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ORIGINAL ARTICLE

Curing efficiency of modern LED units

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Abstract Recent reports claim that modern light-emitting diode (LED) curing units improve curing efficiency by increasing the units' irradiance. In this context also, short polymerisation times up to 5 s are proposed. The aim of this study was to examine whether there are differences in the curing efficiency of modern LED curing units by assessing their effect on two different composite materials and by varying the irradiation time. A nano- and a micro-hybrid resin-based composite (RBC) were polymerised for 5, 10 and 20 s with three commercial and a Prototype LED unit (Elipar™ S10). Cylindrical specimens (6 mm in depth, 4 mm in diameter) were prepared in three increments, each 2-mm thick, and were consecutively cured. Degree of cure was measured for 20 min in real time at the bottom of the samples, starting with the photoinitiation. The micro-mechanical properties (modulus of elasticity, *E* and Vickers hardness, HV) were measured as a function of depth, in 100-μm steps, on the above described samples stored in distilled water for 24 h at 37°C. Data were analysed with multivariate ANOVA followed by Tukey's test, *t* test and partial eta-squared statistics. In descending order of the strength of their effect, the type of RBC, depth, polymerisation time and curing unit were significant factors affecting the micro-mechanical parameters ($p<0.05$). The degree of cure at 6-mm depth was less but significantly influenced by the curing unit and curing time and was independent from the type of RBC. A 5-s irradiation time is not recommended for these units. Whereas a 5-s irradiation is acceptable at the sample's surface, a minimum of 20 s of irradiation is necessary for an adequate polymerisation 2 mm beyond the surface.

Keywords LED units · Micro-mechanical properties · Degree of cure

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Introduction

The quality of polymerisation in resin-based composites (RBCs) is determined by a variety of factors including not only the light-curing unit (LCU), irradiance and spectrum, irradiation time and technique ('soft-start', pulsed, high intensity), but also the type of resin-based composite and its formulation (shade, monomer composition, filler properties) [1]. The size of filler particles incorporated in the resin matrix of commercial composites has continuously decreased over the years from the traditional to the nano-hybrid materials, thus influencing also the light attenuation due to transmittance, absorption and scatter within the material [2, 3]. The modification of filler size and morphology created RBCs with improved mechanical properties and aesthetics compared with earlier composite materials [4]. The main advantages of nano-RBCs are seen in their improved aesthetics, being easy to polish, with polish retention similar to those of microfilled composites, and high translucency. However, their physical properties and wear resistance are equivalent to those of several hybrid composites [5]. Nano-hybrid RBCs are also characterised by a similar flexural strength, higher diametral tensile strength but a lower flexural modulus, compared to micro-hybrid RBCs [6].

While most dentists are still using quartz–tungsten–halogen (QTH) light-curing units, the convenience of light-emitting diode (LED) units is making them more and more popular [7, 8]. Designed to be perfectly adapted for activating camphorquinone (CQ) [9], the most popular initiator in resin-based composites, the emission spectra of the LED units is narrow, excluding an infrared emission.

For properly curing RBCs, a minimum dose was proposed (16.8 J/cm² for a 1-mm increment [10], 24 J/cm² for 2-mm increments [11]), being calculated as a simple reciprocal relationship between irradiation and irradiation time. According to the reciprocity, if the irradiation is increased, the corresponding time can be proportionally decreased. Within a given dose, statistical equivalence was noted for most of the combinations of irradiation–irradiation time, but exceptions occurred by short exposure times [12]. Criticism to this concept also arises, demonstrating that calculations based on total energy delivered to guide irradiation protocols are invalid and do not recognise product behaviour [13].

The majority of the currently used LED LCUs belong to the second-generation LED LCUs with a single, high-powered diode. Improving the diode technology allowed a continuous increase in the unit's irradiance and, consequently, a reduction in the recommended irradiation time. Studies demonstrated that polymerisation times of 10–20 s with modern LED LCUs are sufficient for proper curing of RBCs [14, 15]. These findings encouraged the manufacturer of LED LCUs to claim that a further increase in irradiance will allow even shorter polymerisation times, up to 5 s, for a clinically appropriate polymerisation [16].

