Translucency & Radiopacity of Five Resin Composites

James M. Thompson, Jr. DMD

A thesis submitted in partial fulfillment of the requirements
for the degree of Masters of Science in Restorative Dentistry

Horace H. Rackham School of Graduate Studies
The University of Michigan
Ann Arbor, Michigan
2011

Thesis Committee Members:

Peter Yaman, D.D.S., M.S. (Chairman)
Joseph B. Dennison, D.D.S, M.S.
José Vivas, D.D.S.

Dedication

To my wife Lacy and son Colin.

To my parents Jim & Sue Thompson.

Acknowledgements

To the United States Navy for providing me the opportunity to continue my professional development.

To the members of my thesis committee for providing advice and guidance in the design and completion of this research.

To the staff and faculty of the Graduate Dentistry Clinic for their assistance during an educational three years.

To Delta Dental Fund for generously providing funding for this research.

To my classmates Fahad, Sarah, & Daisy for their friendship and camaraderie. The past three years wouldn’t have been the same without you.

Table of Contents

List of Tables

List of Figures

Chapter 1

Background

In recent years resin composites have been used extensively as an alternative to dental amalgams. With this increase in use has come the desire to improve the various properties (optical, physical, mechanical, etc.) of resin composites.

One property (optical) to consider is translucency. Translucency is a property of substances that permits the passage of light but disperses the light, so objects cannot be seen through the material[1]. Tooth enamel has inherent translucency, thus the task in dentistry is finding an esthetic dental restoration that has translucency properties similar to human enamel. The most common esthetic restorative material used is dental resin composite. The translucency of dental resin composites depends on their thickness and the scattering and absorption coefficients of the resin, filler particles, pigments, and opacifiers[2-4]. Thus, the inherent translucency of the material may contribute to matching the shade of the underlying tooth and the tooth adjacent to it.

Translucency of esthetic materials is usually determined with the translucency parameter or contrast ratio[5]. Translucency parameter refers to

the color difference between a uniform thickness of material over a black and white background, and corresponds directly to common visual assessments of translucency[6, 7]. If a material is absolutely opaque then translucency parameter will equal zero. Thus the higher the translucency parameter values, the higher the translucency of the material. The color of the esthetic material is measured using a reflection spectrophotometer and these coordinate values are used to determine translucency parameter. The coordinate values are part of a color notation system developed by Commission Internationale de l'Eclairage (CIE). The CIE L*a*b* (CIE76) system is predominantly used in dental related studies. The color coordinates are lightness/value (L*); and chromatic coordinates: green/red (a*) and blue/yellow (b*)[8, 9]. Once these coordinates are known translucency parameter (TP) can be found by the following equation:

$$\mathbf{TP= [(L^*_w-L^*_b)^2 + (a^*_w-a^*_b)^2 + (b^*_w-b^*_b)^2]^{1/2}.}$$

Translucency can also be determined by contrast ratio, which is used to measure the opacity of a dental material. Opacity, represented by contrast ratio, is the ratio between the daylight apparent reflectance of the specimen when backed by a black standard and the daylight apparent reflectance of the specimen when backed by a white standard[1]. Contrast ratio is calculated

using the following formula: Y_b/Y_w where Y_b represents the luminous reflectance against a black background and Y_w represents the luminous reflectance against a white background[10]. In comparison, as translucency parameter increases contrast ratio decreases.

There are many variables that may affect the translucency of a material. Such variables may include polymerization, shade, saliva, aging, and filler particle composition and size. The size and number of internal filler particles affect light scattering in resin materials thus affecting the translucency and visual appearance of the composite in relation to the underlying tooth[11].

Another property to consider is the radiopacity of a composite. Radiopacity is important because it can be used to evaluate marginal adaptation, detect caries, and assess the overall quality of a restoration, such as interproximal contours, contacts, overhangs, and voids[12-15]. Furthermore, composites that are not adequately radiopaque have been confused as secondary caries in subsequent recall appointments and restored unnecessarily.

One of the commonly used techniques to determine the radiopacity of a resin composite is the transmission densitometer. According to the International Standards Organization (ISO) 4049, the radiopacity of a 1.0

mm thick composite specimen should be equal to or greater than the same thickness of aluminum to be deemed radiopaque[16]. According to this guideline a 1mm thick specimen equivalent to 1mm thick aluminum would have a radiopacity approximately similar to dentin[12, 13].

Purpose

Determine and compare the translucency and radiopacity of five different composites.

Hypothesis

Primary

Ho_1 - There is no significant difference in translucency among 5 different composites.

Ha_1 – There is a significant difference in translucency among 5 different composites.

Secondary

Ho_2 – There is no significant difference in radiopacity among 5 different composites.

Ha_2 – There is a significant difference in radiopacity among 5 different composites.

Tertiary

Ho_3 – There is no correlation between translucency and radiopacity.

Ha_3 – There is a correlation between translucency and radiopacity.

Specific Aims

1. Determine if there is a statistically significant difference in translucency among different composites.
2. Determine if there is a statistically significant difference in radiopacity among different composites.
3. Determine if there is a statistically significant difference in radiopacity when comparing results from a photographic transmission densitometer and results from visual evaluation by two independent examiners.
4. Determine if there is a correlation between translucency and radiopacity.

Literature Review

Translucency

Thickness

Thickness of the composite is important in determining translucency. Ikeda, et al[17] evaluated the translucency parameter of three different composites based on shade (opaque A3 and A3), filler system (semi-hybrid, microfill, and small-particle-filled) and specimen thickness (1mm, 2mm). They also wanted to evaluate the ability of the composites to mask dark background color. Eighty-four (42 each) 1mm and 2mm disk shaped specimens were fabricated by placing composite in a 10mm diameter acrylic mold and held in place by two glass slides on each side. Each specimen was then cured 60 seconds each side. A colorimeter was used to record color measurements. Measurements were taken with the specimens against a black and white backing and also against a backing of the composite itself. From these measurements, translucency parameter (TP) was calculated and also ΔE^*, which was calculated from the coordinate values of the black backing and composite backing. Delta E was used to determine the ability of the composite to mask a dark background color. Results showed that opaque shades and 2mm thick specimens had lower TP values, thus less translucent, when compared to the regular shade composites and 1mm thick composites.

Also, 1mm thick specimens had a higher ΔE* thus demonstrating a lesser ability to mask dark background colors. This article is important because it adequately shows that there are multiple factors that affect translucency and all must be considered to a degree when selecting a composite.

Kamashima, et al[18] also looked at the translucency of different materials (composites of different shades- enamel, body, opaque) at varying thickness (0.5mm, 1mm, 2mm, 3mm, 4mm). They also wanted to evaluate the inherent colors of composites used for the layering technique. Acrylic molds 8mm in diameter and corresponding to the varying thickness were packed with composite, placed between glass slides, and held with finger pressure while cured 60 seconds on each side. Color measurements were taken with a colorimeter against a white and black backing and from these measurements translucency parameter (TP) was determined. Inherent color was determined by statistically analyzing (1 way ANOVA and Games-Howell post hoc test) the L*, a*, and b* values of the 4mm thick specimens over white backing. Results showed that in general as thickness increased, the TP values decreased regardless of shade. Among shades, there was less variation as thickness increased but the enamel shade tended to be the most translucent followed by the body shade then the opaque shade. Results of color tests showed that enamel shades were more bluish and the body and

opaque shades tended to exhibit brighter more yellowish characteristics with opaque shades having the yellowish characteristics. A potential flaw in this study is the fact they placed an importance on thickness of the specimen yet they used finger pressure to hold the glass slides over the acrylic mold. Something that applied consistent pressure should have been used and also the authors should have stated each specimen was measured with a micrometer to verify thickness.

Storage, Thermocycling, Aging

Buchalla, et al[19] wanted to determine if storage of specimens in a solution affected the color and translucency of resin composites. The purpose of this study was to determine color and translucency changes of 2 resin composites in dry storage versus wet storage. Ten specimens (1.2mm x 15.5mm) of each composite were placed in either dry storage or wet storage (distilled water) for 1 month. Specimens were also subjected to artificial light (10 hours/day) for 1 month. Color properties (L*, a*, b*) of each specimen were then recorded using a colorimeter after 1, 2, 4, 8, 16, 32, and 48 hours and then after 1 month. Contrast ratio was used for translucency and was configured after 1 month. Results showed wet storage resulted in significantly higher changes in color and contrast ratio (more

opaque) from baseline to the 1-month measurement. Changes were greater in the wet storage specimens when compared to those stored in dry storage. Those exposed to artificial light also showed greater color changes than those stored in the dark. However, even though these changes were significant in certain situations the authors pointed out that these changes would most likely not be perceptible under normal clinic conditions.

In 2005 Lee, et al[20] examined how translucency is affected by storage in salivary enzymes versus a phosphate buffered saline solution. The colors of specimens of 3 brands of resin composites of varying shades were measured after immersion in a phosphate based solution or a salivary enzyme esterase (ETE) for 9 weeks. From these color readings translucency parameter (TP) was determined and the results compared. Specimens were 1.75mm by 8mm and 10 specimens for each shade were prepared. Results showed much variation in translucency between shades of each composite and also among the 3 composites. In addition, translucency tended to decrease after 9 weeks storage in solution, regardless if it was the saline or ETE. However, there was no significant difference between translucency parameter whether stored in saline or the ETE solution. This is important because the results show that enzymes of saliva probably have little effect on the translucency of composite.

In 2006, Lee, et al[21] looked at 4 different types of materials (resin composite, glass ionomer, resin-modified glass ionomer, compomer) and examined the changes in optical properties after accelerated aging in an aging chamber. Specimens were of the same A2 shade and were 1mm thick by 38mm in diameter. Baseline and aging measurements were recorded with a reflection spectrophotometer and 2 modes (reflectance and illumination) of measurement were used. After baseline measurements, 3 specimens of each material were aged for an energy exposure of 150 kJ/m2 (approximately 3 months clinical service) under varying conditions. Condition variables included lighting, humidity, and temperature. After aging, the authors were looking for changes in color (ΔE^*), translucency parameter (TP), and opalescence parameter (ΔO^*). Results showed that accelerated aging influenced all materials and all optical properties significantly. Both glass ionomer materials were influenced the greatest, with the drop in TP being the biggest change. The resin composite and the compomer were the most stable with the authors determining the compomer the most stable. The biggest surprise here is the stability of the compomer but it would have been interesting to see if the changes would have been greater if the materials were aged longer.

As a follow up to the previous study, Lee, et al[22] looked at the opalescence and fluorescence of only resin composites after accelerated aging. The authors stated that since opalescence and fluorescence can influence translucency and masking effect, those properties after aging needed to be further investigated. Methods were similar to the previous study in respect to specimen size, aging procedures, and 2 modes of measurement with the reflection spectrophotometer. In this study, seven resin composites were used and an unfilled composite was used as a reference. An additional variable added to this study was inclusion/exclusion of UV-light. The authors stated that since UV light causes fluorescent emission in resin composites they wanted to examine what influence the inclusion/exclusion of UV light had on translucency parameter and masking effect of the composites. Results showed that opalescence values did not change significantly after aging even though UV inclusion/exclusion affected values significantly. Fluorescence, TP, and masking effect values changed significantly after aging. For fluorescence, the composite material influenced the value significantly but the mode of measurement did not. For translucency parameter, the composite material influenced the value significantly but inclusion/exclusion of UV light did not influence the values. The authors stated that since UV light

exclusion/inclusion affected values for opalescence and fluorescence significantly then the two variables were correlated. The significance of this article demonstrates once again how much translucency decreases with aging and this should be taken into consideration during shade selection of a resin composite.

In 2008, Lee, et al[23] examined how thermocycling 8 composites of varying shades affected different optical parameters (TP, ΔE*, Δ's in each coordinate, Δ in chroma). Specimens were 1mm thick by 12mm in diameter. Color coordinates were determined using a reflection spectrophotometer. Results showed color change was in the range of 1.1 to 4.6 ΔE* units and TP change was in the range of -3.8 to 0.1 which corresponds to a decrease in translucency. Chroma change was -2.0 to 4.6. The changes for the color coordinates were as follows: -2.4 to 1.3 for ΔL*, -0.3 to 2.1 for Δa*, and -2.0 to 4.5 for Δb*. Changes in all of the optical parameters were influenced by the brand of composite. These changes were consistent even with different brands of the same shade. Finally, the authors noted that Δb* was the most influencing factor on color change after thermocycling. The importance of this study supports other studies that color change and other optical parameters such as translucency parameter tend to vary according to the individual brand of composite.

