Colour comparison of two composite materials to natural tooth structure: an in vitro study

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A mini thesis submitted in partial fulfilment of the requirements for the degree of Magister Chirurgiae Dentium (MChD) in the Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape, 2013.

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Co-supervisor: SR Grobler
Declaration

I, Andries Adam Grundlingh declare that the work in the mini thesis is my own original work. I have not previously submitted this research to any university or institution for a degree or examination.
Acknowledgements

Dr Naren Patel for your guidance and support throughout my studies.

Prof Sias Renier Grobler for your guidance and support with this mini thesis.

Mnr Theunis van Wyk Kotze for statistical analysis.
Dedication

This mini thesis is dedicated to my wife, Sonja and children, Jana and Bea for believing in the vision and walking the path with me.
Abstract

Objectives: This in vitro study compares the ability of two composite materials Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) against extracted tooth structure using the modern two layering concept.

Materials and Methods: Fifty six extracted anterior maxillary central incisor teeth were selected which were caries free, had no surface defects and within the colour range A3, B3, C3 or D2. The teeth were randomly divided into four colour groups (A3, B3, C3 and D2), each containing 14 teeth. A class IV cavity was prepared on all the teeth and the two composite materials were used alternately with no bonding agent to restore the cavity. The colour of both composites was assessed immediately after restoration, 24 hours and after two weeks using the SpectroShade™ (MHT) spectrophotometer. The MHT SpectroShade™ version 3.3 software was used with the CIE L*a*b* colour system to evaluate the colour of the teeth and restorations. The Kruskal-Wallis One-Way analysis of variance was used to compare the differences between the medians of the two composite materials. The significance was set at $z > 3.1237$. The Spearman's rank correlation coefficient was set at a significance of $p < 0.01$ to evaluate colour change ($\Delta E_{ab}$) in the restorations over three time intervals (immediate restoration, 24 hours and two weeks).
Results: The median ($\Delta E_{ab}^*$) colour distance for both Filtek Supreme XTE™ (3M, ESPE) [A3 colour 2 weeks: 12.4, B3 colour 2 weeks: 6.1, C3 colour 2 weeks: 7.8, D2 colour 2 weeks: 7.9] and CeramX™ Duo (Dentsply) [A3 colour 2 weeks: 15.9, B3 colour 2 weeks: 15.8, C3 colour 2 weeks: 13.7, D2 colour 2 weeks: 6.1] composite materials were far away from the natural tooth colour.

Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) restoration colours (A3, C3 and D2) revealed no significant difference (p>0.01) for the 24 hours versus 2 weeks time interval. However, the B3 colour restorations were significantly different for the 24 hours versus 2 weeks time interval.

A strong relationship (p<0.01) was found for the restoration colour distance ($\Delta E_{ab}^*$) over the three time intervals (immediate restoration versus 24 hours, immediate restoration versus 2 weeks and 24 hours versus 2 weeks) for Filtek Supreme XTE™ (3M, ESPE) restoration colours A3, C3 and D2. However, no relationship was found (p>0.05) for the restoration colour distance ($\Delta E_{ab}^*$) over these three time intervals for Filtek Supreme XTE™ (3M, ESPE) B3.
A strong relationship was found (p<0.01) for the restoration colour distance ($\Delta E_{ab}^*$) over the three time intervals (immediate restoration versus 2 weeks, 24 hours versus 2 weeks and 24 hours versus 2 weeks) for CeramX Duo (Dentsply) restoration colours B3 and C3. A strong relationship was found for the restoration colour distance ($\Delta E_{ab}^*$) for CeramX Duo (Dentsply) restoration colour A3: immediate restoration versus 24 hours. However, no relationship (A3 colour) was found for the time intervals: immediate versus 2 weeks as well as 24 hours versus 2 weeks. The restoration colour distance ($\Delta E_{ab}^*$) for the CeramX Duo (Dentsply) D2 immediate restoration versus 24 hours showed a strong relationship; immediate versus 2 weeks showed no relationship and 24 hours versus 2 weeks also showed a relationship at a five percent significant level.

