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Research Article

COMPARISON OF THERMAL INSULATIVE PROPERTY OF VARIOUS PROVISIONAL CROWN MATERIALS: AN INVITRO STUDY

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ABSTRACT

Aim: Superiority of the temporary provisional crown materials have not been established in terms of their insulative property.
Purpose: This experimental study was designed to compare the relative thermal insulative property of four different provisional crown materials.
Materials and Method: For this four provisional crown materials were taken i.e. poly methyl methacrylate, poly ethyl methyl methacrylate, bis-acrylate and urethane dimethacrylate. For testing purpose a machine was specially designed in which the samples made up of these provisional crown materials were tested. For all the materials 10 samples were fabricated and every sample was tested at temperatures of 50°C, 55°C and 60°C respectively. Samples of equal dimension were fabricated with the help of stainless steel die of dimension 4cm length x 2.5cm width x 3mm thickness. The temperature differences were recorded for each sample at these specific temperatures with the help of 6 channel thermocouple and the readings were tabulated accordingly.
Results: the analysis of variance of temperature change in different materials at different heater temperatures as well as for overall assessment was done. It was observed that Polyethyl methyl methacrylate had temperature change of lowest order in all the simulations while Urethane dimethacrylate had the temperature change of highest order in all the simulations. Polymethyl methacrylate and Bis-Acrylic had temperature change values of middle order. For all the combinations, mean difference was found to be significant statistically ($p<0.001$). Maximum difference was observed between PEMMA and UDMA. Minimum difference was observed between Bis-Acrylic and UDMA at 50°C and 60°C as well as overall assessment and between PMMA and Bis-acrylic at 55°C.
Conclusion: After the final testing of the 4 provisional crown materials, following was the relative degree of insulation that a temporary crown material could provide:
UDMA > Bis-Acrylic > PMMA > PEMMA

INTRODUCTION

Biologically acceptable fixed prosthodontic treatment demands the prepared teeth to be protected and stabilized with provisional restorations that resemble the form and function of the planned definitive treatment[1,2,3]. It is this provisional restoration that not only provides the mechanical protection to the pulpal tissue of the prepared tooth, but also helps to protect the pulp from the temperature variations that occur whenever the patient is consuming hot or cold food beverages. Teeth are subjected to temperature variations of upto 60^0C during consumption of hot food therefore the provisional crown should be of such an insulative material that it should not allow the conduction of heat through it and thereby preventing the prepared tooth from thermal shocks[4,5].

Heat application to pulp and periodontium may cause reversible or irreversible necrotic and histopathologic changes such as burn reactions at the periphery of the pulp including formation of "blisters", ectopic odontoblasts and their destruction, protoplasm coagulation, expansion of liquid in dentinal tubules and pulp with increased outward flow from tubules. This process can affect pulpal vessels and lead to vascular injuries with tissue necrosis[6,7,8].

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So far the effect on pulp of the thermal conductivity of different restorative materials and procedures has mostly been investigated.

It was felt necessary to investigate the heat conduction characteristics of different temporary crown materials in order to determine the extent of heat transfer through a temporary crown material. A best temporary crown material would not allow heat conduction through it, but unfortunately none of the materials which are used presently in dentistry are perfectly insulative, therefore this comparative study of thermal insulation has been designed.

The aim of the study was to compare the relative thermal insulative property of 4 different provisional crown materials after polymerization so as to evaluate that which of these provisional crown materials has the best insulative property and would be the best material for a vital tooth abutment.

MATERIALS AND METHODS

For the purpose of performing the experiment following 4 provisional crown materials were been taken:

1. Poly Methyl Methacrylate (DPI; Avco; India)
2. Poly Ethyl Methyl Methacrylate (Unifast III ; GC Corporation; Tokyo; Japan)
3. Bis- Acylate (Protemp Star; DMG; Hamburg; Germany)
4. Urethane Dimethacrylate (Revotec LC; GC America)

Sample making

A stainless steel die was specially designed with dimensions of (4cm length x 2.5cm width x 3mm thickness)[9]. This die was fabricated such that it could split into two equal halves and could be again re-joined in the same way (Fig1). This rejoining was possible as both the halves contain one male and one female lock system, which could hold the whole die as one.