Curing, Polishing, Shade

Yu, et al[5] aimed to measure and classify the translucency of varied brands and shades of resin composites. Yu looked at eight different composites and 41 different shades among these composites. Specimens were 1mm thick by 12mm in diameter. Color coordinates were measured with a reflection spectrophotometer against a white and black backing and also against the material itself. Translucency parameter (TP) and contrast ratio (CR) were calculated from the coordinate values. The results showed a TP value range from 8.5 to 20.6. This was significantly influenced by the shade designation of resin composite. Within each brand, TP values varied by shade designation. When comparing shades across brands there was no significant difference, although A1 shades had the highest mean TP values and A3.5 the lowest mean TP values. When comparing TP values to CR values there was a Pearson correlation coefficient -0.84. This means TP and CR are highly correlated and can be used interchangeably.

Ryan, et al[24] also looked at the translucency of composites in respect to shade. However, here the authors used only A2 or B2 shades and divided the classification of composites into opaque, dentin, body (universal), and enamel based on how the manufacturer classified the composite. The authors tested 39 composites (9 different brands) fabricating 4 specimens for

each composite. Specimens were 2mm thick by 13mm in diameter. They used a chroma meter to measure the specimens. Results showed, in general, opaque and dentin composites yielded relatively low TP values, body composites yielded intermediate values and enamel shades yielded the highest TP values. However, the values were indistinct and multiple values overlapped. The authors concluded that the values provided more information than the respective category types and thus it is best to know the translucency of a particular brand versus a particular category shade.

It is important to look at how curing and polishing affect translucency and color change and also what influence shade has on these optical parameters. In 2004, Lee, et al[25] examined all three variables when looking at a new nano-filled composite. The authors examined the color change, translucency parameter, and contrast ratio of a nano-filled composite before and after curing, polishing, and thermocycling. They used an enamel shade and translucent shade. The control composite was a hybrid. There were five specimens for each color measurement and all specimens were 2mm thick by 10mm in diameter. After measurements for pre-cure and after-cure were made, specimens were polished with 1500-grit wet and dry SiC paper on both sides. After measuring again, specimens were thermocycled for 2000 cycles then measured again. All color measurements were done with a

reflection spectrophotometer. Results showed that the average color change after curing was greatest with the translucent shade nano-filled group and least with the control hybrid group. After polishing and thermocycling there was no significant differences among the three groups of specimens. Translucency parameter increased for the enamel shade nano-filled specimens and control group but decreased for the translucent shade nano-filled composite after curing. Translucency parameter values increased for all groups after polishing. After thermocycling, TP values decreased for enamel shades and the control group but did not significantly change for the translucent shade group. Changes in contrast ratio values showed similar trends to the translucency parameter values. What is important about this study is that the mean values of color change of all the composites after curing was above 3.3, which means the change, would be clinically perceptible[1]. Therefore, composites, regardless of shade or type should be cured before shade selection.

Lee, et al[10] followed this study by examining how curing (before and after), polishing, and thermocycling affected changes in color, translucency parameter, and contrast ratio of many different brands of composites of the same A2 shade. Eight different brands of varying filler types were used. Methods and materials were the same as the previous study. Results showed

that color, translucency parameter, and contrast ratio changes varied specifically by brand of composite. Similar to the previous study all composites showed clinically perceptible color change after curing but only five of the eight composites showed clinically perceptible change after polishing and none of the composites after thermocycling. This study confirms the importance of curing the composite before shade selection but more explanation should have been given to the variability among brands of composites such as filler, organic matrix, etc.

Sidhu, et al[26] also looked at the effect curing had on the color change and translucency parameter of resin composites. The study compared three composites (Charisma, Solare, Filtek Supreme) and two shades (A2, opaque A2) of each composite. The specimens were 2mm thick by 8mm in diameter and color measurements were gathered using a colorimeter. Measurements were made before curing and after curing. Results showed that all three composites regardless of shade showed an unacceptable color change but the newer (author description) composites (Solare, Filtek Supreme) changed the least. The opaque A2 shades tended to change less than the A2 shade. As for translucency parameter, TP significantly increased after curing with the Charisma composite regardless of shade. In the other two composites, TP decreased but not significantly. This research

is important because the authors used slightly different methods and a different mode of measurement (colorimeter) yet still came up with the same conclusion that composites should be cured before shade selection.

Del Mar Perez, et al[27] evaluated the effect the method of polymerization had on the color and translucency of composite. Sixteen shades of different composites were polymerized with either a quartz-tungsten-halogen (QTH) light or a light-emitting diode (LED). Color of the specimens was measured with a reflection spectrophotometer pre and post polymerization. Specimens were 2mm thick by 6mm in diameter. Results showed that polymerization dependent changes in color and translucency were influenced by the type of light used. Translucency increased regardless of light but the changes in translucency were different for each light. Changes in translucency were mainly caused by a change in hue for the LED light and by change in chroma for the QTH light.

Filler, Matrix Content

Recently, an effort has been made to look at the inorganic filler and resin matrix of resin composites and what effect these components have on translucency and other optical parameters. In 2008, Lee, et al[11] sought to determine the influence filler size had on the translucency of an

experimental composite. The experimental composite had a resin matrix composed of a 1:1:1 mixture of BisGMA, UDMA, and TEGDMA. Two different sized (0.77um, 0.50um) silanized glass fillers (LG, SG) were added to the resin matrix. The fillers were added at varying percentages of weight (10, 20, 30, 40, 50, 60, 70 for LG and 10, 20, 30, 40, 50 for SG) so each composite had different filler contents. Camphoroquinone, hydroxytolulene, and ethyl methacrylate were added to form the rest of the experimental composites. Specimens were 1mm thick by 38mm in diameter. Color was measured in transmission and reflectance modes with a reflection spectrophotometer and the resulting color coordinates were used to find opalescence parameter and translucency parameter. Results showed that none of the experimental composites had an opalescence value higher than 9, which is what is needed to consider a composite opalescent. The authors speculated that was probably do to experimental design of the composite which caused the refractive index constant to be 1.03 when for a composite to emit opalescence the constant index must be over 1.1. As for translucency parameter, results showed that as the amount of filler increased the translucency decreased. There was no correlation between filler size and translucency in this study. The importance of this study is that filler amount and possibly size has an effect on translucency and other optical parameters.

Yu, et al[28] evaluated the color, translucency, and fluorescence of flowable resin composites and compared them to the corresponding shade (A2) universal resin composite of the same brand. Specimens were 2mm thick by 10mm in diameter and were measured against a black and white background and against the material itself using a reflection spectrophotometer. To measure fluorescent emission, spectrophotometer over a white background was switched to 0% UV light inclusion for an additional measurement. Results showed differences in color between the flowable and universal composite in a range from 1.0 and 6.0 ΔE_{ab} units, which means most of the composites had a clinically perceptible color difference despite being the same shade of the same brand of composite. In general all of the composites showed some form of fluorescent peak but there was no significant difference. As far as translucency, the mean values of TP for the flowable composites were higher than the universal composites and were significantly higher in two of the brands. The authors concluded that the lower filler content of the flowable composites influenced the translucency and also this difference in translucency between the two composites influenced the color. The experimental design of this study is good but the assumption that filler content, while probably correct, is the

only reason for the difference in translucency between the two composite is ignoring other variables that could be in play.

Azzopardi, et al[29] looked at the effect of resin matrix on the translucency of experimental dental composite resins. Three types of unfilled resin matrices (TEGDMA, UDMA, BisGMA based) were formulated then combined with constant filler loading to form different experimental composite resins. In addition, the amount of BisGMA matrix added to the composite varied on some composites. The specimens fabricated were 1mm thick by 15.5mm in diameter. The specimens were measured with a UV/VIS spectrophotometer, which was used to measure total and diffuse translucency transmittance values for each sample at varying wavelengths. Results showed that there was no statistical significant difference between the three unfilled matrices but with the addition of filler, the BisGMA composites showed significantly higher transmittance (translucency) values than the UDMA and TEGDMA based composites. The authors speculated this is probably because BisGMA has a refractive index (1.55) essentially the same as the silica filler used in the study. Finally, there was a linear correlation between the translucency and the percentage amount of BisGMA matrix added to the composite. The authors concluded that translucency is significantly influenced by resin matrix

composition. The experimental design of this study is different than most translucency studies but the conclusion that resin matrix content, especially BisGMA based matrices, contributes to the translucency of composites is important.

Perez, et al[30] also looked at how resin matrix may affect the translucency of composites. In this study, the authors looked at a newer silorane-based composite and compared it to six universal dimethacrylate-based composites. Silorane resin matrix compositions are of a higher molecular weight and contain a cationic ring-opening hybrid monomer system possessing both siloxane and oxirane structural moieties. These composites were designed with the aim of diminishing polymerization shrinkage. Samples were 1mm thick by 5mm in diameter and were measured with a reflection spectrophotometer before and after polymerization. They were looking for changes in color and translucency parameter. The silorane-based composite showed the lowest change in color post polymerization and among each color coordinate showed the least amount of change in the a* and b* coordinates. This means the silorane composite possessed the most chromatic stability. As far as translucency parameter, the change in TP corresponded with the mean changes of the dimethacrylate composites although the TP values of the silorane composite

were the lowest. The importance of this study is that the silorane-based composite exhibited different optical properties than the dimethacrylate composites, which means resin matrix, has an influence on the color and translucency of resin composites.

Radiopacity

According to the International Standards Organization (ISO) 4049, the radiopacity of a 1.0 mm thick composite specimen should be equal to or greater than the same thickness of aluminum to be deemed radiopaque. This means a specimen would have a radiopacity roughly equal to dentin. Much research has been done on various materials to determine if they were adequate to be used in different clinical situations.

Optimal Level of Radiopacity

Goshima, et al[31] wanted to evaluate what level of radiopacity is most compatible with radiographic diagnosis of recurrent caries. There were two parts to this study. In the first part sixteen composites were evaluated and divided into four groups based on their level of radiopacity compared with an aluminum step wedge. The authors followed the guidelines of that time except instead of fabricating disc specimens composite step wedges were

fabricated. Radiographs were taken and optical densities measured with a transmission densitometer. In the second part, caries was simulated by placing grooves of increasing depth (0.5mm to 2.0mm) in aluminum blocks of a thickness equivalent to enamel (3.0mm) and detectability assessed beneath differing thicknesses of three composite resins. Three of the four groups from the first part of the study had an optical density less than the aluminum equivalent of enamel and one composite from each of those groups was used in the second part. Each one of the composite step wedges was superimposed over the aluminum blocks with grooves and radiographed similar to the first part of the study. The optical density was then measured at two points: in the groove visible through the composite and adjacent to the composite itself. Results showed that the group of composites (P-30) that had an optical density closest to enamel also had the highest degree of contrast to facilitate detection of caries. The authors concluded that composites should have a radiopacity similar to that of enamel. One big flaw in this study is a lack of statistics to show significance. Also, a visual assessment of the radiographs by blinded clinicians would have been a good add on to the study.

The purpose of the study by Tveit, et al[14] was to find out if carious lesions and marginal defects were as easy to diagnose radiographically in

connection with the radiopaque composite P-30 as with amalgam. Extracted premolars were used to prepare amalgam and P-30 class II restorations with and without secondary caries. Before placing the restorations in the teeth without caries, a 0.5mm layer of Silux composite (radiolucent) was placed at the gingival margin to simulate a margin defect. Radiographs were made of all teeth and the radiographs were then examined by 10 experienced dentists using a standardized illumination source and 2x magnifying lens. The examiners graded the radiographs on a scale of 1 to 5 as follows: 1- almost definitely caries or marginal defect not present, 2- caries or defect probably not present, 3- unsure, 4- probably present, 5- almost definitely present. Results showed that the diagnosis of secondary caries and margin defects was better with the composite than the amalgam. The frequency of true positives was higher for the composite and the frequency of false positives was lower for the composites. From these results the authors concluded a material with a moderate radiopacity allowed for easier diagnosis of secondary caries and marginal defects.

Espelid, et al[15] also evaluated the optimal level of radiopacity needed to detect secondary caries but compared it to the optical density of a step wedge. The authors selected extracted premolars and molars with interproximal lesions (n=49) and also teeth without any caries (n=29) to

serve as the control. Class II preparations were made in all teeth, and in the teeth with caries, a little carious tissue was left on the gingival wall. The fillings placed in the teeth were a composite (P-30), two experimental composites (one a combo of P-30/Valux and a composite with 80% ZrO_2 and SiO_2), and an amalgam. A filling would be placed, radiographed, and removed to allow placement of another filling material. After processing, each film was measured with a transmission densitometer. Eleven dentists using standard illumination then interpreted the radiographs. They used a rating scale of 1 to 5, where 1 meant almost definitely no caries, 3 meant unsure, and 5 meant almost definitely caries present. The scores were dichotomized as follows: positive diagnosis= scores 4 + 5, negative diagnosis= 1+2+3. The diagnoses were treated statistically according to the receiver operating characteristic method (ROC). Results showed the highest diagnostic accuracy for detection of secondary caries was with the P-30 composite. Observer performance was better with this material as opposed to the other materials as well. These results were statistically significant. The highest sensitivity was found with the P-30 composite and the highest specificity was with the amalgam. Comparing this to the optical densities obtained, the P-30 composite was the material that had an aluminum thickness equivalent slightly greater than enamel. The authors concluded

that a semi-radiopaque material slightly more radiopaque than enamel allowed for the best diagnosis of secondary caries.