**Conclusion:** Both Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) composite materials were unable to mimic the colour for the natural teeth at a five percent level. Therefore the hypothesis was rejected. The second hypothesis that the restoration colour would stay stable from immediate restoration to 2 weeks of storage was accepted for the Filtek Supreme XTE™ (3M, ESPE) restoration colours A3, C3 and D2 and for the CeramX Duo (Dentsply) restoration colours B3, C2 and D2.
Keywords:

1. Anterior maxillary central incisor teeth
2. Composite
3. Layering concept
4. Spectrophotometer
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Chapter 1 Introduction

The preservation of normal tooth structure is the cornerstone of minimal invasive procedures. The demand for these conservative treatment options have increased and given rise to the development of new dental materials. Composite material is one of these materials that can mimic the colour properties of natural tooth structure.

Composite material utilises the layering concept to replace the lost tooth structures (enamel and dentine) in different layers. This technique is well established and especially popular with the restoration of the anterior teeth (Dietschi, 2001). Little scientific evidence is available that compares these composites ability to match the colour properties of the natural tooth.

Tooth colour determination has been traditionally based on the clinician’s abilities using tooth colour shade guides and thus remains subjective. Modern technology has made it possible to do predictable measurements of colour by the use of spectrophotometers. These measurement methods are reliable and reproducible (Kielbassa et al., 2009 and Derdilopoulou et al., 2007).

1.1 Layering concept

The layering concept is a technique where missing tooth structure is replaced by different layers of composite. Dentine reflects light differently from enamel and thus these tissues necessitate the use of different materials to replace them. Different composite materials are used to mimic the natural tooth properties such as colour, translucency, fluorescence and opalescence (Dietschi, 2001).
Missing tooth structure can be replaced using a two or three layer concept (Dietschi, 2001). In the conventional two layer concept two different composites are used, one to replace the dentine and one to replace the enamel. The concept is based on a monochromatic build up of the restoration which blends with the surrounding teeth (chameleon effect). This technique is the ideal and simple to follow. Only a few enamel and dentine shades are available and may not always produce ideal aesthetics (Dietschi, 2001).

The three layer concept uses a polychromatic build-up for the restoration. The restoration can comprise of varying opacities and chroma (the degree of colour saturation) from the inside to the surface of the restoration. The composite material comprises of two sets of dentine and one enamel set. The aesthetic potential of a restoration may be improved with the three layer concept, but the learning curve is difficult and long. This is due to the fact that all the possible layers of material do not match the optical properties of the natural tooth (Dietschi, 2001).

The modern two layering concept utilises two basic composite masses that replicate the optical properties of the natural tooth. Different hues (colours) with varying chroma are available for the dentine. Three basic enamel materials are available (white opalescence, neutral/ivory, grey translucent enamel). The aesthetic potential of this technique is promising and a big improvement on the conventional two layer concept, but may need intensive tints to better match unusual anatomical features (Dietschi, 2001).
1.2 Background for shade selection

Tooth colour selection or shade determination is mainly made using a white or matt black background. Lee et al., (2005) tested these backgrounds and their results suggested that reflection from a white background can influence the colour of a composite resin. The authors suggested the use of a light trap or a matt black background.

1.3 Tooth colour

1.3.1 Evaluation of colour

Tooth colour is made up of numerous chromophores. Chromophores are long chained single and double bonded compounds that absorb visible light and reflect the light to produce the true colour of an object (Joiner, 2007). The tooth colour is evaluated either visually or digitally or using both (Kielbassa et al., 2009, Watts and Addy, 2001). The Munsell’s System (Judd, 1970) and the International Commission of Illumination (CIE) L*a*b* colour system are the two most popular systems used to describe colour (Minolta Co. Ltd., 1994).

