



# 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 ( $T_{Max}$ ) and the time until the maximum temperature ( $t_{T_{Max}}$ ) 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,  $T_{Max}$  increased significantly compared to alginate ( $P<.001$ ) and silicone ( $P<.001$ ). In groups Lux, Pro, and Pre,  $t_{T_{Max}}$  increased when the vacuum formed moulds were used. In groups Exp and Str, there was no influence of the mould material on  $t_{T_{Max}}$ . **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. [J Adv Prosthodont 2017;9:294-301]

**KEYWORDS:** Temporary restoration; Temperature; Material; Form material; Resin

## INTRODUCTION

Temporary restorations (TRs) are needed during treatment with crowns and bridges. TRs restore the function and aesthetics of the prepared teeth, besides forming the marginal gingiva until the new restoration can be cemented. Further-

more, TRs protect the pulp against chemical or thermal damage, which may be their most important function. In most cases, TRs are produced intraorally after tooth preparation using self-polymerizing resin materials. Chemical polymerization of these materials is an exothermic reaction, which may increase the temperature of the pulp<sup>1</sup> and therefore can lead to tissue or cell damage.<sup>2</sup> As early as 1965, Zach and Cohen<sup>3</sup> published a frequently cited *in vivo* study on the influence of thermal irritation on the pulp in monkeys. Pulpitis or necrosis of the pulp was found in 15% of the examined teeth after an increase in temperature of 5.5°C.<sup>3</sup> In contrast, an *in vivo* study of human teeth was published by Baldissara *et al.*<sup>4</sup> in 1997. They found no irritation of the pulp after a temperature increase of 8.9 - 14.7°C. In 2006, Amano *et al.*<sup>5</sup> found that HSP70 protein might play a role in the recovery of pulp after thermal stress in a rat model. The combination of these findings suggests that thermal stress might cause irritation of the pulp, which can be self-cured in some situations. However, it is unclear

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which temperature is tolerated by the pulp and which temperature leads to irreversible damage. In their 2013 literature review, Kwon *et al.*<sup>6</sup> commented that “Previous *in vivo* studies about the range of safe temperatures have reported varied results, indicating that the range of safe temperatures is not accurately known”. The great variation within the literature can be explained by different study designs and the large number of relevant variables.<sup>6</sup> There seems to be a consensus that a temperature increase of less than 5.5°C is harmless.<sup>3,7</sup> It may then well be asked whether the increase of the pulp temperature can be caused by polymerization of materials for TRs. In their *in vitro* studies, Castelnovo and Tjan<sup>7</sup> and Chiodera *et al.*<sup>8</sup> found that the temperature increase in dental pulp during polymerization of temporary restorations varied between 3°C and 12°C.

Depending on the number and size of the TRs, different fabrication techniques can be used. In clinical practice, previously taken alginate or silicone over-impressions are often used as moulds for TRs, especially for single crowns or small FPDs. For larger restorations or full-arch restorations, it is very convenient for the clinician to construct TRs using lab-side prefabricated vacuum-formed moulds (V) (Fig. 1).

Several studies have described the temperature conductivity of these materials. Alginate has a cooling effect.<sup>9</sup> Putty silicone can reduce the increase in temperature, although an increase of up to 5.5°C was found.<sup>7</sup> It might be desirable to precool the putty silicone form to avoid increasing the temperature, although this is time-consuming.<sup>6</sup> There appears to be no published information on the conductivity of vacuum formed moulds. It can be assumed that they have no cooling effect and are poor insulators.

Aside from technical strategies, newly developed materials for TRs might reduce the risk of irritating or damaging the dental pulp. One possible approach might be to develop materials that reach their temperature maximum slowly. This would make it possible to remove the polymerized TR out of the patient’s mouth securely before the maximum temperature has been reached. Another approach might be to change the chemical composition of the resin material to reduce the maximum temperature during polymerization. The type of the mould material might also influence the temperature.