The purpose of this study was, therefore, to examine whether there are differences in the curing efficiencies of several modern LED units and if a short polymerisation time (5 s) is sufficient to properly cure two different types of RBCs in simulated deep cavities.

The null hypotheses were: (a) there would be no significant differences in the effect of the LED curing units on the micro-mechanical properties–Vickers hardness (HV) and modulus of elasticity (*E*)–and degree of cure (DC) of RBCs, (b) the polymerisation time will not affect the measured properties (HV, *E*, DC).

Materials and methods

A nano-RBC (Filtek Supreme XT, 3M ESPE) and a micro-hybrid RBC (Filtek Z250, 3M ESPE; Table 1) were polymerised for 5, 10 and 20 s using three commercially available LED units and a LED Prototype (Table 2). The variation of micro-mechanical properties–HV and *E*–with depth and the degree of cure were measured.

Curing units

Curing units were used in the standard curing mode. Irradiances of the tested curing units were determined by means of a calibrated fibre optic spectrally resolving radiometer equipped with an integrating sphere (S2000, Ocean Optics; USA) by considering the dimension differences between curing unit tip and sample. Irradiances, passed through a round screen with an inner diameter of 4 mm (=dimension of cured samples) positioned at the centre of the curing unit tip, were thus calculated [17]. The distance between curing unit tip and screen was varied in 1-mm steps, starting at the screen surface up to 10 mm (n=10). The irradiance decrease rate as a function of the distance between the sample's surface and light guide was calculated.

Degree of conversion (DC)

DC was measured in a real-time profile (20 min, with 2 spectra/s) with an FTIR Spectrometer with an attenuated total reflectance (ATR) accessory (Nexus, Thermo Nicolet; Madison, USA). The non-polymerised composite paste was applied directly on the diamond ATR crystal in a white Teflon mould 6 mm in height and 4 mm in diameter. To

Table 1 Materials, manufacturer and chemical composition

Composite	Manufacturer LOT	Resin matrix	Filler	wt./vol.%
Micro-hybrid composite				
Z250	3M ESPE LOT 8EP, A3	BisGMA, BisEMA, UDMA	ZrO_2/SiO_2	84.5/60
Nano-composite				
Filtek Supreme XT	3M ESPE LOT 8PJ, A3B body	BisGMA, BisEMA, UDMA, TEGDMA	ZrO_2/SiO_2 cluster SiO_2 nanofiller	78.5/59.5

The filler amount is indicated in weight and volume percent

BisGMA bisphenol A dimethacrylate, *BisEMA* bisphenol A polyetheylene glycol diether dimethacrylate, *UDMA* urethane dimethacrylate, *TEGDMA* triethyleneglycol dimethacrylate

Table 2 Curing units (LED)

Curing unit	Manufacturer	Serial number	Light guide (mm)	Output peak wavelength range (nm)	Irradiance (mW/cm²)[a]
Freelight 2	3M ESPE	939820026192	8	430–480	1,444
Elipar™ S10 (Prototype)	3M ESPE	Prototype 2	10	430–480	1,757
Demi	Kerr	750005139	8	450–470	1,385
SmartLite™ PS	Dentsply DeTrey	DS00584	13	450–490	1,203

[a] Irradiance at the samples' surface, measured through an aperture of 4 mm in diameter

simulate a deep cavity, the mould was filled in three consecutive increments–each 2 mm high–cured by applying the curing unit on each increment surface from the top of the 6-mm high mould. DC was measured on the bottom of the samples (n=5) and was calculated by assessing the variation in peak height ratio of the absorbance intensities of methacrylate carbon double bond (peak at 1,634 cm^{-1}) and that of an internal standard (aromatic carbon double bond, peak at 1,608 cm^{-1}) during polymerisation, in relation to the uncured material.

$$DC_{peak}\% = [1 - \frac{(1,634\,cm^{-1}/1,608\,cm^{-1})_{\text{peak height after curing}}}{(1,634\,cm^{-1}/1,608\,cm^{-1})_{\text{peak height before curing}}}] \times 100$$