Colour is described in terms of value, chroma and hue (Minolta Co. Ltd., 1994 and Paravina, 2008a). Value describes the lightness of a colour on a scale ranging from pure black to pure white. Hue presents the different spectrum of colour (examples: red, blue and green). Chroma is the degree of saturation or intensity of a colour (Joiner, 2004; Watts and Addy, 2001) (Figure 1 and 2).
1.3.2 Munsell Colour Tree

The colours on the Munsell Colour Tree are firstly arranged according to their hue (examples: red, blue and green). The value of the colours are arranged on a vertical achromatic value axis with the darker colours at the bottom and the lighter colours on the top. The chroma of the colours moves away from the vertical achromatic value axis as the saturation intensifies (Figure 1).

The Munsell colour system is based on strict measurements of human subject’s visual responses to colour based on a firm experimental scientific basis. This system is a particularly useful in dentistry where visual colour matching is predominantly used in the chairside situation (Judd, 1970).

Figure 1: The Munsell Colour Tree is a three-dimensional representation of available colour.
1.3.3 International Commission of Illumination (CIE) L*a*b* colour system

The CIE L*a*b* colour system (Figure 2) was established by Commission Internationale de l’Eclairage in 1976 (Minolta Co., Ltd., 1994). This three dimensional colour model describes colours that are visible to the human eye.

In this colour space value (lightness) is represented by L* on a scale of 0 (black) to 100 (white). Hue and chroma is represented by a* and b* respectively. In Figure 2, a* and b* indicate colour directions, +a* is the red direction, -a* is the green direction, +b* is the yellow direction and -b* is the blue direction (Burkinshaw, 2004). The centre of this model is achromatic and the a* and b* values increases outwardly away from the centre. This means that when a* and b* values increases the saturation of the colour increases.

In the L*a*b* colour space, colour difference can be expressed as a single numerical value (\(\Delta E_{ab}^*\)) that indicates the size of colour difference. The colour difference of an object between two measurements can be calculated using the colour components (L*, a* and b*). The colour difference between measurements are represented by \(\Delta L^*\), \(\Delta a^*\) and \(\Delta b^*\). Total colour change is calculated with the following formula:

\[
\Delta E_{ab}^* = \left[ (\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{1/2}
\]

(Minolta Co. Ltd., 1994)

Unfortunately the formula only indicates the size of the colour difference and not the direction of movement (i.e. + or – signs). No indication is provided in what way the colours differ.
1.3.4 Tooth colour assessment

Visual colour assessment using shade guides and charts has been the traditional method to assess tooth colour (Watts and Addy, 2001). Although dental shade guides have improved, they do not cover the colour distribution of natural teeth (Ishikawa-Nagai et al., 2005). Therefore, correctly assessing tooth colour using these guides remains a problem for clinicians.

Visual colour assessment is dependent on the clinician’s ability to discriminate between colours, the light source used, and finally light reflection, refraction and shading. The assessment of the tooth colour is difficult, since natural tooth colour is not uniform and changes from the gingival margin through the tooth body to the incisal edge. The appearance of the body of the tooth is somewhere between the

Figure 2: CIE L*a*b* three dimensional colour space.
cervical area and the incisal edge (Watts and Addy, 2001). The middle third of the facial surface of the tooth represents the basic colour of the tooth and used for visual tooth colour assessment (Cibirka et al., 1999; Rosenstiel et al., 1991).

The conditions and environment in which tooth colour assessment will be performed must be standardised especially for anterior composite restorations. Variables such as the light source, time of day, the surrounding area and the angle at which the tooth is viewed from can affect tooth colour determination. A tooth assessed under different viewing conditions for example different light conditions will also display a different tooth colour (metamerism). This may lead to incorrect tooth colour assessment and incorrect restoration colour (Kielbassa et al., 2009).

Computer-based instruments for shade selection and determination have become commercially available over the last two decades. These instruments were developed to overcome inconsistencies and tooth colour mismatch as seen with visual tooth colour assessment methods (Kielbassa et al., 2009). The instruments are based on the developments in the paint, plastics, printing, ink and textiles industries where spectrophotometry and computer calculations based on colour theory have utilised colour science to express colours numerically. The advancement of technology has made spectrophotometers and colorimeters more accessible to the dentist and is increasingly used to pinpoint the true tooth colour (Joiner, 2004).

