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Influence of the ceramic translucency on the relative degree of conversion of a direct composite and dual-curing resin cement through lithium disilicate onlays and endocrowns

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ABSTRACT

Introduction: The goal of this study was to investigate the influence of the ceramic translucency, restoration type and polymerization time on the relative degree of conversion of a dual-curing resin cement and a conventional microhybrid resin composite using a high-power light-curing device.
Methods and materials: Two 4.0 mm thick onlay (O) and two 7.5 mm thick endocrown (E) lithium disilicate restorations in high and low translucency (HT/LT) were fabricated on a decapitated molar. The pulp chamber was prepared to accommodate a 2 mm layer of a microhybrid resin composite (MHC) or dual-curing resin cement (DCC). Composite specimens were light-cured ($n = 15$; 1200 mW/cm^2) without or through an onlay or endocrown restoration. Fourier-transform infrared spectroscopy (FTIR) absorbance curves were collected for the same composite specimen after 3 × 20, 3 × 40, 3 × 60 and 3 × 90 s of light-curing. The relative degree of conversion (DC%) was calculated and results analyzed using Kruskal-Wallis test and Friedman's ANOVA. Alpha was set at 0.05.
Results: After 3 × 60 s, the DC of MHC was significantly lower ($p = 0.03$; $r = 0.61$) under LT/EC restorations (Mdn: 77.8%) than HT/EC restorations (Mdn: 95.2%). DC of the DCC was not significantly affected by the ceramic translucency or restoration type. MHC had a significant higher DC than DCC under the HT/O, LT/O and HT/E restorations. There were no significant differences between MHC and DCC cured through LT/E restorations.
Conclusion: DC for DCC was not significantly affected by the ceramic translucency or restoration type. DC for MHC was significantly lower for LT/EC than HT/EC restorations after 3 × 60s polymerization, but not different for the high translucent restorations and low translucent onlays.
Clinical relevance: the use of light-curing microhybrid composite for bonding high translucent onlays and endocrowns and low translucent onlays seems feasible.

1. Introduction

Adhesive cementation of glass ceramic restorations increases the survival rate and fracture strength of indirect restorations (Burke et al., 2002; Van den Breemer et al., 2015). Dual-curing (DC) resin cements are widely employed in the luting of indirect composite and glass ceramic restorations and are considered as the golden standard for luting thick or opaque indirect restorations (Kameyama et al., 2015; Van den Breemer et al., 2015). They have some possible drawbacks related to their susceptibility to color change due to an oxidation process of the reactive groups in the tertiary amines (Pissaia et al., 2019). They also have a shorter working time as compared to conventional light-curing (LC)

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direct resin composites. Furthermore, some clinicians prefer the ease of removal of the excess composite due to its higher viscosity (Van den Breemer et al., 2021). Studies also show that indirect restorations luted with a direct composite perform with higher fracture strength (Gresnigt et al., 2017) and bond strength (Kameyama et al., 2015) when compared to dual-curing resin cements.

Concerns have been raised about the use of a direct resin composite under glass ceramic restorations because of compromised light transmittance through the ceramic, which may result in an insufficient degree of conversion (Archegas et al., 2012; Martins et al., 2019). Results from a recent meta-analysis showed that a thickness of 1.0 mm of porcelain significantly reduced the degree of conversion of both dual- and light-curing only resin cements as compared to no restoration (Martins et al., 2019). Light-curing resin cements have therefore been used mainly in the cementation of thin indirect laminate veneers (Peumans et al., 2004). However, new generations of light-curing devices based on light-emitting diode (LED) technology with increased irradiance might broaden the indications for the use of light-curing resin composite as a luting material (Faria-e-Silva and Pfeifer, 2017). Second and third generations of high power light-curing devices can produce an irradiance from 1100 mW/cm^2 up to as much as 3200 mW/cm^2 (Martins et al., 2019). This increased irradiance might aid in the polymerization of resin cements under thick glass ceramic restorations. Furthermore, after a prolonged polymerization time, the mechanical properties and in vivo performance of composite resins under thick glass ceramic restorations seems to be adequate (Bindl et al., 2005; Gregor et al., 2014; Van den Breemer et al., 2021).

For endodontically treated teeth, adhesive rehabilitation using partial indirect restorations promotes tissue preservation. In case of severe coronal destruction, endocrown restorations could be a viable alternative to the conventional post-and-core covering crown, especially in molar teeth (Bindl et al., 2005). Endocrowns are adhesively bonded indirect restorations with an extension into the pulp chamber (Bindl and Mörmann, 1999). One in vitro study investigated the Vickers microhardness under 7.5 mm thick feldspathic and composite endocrowns, comparing a dual-curing resin cement with a conventional microhybrid composite (Gregor et al., 2014). The microhybrid composite performed with significantly higher microhardness than the dual-curing resin cement. However, more research is needed to corroborate the feasibility of bonding lithium disilicate endocrowns using a conventional microhybrid composite alone. Variables that influence the degree of conversion are, amongst others, the translucency of the ceramic restoration, ceramic thickness and the polymerization time (Archegas et al., 2012; Martins et al., 2019).