Experimental Design

Bouslicher, et al[32] compared the relative radiopacity of enamel, dentin, and 20 resin composite materials used in posterior restorations at the time. The materials used were flowable composites, compomers, microfilled composites, hybrid composites, and filled and unfilled adhesive resins. Specimens were fabricated using a split mold 2mm thick by 5mm in diameter. Specimen thickness was verified with a micrometer. When necessary, specimens were sanded using a #320 carbide paper to 2.0mm. Enamel and dentin specimens were obtained from 2.0mm longitudinal sections of recently extracted third molars. Radiographs were made containing one of each of the specimens of composite, enamel, dentin, and the aluminum step wedge. The film used was speed E occlusal film. Films were exposed for 0.4 seconds at 70kV, 10mA at a 400mm target to film distance. Films were processed in a standard film processor. Optical density for each radiograph was measured with a transmission densitometer. Three readings were taken for each specimen. Al equivalent (mm) and % Al were calculated for each material using linear regression. Results showed all

composites tested complied with ISO 4049 guidelines. The unfilled adhesive was radiolucent and the filled adhesive was as radiopaque as dentin. All of the composites except three flowable composites had Al equivalents greater than enamel. The authors recommended based on this study and previous studies that even though all composites met ISO 4049 guidelines that composites should have a radiopacity greater than enamel. In this study, the authors utilized excellent experimental design except for using E speed film instead of D speed film and having 2mm thick specimens. However, they properly compared their specimens to 2mm equivalent Al. It is also possible ISO guidelines previous to the current one did not offer guidelines on speed of film or specimen thickness. Previous guidelines were not available for review.

Hara, et al[33] evaluated the radiopacity of thirteen restorative materials including conventional glass ionomer, resin-modified glass ionomer, compomer, and resin composites. The materials were 2mm thick by 4.1mm in diameter. They were fabricated by loading into a split mold, covered with a Mylar strip and glass slide and pressed with a 1000g load. After 1 minute, the materials were cured for 40 seconds on each side. The conventional glass ionomer was allowed to set 10 minutes before testing. A 2mm thick specimen of tooth, 1mm thick enamel and 1mm thick dentin, was used as the

control. Specimens were placed on E speed periapical film along with a 10-step aluminum wedge and exposed at 60kVp, 10mA, for a time of .4 seconds. A transmission densitometer was then used to gather optical densities of the developed films. The net radiographic density values were derived by subtraction of the inherent film base-plus fog density from the gross radiographic density. Results showed that all materials were more radiopaque than tooth structure and the results were specific for each material not specific for the type of material. The authors showed good initial experimental design, mainly in preparation of the specimens. However, they used the means of the optical densities to determine radiopacity and did not find an Al (mm) equivalent as stated in the ISO 4049 guidelines. Based on this, it is difficult to completely validate the results or conclusions.

Attar, et al[34] looked at the mechanical properties, including radiopacity, of seven flowable, and 2 flowable compomers. One universal composite and one universal compomer were used as controls. For this study, only radiopacity will be discussed, as the other mechanical properties discussed are not pertinent to the study. Specimens were prepared using a split ring mold to produce 5 specimens of each material 1mm thick by 6mm in diameter. The specimens were clamped in the mold and cured. The

specimens were then ground with 400-grit sandpaper to create a flat surface. Specimens were then measured with a micrometer for accuracy in thickness. Five specimens were then placed on an occlusal film along with an aluminum step wedge and longitudinal 1mm thick samples of enamel and dentin. The aluminum step wedge was used to serve as an internal standard for each radiograph so that radiopacity of each material could be measured in terms of aluminum thickness. Films were then exposed and developed. Optical densities were determined for each specimen and each specimen was read 4 times. The Al equivalent was calculated according to ISO guidelines. Results showed all of the materials tested met ISO 4049 guidelines. Revolution was closest to not meeting the guidelines. The experimental design was correct and closely followed the proper guidelines.

Recently, Tsuge, et al[35] looked at the radiopacity of conventional composites, resin-modified glass ionomers, and resin-based luting materials. Specimens were initially 2.3mm thick by 10mm in diameter but were ground to 2mm thick specimens with #600 silicon-carbide paper. A 99% pure aluminum step wedge was used along with human molars sliced 2mm thick. The sample specimens were placed on a D speed occlusal film along with the step wedge and tooth section. The films were exposed for 0.6 sec at 60 kVp, 15mA, at a target to film distance of 35cm. After the films were

processed the films were read with a transmission densitometer. The authors did not explain how they came up with the Al equivalent (mm) but did state radiopacity values were expressed in terms of the equivalent thickness of aluminum per 2mm thickness of material. Results once again showed radiopacity was material specific and not type of material specific as some luting materials, composites, and glass ionomers were radiopaque and some were not. One flaw in the experimental design is the authors used different exposure settings than recommended in the ISO guidelines. El-Mowafy, et.al[36] showed that changing exposure time and kVp can possibly affect radiopacity values. The biggest flaw in this design was not explaining how they came up with the aluminum equivalent (mm). Other statistical analysis was explained but this one was left unexplained.

Turgut, et al[37] had an experimental design that best followed the ISO 4049 guidelines. The purpose of this study was to find the radiopacity of 21 direct esthetic restorative materials according to ISO guidelines and compare them to enamel and dentin. The materials consisted of packable composites, flowable composites, hybrid composites, glass ionomers, resin-modified glass ionomers, and compomers. Samples were fabricated in 1mm thick by 6mm in diameter Teflon molds and cured 30 seconds on each side. Each material was polished with different grits of sandpaper and measured with a

micrometer to verify thickness. There were eight samples for each material. One millimeter enamel and dentin slices were also prepared. The materials were divided into eight groups and placed on a occlusal film along with a 99.5% aluminum step wedge with 0.5 mm steps. The films were exposed at 70 kVp, 10 mA for 0.37 sec at a target distance of 40cm. The optical densities were measured with a transmission densitometer. A graph was plotted between the entire step wedge and its optical density values. From this graph, the optical density values of the specimens were used to find the value of the aluminum equivalent thickness of each specimen. Results showed radiopacity was material specific. All but eight of the materials had radiopacity values greater than enamel (2.02mm). Only one material did not meet ISO 4049 guidelines. This study had an excellent experimental design because it followed ISO 4049 guidelines and thus is an excellent resource for future research.

Shade

Even though ISO 4049 suggest a certain shade to test radiopacity, Marouf, et al[38] wanted to see if shade had an effect on radiopacity. Three resin-modified glass ionomers of various shades were used in the study. Specimens were prepared according to ISO guidelines and were 1mm thick

by 10mm in diameter. The specimens were placed on an occlusal film along with an aluminum step wedge and exposed at 70kVp, 7mA, for 0.25 seconds. The films were then processed and read with a transmission densitometer. Radiographic density values related to thickness of aluminum were then were derived according to guidelines. Results once again showed radiopacity to be material specific. In addition, there was no statistically significant difference among shades of the different materials. This is important because it shows shade designation has no effect on how radiopaque a material is. However, the study could have been more complete if resin composites (flowable and universal) would have been used as well as the resin-modified glass ionomers.

Filler

Van Dijken, et al[39] were one of the first to look at what makes a composite radiopaque. The purpose of the study was to measure the radiopacity of eighteen brands of composites and to analyze the composition of the inorganic fillers of the materials. Five specimens, 2mm thick by 15mm in diameter, were fabricated for each composite material. A 2mm thick mesiodistal slice of human molar was also tested. The author stated that all composites were fabricated, exposed, and tested according to the ISO

guidelines at the time. Calibration curves were made for each film to enable transposition of the measured optical densities to an equivalent thickness of aluminum. To analyze the inorganic portion, the composite materials were placed in a combustion oven at 575 ± 5^0 C for 30 minutes. They were then analyzed using optical emission spectroscopy, which is a semi quantitative method that can identify and roughly estimate the elemental composition of different filler particles. Results showed fourteen composites showed radiopacity greater than an equal thickness of aluminum and twelve of the composites showed radiopacity greater than the thickness of an equal thickness of enamel which would be twice as that of an equal thickness of aluminum. Analysis of the inorganic filler showed that the elements added to the composite to increase radiopacity were barium, strontium, zirconium, zinc, and ytterbium. Of these barium displayed the highest radiopacity.

Toyooka, et al[40] also looked at the filler particles which give composites their radiopacity. The purpose of the study was to measure radiopacity of twelve light cured composites and to relate radiopacity of the composite to the chemical composition of the filler particles. Composites were prepared 6mm in diameter by 1mm, 2mm, and 3mm thick. A 1mm and 2mm longitudinal slice of human molar was also used for comparison. Specimens were placed on a ultra speed occlusal film along with tooth slices

and an aluminum step wedge and exposed at 70kVp, 8mA, for 0.4 seconds. Optical densities were read with a transmission densitometer. Radiopacity of the specimen was then expressed in terms of aluminum equivalent thickness by reference to the calibration curve for the radiographic density of the aluminum step wedge. The inorganic filler content was determined by heating the composite at 575^0 C in a thermal analyzer. A SEM coupled with an energy dispersed X-ray microprobe (EDX) was used for the size identification and chemical analysis of the inorganic fillers extracted by acetone. Results showed that six of the composites had a radiopacity value higher than that of enamel or twice that of the equivalent thickness of aluminum. In addition, as the thickness of the most radiopaque composites increased so did the radiopacity. This was not true of the most radiolucent composites. Results of filler composition showed that radiopacity was linearly proportional to the radiopaque oxide content of the composite. Barium and Zirconium were the most radiopaque with zirconium demonstrating a slightly higher radiopacity. The experimental design in the radiopacity part of the study is weak and not well explained but the filler part of the study has foundation and importance.

Hotta, et al[41] also recently looked at filler content and how it related to radiopacity. The purpose of this study was to determine the content and

constituent elements of inorganic fillers as well as the radiopacity of 15 adhesive resins. Three cylindrical specimens of each adhesive material were weighed in an analytical balance to determine the mass of the polymerized bonding agent (Wa). To obtain the weight of the inorganic filler, the organic phase was eliminated by firing the adhesive in a furnace at 700^0 C for 30 minutes. Each sample was allowed to cool for 90 minutes. The mass of inorganic fillers measured in the air was weighed in the analytical balance (Wb). The percentage of the inorganic phase of each product by weight was calculated using the following equation: inorganic filler percentage by weight= (Wb/Wa) x 100 wt%. The inorganic fillers were then examined by using an energy-dispersed x-ray detection system attached to an SEM. The bonding agents were then prepared for radiopacity testing. Specimens were 1mm thick by 15mm in diameter. Enamel and dentin slices, 1mm thick, were also prepared for comparison. After the films were exposed, optical density was measured with a transmission densitometer. Aluminum equivalent thickness was derived according to ISO guidelines. Results of radiopacity showed none of the adhesive resins were more radiopaque than enamel and 14 of the 15 adhesive resins were less radiopaque than dentin (1.0mm Al equivalent). For the inorganic part of the study, filler content ranged from 0.0% to 43.5%. Silicon and aluminum were the main

constituents of the fillers but there was much variation among the other fillers in each material. The bonding agent that had the highest weight (43.5%) also had the highest radiopacity. Finally, those materials that had fillers with the highest atomic numbers or highest weight had the highest radiopacity. This study confirms previous studies showing materials that have inorganic fillers with high atomic weights (barium, strontium, zinc, etc.) tend to have higher radiopacity values.

Alternatives to Determining Radiopacity

Murchison, et al[42] looked at two different ways to determine radiopacity. The purpose of this study was to compare radiopacity of eight flowable composites and to compare two different radiographic densitometric analyses. Five specimens, 2mm thick by 6mm in diameter, were prepared for each material. Five 2mm thick enamel/dentin tooth slices were also prepared. The specimens were then placed on a size 2 film along with a 4mm thick piece of amalgam. No aluminum step wedge was utilized with the specimens. A separate radiograph of the aluminum step wedge alone was taken and used as an internal standard. The films were exposed then measured with a transmission densitometer to obtain optical density values of the specimens and step wedge. Based on this data, using best-fit

logarithmic regression, equivalent aluminum thickness was determined. To test the other method, the films were digitized onto a computer, analyzed for density with the free UTH-SCSA Image Tool program. A calibration curve for gray pixel values was generated and correlated with values of optical density obtained from the densitometer. Results showed that radiopacity was material specific and only three of the flowable composites had radiopacity greater than enamel. Comparison of the methods of data collection showed a very high correlation (-0.98) and the authors concluded either method is acceptable to measure optical density. The one big flaw in this study is the authors did not include the aluminum step wedge on the same radiograph as the specimens. This could have likely influenced the results and their conclusions.