Colorimeters measure colour utilising the tristimulus method (XYZ tristimulus values). The light reflected from the object is measured with three sensors (red,
green and blue) filtered to the same sensitivity as the human eye. Spectrophotometers utilise multiple sensors (up to 40 sensors) to measure the spectral reflectance of an object in each narrow wavelength range (Minolta Co. Ltd., 1994). The reflected light from an object (in this case the tooth) is emitted by an intense gas-filled tungsten lamp that is integrated into the spectrophotometer. Thus spectrophotometers do not rely on judgment or environmental conditions to evaluate tooth colour, but measure the reflected emission of spectral colours. This ensures that the surrounding light does not influence the measurement (Horn et al., 1998).

Spectrophotometers provide the highest level of accuracy and have the ability to measure absolute colours. This high accuracy of the spectrophotometer makes the instrument ideal for research purposes and reduces the number of incorrect tooth colour readings, but tooth colour assessment in a patient's mouth remains difficult (Ishikawa-Nagai et al., 2005).

Three previous studies have compared digital with visual colour assessment within a single study (Horn et al., 1998; Jarad et al., 2005; Kielbassa et al., 2009). All found that tooth colour assessment with a spectrophotometer was more reliable and predictable than using standard tooth shade guides. The main difference between tooth colour matching with visual perception techniques and the use of a modern computer colour matching technique lies in the level of accuracy of tooth colour assessment (Chen et al., 2012).
1.3.5 Timing of tooth colour assessment

The term blending effect or “chameleon effect” is used to describe the phenomenon that takes place between dental materials (composite) and the hard dental tissues (enamel and dentine). A smaller colour difference is observed when these different types of materials are viewed together, compared to viewing the materials in isolation (Paravina et al., 2008b). Restoration colour assessment is made 24 hours after the restoration is made to allow for this phenomenon to take place and for rehydration of the natural tooth structure (Nakajima et al., 2012, Tsubone et al., 2012, Kielbassa et al., 2009).

1.4 Composite properties

Both Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) are based on the use of very small particle fillers (nanofillers), but differs in the type of resin system, particle size and particle fillers used. CeramX™ Duo (Dentsply) comprises of organic modified ceramic nano-particles, an adhesive Prime&Bond NT (with highly dispersed and non-aggregated nanofillers) and combined with conventional glass fillers of 1 µm. Filtek Supreme XTE™ (3M, ESPE) is a nano-filled resin-based composite that utilises resins BIS-GMA, BIS-EMA, UDMA with small amounts of TEGDMA. The translucent shades contain a combination of non-aggregated, 75nm silica nanofillers, and a loosely bound agglomerate silica nanocluster consisting of agglomerates of primary silica nanoparticles of 75nm size fillers. The remainder of the shades contain a combination of non-aggregated, 20nm nanosilica filler and loosely bound agglomerated zirconia/silica nanoclusters consisting of particle sizes of 5-20nm fillers.
The use of these smaller particles (nanofillers) is claimed to enhance the ability of the composite materials to mimic the colour properties of natural tooth structure (manufacturer’s manuals).

1.5 Statement of the problem
A number of different brands of composite materials are available on the market and all claiming to produce the best aesthetic result. The clinician is within a maze of available products and has to choose a material that will deliver a predictable aesthetic result. The current study was undertaken since no studies have been reported in South Africa comparing the ability of these modern composite materials (Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) to mimic the colour properties of extracted teeth.

UNIVERSITY of the WESTERN CAPE
Chapter 2 Materials and Methods

2.1 Aim of the study:

The aim of the study was to compare the ability of two composite materials (Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) to mimic the colour properties of extracted teeth using the modern two layering concept (section 1.1). The literature review revealed a few gaps in the knowledge, which has enabled the development of the following hypotheses.