The goal of this in vitro study is to investigate the influence of the ceramic translucency, restoration type and polymerization time on the relative degree of conversion of a dual-curing resin cement and a conventional microhybrid composite using a high-power light-curing device. The null hypothesis is that the translucency would have no effect on the relative degree of conversion of the dual-curing resin cement and the microhybrid composite. The secondary hypothesis is that the restoration type would not influence the relative degree of conversion. The third and fourth hypotheses would be that respectively the cement type and polymerization time would not affect the relative degree of conversion.

2. Materials and methods

2.1. Fabrication of the tooth mold and indirect restorations

In order to simulate the clinical situation, two tooth molds were fabricated. Two freshly extracted mandibular molar teeth of similar mesio-distal dimensions (10 mm) and height (occlusal – cemento-enamel junction; 7.5 mm) were embedded in auto-polymerizing acrylic resin (Autoplast, Condular) with adjacent teeth and subsequently scanned using an intraoral scanning device (CEREC Omnicam, Dentsply Sirona). The scans were saved as a biogeneric copy. Subsequently, the molar teeth were decapitated 1 mm above the cemento-enamel junction. The pulp chamber was prepared using a red ring diamond shoulder bur (899 KR.314.018, Komet Dental) to a dimension of 5 mm in length and 4 mm in width and tapered to the occlusal.

The molar teeth were assigned to two restoration types, being the onlay group or endocrown group. For the onlay group, the pulp chamber was filled up to the decapitated surface using wax (Cavex Yellow Wax; Cavex Holland; Haarlem, the Netherlands). For the endocrown group, a flat pulpal floor was created using the same wax, resulting in a 2 mm deep preparation. The dimensions of both groups were now scanned using the intraoral scanning device. The previously saved biogeneric copy was used to design an indirect restoration, ensuring a ceramic thickness in the central groove of 4.0 mm for the onlay and of 7.5 mm for the endocrown restorations (see Fig. 1).

Two identical onlays were milled out of a low (LT) and high translucency (HT) lithium disilicate CAD/CAM block (IPS e.max CAD A2 HT/LT; Ivoclar Vivadent; Schaan; see Table 1). Restorations were fired according to the recommendations of the manufacturer. The same process was followed for two identical endocrown restorations.

Subsequently, the tooth molds were completed. By using a dental model trimmer, the bottom of the mold was removed up to a depth that could accommodate 2 mm of composite in the pulp chamber and could be placed over the ATR diamond crystal (attenuated total reflectance, Platinum ATR-QL; Bruker Optics; Ettlingen, Germany; see Fig. 1 and paragraph 2.2).

2.2. Fourier-transform infrared spectroscopy

Tooth molds were placed over the ATR diamond crystal (attenuated total reflectance, Platinum ATR-QL; Bruker Optics; Ettlingen, Germany) of a FTIR spectrometer (Vertex 70; Bruker Optics; Ettlingen, Germany). The FTIR spectra were recorded with a range from 400 to 4500 cm^{-1} with 16 scans at a resolution of 4 cm^{-1}. In order to standardize the surrounding, the spectrometer was purged with nitrogen gas during the experiments. Before application of the composite, a background scan was performed at the same settings. A dual-curing resin cement (DCC; Variolink Esthetic DC Warm; Ivoclar Vivadent; Schaan, Liechtenstein) or a microhybrid composite (MHC; Enamel HFO UD3; Micerium; Avegno, Italy) was placed over the detector and a measurement was performed before polymerization. Subsequently, the composite samples were light-cured without a restoration (control group) or with a high or low translucent indirect restoration. For the control group (n = 15 per composite), both the dual-curing resin cement and microhybrid composite were polymerized perpendicular to the surface without any restoration for 3 × 20 s, in direct contact with the tooth mold, with a high-power light-curing device (Bluephase 20i; wave length range: 385–515 nm, light tip diameter 8 mm; Ivoclar Vivadent; Schaan, Liechtenstein). Before polymerization, the output of the polymerization device was verified to be at least 1200 mW/cm^2 (Bluephasemeter II; Ivoclar Vivadent; Schaan, Liechtenstein).

After this polymerization step, a FTIR spectrum was recorded. Thereafter the same composite specimen was additionally light-cured and FTIR spectra were collected for 3 × 40 (occlusal, lingual, buccal side), 3 × 60, 3 × 90 and 3 × 180 s (control group). After all polymerization steps were completed, the composite sample was removed from the tooth mold and the FTIR detector was cleaned with an 80% ethanol solution. A new background scan was performed after evaporation. For the indirect restorations, depending on the treatment group, a lithium disilicate onlay (high or low translucency: HT/LT; n = 15 per translucency subgroup) or endocrown (high or low translucency: HT/LT; n = 15 per translucency subgroup) were seated and the composite was polymerized through the restoration for 3 × 20 s (occlusal, buccal and lingual direction at an angle of 45°). The FTIR spectra thereafter were collected as described for the control group.

