Influence of the material for preformed moulds on the polymerization temperature of resin materials for temporary FPDs

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PURPOSE. Temperature increase of 5.5 °C can cause damage or necrosis of the pulp. Increasing temperature can be caused not only by mechanical factors, e.g. grinding, but also by exothermic polymerization reactions of resin materials. The aim of this study was to evaluate influences of the form material on the intrapulpal temperature during the polymerization of different self-curing resin materials for temporary restorations.

MATERIALS AND METHODS. 30 provisional bridges were made of 5 resin materials: Prevision Temp (Pre), Protemp 4 (Pro), Luxatemp Star (Lux), Structure 3 (Str) and an experimental material (Exp). Moulds made of alginate (A) and of silicone (S) and vacuum formed moulds (V) were used to build 10 bridges each on a special experimental setup. The intrapulpal temperatures of three abutment teeth (a canine, a premolar, and a molar,) were measured during the polymerization every second under isothermal conditions. Comparisons of the maximum temperature (Tmax) and the time until the maximum temperature (tTmax) were performed using ANOVA and Tukey Test.

RESULTS. Using alginate as the mould material resulted in a cooling effect for every resin material. Using the vacuum formed mould, Tmax increased significantly compared to alginate (P<.001) and silicone (P<.001). In groups Lux, Pro, and Pre, tTmax increased when the vacuum formed moulds were used. In groups Exp and Str, there was no influence of the mould material on tTmax.

CONCLUSION. All of the mould materials are suitable for clinical use if the intraoral application time does not exceed the manufacturer’s instructions for the resin materials.

KEYWORDS: Temporary restoration; Temperature; Material; Form material; Resin
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The aim of the current study was to evaluate the influence of different mould materials on the maximal intra-pulpal temperature ($T_{\text{Max}}$) and the time until $T_{\text{Max}}$ ($t_{\text{TMax}}$). Therefore two-span five-unit temporary FPDs, made from different materials for TRs, were produced in vitro and the temperature in the abutment teeth was measured. One of the tested materials was a new experimental material. To evaluate the new material, three hypotheses were postulated: 1) the new experimental material leads to a lesser increase in $T_{\text{Max}}$ in the pulp than do other materials; 2) $t_{\text{TMax}}$ of the experimental material is longer than $t_{\text{TMax}}$ of the other materials; 3) the mould material has a significant influence on $T_{\text{Max}}$ and $t_{\text{TMax}}$.

MATERIALS AND METHODS

A special experimental setup to measure the temperature in the pulp chamber of extracted teeth has been developed at Hannover Medical School (Fig. 2). This setup includes three extracted human teeth, a canine (C), a premolar (P), and a molar (M), which had to be extracted for periodontal reasons. The pulps of these teeth were removed via an apical access cavity and temperature sensors were placed in the cleaned pulp chambers. Depending on their positions, the sensors are designated as C (canine), P (premolar), M, (molar oral), or Mb (molar buccal). The teeth were embedded into an acrylic block and prepared with a diamond bur to have a circumferential chamfer preparation with 0.8 mm depth. The acrylic block was placed in an acrylic chamber with a lid on the top. The chamber and the acrylic block were tempered by a heating pipe, which was connected to a temperature water bath (ministat 125, Peter Huber Kältemaschinen GmbH, Offenburg, Germany) to establish a constant temperature of $36.0 +/− 0.1°C$ of the entire experimental setup (Fig. 2). A silicone impression (Silagum Putty & Silagum light, DMG, Hamburg, Germany) of the prepared teeth was taken and a plaster model was cast (SHERA maximum, SHERA Werkstoff-Technologie GmbH & Co. KG, Lemförde, Germany). A wax-up of a 5-unit FPD was modelled and transferred to metal (Phantommetall NF, Degudent GmbH, Hanau, Germany). This metal bridge was adjusted to fit into the prepared teeth. A silicone over-impression (Silagum Putty & Silagum light, DMG, Hamburg, Germany) was taken over the bridge and a resin model (Diemet, Erkodent, Pfalzgrafenweiler, Germany) was cast of the acrylic block with the adapted bridge. This model was used as a master model for production of the TR’s moulds for five different resin materials (Table 1) with three different techniques. Figure 3 shows the wax-up, the metal bridge, and the acrylic resin model (Fig. 3). The TRs were produced of five different resin materials (Table 1) directly on the prepared teeth, using moulds made of alginate (A) (ALGINoplast fast, Heraeus, Hanau, Germany) or putty silicone (S) (Silagum Putty, DMG, Hamburg, Germany), or using a lab-side prefabricated vacuum formed mould (V) (Erkodur 1.5 mm, Erkodent, Pfalzgrafenweiler, Germany). All materials, composites as
As well as mould materials, were stored in a climate cabinet at 22.5°C to comply with their manufacturer’s instructions, which ensured that all of the materials had the same starting temperature at the beginning of the experiment. In dental practice, materials for temporary restorations are normally stored at room temperature, which is in line with the chosen temperature. The ambient room temperature in the laboratory did not exceed 23°C. The resin materials were applied following the manufacturer’s instructions. The temperature inside the teeth was measured and recorded automatically by a computer every second. Before the beginning of each measurement, the temperature inside the prepared teeth had to be constant at 36.0 +/- 0.1°C for 30 seconds, in order to ensure the same starting conditions for each experiment.