The hypotheses that was be tested are the following:

1. Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) are equally efficient in mimicking the natural extracted tooth structure.
2. Composite colour remained stable immediately after the restoration is made, 24 hours to two weeks of storage time.

2.2 Objectives of the study:

The objectives of this in vitro study was formulated to test the hypotheses.

1. Colour obtained from the Filtek Supreme XTE™ (3M, ESPE) restoration was compared to the extracted teeth.
2. Colour obtained from the CeramX™ Duo (Dentsply) restoration was compared to the extracted teeth.
3. The accuracy of the restoration colour from both composite materials was compared with each other.
4. Determine if any restoration colour change occurred between the immediate restoration, 24 hours and two weeks later (Magne and So, 2008).
2.3 Ethics clearance

Permission to use human extracted teeth in this study was obtained through the HUMAN RESEARCH ETHICS COMMITTEE at the University of the Western Cape, ethics clearance certificate (12/7/18). A copy of this certificate can be found in Appendix A (page 49).

2.4 Storage of teeth

A total of 56 extracted anterior maxillary incisors were collected and stored in individual labelled bottles containing 1% thymol (Lot: 6282) (Riedel-de Haën, Germany) at 4°C (Figure 3).

Figure 3: All the teeth in this study were stored in numbered bottles containing 1% thymol.
2.5 Construction of a jig

A customised jig (Micro manipulator, Narishige, Japan) was used to hold the teeth in position to enable the positioning of the spectrophotometer in the same position for all tooth colour determinations (Figure 4 and 5).

Figure 4: The jig was used to keep the teeth in position during colour determination.

Figure 5: The spectrophotometer was placed in the same position for each colour determination against the tooth.
2.6 Acquiring and cleaning of the teeth

Extracted caries free human maxillary anterior central incisors were selected for this *in vitro* study to evaluate available tooth colours. The external debris and stains on the teeth were removed with a Cavit-Jet (Cavitor Dentsply, USA) scaler. A polishing cup [KerrHawe OptishineTM; Batch number 10/Art. No.2514 (Switzerland)] and polishing paste [Glitter® prophylaxis paste with fluoride, medium min; Lot: 31618 (USA)] were used to polish the tooth surface for one minute.

2.7 Inclusion criteria

The human maxillary anterior central incisors teeth were re-examined and only those with no caries and no visual surface defects were assessed further for colour.

2.8 Colour evaluation

The tooth colour was evaluated using the SpectroShade® (Medical High Technologies Corporation; S/N: HDL2173) spectrophotometer against a matt black background. The teeth were divided into groups of matching tooth colour. The four groups were chosen due to the availability of teeth and to present a wide range of colour: A3, B3, C3 and D2. Fourteen teeth were chosen randomly from each group giving a total of 56 anterior maxillary central incisor teeth for use in this *in vitro* study (Table 1).
Table 1: Selected tooth colour shades and groups

<table>
<thead>
<tr>
<th>Selected tooth colours</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>n</td>
</tr>
</tbody>
</table>

2.9 Composite shades for the selected tooth colour shades

The acquired composite shades needed to match the selected tooth colours (A3, B3, C3 and D2) were retrieved from the two composite shade guides (Table 2 and 3). The Filtek Supreme XTE™ (3M, ESPE) shade guide provides different composite combinations according to the class of restoration to be restored. For this study only Class IV restorations would be built and therefore the corresponding shade guide for Class IV restorations was chosen (as per manufacturer’s instruction).