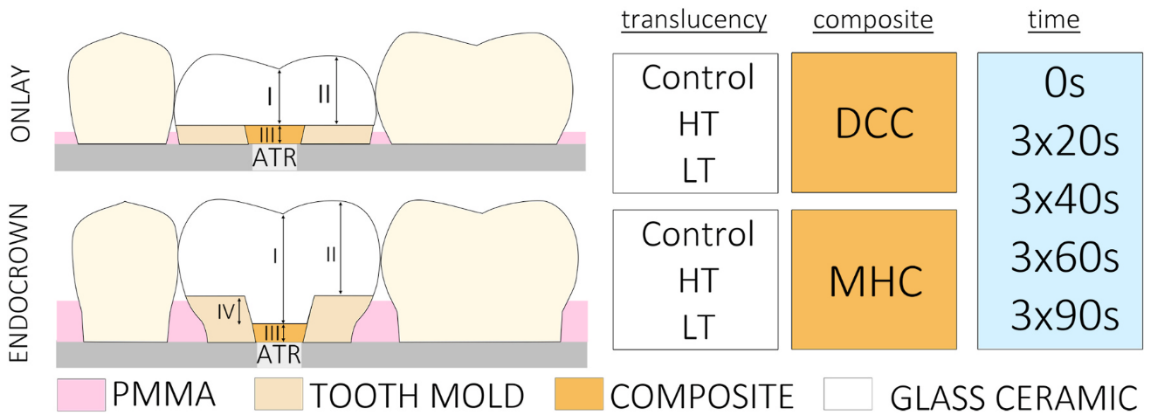

Fig. 1. Workflow and dimensions of the tooth molds for the onlay and the endocrown restorations. Dimensions of the onlay restorations: I: 4 mm, II: 4.5 mm, III: 2 mm. Dimensions of the endocrown restorations: I: 7.5 mm, II: 6 mm, III: 2 mm, IV: 2 mm. ATR: Attenuated Total Reflectance diamond crystal; Control: no restoration; HT: High Translucency; LT: Low Translucency; DCC: Dual-curing Resin cement; MHC: MicroHybrid Composite.

Table 1
Overview of the material used in this study.

Brand	Type	Chemical composition	Manufacturer	Batch number
IPS e.max CAD A2	Lithium disilicate glass ceramic	97% silicon dioxide, aluminium oxide, phosphorus pentoxide, potassium oxide, sodium oxide, calcium oxide, fluoride, 3% titanium dioxide, and pigments, water, alcohol, chloride	Ivoclar Vivadent, Schaan, Liechtenstein	High translucency: X35375 Low translucency: X42738
Variolink Esthetic DC	Dual-curing resin cement	• Base: ytterbiumtrifluoride, Urethane dimethacrylate (UDMA), acetyl-2-thioureum • Catalyst: ytterbiumtrifluoride, Urethane dimethacrylate (UDMA), acetyl-2-thioureum, α,α-dimethylbenzylhydroperoxide	Ivoclar Vivadent, Schaan, Liechtenstein	X29892
Enamel Plus HFO UD3	Light-curing microhybrid composite	Diurethandimethacrylate (DUDMA), Iso-propyliden-bis (2(3)-hydroxy-3(2)- 4(phenoxy)propyl)-bis(methacrylate)(Bis-GMA); 1,4 - Butandioldimethacrylate	Micerium, Avengo, Italy	2018006730

2.3. FTIR analysis

The FTIR spectra were imported in a spectroscopy analyzing software (OriginPro, 2020; OriginLab Corporation; Massachusetts, United States). Baseline correction was performed by connecting the troughs between the spectral lines at 1570 cm^{-1}-1590cm^{-1} and 1590 cm^{-1}-1650cm^{-1} and subtracting the resulting baseline (E-peak method (Rueggeberg et al., 1990)). As an internal reference, peak height at 1581 cm^{-1} was chosen, since this peak was the most stable throughout the polymerization process (see Fig. 2). Batch peak analysis was performed and the height of the absorption peaks at bands 1581 cm^{-1} and 1638 cm^{-1} was noted. To calculate the relative degree of conversion, the following formula was used:

$$DC = \left[\frac{\Delta A'(1638)_{sample}}{\Delta A'(1638)_{control}}\right] \times 100\%$$

with

$$\Delta A'(1638) = A'(1638)_{uncured} - A'(1638)_{cured}$$

and

$$A'(1638) = A(1638) - A(1581)$$

where A(1581) is the absorbance at 1581 cm^{-1} that is unaffected by polymerization and is thus suitable for use as a reference peak. The mean difference between peaks 1581 cm^{-1} and 1638 cm^{-1} before and after 3 × 180 s of polymerization of the control groups was used to create a linear conversion rate for the experiment groups (Monterubbianesi et al., 2016).

2.4. Statistical analysis

Data was analyzed using SPSS (IBM Statistics, version 24) and checked for the assumptions of normality and sphericity. Since the assumptions for a parametric test were violated, a Kruskal-Wallis test was conducted with the degree of conversion as the dependent and the group (10 levels: 8 experiment groups, 2 control groups) as the independent variable. To inspect the influence of exposure time per group, a Friedman's ANOVA was done with the degree of conversion as the dependent and the exposure time as the within-subject variable. Multiple Dunn's tests with Bonferroni corrections were done for the pairwise comparisons as post hoc analysis. An alpha-level of 0.05 was considered significant in all aforementioned tests.

3. Results

A total of 150 FTIR spectra were analyzed (see supplement 1). There was a significant effect of the group variable (restoration/translucency) on the relative degree of conversion after 3 × 20 ($H(9) = 136.99$, $p = 0.00$), 3 × 40 ($H(9) = 125.58$, $p = 0.00$), 3 × 60 ($H(9) = 112.18$, $p = 0.00$) and 3 × 90 s ($H(9) = 90.81$, $p = 0.00$).

