاكريليت المعالج بالحرارة له تأثير ايجابي على المركب النانوي المتولد من حيث التوصيلية الحرارية لمادة قاعدة أطقم الاسنان.

DOI: 10.33899/RDENJ.2022.134368.1164, © Authors, 2024, College of Dentistry, University of Mosul

INTRODUCTION

Polymers have a wide range of uses, one of which is as a base material for dentures. It cannot transfer heat, which is required for patient response to hot or cold treatments when wearing a full or partial denture. As a result, it would be necessary to use a thermally conductive polymer. Metallic and ceramic nanoparticles have been used to make thermally conductive polymer composites [(1)].

Acrylic resin and flexible denture materials exhibit poor heat conductivity and diffusivity as contrasted to metallic denture bases, which may negatively affect acceptability and compliance, particularly in patients wearing full dentures [(2)].

Thermal conductivity is one of the most essential thermal characteristics of dental materials and is simply described as the material's capacity to transfer heat [(3)].

The thermal conductivity of a material is defined as the amount of heat in calories or joules per second that passes through a body of 1 cm thickness with a cross-section of 1 cm^2 when the temperature difference is 1°C. Thermal conductivity is measured in a steady-state condition where the temperature gradient is constant. Heat flows from places of greater temperature to areas of lower temperature, according to the second rule of thermodynamics [(4)].

Thermally conductive polymers provide new opportunities for eliminating metals in a variety of applications, as well as the benefits of polymers such as lightweight, corrosion resistance, and simplicity of processing. As a result, the current focus is on improving polymer thermal conductivity through the use of high-thermal conductivity nanofillers [(5)].

As a result, care should be taken while selecting the appropriate kind and concentrations of reinforcement materials that have been utilized to improve the mechanical qualities of PMMA denture base resin without negatively influencing its other features [(6)].

HA will not be recognized by the body as a foreign substance since they are biocompatible [(7)].

This research aimed to study the influence of hydroxyapatite nanoparticle addition at two concentrations (0.5% and 1%) on the thermal conductivity of heat-cured acrylic resin material.

MATERIALS AND METHODS

Sampling

Approval of the study was from the Scientific Research Committee / Department of Prosthodontics / College of Dentistry (UoM.Dent / DM. L.43/21)

The total number of specimens was thirty which divided into three groups, ten specimens for each one which was (control, 0.5 % HA NPs and 1 % HA NPs).

Preparation of the mold

During the mold preparation, a conventional flaking procedure was used for full dentures. A separating medium (cold mold seal) was used and allowed to dry for the layer of plastic before putting the lower part of metal flasks filled with dental stone and combining in vibration according to the directions of the manufacturer to release the trapped air, then left to set.

Acrylic sheets were utilized to make the plastic model, which was produced using computer software (AutoCAD) and then carved with a computer-controlled laser-cutting machine. The length, width, and thickness of the plastic models used in mold fabrication were precisely established according to the specifications needed for each test. Specimens of all groups were then stored in distilled water at 37ºC for 2 days using an incubator [8].

Preparation of the Specimens

The mixing ratio of powder to liquid for heat-cured PMMA polymer material was 2:1 by weight, according to the manufacturer's instructions. The weight of the hydroxyapatite nanoparticles was subtracted from the weight of the heat-cured PMMA polymer powder to produce the precise powder-to-liquid ratio stated by the manufacturer [9].

The specimens were first prepared by mixing the weight of hydroxyapatite nanopowder with "heat-cured PMMA" fluid monomer, which was sonicated and dispersed in the liquid monomer for 3 minutes using an ultrasonic probe of 20W and 60 kHz, and then the Heat-cured PMMA polymer powder was added and manually mixed to avoid particle agglomeration [10].

Thermal Conductivity Test

The thermal conductivity of the samples is calculated using Lee's disc apparatus. The samples were constructed using measurements (50.8 mm diameter × 3 mm thickness) following American Society of the International Association for Testing and Materials (ASTM) standard E1530-06, [11] as presented in (Figure 1).

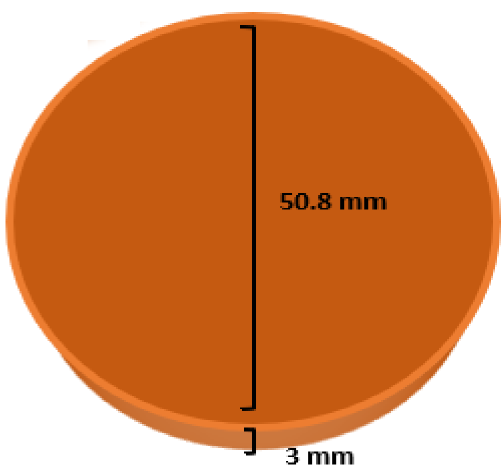

Figure (1): Dimensions of thermal conductivity testing specimen.

Lee's disc apparatus was constructed from three brass discs and a heater. The heater is placed between discs (C, B), and the sample is placed between discs (A, B) Heat is transferred across the sample from the heater to the two discs and subsequently to the third disc, as presented in (Figure 2).