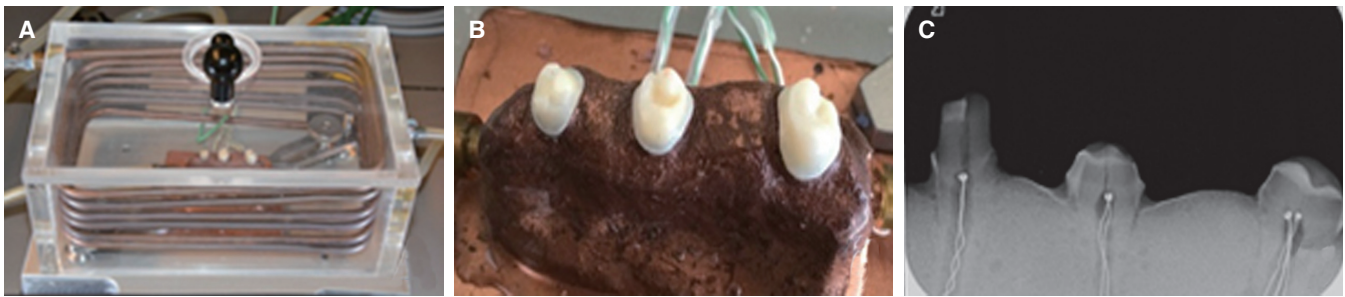


**Fig. 1.** Lab-side prefabricated vacuum-formed mould for temporary restorations in clinical use.

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),  $M_o$  (molar oral), or  $M_b$  (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



**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).

**Table 1.** Materials for temporary restorations

Material			Manufactures instructions for:			
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		4 - 23°C	60 - 90 s	240 s	
Luxatemp Star	Lux	DMG Chemisch Pharmazeutische Fabrik GmbH, Hamburg, Germany	15 - 25°C	90 - 150 s	300 s	Silicone material
Protemp 4	Pro	3M ESPE, Neuss, Germany	15 - 25°C	40 - 100 s	300 s	Alginate, Silicone, Polyether, Vacuum formed mould
Prevision Temp	Pre	Heraeus Kulzer GmbH, Hanau, Germany	< 25°C	60 - 120 s	180 - 240 s	Alginate, Silicone

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 labora-

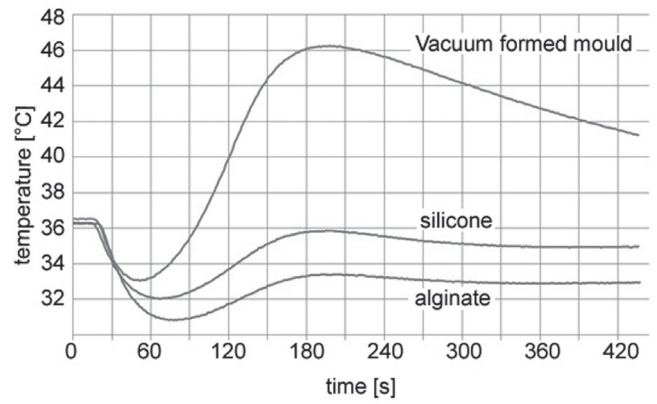
tory did not exceed 23°C. The resin materials were applied following the manufacturer’s instructions. The temperature inside the teeth was measured and recorded automatically by a computer every second. Before the beginning of each measurement, the temperature inside the prepared teeth had to be constant at 36.0 +/- 0.1°C for 30 seconds, in order to ensure the same starting conditions for each experiment.

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 " $T_{Max}$ " was measured and the time until the maximum temperature - " $t_{TMax}$ " - 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