### Table 1. Materials for temporary restorations

| Material                  | Complete name | Acronym | Manufacturer                        | Storage conditions | Intraoral working time | Complete setting time | Possible mould materials                  |
|---------------------------|---------------|---------|-------------------------------------|--------------------|------------------------|------------------------|--------------------------------------------|
| Experimental Temporary K+B Material | Exp           | VOCO GmbH, Cuxhaven, Germany | 4 - 23°C            | 60 - 90 s            | 240 s                  | No information          |                                            |
| Structure 3               | Str           |         | DMG Chemisch Pharmazeutische Fabrik GmbH, Hamburg, Germany | 4 - 23°C            | 60 - 90 s            | 240 s                  |                                            |
| Luxatemp Star             | Lux           |         | Pro 3M ESPE, Neuss, Germany         | 15 - 25°C          | 90 - 150 s            | 300 s                  | Silicone material             |
| Protemp 4                 | Pro           |         | Heraeus Kulzer GmbH, Hanau, Germany | < 25°C             | 60 - 120 s            | 180 - 240 s            | Alginate, Silicone               |

Fig. 2. Experimental setup, overview (A), prepared teeth (B) and radiograph of the temperature sensors in the teeth (C).

Fig. 3. Wax-up (A), metal bridge (B) and resin model of the bridge positioned onto the measurement arrangement (C).
During the polymerization, the temperature in the pulp chambers was recorded. The measurements were stopped after 420 seconds, at a time where the polymerization of all materials was completed. For statistical evaluation, the maximum temperature “$T_{\text{Max}}$” was measured and the time until the maximum temperature - “$t_{\text{TMax}}$” was identified for each specimen.

Statistical analysis using the Kolmogorov Smirnov test, Levene analysis, two-way ANOVA, and the Post-Hoc Tukey Test was performed using SPSS (IBM SPSS Statistics V23.0.0.0, IBM Corp., Armonk, NY, USA). The level of significance was set to $P = .05$.

**RESULTS**

The data for $T_{\text{Max}}$ and $t_{\text{TMax}}$ are given in Table 2 for the three mould materials and the five resin materials for the four measuring points in the prepared teeth. Figure 4 shows the temperature profiles of measuring point “P” during polymerization of the experimental material with different mould materials. These profiles are typical of all the measurements performed. All curves showed a decrease in temperature, which was caused when the acrylic climate chamber was opened to place the form with the resin material onto the prepared teeth. A further decrease in the temperature in the pulp chamber was then observed, as the resin material was cooler than the temperature of the climate chamber. Because of the exothermic polymerization reaction, the temperature increased again until a maximum temperature was reached. The further progression of the curves varied and depended on the cooling effects of the mould materials: The alginate curve showed the smallest inclination and a maximum temperature below the base line temperature. The silicone curve had a higher inclination than the alginate curve and exhibited a maximum temperature nearly as great as the baseline temperature. The vacuum-formed mould curve showed the highest inclination and a maximum temperature greatly above the baseline temperature (Fig. 4).