Figure (2): Thermal conductivity measurement using Lee's disc

The temperatures of the discs (TA, TB, and TC) may be determined using thermometers. To achieve the best heat transfer through these discs, their surfaces should be clean and in close contact.

After powering up the heater (6 V), the current across the electrical circuit was calculated to be about (0.25 A), and the temperatures of the discs were measured after achieving thermal equilibrium (nearly 45 min).

The following equation is used to estimate thermal conductivity values:

$$IV = \pi r^2 e (T_A + T_B) + 2\pi r e \left[d_A T_A + d_S \left(\frac{1}{2}\right)(T_A + T_B) + d_B T_B + d_C T_C\right] \quad (1)$$

I: The electrical circuit's current value.

V: Supplied voltage.

r: Radius of the disc.

TA, TB, and TC: Temperature of the brass discs A, B, and C respectively.

dA, dB, and dC: Thickness of the brass discs A, B, and C respectively.

dS: Thickness of the specimen.

From Eq. (1), the value of (e) is calculated which represents the quantity of heat that flows through the cross-sectional area of the sample per unit time ($W/m^2.{}^\circ c$). The K-values can be calculated from the following equation [12]:

$$K\left(\frac{T_B - T_A}{d_s}\right) = e\left[T_A + \frac{2}{r}\left(d_A + \left(\frac{1}{4 d_S}\right)\right) T_A + \frac{1}{2r} d_S T_B\right] \quad (2)$$

Where K is the thermal conductivity coefficient (W/m.°c).

RESULTS

The statistical analysis: Descriptive statistics, the test of normality, and Inference statistics (ANOVA and Duncan's test) were done by using the SPSS program version (19).

One-way analysis of variance (ANOVA) was used to assess the thermal conductivity data of the control and (0.5 % and 1%) hydroxyapatite nanoparticles, table (1), A substantial difference ($P \leq 0.05$) between groups was discovered in this investigation.

Table (1): ANOVA for thermal conductivity of control and HA nanoparticles groups:

SOV	SS	Df	MS	F	P
Between Groups	0.027	2	0.013	324.563	.000
Within Groups	0.001	27	0.000		
Total	0.028	29			

Duncan's multiple range test of thermal conductivity demonstrated a significant increase in HA nanoparticles (0.5%) and (1%), respectively when compared to the control. The (0.5%) and

(1%) HA nanoparticle groups did not differ significantly (Figure 3).

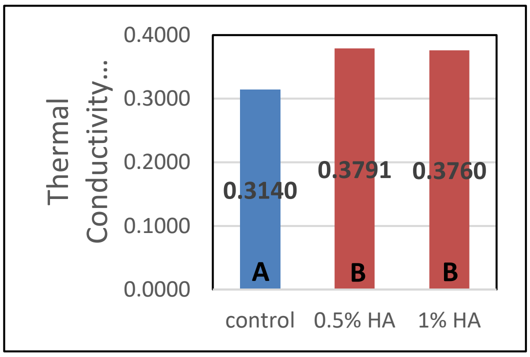

Figure (3): Duncan's multiple range test for thermal conductivity of control and HA nanoparticles groups.

DISCUSSION

According to research published in 1998 by Messersmith *et al.* [13], the physical properties of denture base material might influence patient acceptance of the prosthesis by altering the sensory experience of food during mastication. The capacity to sense transitory temperature changes at the palate is influenced by the thermal properties of the denture base material. Also, the thermal properties of the denture base might have an impact on the gustatory reaction.

The inclusion of thermally conductive fillers, and ceramic or metal particles improved the polymer's thermal conductivity [14]. The inclusion of hydroxyapatite nanoparticles resulted in a relatively substantial rise in thermal conductivity values, as shown in Tables (1) and Figure (3). This might be owing to the particles progressively touching one other to form a chain-like or network-like structure known as heat conductive pathways, which allow heat to be transferred from one side of the specimen to the other while also bridging the polymer's insulating effect. The polymer will have a high heat conductivity as a result.

The findings of this study suggest that the inter-particle distance may be smaller due to the use of nano-sized fillers (hydroxyapatite) in this study, which may result in paths or bridges conducting heat and significantly increasing the thermal conductivity of the composite when compared to the control group. In addition to their influence on the mechanical characteristics of the composite, Zhang *et al.* [15] determined that particle size in the composite affects the spacing between particles, which boosts the heat conductivity of the composite. Also, the smaller the particles, the more essential would-be surface features impacting interfacial properties, agglomeration behavior, and physical properties.

Our findings are in agreement with those of Kul *et al.* [16], who found that the mean thermal conductivity of acrylic resin reinforced with nano-hydroxyapatite was significantly higher than that of unmodified acrylic resin, implying that hydroxyapatite nanoparticles have a beneficial effect on improving the thermal conductivity of acrylic resin and the use of this composite in palatal area axillary acrylic resin dentures. Jarboo and Alsarraf [17] agreed that adding hydroxyapatite nanoparticles to acrylic resin increased the thermal conductivity of the composite.