Micro-mechanical characteristics

Vickers hardness and modulus of elasticity profiles (n=5) were measured according to DIN 50359-1:1997-10 [18] through the middle of the samples described above and stored in distilled water for 24 h at 37°C. Prior to testing, the 6-mm-high samples were sectioned in the middle with a slow-speed diamond saw (Isomet low speed saw; Buehler, Germany) under water, ground (silicon carbide paper, LECO P1200) and polished with a diamond suspension (mean grain size, 1 μm). Measurements were made with an automatic micro-hardness indenter (Fischerscope H100C, Fischer; Sindelfingen, Germany) starting from 0.1 mm under the surface, with 100-μm intervals between the measuring points. The test procedure was carried out force-controlled, where the test load increased and decreased with constant speed between 0.4 mN and 500 mN. Load and penetration depth of the indenter were continuously measured during the load–unload hysteresis. Universal hardness is defined as the test force divided by the apparent area of indentation under the applied test force and was converted in the more familiar Vickers hardness units. The indentation modulus was calculated from the slope of the tangent of indentation depth curve at maximum force. Hardness and modulus of elasticity variations with depth were calculated for each group as a curve-fitted line, based on data from five samples (300 measuring points) (Fig. 1)

Statistical analysis

The Kolmogorov–Smirnov test was applied to verify if the data were normally distributed. Results were compared using one-way and multiple-way ANOVAs and Tukey's HSD post hoc test (α = 0.05). A multivariate analysis (general linear model) assessed the effect of the parameters' material type, depth, curing unit and curing time on the measured properties. A t test additionally analysed the differences in HV and E, measured at 0.1 mm and 6 mm (SPSS Inc., version 17.0; Chicago, IL, USA).

Results

For all curing units, irradiance decreased considerably with increased distance between the sample surface and curing unit tip, with less than one third of the total irradiance being available at a distance of 1 cm (Fig. 2a). The highest irradiance was produced by the Elipar™ S10 (Prototype) LCU (1,757 mW/cm²), followed by Freelight 2 (1,444 mW/cm²), Demi (1,385 mW/cm²) and Smartlite (1,203 mW/cm²). The irradiance decrease rate showed two different behaviour patterns (Fig. 2b), distinguishing between Smartlite, exhibiting the highest decrease rate until a distance of 5 mm and the lowest afterwards, and the other three units.

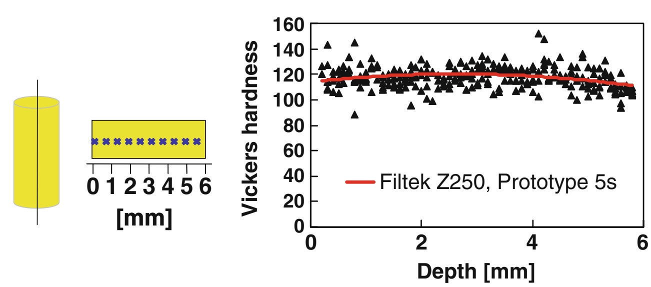

Fig. 1 Sample preparation and measurement of the micro-mechanical properties in 100-μm steps (*left*). Example of hardness variations with depth, calculated for each group as a *curve-fitted line*, based on data from five samples (300 measuring points) (Filtek Z250, cured with the Elipar™ S10 (Prototype) unit for 5 s).

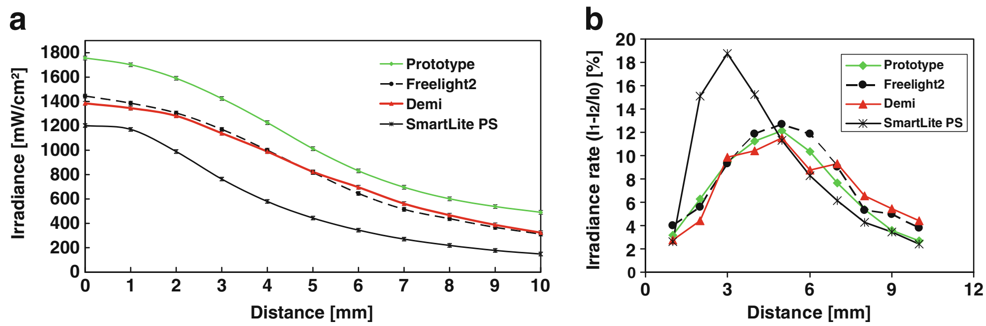

Fig. 2 **a** Irradiance passed through a round screen with an inner diameter of 4 mm, as a function of distance (average of ten measurements). **b** Irradiance decrease rate refers to the maximum irradiance of individual curing units

Figure 3 presents an example of the variation of HV as function of depth and curing time. The evolution of DC with time by different photoinitiation times of the same curing unit is presented in Fig. 4.