Figure 5 shows the temperature for each measuring point for each group. Three lines are highlighted in the diagram. The red line shows the baseline temperature of 36°C. The lines at 30.5°C and 41.5°C mark the temperature variation of ±5.5°C from the baseline temperature. According to Zach and Cohen, a temperature increase of 5.5°C does
| Form material | Resin material | Group | Measuring point | $T_{\text{Max}}$ ± SD [°C] | $t_{\text{TMax}}$ ± SD [s] |
|---------------|---------------|-------|----------------|-----------------|----------------|
| A             | Exp           | Exp_A | C              | 31.1 ± 0.7      | 230.9 ± 73.1  |
|               |               |       | P              | 33.1 ± 0.5      | 198.2 ± 11.3  |
|               |               |       | MB             | 32.4 ± 0.9      | 199.1 ± 9.2   |
|               |               |       | MB             | 31.9 ± 0.8      | 205.3 ± 13.9  |
| Str           | Str_A         | C     | 31.9 ± 1.1     | 165.8 ± 10.2    |               |
|               |               | P     | 34.8 ± 0.8     | 160.7 ± 6.8     |               |
|               |               | MB    | 33.4 ± 1.1     | 163.6 ± 9.3     |               |
|               |               | MB    | 33.0 ± 1.1     | 167.2 ± 10.3    |               |
| Lux           | Lux_A         | C     | 33.7 ± 0.4     | 123.8 ± 5.6     |               |
|               |               | P     | 35.8 ± 0.4     | 130.2 ± 3.2     |               |
|               |               | MB    | 34.7 ± 0.3     | 125.9 ± 5.6     |               |
|               |               | MB    | 34.3 ± 0.4     | 131.3 ± 5.4     |               |
| Pro           | Pro_A         | C     | 32.1 ± 0.7     | 94.5 ± 6.3      |               |
|               |               | P     | 34.4 ± 0.5     | 96.1 ± 4.1      |               |
|               |               | MB    | 33.6 ± 0.6     | 89.2 ± 5.0      |               |
|               |               | MB    | 32.8 ± 0.6     | 93.3 ± 3.1      |               |
| Pre           | Pre_A         | C     | 31.8 ± 0.7     | 139.5 ± 8.0     |               |
|               |               | P     | 33.9 ± 0.9     | 145.0 ± 6.6     |               |
|               |               | MB    | 32.9 ± 0.9     | 140.4 ± 6.0     |               |
|               |               | MB    | 32.4 ± 0.8     | 145.0 ± 5.6     |               |
| S             | Exp           | Exp_S | C              | 34.7 ± 1.3      | 176.7 ± 13.7  |
|               |               |       | P              | 37.7 ± 1.4      | 173.8 ± 14.2  |
|               |               |       | MB             | 36.7 ± 1.2      | 178.5 ± 14.9  |
|               |               |       | MB             | 36.4 ± 1.1      | 180.1 ± 11.4  |
| Str           | Str_S         | C     | 33.8 ± 0.6     | 173.0 ± 5.4     |               |
|               |               | P     | 37.1 ± 0.6     | 168.7 ± 7.7     |               |
|               |               | MB    | 35.3 ± 0.6     | 178.1 ± 12.2    |               |
|               |               | MB    | 35.2 ± 0.6     | 178.9 ± 10.5    |               |
| Lux           | Lux_S         | C     | 35.5 ± 1.1     | 135.6 ± 10.7    |               |
|               |               | P     | 37.8 ± 1.0     | 143.8 ± 7.1     |               |
|               |               | MB    | 36.6 ± 0.9     | 143.2 ± 8.4     |               |
|               |               | MB    | 36.3 ± 0.9     | 146.5 ± 10.3    |               |
| Pro           | Pro_S         | C     | 35.5 ± 0.9     | 94.0 ± 8.4      |               |
|               |               | P     | 37.8 ± 1.3     | 105.7 ± 14.2    |               |
|               |               | MB    | 36.7 ± 1.0     | 96.8 ± 7.1      |               |
|               |               | MB    | 36.2 ± 0.9     | 101.8 ± 5.9     |               |
| Pre           | Pre_S         | C     | 34.9 ± 1.3     | 133.1 ± 11.6    |               |
|               |               | P     | 37.2 ± 1.3     | 141.6 ± 8.5     |               |
|               |               | MB    | 35.7 ± 1.3     | 141.9 ± 9.2     |               |
|               |               | MB    | 35.2 ± 1.2     | 149.1 ± 10.6    |               |
| V             | Exp           | Exp_V | C              | 44.5 ± 0.3      | 193.2 ± 6.1   |
|               |               |       | P              | 46.1 ± 0.6      | 192.3 ± 5.1   |
|               |               |       | MB             | 43.5 ± 0.4      | 198.8 ± 7.6   |
|               |               |       | MB             | 43.2 ± 0.4      | 202.9 ± 6.9   |
| Str           | Str_V         | C     | 45.0 ± 0.4     | 165.1 ± 8.3     |               |
|               |               | P     | 46.6 ± 0.6     | 170.6 ± 10.9    |               |
|               |               | MB    | 44.5 ± 0.5     | 173.9 ± 9.4     |               |
|               |               | MB    | 44.1 ± 0.4     | 177.2 ± 8.0     |               |
| Lux           | Lux_V         | C     | 44.1 ± 0.7     | 174.6 ± 16.7    |               |
|               |               | P     | 45.2 ± 0.5     | 190.1 ± 4.0     |               |
|               |               | MB    | 42.9 ± 0.5     | 193.5 ± 5.3     |               |
|               |               | MB    | 42.6 ± 0.5     | 196.4 ± 5.3     |               |
| Pro           | Pro_V         | C     | 43.7 ± 0.4     | 138.7 ± 6.3     |               |
|               |               | P     | 44.6 ± 0.3     | 153.1 ± 4.7     |               |
|               |               | MB    | 42.5 ± 0.3     | 155.6 ± 4.5     |               |
|               |               | MB    | 42.2 ± 0.3     | 160.9 ± 5.2     |               |
| Pre           | Pre_V         | C     | 44.1 ± 0.6     | 176.1 ± 10.4    |               |
|               |               | P     | 45.1 ± 0.8     | 182.2 ± 8.6     |               |
|               |               | MB    | 42.9 ± 0.4     | 185.4 ± 5.2     |               |
|               |               | MB    | 42.5 ± 0.4     | 189.3 ± 4.7     |               |