This study by Hara, et al[43] visually compared the radiopacity of materials as opposed to the normal way described in the ISO 4049 guidelines. The purpose of this study was to visually evaluate the radiopacity of glass ionomers and composite resins and compare it to a conventional glass ionomer cement and to tooth structure. Seven restorative materials were evaluated: 3 resin-modified glass ionomer cements, 3 compomers, and the conventional glass ionomer cement. Specimens were 2mm thick by 4.1mm in diameter and there were 24 specimens for each

material. A specimen for each of the materials was placed in random order on a radiograph along with the tooth structure and an aluminum step wedge. Three examiners, independent and blinded, viewed the 24 radiographs using standardized illumination and 2X magnifying lenses. Scores from 1 to 5 (radiolucent to radiopaque) were given to each of the materials and tooth structure on each radiograph by comparing them to the aluminum step wedge. For example, a score of 1 meant the material was equivalent to the 1st and 2nd step of the aluminum step wedge. Results showed that examiners found two of the materials more radiolucent than the tooth structure or a grade of 1 on the step wedge. All other materials were more radiopaque than tooth structure. Combining this study with a study utilizing the ISO guidelines would be good way to evaluate two ways of determining radiopacity.

Determining Radiopacity Digitally

In recent years many dentists have switched from traditional x-ray techniques to using digital x-ray systems. The recent ISO 4049 guidelines have included a method to determine radiopacity digitally[16]. For completeness, the following study has been included for review.

Sabbagh, et al[44] compared the radiopacity of 41 resin-based materials using conventional dental x-ray film and a digital system (Digora) based on storage phosphor plate technology. Materials, 2mm thick by 6mm in diameter, were prepared close to ISO 4049 guidelines. For the conventional film technique, optical density measurements were carried out using a transmission densitometer and aluminum thickness equivalent was calculated as previously described. For the digital portion of the study, phosphor plates were used instead of film. The plates were exposed at two different times (0.32 sec and 0.16 sec) to see if reducing exposure time affected radiopacity. After exposure, gray values of images had to be calibrated, so the images were sent as TIFF files to an image processing software. This software allows the transformation of pixel values directly from a linear scale into a scale that correlates with optical density. A similar method as conventional film was then used to convert these values to aluminum thickness equivalent. Results showed that regardless of the method of determining radiopacity, radiopacity varied among materials. Changing exposure time did not change the radiopacity. Between systems, there was variation among radiopacity of some of the materials. Sometimes the digital system measured a lower radiopacity for a material than the conventional system and with another material it would measure a higher

radiopacity. Even though the systems showed linear correlation, the authors concluded the conventional x-ray technique might be slightly more accurate.

References

1. Powers JM, Sakaguchi RL. . Restorative dental materials. . 12th edition ed. St. Louis: Mosby; 2006.

2. Powers JM, Dennison JB, Lepeak PJ. Parameters that affect the color of direct restorative resins. J Dent Res 1978;57(9-10):876-80.

3. Miyagawa Y, Powers JM, O'Brien WJ. Optical properties of direct restorative materials. J Dent Res 1981;60(5):890-4.

4. Paravina RD, Kimura M, Powers JM. Evaluation of polymerization-dependent changes in color and translucency of resin composites using two formulae. Odontology 2005;93(1):46-51.

5. Yu B, Lee YK. Translucency of varied brand and shade of resin composites. Am J Dent 2008;21(4):229-32.

6. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont 1995;8(1):79-86.

7. Johnston WM, Reisbick MH. Color and translucency changes during and after curing of esthetic restorative materials. Dent Mater 1997;13(2):89-97.

8. Joiner A. Tooth colour: a review of the literature. J Dent 2004;32 Suppl 1:3-12.

9. Westland S. Review of the CIE system of colorimetry and its use in dentistry. J Esthet Restor Dent 2003;15 Suppl 1:S5-12.

10. Lee YK, Lim BS, Rhee SH, Yang HC, Powers JM. Color and translucency of A2 shade resin composites after curing, polishing and thermocycling. Oper Dent 2005;30(4):436-42.

11. Lee YK. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. Dent Mater 2008;24(9):1243-7.

12. Abou-Tabl ZM, Tidy DC, Combe EC. Radiopacity of composite restorative materials. Br Dent J 1979;147(7):187-8.

13. Cook WD. An investigation of the radiopacity of composite restorative materials. Aust Dent J 1981;26(2):105-12.

14. Tveit AB, Espelid I. Radiographic diagnosis of caries and marginal defects in connection with radiopaque composite fillings. Dent Mater 1986;2(4):159-62.

15. Espelid I, Tveit AB, Erickson RL, Keck SC, Glasspoole EA. Radiopacity of restorations and detection of secondary caries. Dent Mater 1991;7(2):114-7.

16. 4049 ISI. Polymer-based filling, restorative and luting materials. Technical Committee 106-Dentistry. In: Organization IS, editor. Geneva, Switzerland; 2000.

17. Ikeda T, Murata Y, Sano H. Translucency of opaque-shade resin composites. Am J Dent 2004;17(2):127-30.

18. Kamishima N, Ikeda T, Sano H. Color and translucency of resin composites for layering techniques. Dent Mater J 2005;24(3):428-32.

19. Buchalla W, Attin T, Hilgers RD, Hellwig E. The effect of water storage and light exposure on the color and translucency of a hybrid and a microfilled composite. J Prosthet Dent 2002;87(3):264-70.

20. Lee YK, Kim SH, Powers JM. Changes in translucency of resin composites after storage in salivary esterase. J Esthet Restor Dent 2005;17(5):293-9; discussion 99-302.

21. Lee YK, Lu H, Powers JM. Optical properties of four esthetic restorative materials after accelerated aging. Am J Dent 2006;19(3):155-8.

22. Lee YK, Lu H, Powers JM. Changes in opalescence and fluorescence properties of resin composites after accelerated aging. Dent Mater 2006;22(7):653-60.

23. Lee SH, Lee YK. Effect of thermocycling on optical parameters of resin composites by the brand and shade. Am J Dent 2008;21(6):361-7.
24. Ryan EA, Tam LE, McComb D. Comparative translucency of esthetic composite resin restorative materials. J Can Dent Assoc 2010;76:a84.

25. Lee YK, Lim BS, Rhee SH, Yang HC, Powers JM. Changes of optical properties of dental nano-filled resin composites after curing and thermocycling. J Biomed Mater Res B Appl Biomater 2004;71(1):16-21.

26. Sidhu SK, Ikeda T, Omata Y, Fujita M, Sano H. Change of color and translucency by light curing in resin composites. Oper Dent 2006;31(5):598-603.

27. del Mar Perez M, Saleh A, Pulgar R, Paravina RD. Light polymerization-dependent changes in color and translucency of resin composites. Am J Dent 2009;22(2):97-101.

28. Yu B, Lee YK. Differences in color, translucency and fluorescence between flowable and universal resin composites. J Dent 2008;36(10):840-6.

29. Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, van Noort R. Effect of resin matrix composition on the translucency of experimental dental composite resins. Dent Mater 2009;25(12):1564-8.

30. Perez MM, Ghinea R, Ugarte-Alvan LI, Pulgar R, Paravina RD. Colour and translucency in silorane-based resin composite compared to universal and nanofilled composites. J Dent 2010.

31. Goshima T, Goshima Y. The optimum level of radiopacity in posterior composite resins. Dentomaxillofac Radiol 1989;18(1):19-21.

32. Bouschlicher MR, Cobb DS, Boyer DB. Radiopacity of compomers, flowable and conventional resin composites for posterior restorations. Oper Dent 1999;24(1):20-5.

33. Hara AT, Serra MC, Haiter-Neto F, Rodrigues AL, Jr. Radiopacity of esthetic restorative materials compared with human tooth structure. Am J Dent 2001;14(6):383-6.

34. Attar N, Tam LE, McComb D. Flow, strength, stiffness and radiopacity of flowable resin composites. J Can Dent Assoc 2003;69(8):516-21.

35. Tsuge T. Radiopacity of conventional, resin-modified glass ionomer, and resin-based luting materials. J Oral Sci 2009;51(2):223-30.

36. el-Mowafy OM, Benmergui C. Radiopacity of resin-based inlay luting cements. Oper Dent 1994;19(1):11-5.

37. Turgut MD, Attar N, Onen A. Radiopacity of direct esthetic restorative materials. Oper Dent 2003;28(5):508-14.

38. Marouf N, Sidhu SK. A study on the radiopacity of different shades of resin-modified glass-ionomer restorative materials. Oper Dent 1998;23(1):10-4.

39. van Dijken JW, Wing KR, Ruyter IE. An evaluation of the radiopacity of composite restorative materials used in Class I and Class II cavities. Acta Odontol Scand 1989;47(6):401-7.

40. Toyooka H, Taira M, Wakasa K, et al. Radiopacity of 12 visible-light-cured dental composite resins. J Oral Rehabil 1993;20(6):615-22.

41. Hotta M, Yamamoto K. Comparative radiopacity of bonding agents. J Adhes Dent 2009;11(3):207-12.

42. Murchison DF, Charlton DG, Moore WS. Comparative radiopacity of flowable resin composites. Quintessence Int 1999;30(3):179-84.

43. Hara AT, Serra MC, Rodrigues Junior AL. Radiopacity of glass-ionomer/composite resin hybrid materials. Braz Dent J 2001;12(2):85-9.

44. Sabbagh J, Vreven J, Leloup G. Radiopacity of resin-based materials measured in film radiographs and storage phosphor plate (Digora). Oper Dent 2004;29(6):677-84.

Chapter 2 (Pilot Study)

Introduction

In recent years, resin composites have been used extensively as an alternative to dental amalgams. With this increase in use has come the desire to improve the mechanical and optical properties of resin composites. One property to consider is the radiopacity of a composite.

Radiopacity is important because it can be used to evaluate marginal adaptation, detect caries, and assess the overall quality of a restoration, such as interproximal contours, contacts, overhangs, and voids [2, 3, 4, 5]. Furthermore, composites that are not adequately radiopaque have been confused as recurrent caries in subsequent recall appointments and restored unnecessarily [2, 3, 4, 5].

One of the commonly used techniques to determine the radiopacity of a resin composite uses a transmission densitometer. In order to make comparisons of radiopacity, an aluminum step wedge is used because its linear absorption coefficient is of the same order as enamel [4]. According to the International Standards Organization (ISO) 4049 specification, the radiopacity of a 1.0 mm thick composite specimen should be equal to or

greater than the same thickness of aluminum to be deemed radiopaque [1, 2, 5].

Purpose

Determine the radiopacity of a new flowable composite and compare it to the radiopacity of 4 currently available flowable composites.

Specific Aims

1. Evaluate the radiopacity of five flowable composites using a transmission densitometer according to ISO guideline 4049.

Materials and Methods

The flowable composites used in this study are listed in Table 1.

Table 1. Flowable Composite Material

Composite	Manufacturer
Experimental	Heraeus Kulzer LLC., Hanau, Germany
Revolution Formula 2	Kerr Corporation, Orange, CA, USA
X-Flow	Dentsply International, York, PA, USA
Filtek Supreme XT	3M ESPE Incorporated, St. Paul, MN, USA
Tetric Evo-Flow	Ivoclar Vivadent Inc., Amherst, NY, USA

Equipment

1. Single-phase dental X-ray unit (Kodak 2000, Kodak Dental Systems, Atlanta, GA, USA)- total filtration 1.5 mm aluminum, 70 kV.
2. Dental X-ray film speed group D (Sensa, Air Techniques, Inc. Melville, NY, USA) as specified in ISO 3665) and film processor (Air Techniques A/T 2000 XR) temp 82°.
3. Aluminum Step Wedge- free standing, 99% purity.

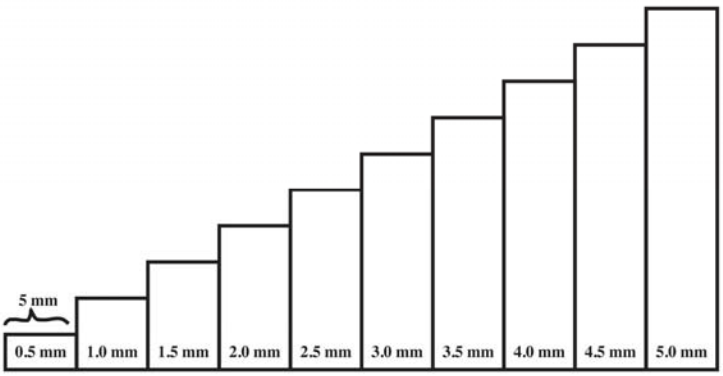

Figure 1. Aluminum Step Wedge 20 mm x 50mm having a thickness range from 0.5 mm to 5.0 mm in equally spaced steps.