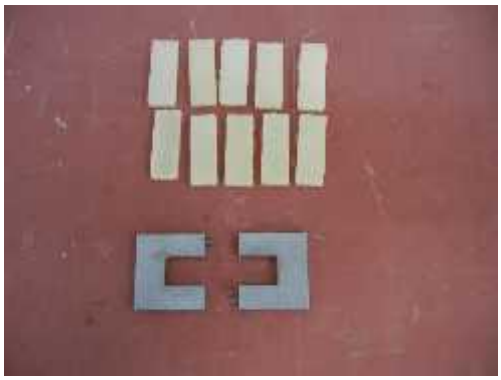

Fig 1 Stainless steel die and samples fabricated through it

This splitting of the die was been designed intentionally so that after the provisional crown material gets polymerized, the set strip could easily be retrieved without any distortion. This die was fabricated to ensure that all the test samples should be of equal dimension.

For poly methyl methacrylate (PMMA)[10,11] and Poly ethyl methyl methacrylate (PEMMA), the monomer and polymer were mixed according to the manufacturer's instructions. This whole mix was poured into the stainless steel die and after 15 mins the polymerized strip was retrieved by splitting the die into two halves. For making Bis acrylate samples the material was mixed with an auto-mixing system that was supplied by the manufacturer (which mixes the two syringes to an appropriate consistency when the cartridge is triggered through its gun. When triggered through the gun of 1:10 ratio, the catalyst and provisional material gets mixed and is delivered through a nozzle). This mixed material was loaded into the prepared stainless steel die, and after 15 mins the polymerized material sample was retrieved by splitting the die into two halves.

For making urethane dimethacrylate samples the material was delivered out from its cartridge and was condensed straight into the prepared stainless steel die in small increments. As this material was a visible light cured material which gets polymerized when exposed to a light source, it was cured with the LED of 700mW/cm^2 light intensity for 45 secs[12]. This procedure was repeated until the die was evenly filled with the material and the whole strip was polymerized. Thereafter the samples were retrieved by sectioning the die into two halves. In this way 10 samples of all these 4 provisional crown materials of equal dimension were fabricated.

Sample Testing Machine

In order to record the thermal conductivity of provisional crown materials a machine was designed especially for this purpose (Fig 2).

Fig 2 Sample testing machine

This machine comprised of various entities that were connected to one another to receive accurate results. They were:

- 6 channel thermocouple were connected to digital thermometer[13, 14]. The metal wires that were used in these thermocouples were made up of tin and copper. There were 6 thermocouple wires and were designated with nos. 1 to 6
- Digital thermometer The 6 channel thermocouples are connected to digital thermometer that could give the

readings of the experiment with an accuracy of 0.1^0C. The digital thermometer was set with the 6 channels such that the difference of temperatures at each end of the hermocouple could easily be read simultaneously, just by switching the channels of the thermocouple[15]

- Variable transformer was fitted that could vary the output voltage from 5 to 240 volts and thereby could control the amount of heat that is desired to be produced through the electric heater connected through it.
- Electric heater an electric heater of dimension of 3cm length x 1.5cm width with heating elements attached to both the sides was fabricated. This heater could give the temperatures ranging from 30^0C to 100^0C depending upon the potential difference applied.
- Insulation box an insulation box was fabricated made up of hard plastic. This box had a removable lid so that the complete clamped assembly of testing unit could be placed into it and thereby giving an insulated environment to the experiment. This box had a small opening in its lid through which all the wires of the thermocouple could easily be passed through. In order to give the experimental assembly a completely insulated environment, the box was filled with the refrigeration wool.
- Wooden strips For the purpose of holding the sample materials in intimate contact and todecrease the amount of heat lost by radiation. These wooden strips were of the same dimension as originally the test samples were, i.e. 4cm length x 2.5cm width x 3mm thickness. Wooden strips were chosen because they are excellent insulators and would minimize the chances of heat loss through radiation.
- Clamp stand two stainless steel clamps were fabricated which could hold the whole experimental assembly together in intimate contact. This would give the accurate readings of the temperatures around the experimental units.
- Digital voltmeter and digital ammeter were connected with the assembly

Experimental Procedure

For performing the experiment 2 sample strips of the first material were taken simultaneously (i.e. two prepared PMMA strips) [15, 16]. On one strip thermocouple No. 1 was secured at the middle point and on the other side of that same strip thermocouple No. 2 was secured at the middle (Fig 3).