At the sample's surface, no significant difference in HV and *E* was observed in both RBCs as a function of curing time and curing unit. Significantly higher HV and *E* were measured in the micro-hybrid RBC when compared to the nano-RBC (Filtek Z250, E=18.14±1.44, HV=117.31±9.19; Filtek Supreme XT, E=15.24±1.93, HV=111.73±15.27). Similar is valid also at the 2-mm depth (Table 3), except for three groups showing significant higher values for *E* after curing for 20 s, compared to 5 s (Filtek Supreme XT cured with the Prototype and Filtek Z250 cured with Demi and Freelight 2). At the 6-mm depth, significantly decreased HV and *E* values were measured for all curing units and curing times between the top (0.1 mm) and bottom (6 mm) of the samples (*t* test analysis).

In descending order of the power of their effects, the type of RBC, depth, polymerisation time and curing unit were significant factors affecting HV and *E* (p<0.05; Table 4). The degree of cure at the 6-mm depth was weakly but significantly influenced by the curing unit and curing time and was independent from the type of RBC. Compared to the Elipar™ S10 with the highest irradiance, Demi induced significantly lower micro-mechanical properties, whereas Freelight 2 and Smartlite induced a significantly lower DC.

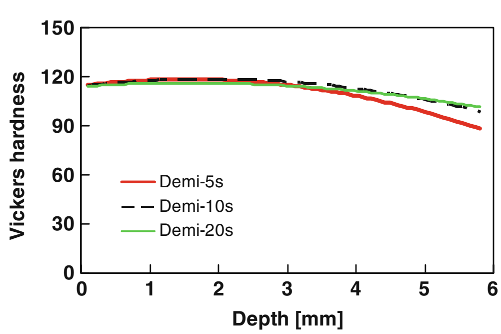

Fig. 3 Example for the variation of hardness as a function of depth and polymerisation time (Filtek Supreme XT, cured with the unit Demi for 5, 10 and 20 s)

Discussion

Within classical hardness measurements–Brinell, Knoop, Rokwell or Vickers hardness–only the plastic part of the indentation process is considered. But the deformation of a polymer-based material is a mixture of plastic and elastic components, thus necessitating new measuring approaches [18, 19]. To assess both the elastic and the plastic parts of deformation, a depth-sensing hardness measurement device was used in this study, where a dynamic measuring principle was applied by recording simultaneously the load and the corresponding penetration depth of the indenter [18, 19]. Besides hardness, the modulus of elasticity was considered as well, since it was found in previous studies that this parameter correlates well with the modulus of elasticity and strength measured in the more familiar three-point bending test [20]. Therefore, the results of the present study are able to provide an informative basis about the mechanical behaviour of the tested materials under the selected polymerisation conditions. In addition, these results at a macroscopic scale are of great importance clinically, since a material with a low modulus will more readily elastically deform under functional stresses, especially in a stress-bearing area. As for the degree of cure, the measurements were done at a clinically relevant depth by

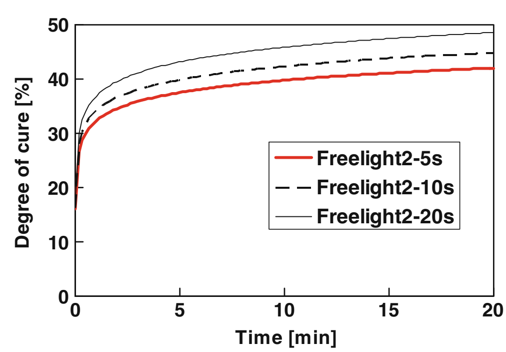

Fig. 4 Example of the evolution of the degree of conversion with time for the micro-hybrid composite Filtek Z250 by different photo-initiation times (5, 10 and 20 s) of the same curing unit (Freelight 2). *Curves* represent the mean values of five samples and were recorded with two spectra per second for 20 min (2,400 measurements per sample)