4. Sheet of lead not less than 2 mm thick
5. Micrometer (Mitutoyo America Corporation, Aurora, IL, USA)
6. Photographic Transmission Densitometer (Macbeth TD 502, Macbeth Corporation, Newburgh, NY, USA)- capable of measuring optical density in the range of 0.5 to 2.5 mm.

Procedure

Five flowable composites (Table 1), shade A3, were used in this study. An aluminum mold was used to prepare 10 disk specimens 10 mm in diameter and 1 mm thick for each composite material. The five flowable composites were flowed carefully into the lubricated aluminum mold. After the mold was filled, the composite was covered with a Mylar strip and a microscope slide. The microscope slide was clamped to the aluminum mold to ensure stability and force out excess composite. The composite materials

were light cured with a light-curing unit (FUSION™ LED, DentLight, Inc., Richardson, TX, USA) for 60 seconds. The top of the specimen was cured 30 seconds, then flipped over and cured for an additional 30 seconds. The intensity of the light was checked after every 10 specimens using an Espectro photometer (3M™ ESPE™, Minneapolis, MN) to ensure efficient light output. Each specimen was then measured with a micrometer (Mitutoyo) to verify a thickness of 1 +/- .1 mm. The specimens were then stored in 100% humidity for 24 hours.

After 24 hours, 5 disk specimens (1 specimen for each flowable composite) and the aluminum step wedge were placed on an occlusal speed group D film (Sensa). The specimens were placed in random order along the aluminum step wedge. The X-ray film, specimens, and step wedge were placed on a sheet of lead. The film, specimens, and aluminum step wedge were then exposed at 70kV, 7 mA, for 0.339 seconds at a target to film distance of 360 mm using the Kodak 2000 intraoral X-ray system. A special tube was constructed to ensure the same target to film distance.

The film was then immediately processed in an automatic processor (Air Techniques A/T 2000 XR) at 82° Fahrenheit. This same procedure was followed until all 50 specimens had been irradiated, a total of 10 radiographs. All occlusal film used was from the same box.

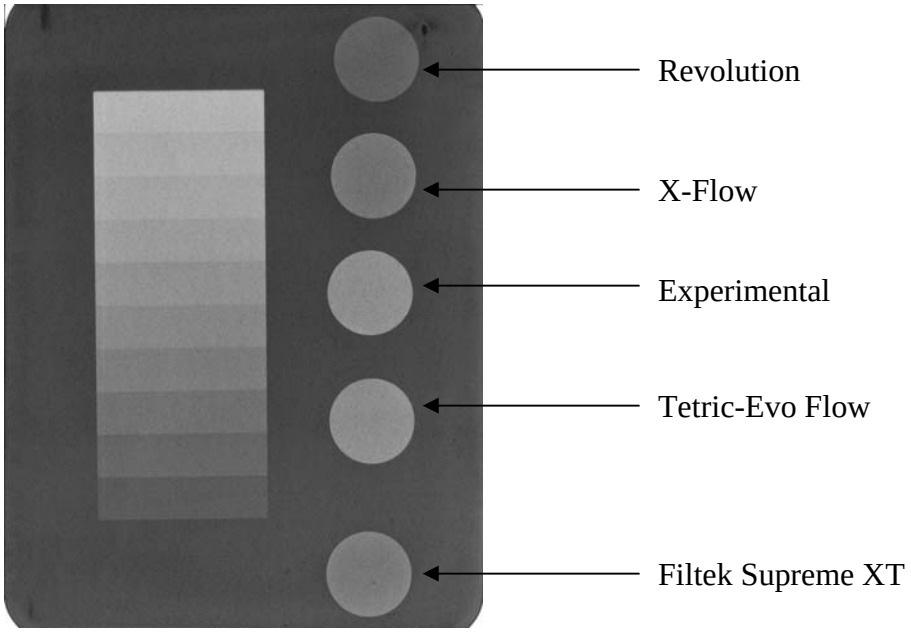

Figure 2. Radiograph 1 showing step wedge and five specimens in random order.

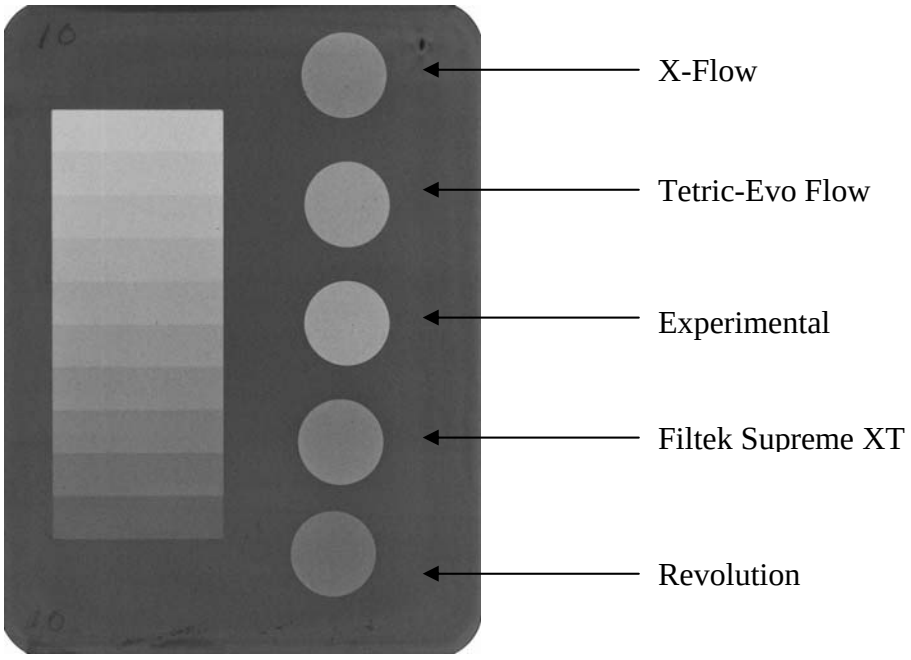

Figure 3. Radiograph 10 showing step wedge and five specimens in random order.

Radiographic optical densities (overall darkening of an exposed film) of the aluminum step wedge and specimens were then measured with a photographic transmission densitometer (Macbeth TD 502) with an aperture of 1 mm. Three readings were made for each specimen along with three readings of each step of the aluminum step wedge. The optical densities were recorded in this manner for all 10 occlusal films.

Statistical Analysis

The means and standard deviations for optical densities of the specimens and aluminum step wedge of each radiograph were calculated by averaging the three repeated measurements to create a single value for each specimen. A linear regression analysis was calculated for each film, relating the OD of the steps in the wedge to the thickness of each step. The aluminum equivalent (Al) was then calculated for each sample by using the regression analysis equation of:

$$\mathbf{y = a + bx,}$$

where:

y = the optical density (OD) of the specimen;

a = the coefficient of the regression;

b = the regression constant and

x = the aluminum equivalent value for that sample.

Solving the equation for aluminum equivalent, the final equation is as follows:

Al= [OD - Coefficient]/ Constant

One-way ANOVA was used to determine statistical significance of Optical Densities among the materials. The Tukey multiple comparison test was used to compare significant differences among the means of the materials. The same tests were also done to analyze the data for Aluminum Equivalents.

Results

Table 1 illustrates the means and standard deviations of optical density and aluminum equivalent among the five materials. For optical density, a lower number indicates a more radiopaque composite. For aluminum equivalent, the higher number indicates a more radiopaque composite.

Table 1. Values for Optical Density and Aluminum Equivalents by Material; Mean (SD)

	Heraeus Kulzer	Revolution	X-Flow	Filtek Supreme XT	Tetric Evo-Flow
Optical Density	0.933(0.028)[a]	1.226(0.040)[c]	1.102(0.034)[b]	1.132(0.045)[b]	0.956(0.027)[a]
Aluminum Equivalent	3.098(0.173)[d]	0.619(0.387)[f]	1.671(0.268)[e]	1.415(0.358)[e]	2.898(0.258)[d]
Note: Means with same letters are not significantly different with $p < 0.001$					

According to ISO guidelines 4049, a composite material is deemed radiopaque if the aluminum equivalent value of the material is greater than 1 mm. Only Revolution did not meet this criterion (0.619 Al Eq.). The experimental composite from Heraeus Kulzer had the highest radiopacity (3.098 Al Eq.) but was not significantly different from Tetric Evo-Flow

(2.898 Al Eq.). Filtek Supreme XT and X-Flow were similar but lower in Aluminum Equivalent values.

References

1. Attar N, Tam L, McComb D. Journal of the Canadian Dental Association. Flow, Strength, Stiffness and Radiopacity of Flowable Resin Composites. 2003; 69(8): 516-21.

2. Bouslicher MR, Cobb DS, Boyer DB. Operative Dentistry. Radiopacity of Compomers, Flowable and Conventional Resin Composites for Posterior Restorations. 1999; 24: 20-25.

3. Murchinson DF, Charlton DG, Moore WS. Quintessence International. Comparative radiopacity of flowable resin composites. 1999; 30: 179-184.

4. Sabbagh J, Vreven J, Leloup G. Operative Dentistry. Radiopacity of Resin-based Materials Measured in Film Radiographs and Storage Phosphor Plate (Digora). 2004; 29-6: 677-684.

5. Turgut MD, Attar N, Onen A. Operative Dentistry. Radiopacity of Direct Esthetic Restorative Materials. 2003; 28-5: 508-514.

Chapter 3

Abstract

Objective: Determine the translucency and radiopacity of five commercially available composites: Aelite LS(AE), Filtek LS(FS), GC Kalore(KA), Empress Direct Enamel(EE), Empress Direct Dentin(ED)

Experimental Methods: Experiment conducted according to ISO guideline 4049. Five composites(n=50), shade A2, were packed into an aluminum mold(10-mm diameter, 1-mm thick) and light cured for 80 seconds(40 sec each side). The color of each specimen was measured according to the CIELAB color scale relative to the standard illuminant D65 against a white background and a black background using a reflection spectrophotometer with a 8mm (MAV) diameter target mask. Using color data, translucency parameter and contrast ratio were calculated for each sample. For radiopacity, five specimens(1 for each composite) were placed in random order with an aluminum step wedge(20-mm x 50-mm, 10 0.5-mm steps) on an occlusal film and exposed at 70kV, 7mV, 0.339sec from a target-film distance of 360-mm. After immediately being processed(10 radiographs), the radiographic optical densities of the specimens and aluminum step wedge were read with a photographic transmission densitometer(aperture 1-mm). Aluminum equivalent was calculated using regression analysis(mean optical density vs. mean thickness aluminum step wedge). A visual analysis by two independent examiners was also done and compared to the ISO 4049 radiographic method. One-way ANOVA($p<0.05$) and Tukey multiple comparison tests($p<0.05$) were used for statistical analysis.

Results: EE was the most translucent (22.089) and had the lowest contrast ratio(0.783) while AE was the least translucenct(11.808) and had the highest contrast ratio(0.908). For translucency all five composites were significantly different. For contrast ratio, except KA and FS, which were similar, all composites were significantly different. There was a very strong inverse correlation between translucency parameter and contrast ratio(-0.944). According to ISO guidelines 4049, a composite material is deemed radiopaque if the aluminum equivalent value of the material is greater than 1 mm. All five composites met this criteria with ED having the highest radiopacity(3.609 AlEq) and AE having the lowest radiopacity(1.263AlEq). All of the composites were significantly different except AE and FS, which were similar. Visually, ED was deemed the most visually radiopaque by examiners and was significantly different than the other composites while EE/KA and FS/AE were not significantly different. FS and AE were least radiopaque visually. There was a strong correlation(0.938) between Al Radio Equiv and Visual Al Equiv when comparing the materials as a group. There was much variation when correlating between each material. There was a very weak to no correlation between radiopacity Al Equiv and translucency(0.084) and contrast ratio(0.053).

Conclusions: EE was the most translucent material. AE can be considered a very opaque material but was the second most radiolucent material. ED had the highest radiopacity of the five composites but all five composites met ISO 4049 guidelines for radiopacity. Radiopacity and translucency were not correlated.

Introduction

In recent years resin composites have been used extensively as an alternative to dental amalgams. With this increase in use has come the desire to improve the various properties (optical, physical, mechanical, etc.) of resin composites.