In general, the thermal conductivity of the composite increases with increasing filler loading, however, this increase is generally non-linear. Furthermore, these increases are heavily influenced by various factors, including the type of the filler and how it is dispersed within the matrix. However, grain size has an impact on conductivity since the interface layer is inversely related to grain size and these layers frequently function to spread phonons, resulting in low thermal conductivity.

Thermal conductivity is highly influenced by voids or pores caused by inadequate polymerization or casting process flaws. Particle aggregation, on the other hand, may boost thermal conductivity by establishing a continuous path of the filler's particles utilized as phonon transporters throughout the composite [5].

CONCLUSIONS

The incorporation of hydroxyapatite nanoparticles into the "heat-cured PMMA" enhanced the thermal conductivity of the heat-cured PMMA denture base material.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

REFERENCES

1. Asar N.V, Albayrak H, Korkmaz T, and Turkyilmaz I. Influence of Various Metal Oxides on Mechanical and Physical Properties of Heat-Cured Polymethyl Methacrylate Denture Base Resins. *J Adv Prosthodont.* 2013;5(4):241–248.
2. Abdulhamed A.N. and Mohammed A.M. Evaluation of Thermal Conductivity of Alumina Reinforced Heat Cure Acrylic Resin and Some Other Properties. *J Bagh College Dent*. 2010; 22(3):1–7.
3. Bagby M, and Gladwin M. ″ Clinical aspects of dental materials: theory, practice, and cases″. *Wolters Kluwer business*. 2013; 280-281.
4. Anusavice, K.J., Shen, C. and Rawls, H.R., Phillips' science of dental materials. 12th edition. *Elsevier Health Sciences.* 2013; P:100- 1.
5. Han, Z. and Fina, A. ″ Thermal conductivity of carbon nanotubes and their polymer nanocomposites: a review ″. *Progress in polymer science.* 2011; 36(7): 914-944.
6. Gad, M.M, Rahoma A, and Al-Thobity M.A. Effect of Polymerization Technique and Glass Fiber Addition on the Surface Roughness and Hardness of PMMA Denture Base Material. *Dent Mater J.* 2018; 37(5): 746–753.
7. Miljkovi´c M, Kljajevi´c L, Filipovi´c S, Pavlovi´c V.B, Nenadovi´c S.S. Study of

Nanosized Hydroxyapatite Material Annealing at Different Retention Times. *Sci. Sinter.* 2020; 52, 405–413.

8. Fatalla A, Tukmachi M, Jani H. Assessment of some mechanical properties of PMMA/silica/zirconia nanocomposite as a denture base material. *IOP Conference Series: Materials Science and Engineering.* 2020; 987 012031.
9. AbdulJaleel A, and Ismael T. The Effect of Aluminum Oxide Nanoparticles on Some Mechanical Properties of Room Temperature Vulcanized Maxillofacial Silicone After Artificial Aging.2019. *M.Sc. Thesis. Baghdad University, Dentistry College, Baghdad, Iraq.*
10. Lazouzi G, Vuksanović MM, Tomić NZ, Mitrić M, Petrović M, Radojević V. Optimized preparation of alumina-based fillers for tuning composite properties. *Ceramics International*. 2018;44(7):7442-9.
11. American Society of the International Association for Testing and Materials. International designation: E1530-06. Standard test method for evaluating the resistance to thermal transmission of materials by guarded heat flow meter technique. *West Conshohocken*: ASTM; 2006.
12. Hamza M., Oleiwi J., and Nassir N. *Eng. & Tech. J*. 2011; 29(5): 856-870
13. Messersmith P, Obrez A, Lindberg S. New acrylic resin composite with improved thermal diffusivity. *J Prosthet Dent.* 1998 ;3(79):278-284.
14. Atla J, Manne P, Gopinadh A, Sampath A, Muvva S, Kishore K, Sandeep C, Chittam-settee H The Effect of AL2O3 addition on the thermal diffusivity of heat activated acrylic resin. *J of Clinical and Diagnostic Resea.* 2013; 7:1797-1798.
15. Zhang S, Cao X, Ma Y, Zhang J, Wang F The effect of particle size and content on the thermal conductivity and mechanical properties of AL2O3 / high density poly ethylene (HOPE) composite. *Express Polymer Letters*. 2011;5(7):581-590.
16. Kul, E, Aladağ L, and Yeşildal R. Evaluation of thermal conductivity and flexural strength properties of poly (methyl methacrylate denture) base material reinforced with different fillers. *The Journal of Prosthetic Dentistry*. 2016; 116(5), 803–810.
17. Jarboo N, and Alsarraf A. Influence of adding nano / micro hydroxyapatite (HA) particles on tribological characteristics of polymethyl methacrylate (PMMA). *AIP Conference Proceedings*. 2020; 2307(1):1-10.