Table 2: Layering composites for Filtek Supreme XTE™ (3M, ESPE)

<table>
<thead>
<tr>
<th>Composite layers</th>
<th>Composite colour</th>
<th>A3</th>
<th>B3</th>
<th>C3</th>
<th>D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>A3E</td>
<td>B3B</td>
<td>D2E</td>
<td>D2E</td>
<td></td>
</tr>
<tr>
<td>Lot number:</td>
<td>N288994</td>
<td>N255382</td>
<td>N403775</td>
<td>N403775</td>
<td></td>
</tr>
<tr>
<td>Dentine</td>
<td>A4D</td>
<td>B3D</td>
<td>C4D</td>
<td>A3D</td>
<td></td>
</tr>
<tr>
<td>Lot number:</td>
<td>N289882</td>
<td>N286289</td>
<td>N337802</td>
<td>N333028</td>
<td></td>
</tr>
</tbody>
</table>
The CeramX Duo (Dentsply) shade guide was utilised for the correct composite combinations for each colour (as per manufacturer’s instruction).

### Table 3: Layering composites for CeramX™ Duo (Dentsply)

<table>
<thead>
<tr>
<th>Composite layers</th>
<th>Composite colour</th>
<th>A3</th>
<th>B3</th>
<th>C3</th>
<th>D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td></td>
<td>E2</td>
<td>E3</td>
<td>E2</td>
<td>E2</td>
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#### 2.10 Production of a matrix

A vinyl polysiloxane impression material; Lot B05882 (President® Clotène/Whaledent) was used to fabricate a palatal matrix for all the teeth in each of the four selected groups. The teeth in each group were randomly positioned into the vinyl polysiloxane impression material and left to set until hard.

The matrices were adhered to a board with the numbered sequence of the teeth (Figure 6). This helped with the correct use of the matrices with the correct tooth during the layering of the Class IV restoration for standardisation between the two composite groups.
Figure 6: Matrices and tooth sequence for the A3, B3, C3 and D2 colour groups.
2.11 Tooth preparation

A Class IV cavity was prepared on all the selected teeth. A slight bevel of 1.0-1.5mm was made on the buccal surfaces of the teeth for increase retention for the future restoration. The preparation removed two thirds of the mesial clinical crown height, maintaining one third of the incisal edge (Figure 7) (Magne and So, 2008). The preparation ensured exposure of dentine and enamel without pulpal involvement.

![Figure 7](image)

**Figure 7:** Two thirds of the mesial clinical crown height was removed, maintaining one third of the incisal edge.

2.12 Composite material application and the control

Each tooth served as its own control. The two composite materials were used on all the teeth with no bonding agent. The first composite was used to restore the Class IV cavity and the colours were recorded using the spectrophotometer immediately after restoration, 24 hours and after two weeks (as per manufactures instruction).
The restoration was removed from the tooth, ensuring complete removal of all composite material and causing no damage to the tooth. The second composite was applied according to the same methods and the colours were recorded using the spectrophotometer immediately after restoration, 24 hours and after two weeks (as per manufacturer’s instruction).

2.13 Layering concept

The layering concept technique used was identical for both composite materials. The LED B curing light; Milestone CE International (Lot: B12010015A) with a wavelength of 420nm to 480nm was used to polymerise the composite layers throughout the study.

A thin layer (0.5 to 1.0mm of thickness) of enamel material was placed into the palatal matrix and placed on the palatal surface of the tooth and polymerised for 20 seconds. A second layer of dentine composite material was placed onto the first layer and polymerised for 20 seconds leaving a space of 0.5 to 1.0mm for the final layer of enamel composite material. The final layer of enamel composite was placed and polymerised for 20 seconds (Magne and So, 2008).

2.14 Colour measurement

The SpectroShade™ (MHT Corporation) spectrophotometer was used to accurately capture the tooth and restoration colours. The spectrophotometer was calibrated with the white, followed by the green calibration block according to the manufacturer’s instructions. The colour determination was performed with the
tooth at a ninety degree angle to the spectrophotometer probe using the customised jig.

The SpectroShade™ (MHT Corporation) spectrophotometer has a cross for orientation of the tooth to the spectrophotometer’s probe. A green horizontal line appeared over the image of the tooth to indicate a correct exposure. A yellow horizontal line indicated an acceptable exposure and a red horizontal line indicated an unacceptable exposure. Only exposures of the teeth with a green line was accepted (Figure 8).