One property (optical) to consider is translucency. Translucency is a property of substances that permits the passage of light but disperses the light, so objects cannot be seen through the material[1]. It could better be described as a partial opacity or a state between complete opacity and complete transparency[2]. Tooth enamel has inherent translucency, thus the difficult task in dentistry is finding an esthetic dental restoration that has translucency properties similar to human enamel. The most common esthetic restorative material used is dental resin composite. The translucency of dental resin composites depends on their thickness and the scattering and absorption coefficients of the resin, filler particles, organic matrix, pigments, and opacifiers[3-7]. Of these, filler composition and organic matrix seem to have a strong influential effect[4, 5, 7]. The type, size, and number of internal filler particles affect light scattering in resin materials thus affecting the translucency and visual appearance of the composite in relation to the underlying tooth[4]. Lee[4] suggested there was an inverse correlation between

translucency and filler content thus as the amount of filler increased translucency decreased. There are different organic matrices that can be added to resin composites with the most common being BisGMA, UDMA, TEGDMA, and Silorane. Recently, Azzopardi[5] and Perez[7] suggested there is a linear correlation between translucency and quantity of organic resin matrix.

Translucency of esthetic materials is usually determined with the translucency parameter or contrast ratio. Translucency parameter refers to the color difference between a uniform thickness of material over a black and white background, and corresponds directly to common visual assessments of translucency[8, 9]. If a material is absolutely opaque then the translucency parameter will equal zero. Thus the higher the translucency parameter values, the higher the translucency of the material. The color of the esthetic material is measured using a reflection spectrophotometer and these coordinate values are used to determine translucency parameter. Once these coordinates are known translucency parameter (TP) can be found by the following equation:

$$\mathbf{TP= [(L^*_w-L^*_b)^2 + (a^*_w-a^*_b)^2 + (b^*_w-b^*_b)^2]^{1/2}.}$$

Translucency can also be determined by contrast ratio, which is used to measure the opacity of a dental material. Opacity, represented by contrast ratio, is the ratio between the daylight apparent reflectance of the specimen when backed by a black standard and the daylight apparent reflectance of the specimen when backed by a white standard[1]. Contrast ratio is calculated using the following formula: $\mathbf{Y_b/Y_w}$ where Y_b represents the luminous reflectance against a black background and Y_w represents the luminous reflectance against a white background[10]. In comparison, as translucency parameter increases contrast ratio decreases[2].

Another optical property to consider is the radiopacity of a composite. Radiopacity is important because it can be used to evaluate marginal adaptation, detect caries, and assess the overall quality of a restoration, such as interproximal contours, contacts, overhangs, and voids[11-14]. Furthermore, composites that are not adequately radiopaque have been confused as secondary caries in subsequent recall appointments and restored unnecessarily.

One of the commonly used techniques to determine the radiopacity of a resin composite is the transmission densitometer. In order to make comparisons of radiopacity, an aluminum step wedge is used as an internal standard to allow for calculation of radiopacity. When an aluminum step

wedge is used to determine radiopacity, radiopacity is described by the measurement aluminum equivalence (Al). According to the International Standards Organization (ISO) 4049, the radiopacity of a 1.0 mm thick composite specimen should be equal to or greater than the same thickness of aluminum to be deemed radiopaque[15]. According to this guideline a 1mm thick specimen equivalent to 1mm thick aluminum would have a radiopacity approximately similar to dentin[11, 12]. However, some believe radiopacity should more approximate enamel instead of dentin[16-19]. It has been determined the aluminum equivalence of enamel is approximately twice the aluminum equivalence of dentin[16-18, 20]. Radiopacity is primarily influenced by filler composition but more importantly by compositions containing fillers with high atomic weights[21-23].

Therefore, this study was designed to determine the translucency (translucency parameter and contrast ratio) and radiopacity of five commercially available composites. A spectrophotometer was used to determine translucency and a transmission densitometer was used to determine radiopacity. In addition, a visual assessment of radiopacity by two examiners was done to determine if there is correlation between the two-radiopacity methods. A final aim of the study was to determine if there is a correlation between translucency and radiopacity.

Methods and Materials

The five composites tested in this study were chosen based on their commercial advertising as the latest product in their line.##All the materials differ with respect to polymeric matrices, filler particle types, and filler content. The filler content by weight percentage and the organic matrix as well as the type of composite are described in **Table 1, 2, and 3**. Ten samples of each composite material in shade A2 were used for each experiment.

Table 1 - Descriptive table of materials used in the research.

COMPOSITE	MANUFACTURER	TYPE	LOT NUMBER
Aelite LS	Bisco Inc. (Schaumburg, IL)	Microhybrid	1000011945
Filtek LS	3M ESPE (St Paul, MN)	Microhybrid	N206306
GC Kalore	GC Corp (Tokyo, Japan)	Nanohybrid	1011112
Empress Direct Dentin	Ivoclar Vivadent (Amherst, NY)	Nanohybrid	N10129 M68450
Empress Direct Enamel	Ivoclar Vivadent (Amherst, NY)	Nanohybrid	N21727

Table 2 – Filler compositions taken from manufacturers' instruction and data sheet.

COMPOSITE	FILLER COMPOSITION	% WEIGHT
Aelite LS	Glass filler, amorphous silica	88%
Filtek LS	Quartz, yttrium fluoride	76%
GC Kalore	Fluoroaluminosilicate glass, strontium glass, pre-polymerized filler (HDR - proprietary), silicon dioxide	82%
Empress Direct Dentin	Barium glass, ytterbiumtrifluoride, mixed oxide, silicon dioxide, prepolymer	79%
Empress Direct Enamel	Barium glass, mixed oxide, silicon dioxide	79%

Table 3 – Organic matrix compositions taken from manufacturers' instruction and data sheet.

COMPOSITE	ORGANIC MATRIX	% WEIGHT
Aelite LS	Ethoxylated Bis-GMA	25%
Filtek LS	Silorane	23%
GC Kalore	Urethane Dimethacrylate, DX - 511 (proprietary formula) , dimethacrylate	18%
Empress Direct Dentin	Dimethacrylate	21%
Empress Direct Enamel	Dimethacrylate	21%

Equipment

1. Single-phase dental X-ray unit (Kodak 2000, Kodak Dental Systems, Atlanta, GA, USA) - total filtration 1.5 mm aluminum, 70 kV
2. Dental X-ray film speed group D (Sensa, Air Techniques, Inc. Melville, NY, USA) as specified in ISO 3665 and film processor (Air Techniques A/T 2000 XR) temp 82°
3. Aluminum Step Wedge- free standing, 99% purity (**Fig. 1**)
4. Sheet of lead not less than 2 mm thick
5. Micrometer (Mitutoyo America Corporation, Aurora, IL, USA)
6. Photographic Transmission Densitometer (Macbeth TD 502, Macbeth Corporation, Newburgh, NY, USA)- capable of measuring in the range 0.5 to 2.5 of optical density (**Fig. 2**)
7. Reflection Spectrophotometer (CM-2600d, Konica Minolta, New Jersey, USA) (**Fig. 3**)

8. White/Black Background (Form N2A Unsealed Test Chart; The Leneta Company, Mahwah, NJ) (Fig. 3)
9. Translucency/Color Software (SpectraMagicNX; Konica Minolta, Ramsey, New Jersey)

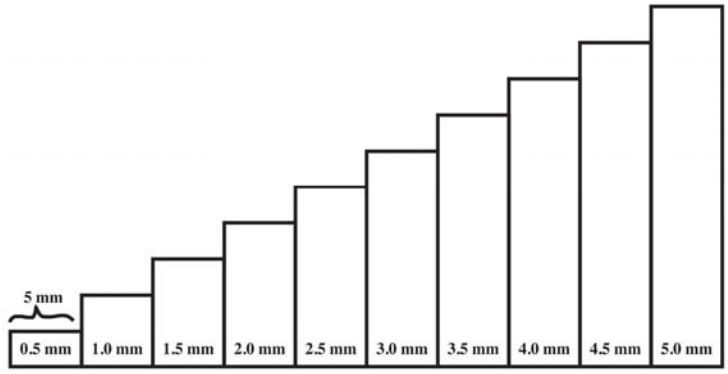

Fig. 1 Aluminum Step Wedge 20 mm x 50mm having a thickness range from 0.5 mm to 5.0 mm in equally spaced steps.

Fig. 2 Photographic Transmission Densitometer

Fig. 3 Reflection Spectrophotometer

Sample Preparation

An aluminum mold was used to prepare 10 disk specimens' 10mm in diameter and 1 mm thick for each composite material. The four composites were packed carefully into the aluminum mold. After the mold was filled, the composite was covered with a Mylar strip and a microscope slide. Each microscope slide was clamped to the aluminum mold to ensure stability and force out excess composite. **(Fig. 4)** The composite materials were then light cured with an Optilux 501, Quartz Tungsten Halogen (QTH) light (Kerr Manufacturing Inc., Orange, CA) for 80 seconds. The top of the specimen was cured 40 seconds, then flipped over and cured for an additional 40 seconds. The intensity of the light was checked every 10 samples using an Espectro photometer (3M™ ESPE™ St. Paul, MN) to ensure efficient light output. Each specimen was then measured with a micrometer (Mitutoyo) to verify a thickness of 1 +/- .1 mm. The specimens were then stored in 100% relative humidity for 24 hours.

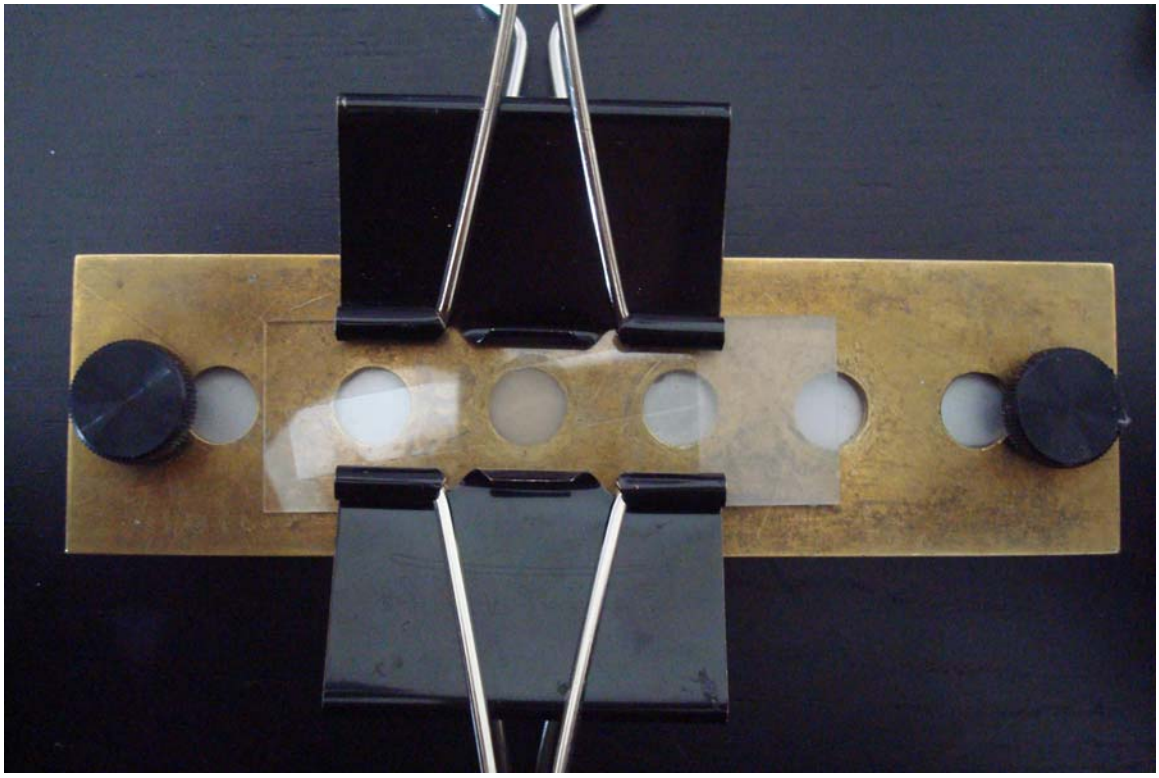

Fig. 4 Sample Fabrication

Translucency

After storage, the color of each specimen was measured according to the CIELAB color scale relative to the standard illuminant D65 against a white background and a black background using a reflection spectrophotometer. The 8mm (MAV) diameter target mask was used on the spectrophotometer. The sample size was selected to ensure that the measuring port had a smaller diameter than the disc. A 2-degree observer function was used with CIE illuminant D65. Diffuse illumination with 8-degree viewing was used to measure the sample. After determining the

color, translucency parameter (TP) was calculated from the difference between the color of the specimen over the white background and the color of the specimen over the black background using the following formula:

$$TP= [(L_B - L_W)^2 + (a_B - a_W)^2 + (b_B - b_W)^2]^{1/2}$$

In the formula, subscript B refers to the color parameters over the black background and subscript W refers to the color parameters over the white background.