A = Alginate, S = Silicone, V = Vacuum-formed mould, Exp = Experimental material, Str = Structure 3, Lux = Luxatemp Star, Pro = ProTemp 4, Pre = Prevision Temp
not cause irreversible damage of the pulp. In the groups where alginate was used as the mould material, a decrease in temperature was seen. All of the mean values in these groups were between 30.5°C and 36.0°C. The lowest mean T_max for all alginate groups was found in group Exp_A on the canine teeth (31.1 +/- 0.7°C). In the silicone groups, the mean T_max varied between 33.0°C and 39.0°C. The highest mean T_max was found in group Lux_S at the premolar (37.8 +/- 1.0°C). In the groups where the vacuum-formed mould was used, an increase in the temperature to more than 41.5 °C was observed for all resin materials and all measuring points. The highest mean temperature was recorded on the premolar in group Str_V (46.6 +/- 0.6°C).

In the groups where alginate or silicone moulds were used, the lowest mean T_max were found in the canines. In the vacuum form groups, mean T_max in the molar was lower than at the other measuring points. In all groups, the highest mean T_max was found in the premolar.

Normal distribution and equality of variances were proved using the Kolmogorov-Smirnov test and Levene analysis. Multivariate factorial analysis revealed significant differences for the mould material (P < .001) and the type of the resin material (P < .001).