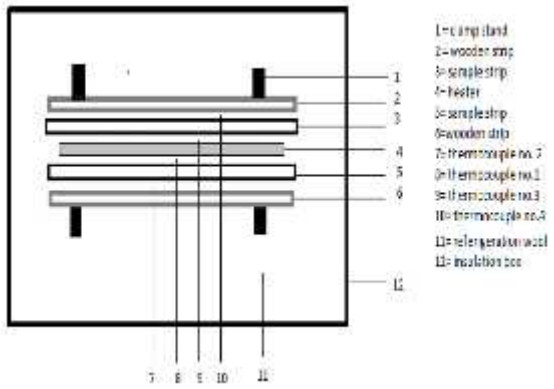

Fig 3 Diagrammatic representation of experimental setup

Similarly No. 3 and No. 4 thermocouples were secured on both the sides at the middle point of the second strip. Now the heater that was prepared was sandwiched between the two strips (i.e. with thermocouple No. 1 on the first strip and thermocouple No. 3 on the second strip are placed in contact with the heating element of the heater). The most outward sides of both the sample strips (i.e. the sides where No.2 thermocouple and No.4 thermocouple are attached) are secured with the wooden strips on both the sides. Thereafter the whole assembly was tightly secured with the help of screws in the two clamp stands. This whole assembly was then put inside the insulation box and the remaining space in the box was filled with the refrigeration wool.

Thermocouple No. 5 was placed inside the insulation box to keep a track of temperature rise in the insulation box. Thereafter the lid was closed and secured with screws tightly, to prevent any air leakage inside the experimental setup. Thermocouple No. 6 is placed outside the insulation box to detect the room temperature.

After this whole assembly had been set up, the current was passed and the voltage difference was controlled with the help of a variable transformer. First the variable transformer was kept at 20 volts and the whole setup was left for 1 hour at this potential difference.

This potential difference created a temperature of 50^0C in the heater which was visible in the digital thermometer when the thermocouples NO. 1 and No.3 were switched. After one hour the temperature difference on the other side of the samples i.e. thermocouples No. 2 and No. 4 were checked and recorded. Thereafter voltage difference was increased to 30 volts with the help of a variable transformer.

Again the setup was left for another 1 hour. The voltage difference of 30 volts increases the temperature of the heater to 55^0C which could be recorded by switching the channel to No.1 and No. 3 thermocouple. At the same time channels were switched to No. 2 and No. 4 thermocouple to get the temperatures that was transmitted through the sample via the heater, and the readings are tabulated. Finally the voltage difference was increased to 40 volts which changes the temperature of the heater to 60^0C and the whole assembly was left for another one hour so that the setup attains equilibrium.

After completion of one round of experiment another 2 similar samples of the same material were taken and the procedure was repeated. This procedure was repeated until all the 10 samples, of all the 4 temporary crown materials, were recorded. Thereafter a comparative chart was tabulated and the results were derived.

A total of 10 specimens each of four materials were taken and tested against three temperature conditions, viz.

- 50^oC
- 55^oC
- 60^oC

Change in temperature of materials was noted at all the temperature conditions. The results obtained are being discussed as under:

RESULTS

The change in material temperature at 50^oC, 55^0C and 60^0C for

the four materials were studied At 50^0C It was observed that PMMA had a temperature change ranging from 4.2 to 4.7°C with a mean value of 4.51°C and a standard deviation of 0.14°C. Median temperature of the group was 4.55°C. On testing the normality of the distribution, it was found to be normal and symmetric (KS=0.233; p=0.133). In PEMMA group, change in material temperature ranged from 2.9 to 3.6°C with a mean value of 3.33 and a standard deviation of 0.23°C. Median value for temperature change in PEMMA group was 3.35°C. On evaluating the distribution for normality, it was found to be normal and symmetric (KS=0.169; p=0.200).

