

LIGHT DIFFUSION THROUGH COMPOSITE RESTORATIONS ADDED WITH SPHERICAL GLASS MEGA FILLERS

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SUMMARY

Purpose. Evaluate how the spherical glass mega fillers (SGMFs) can positively interfere with light diffusion when incorporated in a composite restoration.

Materials and methods. 30 samples (Ss) were performed, applying 2 composite layers of 3 mm each: 6 were made with composite only; 6 with a layer of SGMFs of Ø1.5mm within the first layer of composite; 6 with 2 overlapping layers of SGMFs of Ø1.5mm; 6 with a layer of SGMFs of Ø2mm; 6 with 2 overlapping layers of SGMFs of Ø2mm. The curing time was set at 40s for the first layer, and 120s for the second layer, transilluminated through the first layer. Digital pictures were taken, in standardized settings, during the transillumination, and the light intensity was measured with a digital image analysis software.

Results. From a lateral view the Ss with a single layer of SGMFs of Ø1.5mm and Ø2mm, the relative increments of light intensity, were of 24.37% and 33.33% respectively. Concerning the Ss made with 2 layers of SGMFs, the relative increments were of 67.99% and 66.4% respectively. In front view has emerged a relative increase rate of light intensity of 53.66% and 79.58%, in the Ss with a single layer of SGMFs of Ø1.5mm and of Ø2mm respectively. Furthermore, in the Ss with two layers of SGMFs of Ø1.5mm and Ø2mm the relative increments were of 267.53 and 319.63% respectively.

Conclusion. The SGMFs are reliable in facilitating light diffusion within the light-curing composite resins.

Key words: composite fillers, spherical glass mega fillers, polymerization shrinkage, composite shrinkage, photo-polymerization, curing light, depth of cure.

Introduction

The increasing use of composite restorative materials in direct and indirect dental restoration, when affected by caries or traumatic pathologies, is drawing attention to some problematic related to the use of such materials, including the resistance to wear, the polymerization shrinkage, and the curing light penetration through the composite (1-3).

The research in this field is directed towards the pro-

duction of composite materials that, while ensuring high aesthetics, have both a clinical reliability and good mechanical properties, making these restorations suitable also in areas subjected to masticatory stress. To achieve this purpose, different inorganic fillers have been added to the composite materials, mostly based on glass or ceramic particles. Incorporation of these inorganic particles imparts several advantages: improved strength and wear properties; decreased linear coefficient of thermal expansion; reduced polymerization shrinkage. In addition, due to their transparency, these fillers facilitate the diffusion of the cur-

ing light through the composite material (3, 4).

Curing depth is considered a primary factor for clinical success of composite resin restorations, since it directly affects the physical properties of materials and longevity of restorations (5). Several variables may affect the light-curing effectiveness of composite resin materials, some of these are material-related (i.e.: resin shade; amount of photoinitiators; organic and inorganic matrix), others are operator-related (i.e.: the distance and orientation of light beams; restorative techniques) and others are even light-curing units-related (i.e.: the emission spectrum; light intensity; period of exposure; general status of the equipment) (5-10).

Energy of the light emitted from a light-curing unit decreases drastically when transmitted through resin composite, leading to a gradual decrease in degree of conversion of the resin composite material at increasing distance from the irradiated surface (5-7).

Decreases in degree of conversion compromise physical properties and increase elution of monomer and thus may lead to premature failure of a restoration or may negatively affect the pulp tissue (5, 10). When restoring cavities, with light-curing resin composites, the gold standard procedure recommend to apply and cure the resin composite in increments of limited thickness. The maximal thickness, for the single increment, has been generally defined as 2 mm (5-7). However, restoring cavities, especially deep ones, with resin composite increments of 2 mm thickness is time-consuming and implies a risk of incorporating air bubbles or contaminations between the increments. Thus, various manufacturers have recently introduced new types of resin composites, so-called "bulk fill" materials that are claimed to be curable to a maximal increment thickness of 4 mm (4, 5, 11). The use of Bulk-fill, besides the practical advantages, is also aimed to enable the bulk polymerization, since the latter seems to develop less shrinkage stress, in comparison to the incremental technique (12, 13). However, despite the use these latter materials, the problem to reach an adequate polymerization, in direct composite restorations, is still present and able to influence their ultimate success and longevity (5, 14). This issue depends not only on the irradiance of the curing light and irradiation time but also on the distance of the light tip from the tooth-restorative material (5, 15,

16). Because the light intensity diminishes as the tip of the source light moves away from the resin composite's surface, the light-curing tip unit should be in direct contact with the restoration's surface. However, sometimes cavity design does not allow the polymerization within this distance (5, 17).