3.1. Ceramic translucency

Up to 3 × 40 s of polymerization, there was no influence of the ceramic translucency on the relative degree of conversion of both the light-curing composite and dual-curing resin cement (HT/Onlay versus LT/Onlay, HT/Endocrown versus LT/Endocrown; all $p > 0.05$; see Fig. 3). However, after 3 × 60 ($p = 0.03$, $r = 0.61$) and 3 × 90 s ($p = 0.03$, $r = 0.60$) the light-curing composite cured under a HT/Endocrown

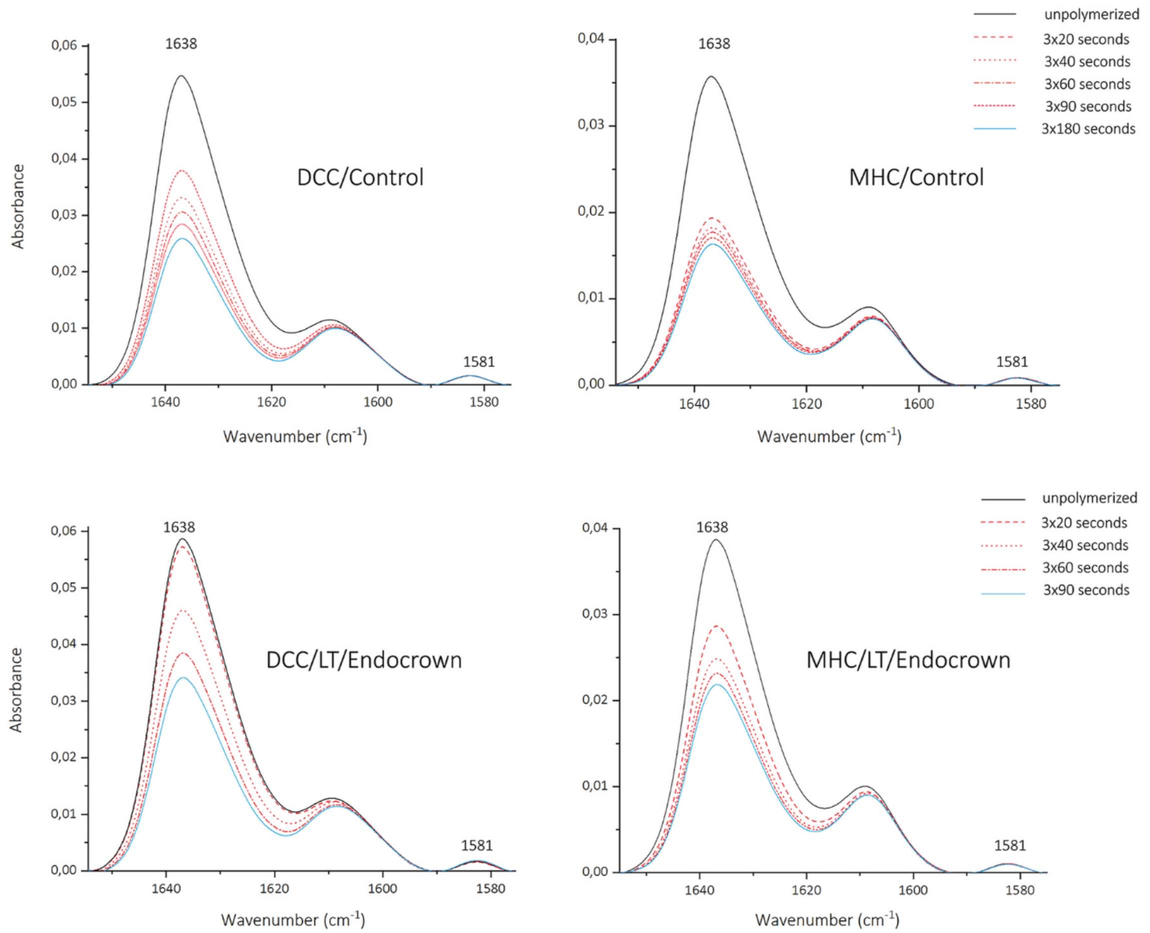

Fig. 2. FTIR absorbance spectra after baseline correction for dual-curing resin cement (DCC) and microhybrid composite (MHC) during the different polymerization times without restoration and polymerized through low translucency (LT) endocrowns.

restoration was significantly more polymerized as compared to a LT/Endocrown restoration (see Fig. 3). This was not the case for the dual-curing resin cement polymerized under the endocrown restorations after 3 × 60 ($p = 0.64$, $r = 0.40$) and 3 × 90 s ($p = 0.64$, $r = 0.29$).

3.2. Type of restoration

For the light-curing composite, only the presence of a LT/Endocrown restoration significantly reduced the relative degree of conversion as compared to the control with no restoration (all $p < 0.00$ after all polymerization times; see Fig. 4). For the dual-curing resin cement, conversion rate was significantly decreased by LT/Onlay and LT/Endocrown restorations as compared to the control (all $p < 0.05$ after all polymerization times). When comparing the type of restoration (HT/Onlay versus HT/Endocrown, LT/Onlay versus LT/Endocrown; see Fig. 4) within the composite (cement) group, there was no significant difference in the relative degree of conversion up to 3 × 60 s (all $p > 0.05$). However, after 3 × 90 s ($p = 0.04$, $r = 0.58$), the light-curing resin composite had a significantly lower relative degree of conversion when cured through the LT/Endocrown than the LT/Onlay. Restoration type had no influence on the relative degree of conversion for the dual-curing resin cement.