In BIS-Acrylic group, change in material temperature ranged from 5.0 to 5.2°C with a mean value of 5.14 and a standard deviation of 0.07°C. Median value for temperature change in BIS-Acrylic group was 5.15°C. On evaluating the distribution for normality, it was not found to be normal and symmetric (KS=0.305; p=0.009).

In Urethane Dimethacrylate group, change in material temperature ranged from 5.2 to 6.0°C with a mean value of 5.67 and a standard deviation of 0.28°C. Median value for temperature change in Urethane Dimethacrylate group was 5.89°C. On evaluating the distribution for normality, it was not found to be normal and symmetric (KS=0.282; p=0.024).

At 55°C heater temperature it was observed that PMMA had a temperature change ranging from 4.2 to 4.7°C with a mean value of 4.5°C and a standard deviation of 0.18°C. Median temperature change in the group was 4.55°C. On testing the normality of the distribution, it was found to be normal and symmetric (KS=0.208; p=0.200).

In PEMMA group, change in material temperature ranged from 2.3 to 3.6°C with a mean value of 3.09 and a standard deviation of 0.38°C. Median value for temperature change in PEMMA group was 3.00°C. On evaluating the distribution for normality, it was found to be normal and symmetric (KS=0.210; p=0.200).

In BIS-Acrylic group, change in material temperature ranged from 4.8 to 5.2°C with a mean value of 4.88 and a standard deviation of 0.13°C. Median value for temperature change in BIS-Acrylic group was 4.80°C. On evaluating the distribution for normality, it was not found to be normal and symmetric (KS=0.328; p=0.003).In Urethane Dimethacrylate group, change in material temperature ranged from 5.1 to 5.9°C with a mean value of 5.46 and a standard deviation of 0.29°C. Median value for temperature change in Urethane Dimethacrylate group was 5.55°C. On evaluating the distribution for normality, it was found to be normal and symmetric (KS=0.214; p=0.200).

At 60°C heater temperature it was observed that PMMA had a temperature change ranging from 4.4 to 4.7°C with a mean value of 4.54°C and a standard deviation of 0.13°C. Median temperature change in the group was 4.60°C. On testing the normality of the distribution, it was found to be asymmetric (KS=0.282; p=0.023).

In PEMMA group, change in material temperature ranged from 3.1 to 3.7°C with a mean value of 3.32 and a standard deviation of 0.23°C. Median value for temperature change in PEMMA group was 3.20°C. On evaluating the distribution for normality, it was found to be asymmetric (KS=0.303; p=0.010).

In BIS-Acrylic group, change in material temperature ranged from 4.7 to 5.3°C with a mean value of 5.14 and a standard deviation of 0.20°C. Median value for temperature change in BIS-Acrylic group was 5.20°C. On evaluating the distribution for normality, it was not found to be normal and symmetric (KS=0.287; p=0.019).

In Urethane Dimethacrylate group, change in material temperature ranged from 5.2 to 5.9°C with a mean value of 5.47 and a standard deviation of 0.23°C. Median value for temperature change in Urethane Dimethacrylate group was 5.40°C. On evaluating the distribution for normality, it was found to be normal and symmetric (KS=0.019; p=0.180) (table 1).

For all the combinations, mean difference was found to be significant statistically (p<0.001). Maximum difference was observed between PEMMA and UDMA. Minimum difference was observed between Bis-Acrylic and UDMA at 50 and 60°C as well as overall assessment and between PMMA and Bis-acrylic at 55°C(Fig 4).

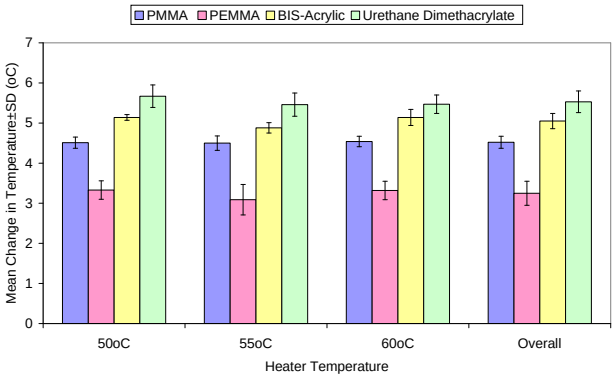

Fig 4 Graphical comparison of material temperature at different heater temperatures

DISCUSSION

Temperature, pressure, density of polymer, orientation of chain segments, crystal structures, degree of crystallinity, and many other factors may significantly affect the thermal conductivity of polymers. Therefore the thermal conductivity values can be varied in literatures for the same polymer.