In previous studies the use of spherical glass mega fillers (SGMFs) was proposed in order to reduce the shrinkage of composite resin in direct restorations (18-23). By means of both clinical evidences and *in vitro* experiments it has been possible to observe that SGMFs enabled the bulk polymerization, of the composite, in particular in the deep proximal boxes of Black class II cavities.

The aim of this article is to investigate the capacity of SGMFs, in increasing the depth of polymerization of photocurable composite resins.

Materials and methods

SGMFs preparation

Soda lime glass balls (SLGBs) (Rgpballs, Cinisello Balsamo - MI, Italy) of different diameter (i.e. 1.5, and 2mm) were selected for this study. The SDGBs were previously acid etched with a 40% Hydrofluoric acid (Suprapur®, Merk Millipore, Darmstadt, Germany) for 20 sec and then washed with deionized water for 3 min, followed by acetone (Emplura®, Merk Millipore, Darmstadt, Germany) for further 3 min prior to be dried in a preheated thermostatic oven (SCN 58 DG; Enrico Bruno, Torino, Italy) (100°C) for 10min. The SLGBs were then silanized with a mixture of silane methacrylate, phosphoric acid methacrylate and sulphide methacrylate in etanol solution (Monobond Plus, Vivadent, Schaan/Liechtenstein) for 60 sec. The silanated SDGBs were dried, in the above-mentioned preheated thermostatic oven, at 80°C for 10 minutes, then left at room temperature for 1h prior to be covered with a photocurable mixture of Bis-GMA (60%wt.) and triethylene glycol dimethacrylate (40%wt.) (Heliobond, Vivadent, Schaan/ Liechtenstein). Two groups, of approximately 300 units each, of SGMFs, were thus prepared.

Calibration method

An halogen curing unit (Blue light Pro, Mectron, Carasco - GE, Italy) was used for the test. Its light intensity was measured by means of a digital radiometer (Cure Rite Efes, model 8000, Efes Inc., Mississauga, Ontario, Canada). After 10 min of use, 6 consecutive measurements were made. The mean value of the light intensity was $307 \pm 30,81 \text{ mW/cm}^2$. The measurement was performed by placing the free end of tip on the sensor of the radiometer (Figure 1b).

Digital color pictures of the tip of the functioning curing lamp were taken, in complete darkness conditions, with a 1:1 ratio, by means of a full-frame digital camera (Alpha 7S, Sony, Tokyo, Japan) equipped with a macro objective (SP AF 90mm – f/2.8 Macro 1:1, Tamron, Saitama, Japan). During the procedure the camera sensor was orthogonal to the main axis of the PVC cylinder.

The digital color pictures were then converted to grayscale (8-bit) to calibrate the digital image analysis software (Image Pro Plus 4.1, Media Cybernetics, US), using Windows OS. Knowing the intensity value of the light, it was possible to assign, to each one of the 256 gray tones, an accurate value of light intensity expressed in mW/cm^2 . To black (tone 0) it was given the intensity value of 0 mW/cm^2 , while to the white color (tone 255) it was assigned the value of 307 mW/cm^2 .

The images were studied using as reference a line having the thickness of a pixel. In correspondence with this line the software attributed to the gray tone of each pixel, on the basis of the calibration, a light intensity value in mW/cm^2 (Figure 1c).

The scale of 256 shades of gray was also converted to a scale of pseudo-color, corresponding to the 256 luminous intensity values detected. Furthermore, 3D images were developed, and at each point of the analyzed section, the light intensity was converted in a height value on a third axis (Figure 1d).

The light emission at the lamp tip level was measured to be seen homogeneous during all tests. Thus the radiometer has been taking measurement characterized by a particularly low standard deviation value.

Samples preparation

A black PVC cylinder was used, one end had an inner diameter of 0.8 cm, equivalent to the diameter of the tip of the lamp, and the other end an inner diameter of 0.74 cm. This latter portion had a height of 0.67 cm.