3.3. Type of cement

After 3 × 20 s of polymerization, the light-curing composite performed with a statistical significantly higher degree of conversion under all restoration types as compared to the dual-curing resin cement (all $p < 0.00$; see Fig. 5). After 3 × 40 s, the light-curing composite polymerized at a higher degree than the dual-curing resin cement for the control group ($p = 0.02$, $r = 0.63$), HT/Onlay ($p = 0.00$, $r = 0.86$), LT/Onlay ($p = 0.00$, $r = 0.91$) and HT/Endocrown ($p = 0.00$, $r = 0.70$; see Fig. 5). However, there was no significant difference in relative degree of conversion between the composites cured under the LT/Endocrown restorations ($p = 0.06$, $r = 0.57$). After 3 × 60 s, there was still a significant difference between the light-curing composite and dual-curing resin cement polymerized through the HT/Onlay ($p = 0.00$, $r = 0.84$) and LT/Onlay restoration ($p = 0.00$, $r = 0.85$) and HT/EC ($p = 0.01$, $r = 0.64$). There was no significant difference between the control groups ($p = 0.08$, $r = 0.55$) and LT/Endocrown restoration ($p = 0.54$, $r = 0.43$). After 3 × 90 s, the light-curing composite performed with higher conversion rates under the HT/Onlay ($p = 0.00$, $r = 0.78$) and LT/Onlay restorations ($p = 0.00$, $r = 0.81$), but not for the control ($p = 0.64$, $r = 0.38$), HT/Endocrown ($p = 0.09$, $r = 0.54$) and LT/Endocrown restorations ($p = 0.64$, $r = 0.29$).

3.4. Polymerization time

For all groups, there was a statistically significant influence of polymerization time on the relative degree of conversion, $\chi^2(3) = 45$, $p = 0.00$. Polymerizing 3 × 20 s resulted in a significantly lower degree of conversion as compared to 3 × 60 ($p = 0.00$, $r = -0.32$) and 3 × 90 s ($p = 0.00$, $r = -0.47$). There was also a significant difference between 3 × 40 and 3 × 90 s ($p = 0.00$, $r = -0.32$). No significant difference was found between 3 × 60 and 3 × 90 s light-curing ($p = 0.20$, $r = -0.16$).

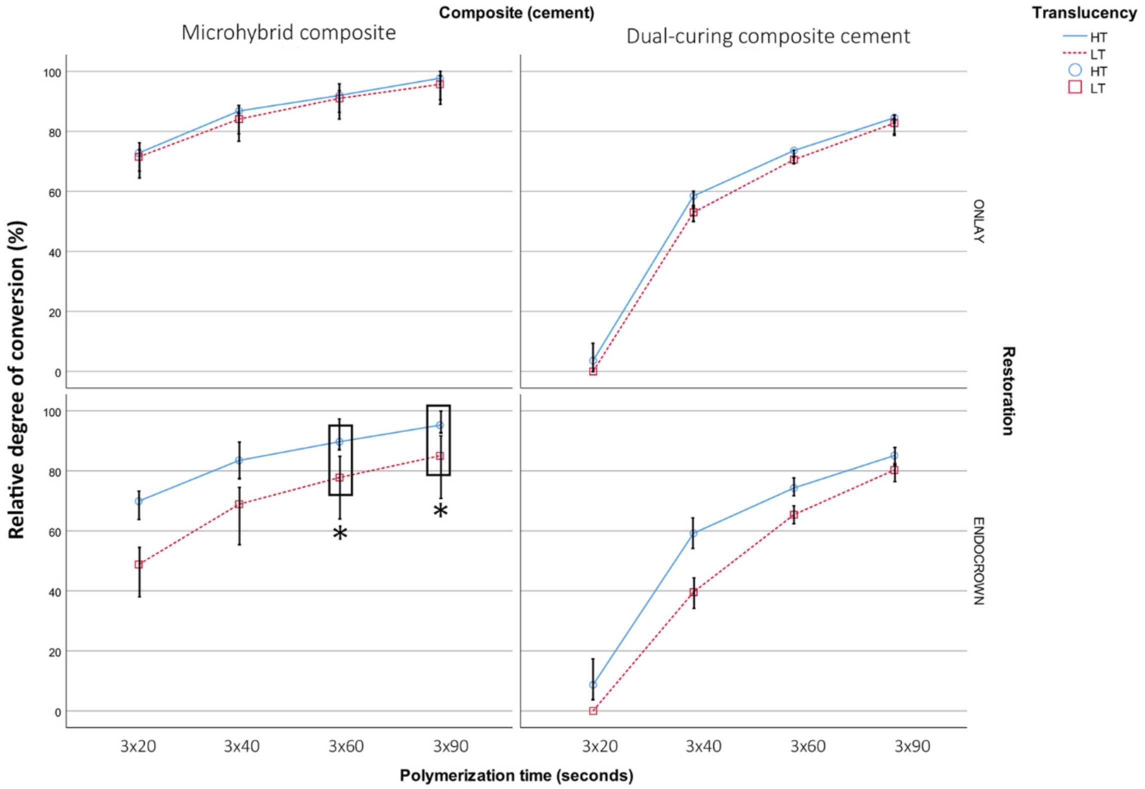

Fig. 3. Line graph with the median relative degree of conversion (including interquartile range) for the light-curing and dual-curing composite (cement) through onlays and endocrowns, grouped by translucency. Black boxes assigned with an asterisk highlight significant differences. HT: High Translucency; LT: Low Translucency.