For further analysis, only mean T_max of position “P” was used, as the highest mean temperatures were measured in the premolar for all resin materials and all mould materials (Fig. 3).

ANOVA showed significant differences among the mould material groups in T_max on position P (P < .001). Single comparisons revealed that the difference in T_max between the alginate groups and the silicone groups, as well as between the alginate groups and the vacuum-formed mould groups, were statistically significant for all resin materials (P < .034). Alginate gave the lowest temperatures for every composite. Single comparisons between silicone moulds and vacuum-formed moulds were statistically significant (P < .001); the temperatures in the vacuum-formed moulds were higher. Pairwise comparisons within the groups using the same mould material found significant differences in only a few cases; within the alginate groups, the new experimental material showed significantly lower mean values for T_max than did the other materials (P < .033). Furthermore, the mean temperature in group Lux_A was significantly higher than in group Pro_A (P = .031) and in group Pre_A (P < .001). Pairwise comparisons within the silicone groups did not show any significant differences between the mean maximum polymerization temperatures (P > .879). With the vacuum-formed mould for production of the TRs, the temperature in group Str_V was significantly higher than in groups Lux_V (P = .017), Pro_V (P < .001), and Pre_V (P = .011). Furthermore, group Exp_V showed significantly higher temperatures than group Pro_V (P = .010).

Besides T_max, the time until maximum temperature (t_Tmax) is an important parameter to characterize the temperature increase during polymerization and the potential risk for the pulp. This time span was identified for each TR and the mean t_Tmax was calculated for each group for the measuring points C, P, Mb, and Mo (Table 2). Figure 6 shows a box-plot with t_Tmax for each group. Beside the boxes for each material, the manufacturer’s information about the intraoral working time and about the complete setting time of the materials are given (Fig. 6). All materials reached T_max after 80 - 240 seconds. The manufacturer’s instructions for the experimental material and for Structure 3 recommend removing the material from the patient’s mouth after 60 - 90 seconds. The material Prevision has to be removed after 120 seconds. Luxatemp and Protemp have an intraoral working time of

Fig. 6. Boxplot of the time until the maximum temperature during polymerization is reached. The manufacturer’s instructions for intraoral working time (blue lines) and the time until complete polymerization (red lines) are also given.
140 seconds. Furthermore, the temperatures at the individual specified times of removal from the patient’s mouth (Table 1) were identified. In alginate or silicone groups, these temperatures did not exceed 38°C.

In the groups where vacuum formed-moulds were used, the mean temperature exceeded 41.5°C after the recommended removal time, except for the experimental material, where the mean temperature did not exceed 38°C during the intraoral working time.

Normal distribution and equality of the variances were proved using the Kolmogorov Smirnov test and Levene analysis. Multivariate analysis revealed a significant influence on T_max of the mould material (P < .001) and of the resin type (P < .001). Similar to the statistical analysis of T_max, further statistics for pairwise comparisons of t_TMax with the Tukey test were only calculated for the measuring point “P” in the premolar. The pairwise comparisons among the groups Exp_A, Exp_S, and Exp_V showed a significantly faster temperature increase in group Exp_S than in groups Exp_A (P < .001) and Exp_V (P < .001). There was no significant difference between groups Exp_A and Exp_V (P = .966). In the groups where Luxatemp Star, Provision 4, and Prevision Temp were used, the longest t_TMax was seen when the vacuum-formed mould was used. Thereby, all of the pairwise comparisons of the groups using the same composite were statistically significantly different (P < .001). The other within-composite comparisons showed no statistically significant differences. In addition, a significant difference (P = .038) could be observed between groups Lux_-_A and Lux_-_S.

When alginate was used as the mould material, pairwise comparisons of t_TMax between the experimental material and the other materials showed significantly longer t_TMax in group Exp_A than in the other groups (P < .001). With silicone as the mould material, t_TMax in group Str_S was significantly longer than in groups Exp_S, Lux_S, Pro_S, and Pre_S (P < .001). For the vacuum formed mould t_TMax in group Exp_V, there was no significant difference from groups Lux_V (P = .999) and Pre_V (P = .345), but there were significant differences from groups Str_V (P < .001) and Pro_V (P < .001).