The PVC black cylinder was inserted, with its large end, on the tip of the curing unit, and used as mold (Figure 1a). With a microhybrid composite resin material (Esthetic shade A2 Vita®, Surgi, Lainate – Mi, Italy) 30 cylindrical composite samples were performed, applying 2 composite layers of 3 mm each. Regarding the production method they were divided in 5 groups, of 6 each, as follow:

- Group 1: samples made with composite only;
- Group 2: samples with a layer of SGMFs of $\varnothing 2 \text{ mm}$, within the first layer of composite;
- Group 3: samples with 2 overlapping layers of SGMFs of $\varnothing 2 \text{ mm}$, each within a layer of composite;
- Group 4: samples with a layer of SGMFs of $\varnothing 1.5 \text{ mm}$, within the first layer of composite;
- Group 5: samples with 2 overlapping layers of SGMFs of $\varnothing 1.5 \text{ mm}$, each within a layer of composite.

The curing time, for the first layer, was set at 40s, while the second composite layer was light cured for 120s, by means of transillumination through the first layer.

Each composite layer, added with SGMFs, contained the same number of spheres: 7 when spheres of $\varnothing 2 \text{ mm}$ were used (Figure 1e), and 16 when spheres of $\varnothing 1.5 \text{ mm}$ were used; thus the total volume occupied by the SGMFs for each layer was comparable and respectively $29,4 \text{ mm}^3$ e $28,8 \text{ mm}^3$. Both the layers of composite only and composite layers added with SGMFs, prior to the photopolymerization, were condensed by means a stainless steel cylinder, with a diameter of 6,5 mm, specifically made for the purpose.

Authors have chosen not to use SGMFs of $\varnothing 1 \text{ mm}$, because it would have been hardly repeatable and reproducible to make samples with 56 spheres each.

The samples were made and held in position, for all the procedure, on top of the free surface of the lamp tip, by means of the PVC black cylinder.

At the end of the process, for each sample during transillumination, a picture from a frontal view, was taken, then, removing the PVC black cylinder, another