Table 3 Micro-mechanical properties–modulus of elasticity *E* (GPa) and Vickers hardness HV (N/mm²)–measured at 2 and 6-mm depths and degree of conversion at 6-mm depth

Unit	Time (s)	*E*–2 mm (GPa)	*E*–6 mm[a] (GPa)	HV–2 mm (N/mm²)	HV–6 mm[a] (N/mm²)	DC–6 mm[a] (%)
Filtek Supreme XT, nano-RBC						
Demi	5	15.61^{bc} (1.10)	8.90^{A} (4.50)	114.79^{abcde} (8.91)	63.50^{A} (39.34)	45.79^{cdef} (2.66)
	10	16.35^{bc} (0.47)	12.44^{BCD} (4.13)	117.20^{abcdef} (5.94)	91.61^{BC} (34.39)	45.83^{cdef} (1.96)
	20	16.19^{bc} (0.66)	14.76^{CDEF} (1.50)	113.99^{abcd} (5.69)	106.60^{CD} (11.41)	46.89^{ef} (2.94)
Elipar™ S10 (Prototype)	5	13.50^{a} (2.39)	13.33^{BCD} (1.98)	108.04^{a} (11.49)	110.95^{CD} (15.11)	45.47^{bcdef} (2.41)
	10	15.87^{bc} (0.49)	14.79^{CDEF} (1.61)	114.91^{abcde} (4.94)	104.28^{CD} (9.76)	46.72^{ef} (2.16)
	20	15.50^{bc} (0.37)	14.99^{DEFG} (1.18)	116.31^{abcdef} (3.30)	108.80^{CD} (10.57)	47.21^{f} (3.86)
Freelight2	5	15.01^{b} (0.62)	12.27^{B} (3.53)	109.55^{ab} (4.47)	83.34^{AB} (36.21)	41.14^{ab} (3.81)
	10	15.73^{bc} (0.75)	14.12^{BCD} (1.29)	114.90^{abcde} (6.33)	104.13^{CD} (11.57)	44.40^{abcdef} (2.65)
	20	16.27^{bc} (0.50)	14.12^{BCD} (1.60)	115.07^{abcde} (4.05)	104.46^{CD} (11.81)	47.31^{f} (2.96)
Smartlite	5	16.11^{bc} (1.29)	14.20^{BCD} (0.50)	116.56^{abcdef} (9.22)	103.00^{BCD} (7.65)	42.42^{abcde} (6.78)
	10	16.54^{cd} (1.30)	15.46^{DEFGH} (0.98)	116.95^{abcdef} (12.07)	112.40^{D} (9.15)	45.53^{bcdef} (3.05)
	20	16.39^{cd} (0.75)	15.15^{DEFG} (0.55)	116.33^{abcdef} (6.40)	109.17^{CD} (6.87)	45.85^{cdef} (2.44)
Filtek Z250, micro-hybrid RBC						
Demi	5	18.34^{ef} (0.86)	17.94^{IJK} (0.93)	118.30^{abcdef} (7.90)	113.89^{D} (7.57)	45.62^{bcdef} (2.61)
	10	19.05^{efgh} (0.68)	17.93^{IJK} (1.01)	119.55^{bcdef} (6.92)	115.72^{D} (7.35)	45.98^{cdef} (1.95)
	20	19.74^{gh} (0.98)	17.94^{GHIK} (1.37)	121.25^{cdef} (7.71)	112.54^{D} (11.04)	46.89^{ef} (2.69)
Elipar™ S10 (Prototype)	5	18.73^{efg} (1.23)	17.76^{IJK} (1.37)	122.01^{cdef} (12.35)	115.49^{D} (9.82)	45.46^{bcdef} (2.31)
	10	18.69^{efg} (1.40)	17.31^{GHIJK} (2.21)	122.06^{cdef} (10.63)	114.93^{D} (15.76)	46.43^{def} (2.10)
	20	18.98^{efgh} (0.67)	19.90^{K} (1.23)	124.75^{def} (15.38)	120.22^{D} (11.23)	46.70^{ef} (4.37)
Freelight2	5	17.71^{de} (1.61)	16.65^{FGHI} (2.30)	122.58^{cdef} (12.94)	112.79^{D} (12.24)	40.78^{a} (3.38)
	10	19.42^{fgh} (1.01)	18.26^{IJK} (1.54)	126.15^{ef} (10.60)	114.79^{D} (11.49)	43.54^{abcdef} (3.41)
	20	20.33^{h} (2.31)	19.40^{IJK} (1.07)	127.37^{f} (18.37)	122.23^{D} (8.93)	46.88^{ef} (2.93)
Smartlite	5	18.20^{ef} (1.28)	16.57^{EFGHI} (1.35)	115.22^{abcde} (10.91)	107.31^{CD} (10.71)	41.73^{abc} (6.63)
	10	18.26^{ef} (0.87)	17.65^{HIJK} (0.83)	112.74^{abc} (8.76)	112.00^{D} (10.42)	42.10^{abcd} (8.29)
	20	18.08^{ef} (1.00)	17.90^{IJK} (1.30)	125.88^{ef} (11.85)	113.96^{D} (7.10)	46.32^{def} (3.84)