![Image of SpectroShade™](image)

**Figure 8:** The green horizontal line signifies the correct exposure.

All the images that were acquired were updated with the necessary detailed notes. The notes contained the tooth number, the time interval and lastly the specific composite and colour used. This prevented any confusion when the images of the teeth and restorations were transferred to the MHT SpectroShade™ version 3.3 software on a desktop computer at all times.
2.14.1 Timing of colour determination

The tooth and composite restoration colours were captured immediately after the restoration was made, at 24 hours and two weeks later (Nakajima et al., 2012, Magne and So, 2008).

2.15 CIE L*a*b* colour system

The CIE L*a*b* colour system was used on the imported images of all the teeth after the final exposure of two weeks. Two measurements were made on the restored tooth images taken directly after the restoration was made, 24 hours and two weeks later. The first measurement was made on the centre of the tooth surface and the second in the centre of the restoration. Care was taken not to include the interface between the restoration and the tooth (Figure 9).

![Figure 9: Colour determination was made in the centre of the restoration and compared to the original tooth colour.](image-url)
Chapter 3 Results

3.1 Statistical Analysis

Descriptive and inferential analyses were used for statistical analysis and the results were stored in a graphical matrix.

The colour distances ($\Delta E_{ab}^*$) of each group was grouped together and compared to the other groups. The Kruskal-Wallis One-Way analysis of variance (Bonferroni Test) was used to compare the differences between the medians of the two composite materials (Table 4, 5 and 6). The significance was set at $z > 3.1237$. The Spearman’s rank correlation coefficient was set at a significance of $p < 0.01$ to evaluate colour change ($\Delta E_{ab}^*$) in the restorations over three time intervals (immediate restoration, 24 hours and two weeks).

Statistical data analysis was performed on the colour assessment readings made at immediate restoration, 24 hours and 2 weeks on the teeth and restorations. The data set of 336 readings ($\Delta E_{ab}^*$) was used to evaluate how close the restorations can replicate the natural tooth colour ($\Delta E_{ab}^* = 0$) and the effect of the different time intervals on the restoration colours (Figure 10, 11 and 12).

The colour was determined with a spectrophotometer throughout the study. The colour of the extracted teeth used in this study remained unchanged throughout the study and was accepted as ($\Delta E_{ab}^* = 0$).
3.2 Immediate restoration colours versus the natural tooth colour

Figure 10 depicts the Box-and-Whisker plots of the median colour distance ($\Delta E_{ab}^*$) differences between the selected immediate restoration colours and the natural teeth. In each diagram, the top line shows the maximum (max) and the bottom line the minimum distance (min) of the restoration colour from the colour of the natural tooth. The box part shows the location of 50% of the values of the restoration colours for each group. The line in the box represents the median of the distance of the restoration colour from the natural tooth colour ($\Delta E_{ab}^* = 0$) for each group. Table 4 represents the pairwise colour differences at immediate restoration between the different restoration colours.

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration A3 colour (median: 15.7, min: 10.5, max: 19.1) and Filtek Supreme XTE™ (3M, ESPE) restoration A3 colour (median: 12.8, min: 6.7, max: 16.4) revealed no significance ($z=1.6672$).

The colour distance $\Delta E_{ab}^*$ between CeramX Duo (Dentsply) restoration B3 colour (median: 14.9, min: 10.3, max: 20.0) and Filtek Supreme XTE™ (3M, ESPE) restoration B3 colour (median: 7.5, min: 4.7, max: 12.0) was significant ($z=4.5186$).

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration C3 colour (median: 12.4, min: 4.4, max: 18.2) and Filtek Supreme XTE™ (3M, ESPE) restoration C3 colour (median: 9.4, min: 3.2, max: 15.1) resulted in no significant difference ($z=1.3384$).
The colour distance ($\Delta E^{*}_{ab}$) between CeramX Duo (Dentsply) restoration D2 colour (median: 7.2, min: 2.0, max: 10.2) and Filtek Supreme XTE™ (3M, ESPE) restoration D2 colour (median: 6.6, min: 4.7, max: 10.1) resulted in no significant difference ($z=0.0756$).