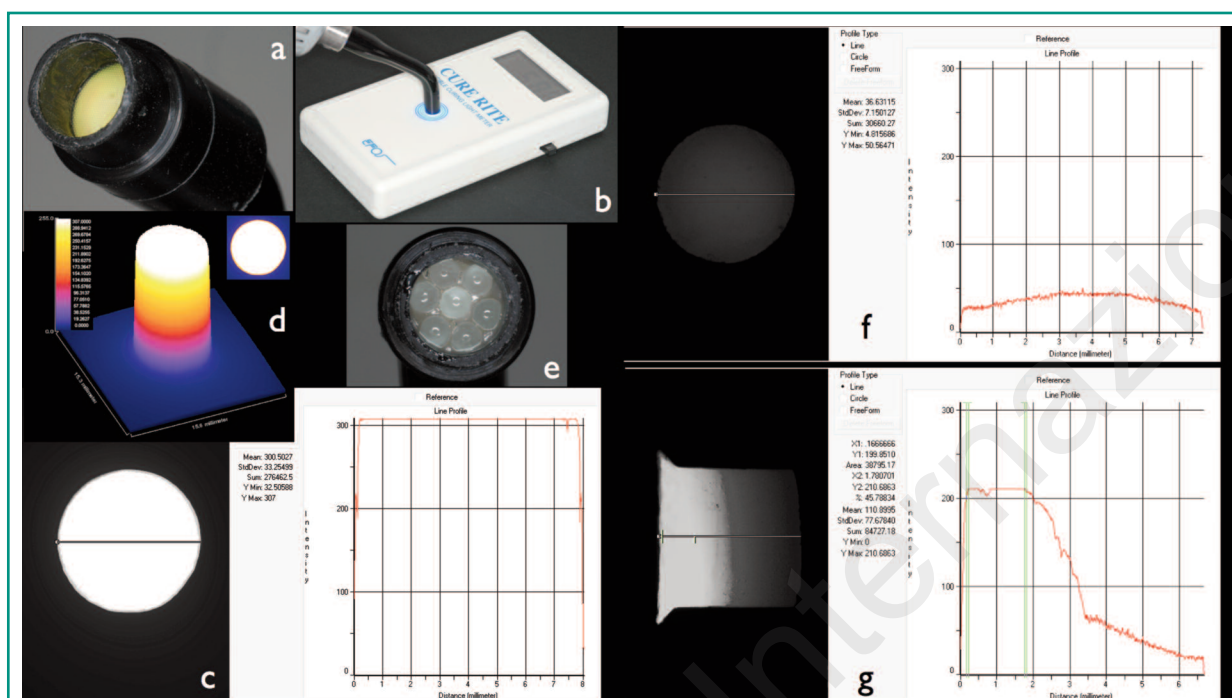


Figure 1
a) The PVC black cylinder, used as a mold for the samples, connected with the tip of the curing unit; **b)** the radiometer used in our experiences; **c)** once recorded the light intensity of the curing unit the calibration of the software was performed; **d)** 3D images were developed converting the light intensity in a height value on a third axis; **e)** the spherical glass mega fillers (SGMFs) of Ø2 mm were placed on the composite layer prior to be condensed; **f, g)** the analysis of a sample made of composite only, in frontal view (f) and lateral view (g).

picture was taken from a lateral view. Then the pictures were analyzed by means of the image analysis software. The both the instruments and the settings were the same of those above described for the calibration method.

Each sample, still connected with the tip of the curing unit, prior to remove the PVC black cylinder, was applied, with its free surface, on the sensor of the radiometer and then transilluminated in order to measure the light intensity.

Results

Group 1

The analysis of the transilluminated samples from a frontal view shows that the maximum values of light intensity are recorded in the central portions of the sam-

ple (mean value [MV] 50.56 ± 4.32 mW/cm²) (Figure 1f). Given the high thickness of the samples (6.7 mm) it is understandable that in these conditions the diffusion by the light is strongly hampered. Observing the samples on their lateral surface, always under transillumination, it's evident that the light intensity remains constant for 1.7 ± 0.2 mm, reaching in these conditions its maximum value (MV 210.6 ± 17.8 mW/cm²). Subsequently the intensity rapidly decreases (MV 60.3 ± 4.8 mW/cm²) in a space of 1.5 ± 0.1 mm, then a further minor decrease is observed (MV 22.5 ± 1.9 mW/cm²) at the distal limit of the sample (Figure 1g). The average values were, for the frontal view 38.2 ± 3.1 mW/cm², while for the lateral view 112.8 ± 10.1 mW/cm².

With regard to the measurements made by the radiometer, these have shown a particularly low value (MV 1.33 ± 0.52 mW/cm²) probably due to both a filter effect exerted by the samples and the modification of the length wave of light when passing through the same samples.

Group 2

The frontal view analysis of the transilluminated samples, made with a layer of spheres of Ø2 mm, highlights that the maximum luminous intensity (MV $84.27 \pm 6.9 \text{ mW/cm}^2$) is reached always in the central area of the sample (Figure 2a).

The analysis of the samples, from a side view, shows that the maximum luminous intensity in this group of specimens is superior to that obtained in those made of only composite (MV $211.89 \pm 17.8 \text{ mW/cm}^2$). The intensity is maintained constant for a mean thickness of $3 \pm 0.2 \text{ mm}$, after which, in the following $1.9 \pm 0.2 \text{ mm}$, rapidly decreases (MV $53.5 \pm 5.1 \text{ mW/cm}^2$), then a further minor decrease is observed, until the distal limit of the sample (MV $42.32 \pm 3.7 \text{ mW/cm}^2$) (Figure 2b). The average values were, for the frontal view $68.6 \pm 5.8 \text{ mW/cm}^2$, while for the lateral view $150.4 \pm 12.6 \text{ mW/cm}^2$.

Even in this case the intensity values, detected by the radiometer, are very low (MV $1.66 \pm 0.75 \text{ mW/cm}^2$).

Group 3

The analysis from the frontal view, of the transilluminated samples, made with 2 layer of spheres of Ø2mm, shows that the maximum values of light intensity are recorded close to the central portions of the sample (MV $205.87 \pm 12.6 \text{ mW/cm}^2$), even if with a slightly less homogeneous distribution in comparison to the samples of the other previous groups (Figure 2c).