**DISCUSSION**

The risk of pulp damage or pulp irritation during dental treatment increases with increasing temperature on the tooth surface. This might be caused by frictional heat during tooth preparation by laser treatment or by polymerization heat of direct temporary restorations. In the current study, the maximum temperatures in the pulp chamber during polymerization differed significantly within each group and between the measuring points C, P, and M_p/M_h. This may originate from the different chemistry of the resin materials and from the different thickness of the residual hard tissues after tooth preparation. In 2016, Pipiani et al. compared temperature increase in the pulp chamber of human teeth during the production of temporary restorations in the direct technique with regard to the width of the finish lines after preparation. They found similar data for the different widths: 40.3°C for a width of 1.0 mm and 40.2°C for a width of 1.2 mm. It can be deduced that the temperature increase in the pulp is greater when the residual hard tissue is thinner. Seelbach et al. found that the temperature increase was critical when the temporary materials were 4 mm thick. In the current study, the highest temperature peaks could be seen on measuring point P, which is the middle tooth between the two temporary pontics.

The data of the current study showed different temperature effects during the exothermic polymerization reaction of the resin materials — depending on the mould materials. The cooling effect of alginate seen in the current study for all materials is in line with the literature. Besides the benefit of the cooling effect, alginate has a disadvantage that the impression cannot be stored to be reused at successive appointments because of the changes in dimensions depending on storage conditions and humidity.

With silicone, storage conditions and dimensional accuracy are not a problem and the silicone moulds can be used for more than one TR. Castelnuovo and Tjan found a cooling effect of putty silicone moulds when they had been previously cooled in a fridge for 30 minutes but not when the mould was at room temperature. A temperature increase in the pulp between 3°C and 12°C has been reported in their study. This is also in line with the current study. T_max in groups Exp_S, Str_S, Lux_S, Pro_S, and Pre_S varied between 34 and 38°C.

The temperature increase in the pulp chamber during the use of vacuum-formed moulds has not been studied in the recent literature. A disadvantage is that an additional appointment is necessary to take an impression because these moulds have to be prepared in the dental laboratory. However, these moulds are very convenient for the clinician, especially for large or for full-arch restorations. In 1990, Moulding and Teplitsky found that the temperature increase in the pulp was greater when temporary restorations were produced using vacuum-formed matrices than with other matrices. This is in line with the current study. More recent information about temperature increase using vacuum formed moulds could not be identified. In the current study, T_max increased to more than 42.2°C for all tested resin materials in combination with vacuum-formed moulds (Table 2). The highest mean temperature of 46.1°C was detected in group Str_V on point P (Fig. 5). Interestingly, the time until T_max was significantly greater (P < .001) when vacuum-formed moulds were used with resin materials Luxatemp Star, Protemp 4, or Prevision Temp. These three resin materials all exceeded 41°C at their individual specified time of removal from the patient’s mouth, irrespective of the mould material. When the experimental material or Structure 3 was used (groups Exp_V and Str_V), there was no increase in the time (Fig. 6). Furthermore, in these two groups, the temperature did not exceed 38°C after the manufacturer’s recommended removal time from the patient’s mouth.
CONCLUSION

Within the limitations of this study, the following conclusions can be drawn.

In combination with the experimental resin material or with Structure 3, the use of vacuum-formed moulds for the production of temporary restorations is an established technique, as long as the intraoral working time of 90 seconds is not exceeded, as recommended in the manufacturer’s instructions. Therefore, vacuum formed moulds can be recommended for clinical use. Further research might be warranted to study subsequent deformation of temporary restorations depending on polymerization time and the type of different mould materials.

The risk of pulp damage does not increase at prolonged intraoral working time if alginate or silicone is used as a mould material.

For the experimental material and for Structure 3, the use of silicone mould and vacuum-formed moulds has no influence on $t_{\text{TMax}}$. If alginate is used as the mould material, $t_{\text{TMax}}$ for the experimental material is longer than for Structure 3.

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