Radiopacity

After 24 hours, 5 disk specimens (1 specimen for each composite) and the aluminum step wedge were placed on an occlusal speed group D film (Sensa Air Techmiques). The specimens were then placed in random order along the aluminum step wedge. The X-ray film, specimens, and step wedge were then placed on a sheet of lead. The film, specimens, and aluminum step wedge were exposed at 70kV, 7 mA, for 0.339 seconds at a target to film distance of 360 mm using a Kodak 2000 intraoral X-ray system. A special tube was constructed to ensure the same target to film distance. The film was then immediately processed in an automatic processor (Air

Techniques A/T 2000 XR) at 82° Fahrenheit. This same procedure was followed until all 50 specimens had been irradiated, a total of 10 radiographs. All occlusal films used were from the same box.

(**Fig. 5 and Fig. 6**)

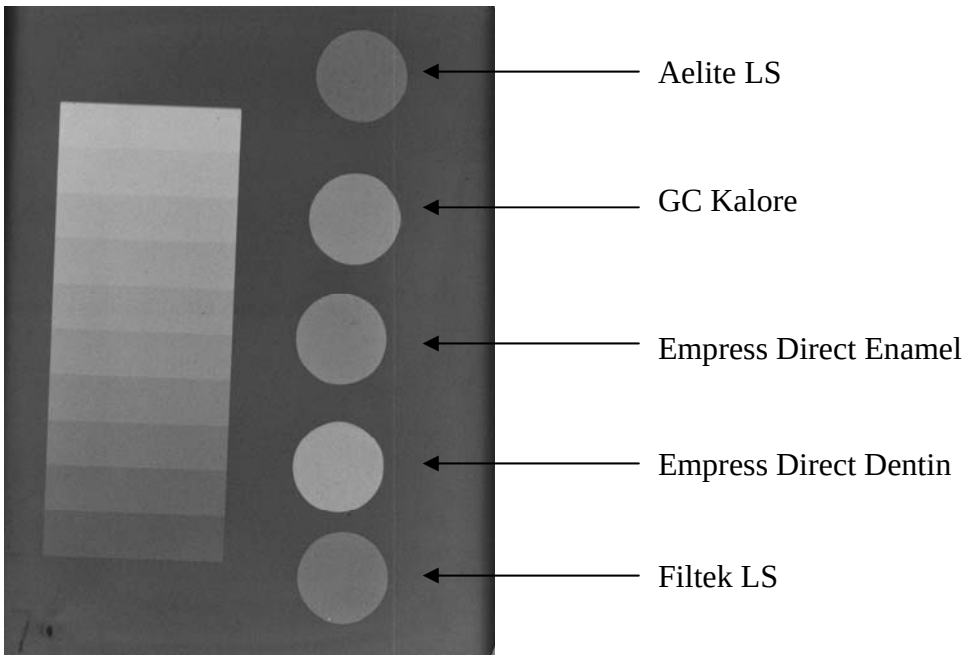

Fig. 5 Radiograph 7 showing step wedge and five specimens in random order.

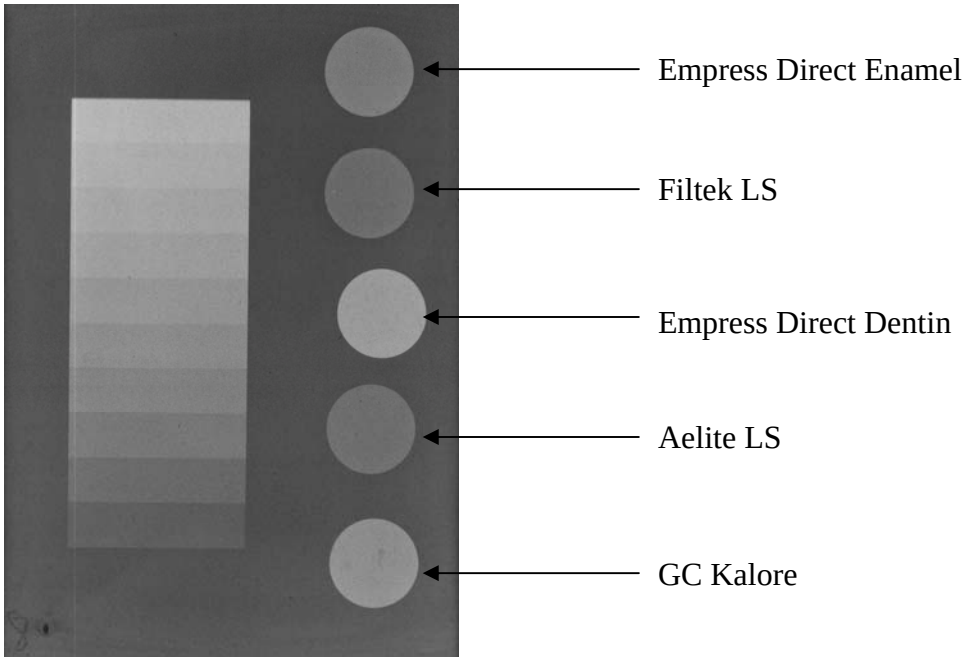

Fig. 6 Radiograph 8 showing step wedge and five specimens in random order

Radiographic optical densities (overall darkening of an exposed film) of the aluminum step wedge and specimens were then measured with a photographic transmission densitometer (Macbeth TD 502) with an aperture of 1 mm. Three readings were made for each specimen along with three readings of each step of the aluminum step wedge. The optical densities were recorded in this manner for all 10 occlusal films.

Two independent examiners visually evaluated each sample on the radiographs and assigned it to a corresponding step on the step wedge that appeared similar in density. The steps were labeled 1 to 10 with 1 being the least radiopaque and 10 being the most radiopaque. The values assigned to each individual sample by the two examiners were then averaged into one

number to give a Visual Average for each sample. For example, if one examiner gave a sample a value of 8 and another examiner gave the same sample a value of 9 the Visual Average for that sample was 8.5. The Visual Average was then divided in half to give the Visual Aluminum Equivalence. Using the previous example, the 8.5 Visual Average was divided in half to give 4.25 Aluminum Equivalent which was then rounded up to the nearest Aluminum Equivalent that corresponded to the step wedge which in this case was 4.5. All light on the x-ray viewer was blocked except for where the radiograph was to be placed. The examiners used no additional magnification or illumination (other than view box) to view the radiographs.

Statistical Analysis

Translucency

One-way analysis of variance (ANOVA) was used to determine statistical significance of translucency parameter and contrast ratio among the materials. The Tukey multiple comparison test was used to determine significant differences among the means of the five materials at 95% confidence ($p < 0.05$). A Pearson Correlation Matrix was also calculated between translucency and contrast ratio.

Radiopacity

The means and standard deviations for optical densities of the specimens and aluminum step wedge of each radiograph were calculated by averaging the three repeated measurements to create a single value for each specimen. A linear regression analysis was calculated for each film, relating the OD of the steps in the wedge to the thickness of each step. The aluminum equivalent (Al) was then calculated for each sample by using the regression analysis equation of:

y = a + bx

where:

y = the optical density (OD) of the specimen;

a = the coefficient of the regression;

b = the regression constant and

x = the aluminum equivalent value for that sample.

Solving the equation for aluminum equivalent, the final equation is as follows:

Al= [OD - Coefficient]/ Constant

One-way analysis of variance (ANOVA) was used to determine statistical significance of Optical Densities among the materials. The Tukey

multiple comparison test was used to determine significant differences among the means of the materials at 95% confidence ($p < 0.05$). The same tests were also done to analyze the data for Aluminum Equivalents, Visual Average, and Visual Aluminum Equivalent. A Pearson Correlation Matrix was calculated between the following: OpticalDensity/AluminumEquivalent (ALEquiv), AlEquiv/VisualAlEquiv, Alequiv/VisualAverage, Examiner1/Examiner2.

Translucency vs. Radiopacity

A Pearson Correlation Matrix was calculated for the following: Translucency Parameter/Aluminum Radiopacity Equivalent, Contrast Ratio/Aluminum Radiopacity Equivalent.

Results

Five commercially available resin composites Aelite LS Posterior, Filtek LS, GC Kalore, Empress Direct Enamel, and Empress Direct Dentin were evaluated for the optical properties translucency and radiopacity. Ten specimens for each composite were evaluated.

Translucency

Table 4 shows the means and standard deviations of the materials in relation to translucency parameter and contrast ratio. For translucency parameter, all materials were significantly different from each other. For contrast ratio all materials were significantly different except GC Kalore and Filtek LS, which were statistically similar. **Table 5** shows that translucency parameter and contrast ratio are highly correlated in an inverse relationship.

Table 4 - Values for Translucency Parameter and Contrast Ratio by Material; Mean (SD)

	Filtek LS	Empress Enamel	Empress Dentin	GC Kalore	Aelite LS
Translucency Parameter	17.503(0.694)[a]	22.089(0.790)[b]	14.413(0.414)[c]	18.394(0.418)[d]	11.808(0.627)[e]
Contrast Ratio	0.805(0.008)[f]	0.783(0.013)[g]	0.885(0.005)[h]	0.806(0.007)[f]	0.908(0.004)[i]
Note: Means with same letters are not significantly different with $p < 0.05$					

Table 5 - Correlation Between Contrast Ratio & Translucency Parameter

Correlation = -0.944

Radiopacity

Table 6 shows the means and standard deviations for the materials in relation to optical density, aluminum radiopacity equivalent, visual average

between two examiners, and the converted visual aluminum equivalent. For optical density, all materials were significantly different except for Filtek LS and Aelite LS, which were similar and higher than the others. Aluminum radiopacity equivalent showed the same results, except both were lower since there is an indirect relationship between optical density and aluminum equivalence. For the visual average among the examiners, Empress Direct Dentin was significantly greater than all of the materials. Filtek LS and Aelite LS were statistically similar, but lower. The difference between Empress Direct Enamel and GC Kalore was not significant, but the values were the lowest. For visual aluminum equivalent, once again Empress Direct Dentin was significantly greater, Filtek LS and Aelite LS were statistically similar and lower, and Empress Direct Enamel and GC Kalore were not significantly different, and lowest. **Table 7** shows that optical density and aluminum radiopacity equivalent are highly correlated, but inversely related.

Table 6 - Values for Optical Density and Aluminum Equivalents by Material; Mean (SD)

	Filtek LS	Empress Enamel	Empress Dentin	GC Kalore	Aelite LS
Optical Density	1.175(0.076)[a]	1.071(0.073)[b]	0.902(0.065)[c]	0.993(0.059)[b]	1.181(0.071)[a]
Aluminum Equivalent	1.317(0.299)[d]	2.181(0.299)[e]	3.609(0.286)[f]	2.837(0.320)[g]	1.263(0.277)[d]
Visual Average	3.150(0.412)[h]	5.800(1.206)[i]	9.350(0.079)[j]	6.900(1.329)[i]	3.200(0.823)[h]
Visual Aluminum Equivalent	1.750(0.264)[k]	3.000(0.577)[l]	4.750(0.354)[m]	3.550(0.685)[l]	1.750(0.425)[k]
Note: Means with same letters are not significantly different with $p < 0.05$					

Table 7 - Correlation Between Optical Density & Aluminum Radiopacity Equivalent

Correlation = -0.896

Table 8 shows the correlation between aluminum radiopacity equivalent and visual aluminum equivalent. When comparing all materials together the two are highly correlated (r= 0.938). When comparing individual materials, Filtek LS iand GC Kalore are moderately correlated and Aelite LS is not correlated. The rest of the materials are weakly correlated. **Table 9** shows the correlation between aluminum radiopacity equivalent and the visual average between two examiners. Results show similar trends as **Table 8** except values for visual average are slightly more

correlated. **Table 10** shows the correlation between the two independent examiners. The two examiners were highly correlated (r=0.889).

Table 8 - Correlation Between Aluminum Radiopacity Equivalent & Visual Aluminum Equivalent

	Correlation
All Materials	0.938
Filtek LS	0.744
Empress Enamel	0.444
Empress Dentin	0.431
GC Kalore	0.693
Aelite LS	0.291

Table 9 - Correlation Between Aluminum Radiopacity Equivalent & Visual Average

	Correlation
All Materials	0.947
Filtek LS	0.880
Empress Enamel	0.567
Empress Dentin	0.582
GC Kalore	0.650
Aelite LS	0.373

Table 10 - Correlation Between Visual Examiner 1 & Visual Examiner 2

Correlation = 0.889

Translucency vs. Radiopacity

Table 11 shows the correlation between aluminum radiopacity equivalent and translucency. When comparing all materials together, the two are not correlated. When comparing the individual materials, all materials, except Empress Direct Dentin, are weakly to moderately correlated and all but Filtek LS are indirectly related. Empress Direct Dentin is not correlated. **Table 12** shows the correlation between aluminum radiopacity equivalent and contrast ratio. When compared together or individually the two are not correlated.