From a lateral view the samples shows that the light intensity reaches the maximum value (MV $276.9 \pm 24.8 \text{ mW/cm}^2$) at a mean distance of $1.9 \pm 0.2 \text{ mm}$ from the light source. At the mean distance of $3.4 \pm 0.3 \text{ mm}$, from the tip of the lamp, the light intensity is still relatively high (MV $208.13 \pm 15.5 \text{ mW/cm}^2$), then progressively decreases, until reaching a MV of $53.5 \pm 3.9 \text{ mW/cm}^2$ close to the distal end of the sample (Figure 2d). The average values were, for the frontal view $160.3 \pm 13.3 \text{ mW/cm}^2$, while for the lateral view $187.7 \pm 13.7 \text{ mW/cm}^2$.

The radiometer recorded very low values of light intensity, not in agreement with those highlighted by the analysis of the images (MV $1.83 \pm 0.37 \text{ mW/cm}^2$).

Group 4

From a frontal view the analysis of this group of samples, made with a layer of spheres of Ø1.5 mm, shows that the maximum intensity of the light is always found in the central portion of the sample (MV $69.82 \pm 4.6 \text{ mW/cm}^2$) (Figure 3a). This value is higher than the ones detected in the samples with only composite, but, as expected, is lower than the value resulting from the analysis on the samples made with a layer of spheres of Ø2 mm.

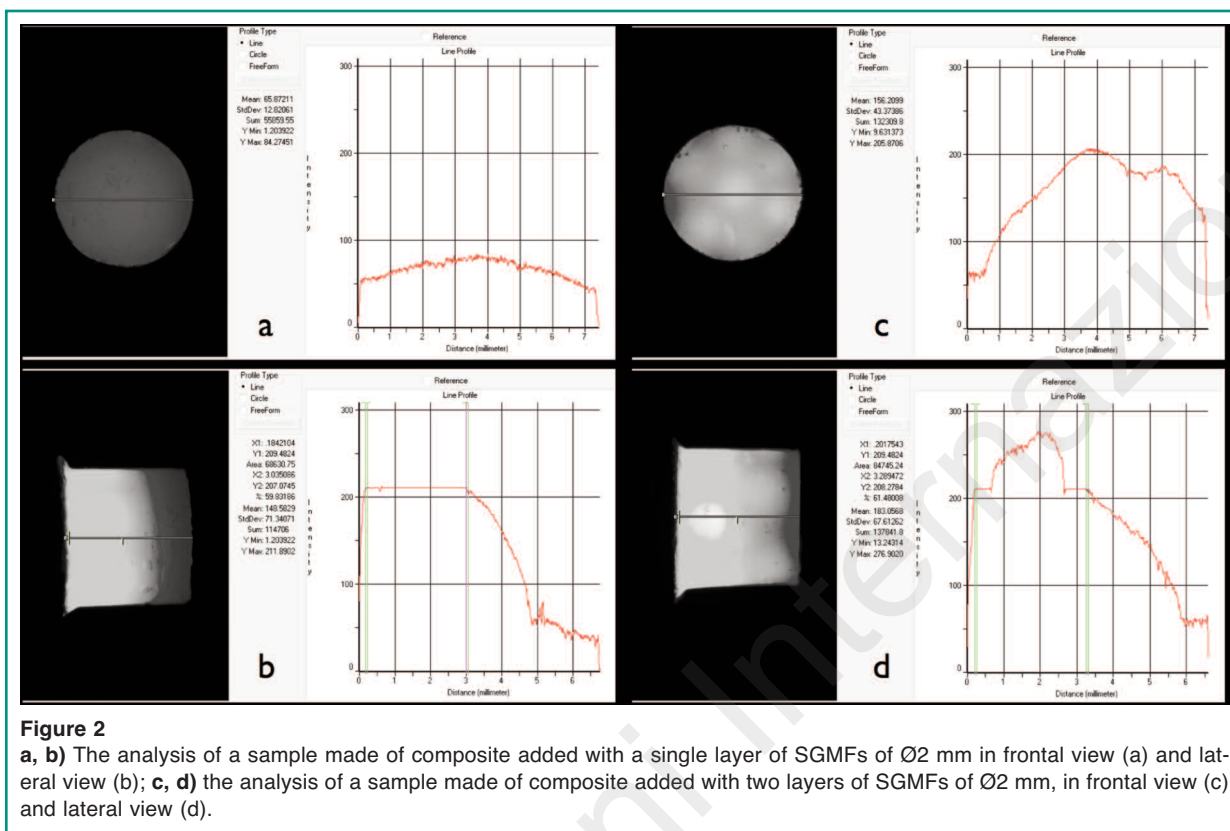
The examination of the side images highlights that for the first $2.7 \pm 0.2 \text{ mm}$ of the sample the light intensity is maintained constant (MV $211.9 \pm 19.7 \text{ mW/cm}^2$), then a sharp decrease, in light intensity, is observed at a mean distance of $4.5 \pm 0.3 \text{ mm}$ (MV $58.14 \pm 5.5 \text{ mW/cm}^2$), while, at the distal end of the sample, the intensity of residual light reached a MV of $34.65 \pm 2.8 \text{ mW/cm}^2$ (Figure 3b). The average values were, for the frontal view $58.7 \pm 4.5 \text{ mW/cm}^2$, while for the lateral view $140.3 \pm 9.8 \text{ mW/cm}^2$.