Table 1 Comparison of Change in Material temperature at different heater temperatures

SN	Heater temperature	No. of samples in each group	PMMA		PEMA		BIS-Acrylic		Urethane Dimethacrylate	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	50°C	10	4.51	0.14	3.33	0.23	5.14	0.07	5.67	0.28
2.	55°C	10	4.50	0.18	3.09	0.38	4.88	0.13	5.46	0.29
3.	60°C	10	4.54	0.13	3.32	0.23	5.14	0.20	5.47	0.23
4.	Overall	30	4.52	0.15	3.25	0.30	5.05	0.19	5.53	0.27

In addition, discrepancies also occur for thermal conductivity values obtained using different test methods. Thermal conductivity of polymers is highly dependent on polymer chain segment orientation[17, 18, 19]. This is because thermal energy transports more efficiently along the polymer chain. Crystalline polymers have highly ordered chain segments, and therefore have higher thermal conductivity than amorphous polymers. Amorphous polymers may exhibit anisotropic thermal transport properties if polymer chains are partially oriented, with thermal conductivity along the chains higher than that perpendicular to the chains[20,21].

Polymers are often reinforced with fillers to improve their mechanical, electrical, and thermal properties. The thermal conductivity of filled polymers is primarily determined by the type and amount of fillers used. The thermal properties of the filler, the size, shape, and orientation of filler particles or fibers in polymer matrix, and the percentage of fillers are all important factors that determine the thermal conductivity of reinforced polymers. Polymers reinforced with inorganic fillers usually increase their thermal conductivities from a few percent to a few times[22].

In this experiment conducted, the thermal insulative capacities of 4 provisional crown materialswere compared. For this a machine was fabricated and the whole setup was kept inside an insulated box so as to prevent the loss of heat through radiation[21]. The testing samples weresecured tightly with the help of wooden strips of the same dimension so as to prevent any lossof heat due to convection or radiation. With this heater guard in place the air in the gapbetween was minimized so no heat is lost at the edge of the main heater. All heat lost from themain heater must flow into the test slabs. Without these wooden strips, cooler air surrounding the edge of the main heater would be heated by conduction and convection. Thus some of the heat supplied to the main heater would be carried away by the surrounding air[40]

In the experiment 10 test samples each of 4 provisional crown materials were subjected to temperature difference of 50^0C, 55^0C and 60^0C and at all the three temperature simulations as well as for overall assessment at different temperatures, Urethane Dimethacrylate had maximum mean value followed by Bis-Acrylic, PMMA and PEMA.

A dental resin is made up of the following main constituents:

- Resin matrix/monomers
- Initiators
- Fillers

The monomers contained in the organic matrix become bonded to each other through a radical polymerization reaction[23,25].

With self-curing materials, this occurs when the initiator components come together during mixing of the base paste and catalyst and react with each other in a redox reaction. It produces a radical R•, which is capable of attacking the double-bond of an acrylate group and itself generating a radical. This process is called a chain initiation reaction. The chain growth reaction will continue as long as a free radical encounters a double bond[26].

As the chain is extended (this process represents actual polymerization reaction) molecules of ever-increasing size are formed. Only when two radicals directly encounter with each other, they recombine and the reaction finishes in a chain termination reaction. This stops further growth of the chain.

If a polymer matrix solely consists of mono functional low-molecular monomers, as in the case with PMMA/PEMA materials, only linear chainlike polymers can be formed (Fig 5). Three-dimensional interlacing is only possible through physical looping of the individual polymer strands, and the resulting framework is not very stable[24].