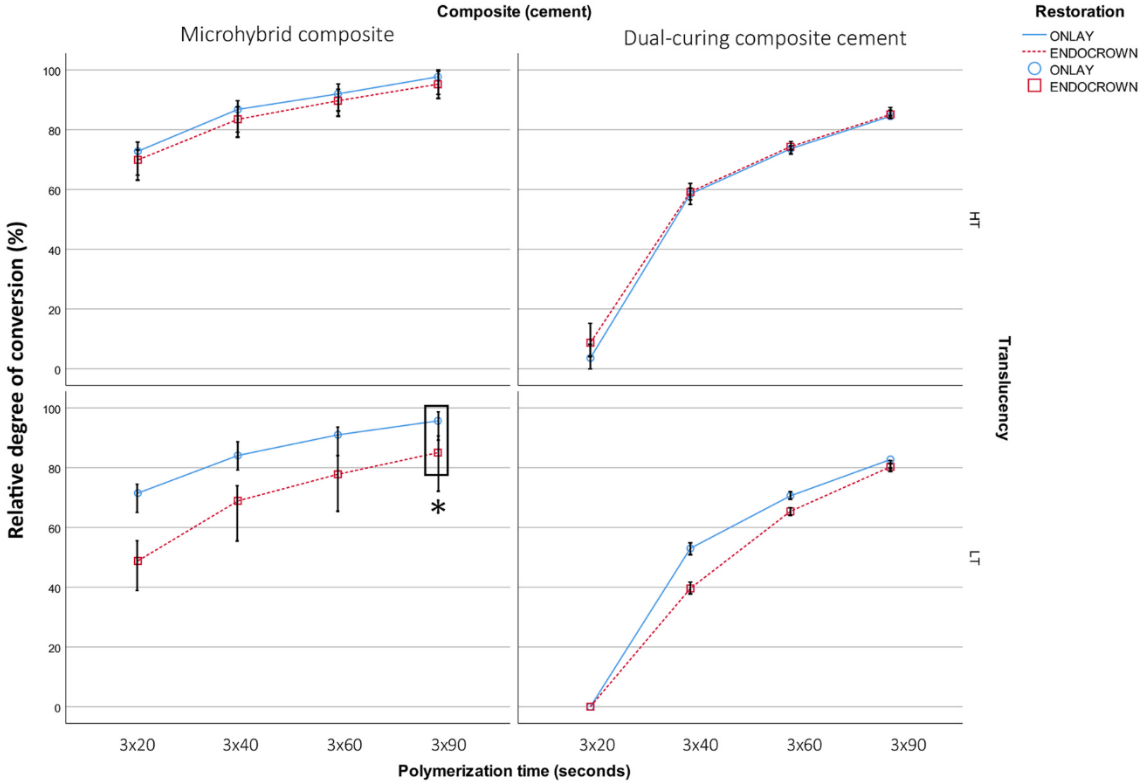

Fig. 4. Line graph with the median relative degree of conversion (including interquartile ranges) for the light-curing and dual-curing composite (cement) through onlays and endocrowns, grouped by restoration. Black boxes assigned with an asterisk highlight significant differences. HT: High Translucency; LT: Low Translucency.