The intensity detected by the radiometer are, also in this case, very low (MV $1.5 \pm 0.5 \text{ mW/cm}^2$).

Group 5

From a frontal view, the analysis of this group of samples, made with 2 layers of spheres of Ø1.5mm, shows that the maximum intensity is close to the central portion of the sample (MV $210.68 \pm 28.9 \text{ mW/cm}^2$) (Figure 3c). The samples express a pattern of the light intensity curve quite irregular, thus not constantly decreasing from the center towards the periphery of the sample circumference.

The analysis of the images shows, in a lateral representation of some samples, a luminous intensity peak (MV $261.25 \pm 25.8 \text{ mW/cm}^2$), likely due to the very peripheral position of some spheres. This phenomenon was also observed in some samples pertaining to Group 3 (Figure 3d). Yet, along the first $3.3 \pm 0.3 \text{ mm}$ of the sample the light intensity is maintained constant (MV $210.46 \pm 25.8 \text{ mW/cm}^2$) then begins to decrease up to the distal portion of the sample (MV $65.11 \pm 5.8 \text{ mW/cm}^2$). The average values were, for the frontal view $140.4 \pm 28.3 \text{ mW/cm}^2$, while for the lateral



view $189.5 \pm 37.3 \text{ mW/cm}^2$.

The intensity measured by means of the radiometer assumes, also in this case, very low values ($\text{MV } 2.17 \pm 0.4 \text{ mW/cm}^2$).