Superscript letters indicate statistically homogeneous subgroups (Tukey's HSD test, α=0.05)

[a] The 6-mm samples were made in three consecutive increments–each 2 mm high–cured by applying the curing unit on each increment surface from the top of the 6-mm high mould

simulating 6-mm deep cavities, being filled in three consecutive and separately polymerised increments.

The measurements were carried out on two different types of RBCs–a micro-hybrid (Filtek Z250) and a nano-RBC (Filtek Supreme XT)–sharing the same chemical formulation of the organic matrix and fillers, but having different filler sizes and consistencies. The influence of filler size, which determines the type of RBCs, on the measured properties could be, therefore, directly assessed. Filtek Supreme XT was the first commercially available nano-RBCs and contains as fillers a combination of non-agglomerated/non-aggregated, 20-nm nanosilica filler and loosely bound agglomerated zirconia/silica nanocluster. As for Filtek Z250, the zirconia/silica fillers are present as larger (3.5–0.01 µm) bulk fillers (manufacturer information).

Table 4 Multivariate test (general linear model): influence of material type, curing unit, curing time and depth on the micro-mechanical properties—modulus of elasticity, *E*, Vickers hardness, HV and degree of cure; the higher the partial eta-squared values, the higher the influence of the selected variables on the measured properties

Variable	Composite	Unit	Time	Depth
E-modulus	.449	.066	.115	.118
Vickers hardness	.145	.061	.079	.108
Degree of cure	Not significant	.041	.064	

The four evaluated LED LCUs belong to the most popular modern units on the market. The prototype included in this study was recently launched on the market under the name Elipar™ S10. Since the sample geometry (4 mm in diameter) and the dimension of the light guides (8 mm–13 mm) are different, only the irradiance reaching the sample surface was calculated [17] and considered in the statistical analysis. Despite the consistent differences in irradiance (1,757 mW/cm² to 1,203 mW/cm²), the effect of the curing unit on the measured properties was low. The results confirm that the efficiency of the polymerisation reaction is limited, and an unrestricted increase in irradiation will neither be able to accelerate nor improve this process. It seems that the irradiance of modern LED LCUs has already reached a saturated level, and there is no need for an additional increase. This is in agreement with reported work showing no benefit from increasing irradiance beyond about 1,000 mW/cm^2 [13]. This statement is, however, valid for situations in which the access of light is easily assured. By polymerising through thick ceramics, enamel etc., higher irradiations will be necessary, since the irradiance is rapidly lowered with the distance (Fig. 2a).

The polymerisation time affected significantly all measured parameters. The most sensitive parameter to variations in polymerisation time was the modulus of elasticity, starting to be noticeably influenced by the polymerisation time beyond a depth of 2 mm. Even though the radiant energy concept is not generally accepted, short polymerisation times of 5 and 10 s gave, in our study, dose values lower than 24 J/cm^2, which is considered a limit value for proper polymerising 2-mm increments [16]. Nevertheless, the modulus of elasticity measured in our study confirms the necessity for this minimum dose and, within the curing conditions we adapted, the necessity for a 20-s polymerisation.