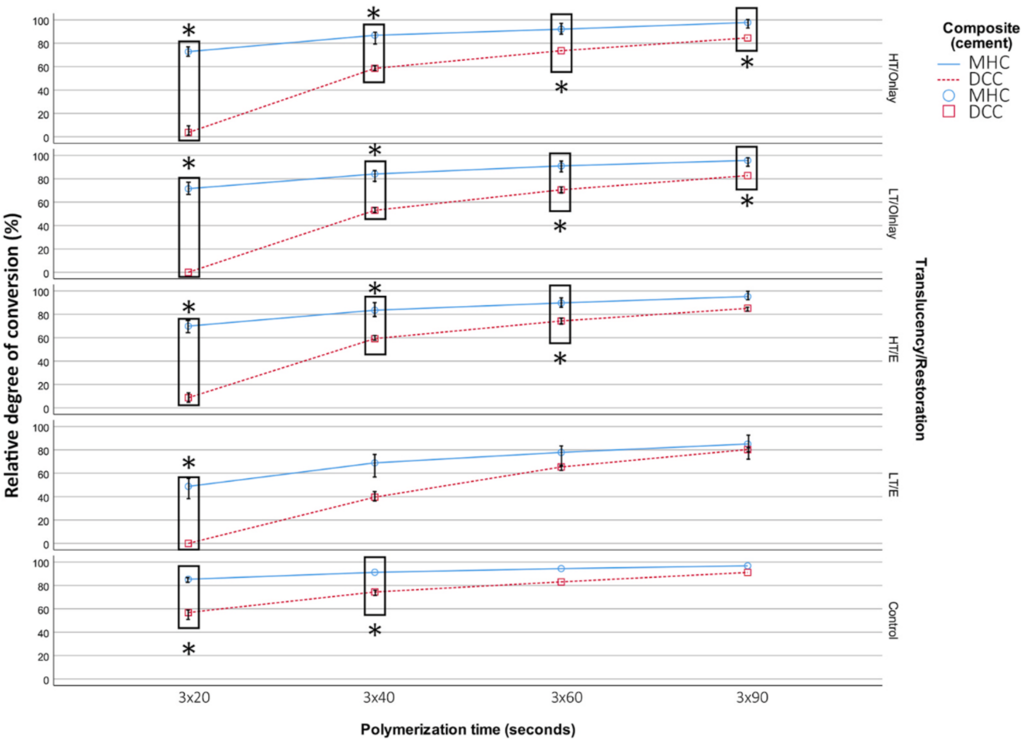

Fig. 5. Line graph with the median relative degree of conversion (including interquartile ranges) for the light-curing and dual-curing composite (cement) through onlays and endocrowns, grouped by cement. Black boxes assigned with an asterisk highlight significant differences. MHC: microhybrid composite; DCC: dual-curing resin cement; HT: High Translucency; LT: Low Translucency; E: Endocrown.

4. Discussion

The goal of this in vitro study was to investigate the influence of the restoration type, ceramic translucency and polymerization time on the relative degree of conversion of a dual-curing resin cement and a light-curing composite using a high-power light-curing device. Null hypothesis was that the restoration type and ceramic translucency would have no effect on the relative degree of conversion of the dual-curing resin cement and the light-curing resin composite. Based on the results, the null hypothesis was rejected, since both restoration type and ceramic translucency influenced the relative degree of conversion of the light-curing composite.

The presence of a low translucent lithium disilicate endocrown restoration significantly reduced the relative degree of conversion for both the light- and dual-curing composite as compared to the control group (no restoration). This was corroborated by a meta-analysis of 7 FTIR studies that investigated the degree of conversion of light- and dual-curing cements under 3.0 mm lithium disilicate discs versus no restoration (Martins et al., 2019). However, in the current study no difference was found after polymerization of the light- and dual-curing composite without a restoration and under high translucent lithium disilicate onlays and endocrowns. A possible explanation for this difference is the pooling of both high and low translucent lithium disilicate discs in the meta-analysis. Light transmittance through the ceramic is of concern when using light-curing composites, since this might result in an insufficient degree of conversion, especially when the translucency of the ceramic is low (Archegas et al., 2012; Martins et al., 2019; Pereira et al., 2015). An increase in ceramic thickness has been shown to decrease irradiance of high-power light-curing devices by 99.4% and 99.7% for 4.5 and 6 mm thick low translucent lithium disilicate discs (Flury et al., 2013). Nevertheless, the 1638 peaks in the FTIR absorbance spectra of the light- and dual-curing composite under 7.5 mm thick low translucent endocrowns decreased after longer exposure times (see Fig. 2). A reason might be that the light-curing was not solely from the occlusal, but also in a 45-degree angle from the buccal and lingual direction, as is done clinically to ensure adequate polymerization in the approximal areas due to limitations in the light tip diameter. This reduces the distance of the light through the ceramic. However, the composite was still covered by the tooth mold. Enamel and dentin has been shown to negatively influence the light transmittance and a 3 mm thick dentin disc reduced the irradiance by 99.2% (Uusitalo et al., 2016). Polymerization is not determined by light transmittance alone. It can be influenced by, amongst others, type of initiators and/or monomer structure, exposure time, light tip diameter, wave length, irradiance or energy density, making polymerization kinetics complex event (Peutzfeldt and Asmussen, 2005; Price, 2017; Watts et al., 2019; Wydra et al., 2014). The exposure times in the current study (minimum of 1 min and maximum of 4.5 min) probably also attributed to the polymerization kinetics.

To the author's knowledge, no study investigated the degree of conversion via FTIR of light- and dual-curing composites lithium disilicate restorations >4 mm. More research is needed to analyze and corroborate the polymerization kinetics under such thick restorations. A low ceramic translucency for endocrown restorations only negatively impacted the relative degree of conversion for the light-curing composite after 3 × 90 s, whereas there was no difference between the relative degree of conversion through high and low translucent onlay restorations. This is in contrast with the results of a FTIR study on the degree of conversion of a light-curing composites under 2.0 mm thick high and low translucency lithium disilicate discs after 40 s, where the more opaque ingot resulted in lower degree of conversion (Liporoni et al., 2020). This was probably due to the longer polymerization times in the current study. However, two studies have investigated mechanical properties of light- and dual-curing composite through thick ceramic restorations (Gregor et al., 2014; Kameyama et al., 2015). Compared to the dual-curing resin cement, the light-curing microhybrid composite performed with significantly higher Vickers microhardness values through 7.5 mm thick resin composite and feldspathic endocrowns after

3 × 90 s of polymerization (Gregor et al., 2014). Also, the microtensile bond strength of a microhybrid composite used to bond 8 mm thick high translucent lithium disilicate inlays was significantly higher than the dual-curing resin cement after 40s of light-curing (Kameyama et al., 2015). Both studies used a high-power light-curing device, a microhybrid composite and golden standard dual-curing resin cement.