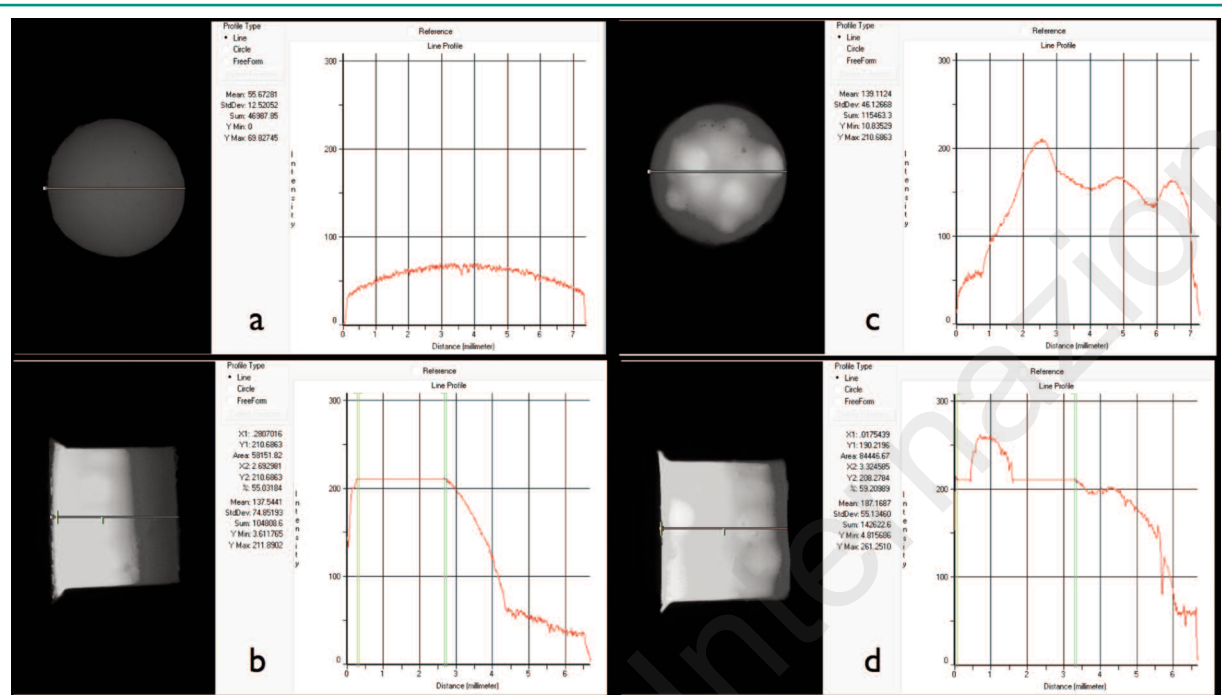
Discussions

Previous studies analyzed, both *in vivo* and *in vitro*, the effectiveness of spherical glass mega fillers (SGMFs) in composite direct fillings (8, 13). SGMFs are introduced into the mass of the composite prior to its polymerization in order to reduce the amount of resinous matrix, thus reducing the polymerization shrinkage. Furthermore SGMFs significantly contribute to the reduction of the adhesive interface solicitation; help to improve the marginal seal in interproximal cavities with cervical margins on the root cementum; facilitate the light diffusion in the context of the filling material; allow to carry out a bulk polymerization; shift to a more coronal level, the shrink-

age stress facilitating its dissipation by the cuspal compliance (18-23). This is relevant since sometime lost teeth can be cause of legal quarrel (24, 25) since they can substitute with dental implant (26-76) or orthodontic treatment (77-83).

The fact that the SGMFs could positively interfere with the photopolymerization reaction had been shown in a previous study which proved that, in accordance with the ISO 4049 regulations, an increase of polymerization depth was shown in samples containing these mega-fillers. This increase was supposed to be dependent to the transparency of the SGMFs, in which the light is diffused in a homogeneous way, thanks to the refractive indices of the constituents of the composite restoration (resin matrix and filler) closer to those of the spheres of mega-filler (22).

This study confirms the validity of SGMFs in increasing the diffusion of light through composite restorations. Results showed that the spheres of Ø2 mm determine, on an equal composite thickness, a lower light intensity attenuation than spheres of Ø1.5 mm. Previously had already been supposed that there was a

**Figure 3**

a, b) The analysis of a sample made of composite added with a single layer of SGMFs of Ø1.5 mm, in frontal view (a) and lateral view (b); **c, d)** the analysis of a sample made of composite added with two layers of SGMFs of Ø1.5 mm, in frontal view (c) and lateral view (d).

direct correlation between the diameter of the sphere and the depth of polymerization gain, along the axis of the light beam, passing through the center of the sphere; in this analysis this hypothesis is supported, especially since it is clear that the greater is the size of the element, with a lower coefficient of light attenuation compared to composite, the lower will be the same light attenuation (22).

The spheres of Ø2 mm are also positioned in the context of the samples in a repeatable and reproducible pattern, ensuring a more uniform distribution of light within the composite, while the spheres of Ø1.5mm, especially in the samples made by 2 layers, are distributed in a not-uniform pattern, thus making the diffusion of the light non-homogeneous.

This phenomenon is probably due to the fact that to obtain comparable samples between the groups, it was necessary to employ a greater number of spheres of Ø1.5 mm that, when compacted in the cylinder, couldn't arrange in a single-layer of spheres, as in the case of Ø2 mm.

The spheres of Ø1.5 mm resulted to be arranged on

two layers, where the spheres often presented a regular distribution on the deep layer, and a random distribution on the surface layer.

From a lateral view, analyzing samples with a single layer of spheres of Ø1.5 mm and Ø2 mm and samples with a two layers of spheres of Ø1.5 mm and Ø2 mm, the relative increments of light intensity compared with whole composite samples were of 24.37, 33.33, 67.99 and 66.4% respectively.

From a front view, analyzing samples with a single layer of spheres of Ø1.5 mm and Ø2 mm and samples with a two layers of spheres of Ø1.5 mm and Ø2 mm, the relative increments of light intensity compared with whole composite samples were of 53.66, 79.58, 267.53 and 319.63% respectively.

Therefore the transparency of the SGMFs facilitates the diffusion of light through the composite restoration, with obvious advantages, especially during critical situations such as in the case of deep proximal boxes in Black class II cavities.

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