Even though a 5-s irradiation induced a significantly lower degree of conversion at the 6-mm depth compared to a higher irradiation time, the differences were lower than expected. These findings could lead to the assumption that short polymerisation times of 5 s are acceptable. However, the degree of conversion measurements at the 6-mm depth (41.14–47.31%) were consistently lower, when compared to those measured under similar conditions at the 2-mm depth for the same nano-RBC Filtek Supreme XT (52.6% for a 10-s polymerisation with the LED unit Bluphase to 59.1% for a 40-s polymerisation with the QTH unit Astralis 10) [15]. This comparison forces the conclusion of the statistical analysis to be drawn thoughtfully. Though the differences in the degree of cure at the 6-mm depth between the 5, 10 and 20-s irradiation times were low, the 20-s irradiation was also insufficient to cure the RBCs as good as in the 2-mm depth. A high degree of cure is, however, of great importance in RBCs, since it was often shown that a lower conversion affects many properties, including mechanical behaviour, solubility, dimensional stability, colour change or biocompatibility [21–23], playing an important role for the ultimate success of a restoration. The degree of conversion in our study was measured during the first 20 min after starting the photoinitiation. Depending upon the RBCs, the post-irradiation conversion was shown to be consistent (19–26% of the final conversion) [24]. Post-irradiation conversion seems, however, not to be sufficient, especially connected with short polymerisation times, since it has been demonstrated that 7 days after polymerisation, leaching of monomers from RBCs, cured for only a few seconds with a high energy unit, was four times higher than those cured with a regular QTH LCU for 40 s [24]. Moreover, the pressure to decrease the irradiation time below the at-present valid recommendations of 20–40 s will have, as a consequence, changes in the initiator systems or, more probably, an increase in CQ amount, again probably creating problems with colour stability or biocompatibility of RBCs.

The present study also showed that the RBC type significantly affected the micro-mechanical properties, but showed no effect on the degree of cure at the 6-mm depth. The influence of the composite material on the micro-mechanical properties was proven to be higher than the influence of polymerisation time, depth or unit. However, this effect resulted not particularly from the size of filler, but from the different filler loadings of the two materials. This is due to the fact that the micro-hybrid composite (Filtek Z250) is higher loaded than the nano-composite (Filtek Supreme XT). Superior mechanical properties, including flexural strength, modulus of elasticity or compressive strength, were observed also in other studies [6, 25] for Filtek Z250 when compared to Filtek Supreme XT. By enlarging the surface area-to-volume ratio of the fillers in nano-filled materials, an increased susceptibility to ageing was also reported [20, 26, 27]. On the other side, the special structure of the filler in nano-composites demonstrated that the 'nanoclusters' (Filtek Supreme) provide a distinct fracture mechanism [28], resulting in significant improvements in strength and reliability when subjected to cyclic pre-loading [29], which potentially in turn could improve the fatigue, hence enhance the clinical longevity of the nano-RBC.

The limitation of the present study is seen in the measurement of only one material of each RBC type–micro-hybrid and nano-RBCs–a fact that hampers the assigning of the determined effect of curing approach to the whole class of RBCs. Furthermore, the effect of ageing on the mechanical stability of RBCs as a function of curing conditions, which was not analysed in this study, could help to elucidate the long-term behaviour of a composite restoration. Therefore, a part (a) of the null hypothesis is partially rejected and a part (b) is rejected.

Conclusion

Significantly lower micro-mechanical properties were found in both types of RBCs and for all curing units and curing times between the top and bottom of the 6-mm samples made in three consecutive increments. While the micro-mechanical properties of the micro-hybrid RBC were higher compared to the measured nano-RBC, the degree of cure of the two materials was similar. There were few differences in the effect of modern LED LCUs on the measured properties. A 5-s irradiation time is not recommended for these units. A minimum of 20 s of irradiation is necessary for an adequate polymerisation 2 mm beyond the surface.

Conflict of interest The authors declare that they have no conflict of interest.

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