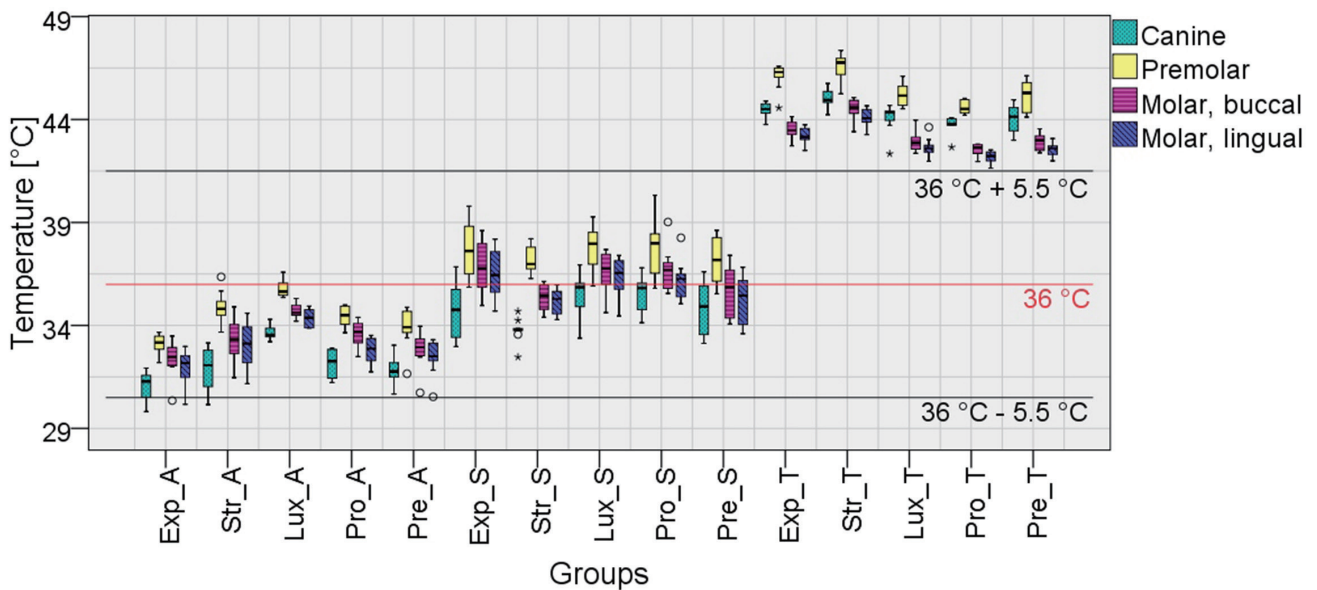
The data for  $T_{Max}$  and  $t_{TMax}$  are given in Table 2 for the three mould materials and the five resin materials for the four measuring points in the prepared teeth. Figure 4 shows the temperature profiles of measuring point "P" during polymerization of the experimental material with different 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



**Fig. 4.** An example of temperature profiles on measuring point "P" during one measurement each of the experimental material (Exp) in combination with alginate, silicone, and the vacuum formed mould.

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  $\pm 5.5^\circ\text{C}$  from the baseline temperature. According to Zach and Cohen, a temperature increase of  $5.5^\circ\text{C}$  does



**Fig. 5.** Boxplot of the intra-pulpal temperature at the measuring points C, P,  $M_b$ , and  $M_o$  for all groups. The baseline temperature and the temperature interval of  $\pm 5.5^\circ\text{C}$  are also given.



**Table 2.** Measurements for all groups. Mean and SD are given for  $T_{Max}$ ,  $t_{TMax}$ 

Form material	Resin material	Group	Measuring point	$T_{Max} \pm SD [^{\circ}C]$	$tT_{Max} \pm SD [s]$	
A	Exp	Exp_A	C	31.1 ± 0.7	230.9 ± 73.1	
			P	33.1 ± 0.5	198.2 ± 11.3	
			M <sub>b</sub>	32.4 ± 0.9	199.1 ± 9.2	
			M <sub>o</sub>	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	
			M <sub>b</sub>	33.4 ± 1.1	163.6 ± 9.3	
			M <sub>o</sub>	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	
			M <sub>b</sub>	34.7 ± 0.3	125.9 ± 5.6	
			M <sub>o</sub>	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	
			M <sub>b</sub>	33.6 ± 0.6	89.2 ± 5.0	
			M <sub>o</sub>	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	
			M <sub>b</sub>	32.9 ± 0.9	140.4 ± 6.0	
			M <sub>o</sub>	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
				M <sub>b</sub>	36.7 ± 1.2	178.5 ± 14.9
				M <sub>o</sub>	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	
			M <sub>b</sub>	35.3 ± 0.6	178.1 ± 12.2	
			M <sub>o</sub>	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	
			M <sub>b</sub>	36.6 ± 0.9	143.2 ± 8.4	
			M <sub>o</sub>	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	
			M <sub>b</sub>	36.7 ± 1.0	96.8 ± 7.1	
			M <sub>o</sub>	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	
			M <sub>b</sub>	35.7 ± 1.3	141.9 ± 9.2	
			M <sub>o</sub>	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
				M <sub>b</sub>	43.5 ± 0.4	198.8 ± 7.6
				M <sub>o</sub>	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	
			M <sub>b</sub>	44.5 ± 0.5	173.9 ± 9.4	
			M <sub>o</sub>	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	
			M <sub>b</sub>	42.9 ± 0.5	193.5 ± 5.3	
			M <sub>o</sub>	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	
			M <sub>b</sub>	42.5 ± 0.3	155.6 ± 4.5	
			M <sub>o</sub>	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	
			M <sub>b</sub>	42.9 ± 0.4	185.4 ± 5.2	
			M <sub>o</sub>	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.<sup>3</sup> 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.