When comparing the luting agents in the current study, the light-curing composite outperformed the dual-curing resin cement in the onlay restorations. This is in line with another study (Scotti et al., 2016). There was no significant difference between the light- and dual-curing composite after 3 × 60 and 3 × 90 s of light-curing without a restoration and through an endocrown. This suggests a comparable result of the light-curing composite when compared to the golden standard dual-curing resin cement in such challenging situations. The polymerization kinetics of a light-curing microhybrid composite might be more efficient than a dual-curing resin cement due to the chemical component (Scotti et al., 2016). This can also be seen in the current study, when looking at the low median values for the dual-curing composite after 3 × 20 and 3 × 40 s.

Besides statistical significance, effect sizes are of importance. All effect sizes of the significant results were medium ($r \approx 0.30$) to large ($r \approx 0.60$). However, when looking at the minimum and maximum values in the worst-case scenario (LT/Endocrown) (supplement 1), it can be noted that for the light-curing composite after 3 × 90 s, the minimum value for the relative degree of conversion was 52.8% versus 75.4% for the dual-curing composite. For low translucent ceramic endocrowns it might therefore be advisable to use a dual-curing resin cement, since the range of values seem to be larger. As to polymerization length, it seems advisable to light-cure a minimum of 3 × 60 s for both types of composites under the high translucent endocrown restoration, since this was not statistically different from 3 × 90 s with a small effect size. For onlay restorations, a shorter polymerization time might be feasible, however more research is needed to confirm this.

In the current study, relative degree of conversion was calculated based on a reference value of the mean maximum difference between absorption peaks after 9 min of the control groups. The degree of conversion (DC) is usually determined by the decrease in aliphatic C=C bonds around 1638 cm^{-1} relative to an internal standard of the aromatic C=C bonds around 1608 cm^{-1} (Rueggeberg et al., 1990). The assumption is that this decrease in absorption reflects a proportional decrease in the concentration of the monomers during the polymerization and that full polymerization corresponds one-on one with the vanishing of the absorbance at 1638 cm^{-1}. However, not all composites contain aromatic molecules, but are based upon aliphatic monomers like urethane dimethacrylate (UDMA) or a mixture of both. Most of the modern composites use a blend of different monomers, as was the case for the composites under investigation (Collares et al., 2014). Besides the presence of UDMA monomers in both composites, they consist of a different monomer blend with unknown ratios of bis-GMA and other dimethacrylate monomers. Therefore the classical formula, based upon the work of Rueggeberg (Rueggeberg et al., 1990), might be suitable for comparisons within the composite groups, but validity can be hindered when one wants to compare both composites together. One way to overcome this problem, is to dilute the monomer blend in different concentrations in order to get a calibration curve which can serve as a reference. Another way is to set a reference value for each composite group that is considered fully cured (Monterubbianesi et al., 2016). In this study, the 9 min-cured samples served as a reference, hence the term ‘relative’ degree of conversion. It can therefore be expected that the values of this relative degree of conversion will be lower when taking a reference set after 24 h. One must keep in mind that the polymerization reaction continues even after light-curing. Degree of conversion of a light-curing resin cement was shown to increase from 39.8% to 71.7% after respectively 5 min and 72 h after polymerization through 2.0 mm lithium disilicate discs (Faria-e-Silva and Pfeifer, 2017). Therefore it is of interest if a difference between the light- and dual-curing composite exists after a prolonged time period, for example 24 h. Due to the nature of the experiment, the sample size and limitations in the accessibility of the FTIR spectrometer in this study, this was however not feasible. From a clinical point of view however, 9 min chairside polymerization can be considered as a ‘clinically optimum’ and further polymerization can be expected to occur. Clinical studies using a conventional direct composite to bond indirect restorations, show a clinical satisfactory performance (Barabanti et al., 2015; Bindl et al., 2005; Bresser et al., 2019; Frankenberger et al., 2000; Gresnigt et al., 2019; Schulte et al., 2005). However, the thickness and translucency of the restoration is not a factor that is clearly described and should be taken into account.

A limitation of FTIR analysis, is that the chemical component in the dual-curing system might influence the results and makes comparison to the light-curing composite at a specific time of polymerization difficult. However, the light-curing component might be more important for the degree of conversion (Flury et al., 2013). Within the limitations of the study, the use of light-curing composite for high translucent onlays and endocrowns and low translucent onlays seams feasible. More research is needed to understand the polymerization kinetics under thick lithium disilicate restorations.

5. Conclusion

The relative degree of conversion of the microhybrid composite was significantly lower under low translucent endocrowns, but was not affected under onlays or high translucent endocrowns. Ceramic translucency or restoration type did not influence the relative degree of conversion of the dual-curing resin cement. The relative degree of conversion of the microhybrid composite was significantly higher than the dual-curing resin cement when cured through onlay restorations, regardless of the ceramic translucency. There was no significant difference between the composites for the high and low translucent endocrown groups after 3 × 90 s of polymerization.

CRediT authorship contribution statement

Maurits C.F.M. de Kuijper: Conceptualization, Methodology, Investigation, Visualization, Data curation, Formal analysis, Writing – original draft. **Yori Ong:** Methodology, Investigation, Validation. **Tobias Gerritsen:** Investigation, Data curation. **Marco S. Cune:** Methodology, Validation, Supervision, Writing – review & editing. **Marco M. M. Gresnigt:** Conceptualization, Validation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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