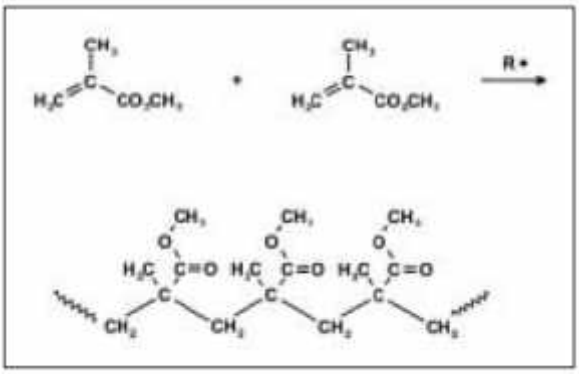

Fig 5 Polymerization of methacrylate monomers into polymethyl methacrylate

In case of polyethyl methyl methacrylate the major disadvantages can easily be concluded from this situation: high polymerization shrinkage[26], low mechanical stability, low color stability and lesser thermal insulative property due to its relatively high residual monomer detachment[27]

The situation is completely different for BIS acrylate composites. Herein, the monomers are bi-functional, i.e. they contain two double-bonds capable of reacting[28]. Bisphenol- A-glycidyl methacrylate (bis-GMA), Triethylene glycol dimethacrylate (TEGDMA) or similar monomer systems are frequently used in here. These resins correspond to derivatives of the bis-acryl compounds that have been rendered hydrophobic[29]. This provides for a major reduction in the water absorption of the materials; the dimensional stability and comparatively more thermal insulation. Themultiple functionality of the monomers mentioned above ensures the formation of a three-dimensional network (Fig 6). Due to this compact three dimensional framework surface hardness, flexural strength, polishability and thermal insulation of the material increases[30]

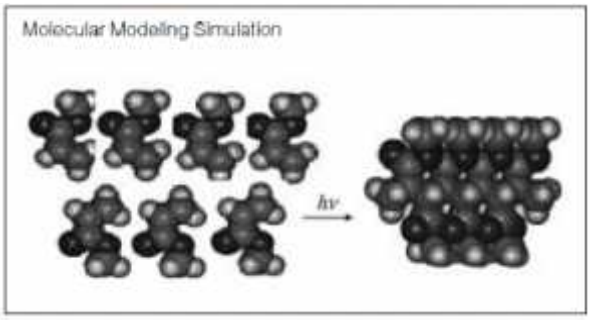

Fig 6 Polymerization of Bis acrylate

In case of urethane dimethacrylate the incorporation of the silica fillers in the organic matrix makes it more esthetic and more thermally insulative. Moreover the filler particles that are added are silanized[34]. This produces a mechanically stable composite material which is wear-resistant, radiopaque and

polishable (Fig 7)

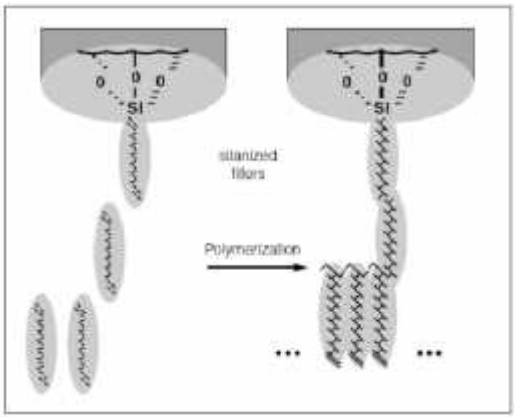

Fig 7 Polymerization of Urethane Dimethacrylate

In addition, polymerization shrinkage, esthetics, wear resistance, fracture repair[30] and thermal insulation is greatly improved in comparison with the PMMA/PEMA/BIS-acrylate materials.

One direct clinical result of this is the good precision of fit of the temporary restorations which is thermally more insulated when compared with these three provisional crown materials.

CONCLUSION

This study was designed to compare the relative thermal insulative property of various provisional crown materials. For this 4 provisional crown materials were taken i.e. poly methyl methacrylate, poly ethyl methyl methacrylate, bis-acrylate and urethane dimethacrylate.

For testing purpose a machine was specially designed in which the samples made up of these provisional crown materials were tested. For all the materials 10 samples were fabricated and every sample was tested at the temperatures of 50^0C, 55^0C and 60^0C respectively. The temperature differences were recorded for each sample at these specific temperatures and were tabulated accordingly.

After the final testing of the 4 provisional crown materials, following was the relative degree of insulation that a material could provide:

UDMA > Bis-Acrylic > PMMA > PEMMA

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