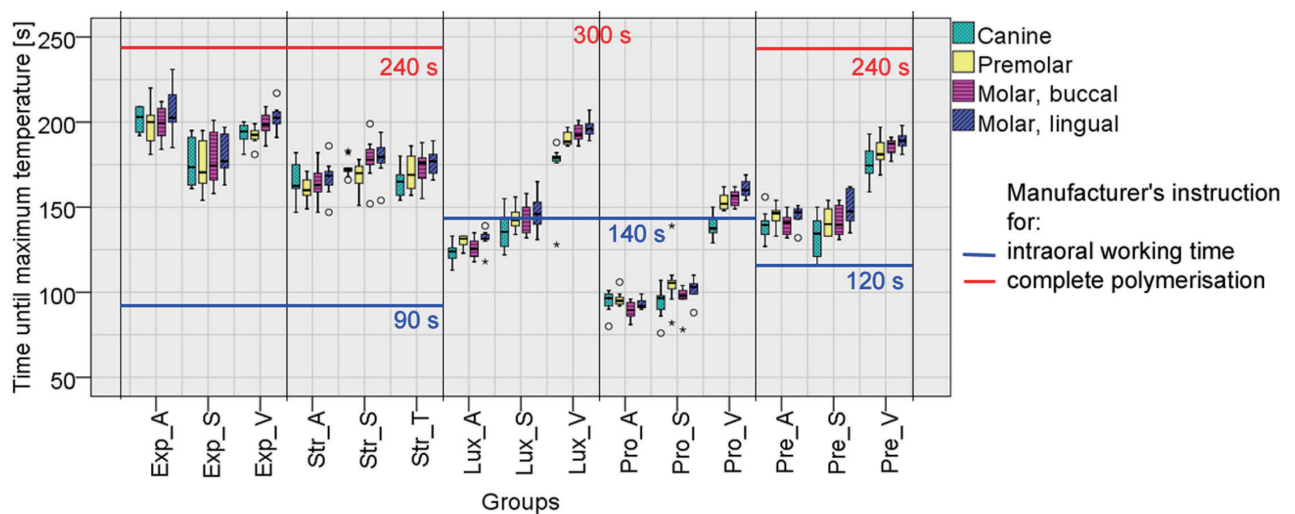
Normal distribution and equality of variances were proved using the Kolmogorov-Smirnov test and Levene analysis. Multivariate factorial analysis revealed significant differences for the mould material ( $P < .001$ ) and the type of the resin material ( $P < .001$ ).

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, M<sub>b</sub>, and M<sub>l</sub> (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 Prottemp 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  $t_{T_{Max}}$  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  $t_{T_{Max}}$  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  $t_{T_{Max}}$  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  $t_{T_{Max}}$  between the experimental material and the other materials showed significantly longer  $t_{T_{Max}}$  in group Exp\_A than in the other groups ( $P < .001$ ). With silicone as the mould material,  $t_{T_{Max}}$  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  $t_{T_{Max}}$  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.<sup>6</sup> This might be caused by frictional heat during tooth preparation,<sup>10</sup> by laser treatment,<sup>10,11</sup> or by polymerization heat of direct temporary restorations.<sup>7,8</sup> 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  $M_o/M_p$ . This may originate from the different chemistry of the resin materials<sup>12</sup> and from the different thickness of the residual hard tissues after tooth preparation.<sup>12</sup> In 2016, Piplani *et al.*<sup>13</sup> compared temperature increase in the pulp chamber of human teeth during the production of temporary restora-

tions 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.*<sup>14</sup> 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.<sup>9</sup> 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.<sup>15</sup>

With silicone, storage conditions and dimensional accuracy are not a problem<sup>16</sup> and the silicone moulds can be used for more than one TR. Castelnovo and Tjan<sup>7</sup> 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.<sup>7,8</sup> This also is 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<sup>17</sup> found that the temperature increase in the pulp was greater when temporary restorations were produced using vacuum-formed matrixes than with other matrixes. 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, Prottemp 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  $t_{\text{Max}}$ . If alginate is used as the mould material,  $t_{\text{Max}}$  for the experimental material is longer than for Structure 3.

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