Table 11 - Correlation Between Aluminum Radiopacity Equivalent & Translucency

	Correlation
All Materials	0.084
Filtek LS	0.328
Empress Enamel	-0.435
Empress Dentin	-0.038
GC Kalore	-0.488
Aelite LS	-0.600

Table 12 - Correlation Between Aluminum Radiopacity Equivalent & Contrast Ratio

	Correlation
All Materials	0.053
Filtek LS	0.225
Empress Enamel	0.118
Empress Dentin	0.158
GC Kalore	0.222
Aelite LS	0.349

Discussion

Translucency

The primary null hypothesis was rejected because all materials were statistically different when comparing translucency parameter values. This is not surprising, as multiple studies have shown that translucency varies by material and sometimes even when comparing materials within the same company[2, 4, 6, 24, 25]. Similar results were found when comparing contrast ratio values. All materials were significantly different except for Kalore and Filtek LS, which were very similar. The similarity between translucency parameter and contrast ratio is expected because previous studies[2], including this one (r= -0.944), show that the measurements are highly correlated thus they can be used interchangeably when measuring translucency. As translucency parameter increases, contrast ratio decreases.

Aelite (AE) was easily the least translucent (most opaque) of the composites. Looking at filler composition (based on manufacture claims), AE was also the most heavily filled at 88%. This is supported in Lee's study[4] where he found that as the amount of filler increased the translucency decreased. In his study, he also found that the size of filler and translucency were not correlated. This can be weakly validated in this study in that Aelite (1 of 2 microhybrids) had the least translucency and Empress Dentin (1 of 3

nanohybrids) had the second least. Microhybrids and nanohybrids utilize different size filler particles and there was variation in translucency regardless of type of composite in this study. One example of where size of particle may have an influence is in comparison of the two Empress Direct composites. According to the manufacturer, both composites have similar percentage filler weight yet Empress Enamel was easily the most translucent and Dentin was the second least translucent. According to the manufacturer, the dentin shade is incorporated with larger coarser particles of barium glass while the enamel shade is incorporated with smaller finer particles of barium glass. The larger particles could influence translucency. However, another difference between the filler content of the composites leads to the same conclusion as Lee[4]. The Empress Dentin composite has large amounts of prepolymer added to the filler composition and the enamel shade does not. From this, it is possible the two composites had similar percentage filler weight but different percentage volume weight (not provided). A separate study breaking down the filler components of each composite by weight and volume would lead to possibly a more definitive answer as to a correlation between translucency and filler composition.

It has also been found that organic matrix can have an influence on translucency[5, 7]. Azzopardi[5] found that as BisGMA increased so did

translucency (linear correlation). In this study, Aelite had the highest matrix composition (25% BisGMA by weight), yet the least translucency. This contradiction to Azzopardi's study can be explained once again by the fact that BisGMA is given in weight and not volume. Both values need to be known before a conclusion can be drawn. Perez[7] found that silorane based composites behaved differently than dimethacrylate based composites after polymerization. Filtek LS has a silorane organic matrix and was in the middle of the group in translucency parameter so it is difficult to make a conclusion on the influence of silorane matrix versus the other composites, which utilize dimethacrylates as organic matrices. This study could be expanded in the future to compare translucency before and after polymerization, after water storage, and after thermocycling to better understand what and how much translucency is affected by these factors.

Using 1mm thick specimens, Yu[2] provided a tentative classification system for translucency where low translucency has a value less than 13, medium translucency a value between 13 and 18, and high translucency a value above 18. Based on this classification, Aelite could be used effectively to mask the dark background of the mouth while Empress Enamel could be utilized as an incisal edge composite where a blue/gray effect from the dark background of the mouth may be more desirable. One

note of interest, it is difficult to clinically determine the actual thickness of composite being placed on the tooth and as the thickness of the tooth increases translucency decreases[3, 26].

Radiopacity

Results showed that the aluminum equivalence of all composites were significantly different except for Filtek LS and Aelite LS, which were statistically similar. This means the secondary null hypothesis was partially rejected. Tooyoka[23], Hotta[22], and van Dijken[21] examined what fillers made composites radiopaque and found that heavy metal fillers such as ytterbium, barium, and strontium are added to resin composites to enhance radiopacity. A good example is the comparison of the two Empress composites. The dentin shade was the most radiopaque of the composites and the manufacturer specifically added Ytterbium in addition to Barium filler particles to enhance radiopacity. Ytterbium was not added to the enamel shade and its aluminum equivalence was significantly lower than the dentin shade. Aelite LS statistically had the lowest aluminum equivalent value and no high atomic weight fillers are listed as a major filler component. A good future study would be to fabricate experimental composites with the same amount of heavy metal filler to determine the major effect on radiopacity.

Another useful study would be to vary the different type of heavy metal filler (barium, ytterbium, etc.) to see if one had a bigger influence than the other. A final question to be asked is whether size of the heavy metal filler particle has an influence on radiopacity. Unlike translucency I would anticipate the answer would be yes.

ISO 4049 guidelines state that a 1.0mm thick specimen must have an aluminum equivalence greater than 1.0mm to be deemed radiopaque. In this study, all of the composites met this criterion. However, Bouschlicher[18] and others[16, 17, 19] in their studies concluded that to best detect secondary caries and poor margins a composite should have a radiopacity greater than enamel and that enamel has aluminum equivalence approximately twice that of dentin. In this study, an aluminum equivalence of 2.0mm would meet this criterion. However, a future study including slices of tooth containing enamel and dentin should be included to statistically justify this statement. With that being said, only Empress Enamel, Empress Dentin and GC Kalore met this guideline.

In this study, two independent examiners were used to determine if they viewed specimens more or less radiopaque than the transmission densitometer. For every composite, the examiners found the composites more radiopaque than the aluminum equivalent values obtained through the

densitometer. This agrees with the same results from the pilot study. From these results, having a composite with an aluminum equivalence greater than enamel may not be as important as previously described since examiners already tend to find composites more radiopaque than the test method followed in the ISO guidelines. A high correlation (r= 0.88) between the examiners supports the accuracy of their interpretations. In a future study including tooth slices, in addition to comparing the specimens to a step on the step wedge, it would be interesting to have the examiners determine if the specimen was more radiopaque than the enamel and dentin of the tooth slice.

In this study, the visual average of the two examiners was converted to a visual aluminum equivalent on the step wedge for what was thought would be a better comparison to the radiopacity aluminum equivalent values. To correspond it to an actual step on the step wedge a value sometimes had to be rounded up to the nearest half millimeter. In future studies, this will not be necessary as the visual average correlated higher to the radiopacity aluminum equivalent values than the visual aluminum equivalent values. This is likely due to the rounding of the numbers involved. Furthermore, there was a high correlation when comparing the materials as a group between visual aluminum equivalent and aluminum radiopacity equivalent

(r= 0.93). However, when running a correlation between the two methods with each individual material, correlation ranged from 0.29 (Aelite LS) to 0.74 (Filtek LS). Ironically, these two composites were statistically very similar using the ISO guidelines method. This variation can be explained in the method used to collect data. Visual data was obtained via a ratings scale and aluminum radiopacity equivalent was obtained by a statistical method. Thus conclusions made from the correlation of the methods may be in question.

Translucency vs. Radiopacity

The tertiary null hypothesis was accepted because results showed that there was no correlation (r= 0.08) between translucency and radiopacity when comparing the materials as a group. When correlating the materials individually, correlation was a little stronger but still very weak. Most were inversely weakly correlated (negative values) with the lone exception being Filtek LS. The type and amount of filler particle used in the composite could explain this varying correlation. A good example is the resin composite Aelite LS. Aelite LS was the most opaque composite but the least radiopaque. As stated earlier, Aelite LS was the highest filled composite tested but, according to the manufacturer listed fillers, very little high atomic weight filler particles were incorporated into the composite.

The weak correlation between translucency and radiopacity could likely depend on other factors besides filler composition. For example, Empress Direct Dentin was the most radiopaque and second most opaque of the five composites yet the correlation between translucency and radiopacity with this composite was the lowest of all (r= -0.038). However, I suspect that if the only filler used in a composite was a high atomic weight filler then the two would be more correlated.

Conclusions

- All composites were significantly different for translucency parameter.

- Empress Direct Enamel was the most translucent material and Aelite LS was the least translucent (most opaque).

- For contrast ratio, all composites were significantly different except for GC Kalore and Filtek LS, which were statistically similar.

- Translucency parameter and contrast ratio were highly correlated thus these terms can be used interchangeably when referring to translucency.

- All composites were significantly different except Filtek LS and Aelite LS, which were statistically similar for radiopacity (Al Equiv).

- All of the materials tested met the International Standards Organization (ISO) 4049 guidelines for radiopacity with Empress Direct Dentin being the most radiopaque and Aelite LS being the least radiopaque.

- Using a visual method to determine radiopacity, two independent examiners found all of the materials more radiopaque than the ISO 4049 method of determining radiopacity.

- There was only a very weak correlation between translucency and radiopacity and it was inverse for most materials.

References

1. Powers JM, Sakaguchi RL. . Restorative dental materials. . 12th edition ed. St. Louis: Mosby; 2006.

2. Yu B, Lee YK. Translucency of varied brand and shade of resin composites. Am J Dent 2008;21(4):229-32.

3. Powers JM, Dennison JB, Lepeak PJ. Parameters that affect the color of direct restorative resins. J Dent Res 1978;57(9-10):876-80.

4. Lee YK. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. Dent Mater 2008;24(9):1243-7.

5. Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, van Noort R. Effect of resin matrix composition on the translucency of experimental dental composite resins. Dent Mater 2009;25(12):1564-8.

6. Lee YK. Influence of scattering/absorption characteristics on the color of resin composites. Dent Mater 2007;23(1):124-31.

7. Perez MM, Ghinea R, Ugarte-Alvan LI, Pulgar R, Paravina RD. Colour and translucency in silorane-based resin composite compared to universal and nanofilled composites. J Dent 2010.

8. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont 1995;8(1):79-86.

9. Johnston WM, Reisbick MH. Color and translucency changes during and after curing of esthetic restorative materials. Dent Mater 1997;13(2):89-97.

10. Lee YK, Lim BS, Rhee SH, Yang HC, Powers JM. Changes of optical properties of dental nano-filled resin composites after curing and thermocycling. J Biomed Mater Res B Appl Biomater 2004;71(1):16-21.

11. Abou-Tabl ZM, Tidy DC, Combe EC. Radiopacity of composite restorative materials. Br Dent J 1979;147(7):187-8.

12. Cook WD. An investigation of the radiopacity of composite restorative materials. Aust Dent J 1981;26(2):105-12.

13. Tveit AB, Espelid I. Radiographic diagnosis of caries and marginal defects in connection with radiopaque composite fillings. Dent Mater 1986;2(4):159-62.

14. Espelid I, Tveit AB, Erickson RL, Keck SC, Glasspoole EA. Radiopacity of restorations and detection of secondary caries. Dent Mater 1991;7(2):114-7.

15. 4049 ISI. Polymer-based filling, restorative and luting materials. Technical Committee 106-Dentistry. In: Organization IS, editor. Geneva, Switzerland; 2000.

16. el-Mowafy OM, Benmergui C. Radiopacity of resin-based inlay luting cements. Oper Dent 1994;19(1):11-5.

17. Williams JA, Billington RW. A new technique for measuring the radiopacity of natural tooth substance and restorative materials. J Oral Rehabil 1987;14(3):267-9.

18. Bouschlicher MR, Cobb DS, Boyer DB. Radiopacity of compomers, flowable and conventional resin composites for posterior restorations. Oper Dent 1999;24(1):20-5.

19. Murchison DF, Charlton DG, Moore WS. Comparative radiopacity of flowable resin composites. Quintessence Int 1999;30(3):179-84.

20. Stanford CM, Fan PL, Schoenfeld CM, Knoeppel R, Stanford JW. Radiopacity of light-cured posterior composite resins. J Am Dent Assoc 1987;115(5):722-4.

21. van Dijken JW, Wing KR, Ruyter IE. An evaluation of the radiopacity of composite restorative materials used in Class I and Class II cavities. Acta Odontol Scand 1989;47(6):401-7.

22. Hotta M, Yamamoto K. Comparative radiopacity of bonding agents. J Adhes Dent 2009;11(3):207-12.

23. Toyooka H, Taira M, Wakasa K, et al. Radiopacity of 12 visible-light-cured dental composite resins. J Oral Rehabil 1993;20(6):615-22.

24. Lee YK, Lu H, Powers JM. Optical properties of four esthetic restorative materials after accelerated aging. Am J Dent 2006;19(3):155-8.

25. Yu B, Lee YK. Differences in color, translucency and fluorescence between flowable and universal resin composites. J Dent 2008;36(10):840-6.

26. Ikeda T, Murata Y, Sano H. Translucency of opaque-shade resin composites. Am J Dent 2004;17(2):127-30.