Figure 10:  Box-and-Whisker plots of $\Delta E^{*}_{ab}$ values for CeramX Duo (Dentsply) and Filtek Supreme XTE™ (3M, ESPE) immediate restorations materials.

Table 4: Pairwise differences between the immediate restoration colours

<table>
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<tr>
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<th>CX C3</th>
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**Bonferroni Test:** Medians significantly different if $z$-value $>3.1237$
3.3 24 hours restoration colour versus the natural tooth colour

Figure 11 and Table 5 represents the results for both the 24 hour restorations for CeramX Duo (Dentsply) and Filtek Supreme XTE™ (3M, ESPE).

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration A3 colour (median: 16.6, min: 11.6, max: 19.3) and Filtek Supreme XTE™ (3M, ESPE) restoration A3 colour (median: 11.8, min: 8.3, max: 15.5) revealed no significance ($z=1.8476$).

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration B3 colour (median: 15.3, min: 8.5, max: 20.8) and Filtek Supreme XTE™ (3M, ESPE) restoration B3 colour (median: 6.7, min: 5.2, max: 13.6) was significantly different ($z=4.7718$).

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration C3 colour (median: 12.3, min: 5, max: 19.9) and Filtek Supreme XTE™ (3M, ESPE) restoration C3 colour (median: 8.6, min: 3.6, max: 12.0) revealed no significance ($z=2.0658$). However on a five percent significance ($z>1.96$) there is a significant difference.

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration D2 colour (median: 7.3, min: 2.9, max: 10.4) and Filtek Supreme XTE™ (3M, ESPE) restoration D2 colour (median: 7.1, min: 5.1, max: 10.9) revealed no significance ($z=0.3113$).
Figure 11: Box-and-Whisker plots of the median ($\Delta E^*_{ab}$) colour distance differences between the selected 24 hours restoration colours and the natural teeth.

Table 5: Pairwise differences between the 24 hour restorations colours

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Bonferroni Test: Medians significantly different if z-value > 3.1237

3.4 2 weeks restoration colour versus the natural tooth colour

Figure 12 and Table 6 represents the results for both the 2 weeks restorations for CeramX Duo (Dentsply) and Filtek Supreme XTE™ (3M, ESPE).

The colour distance ($\Delta E^*_{ab}$) between CeramX Duo (Dentsply) restoration A3 colour (median: 15.9, min: 8.5, max: 22.2) and Filtek Supreme XTE™ (3M, ESPE)
restoration A3 colour (median: 12.4, min: 7.9, max: 15.7) revealed no significance (z=1.5421).

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration B3 colour (median: 15.8, min: 11.5, max: 19.8) and Filtek Supreme XTE™ (3M, ESPE) restoration B3 colour (median: 6.1, min: 3.5, max: 9.6) was significantly different (z=4.7718).

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration C3 colour (median: 13.7, min: 4.4, max: 17.3) and Filtek Supreme XTE™ (3M, ESPE) restoration C3 colour (median: 7.8, min: 3.7, max: 12.4) revealed no significance (z=2.1328). However on a five percent significance (z>1.96) there is a significant difference.

The colour distance ($\Delta E_{ab}^*$) between CeramX Duo (Dentsply) restoration D2 colour (median: 6.1, min: 2.1, max: 11.5) and Filtek Supreme XTE™ (3M, ESPE) restoration D2 colour (median: 7.9, min: 4.6, max: 12.2) revealed no significance (z=1.3501).
Figure 12: Box-and-Whisker plots of the median ($\Delta E^{*}_{ab}$) colour distance differences between the selected 2 weeks restoration colours and the natural teeth.

Table 6: Pairwise differences between the 2 weeks restorations colours

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Bonferroni Test: Medians significantly different if z-value > 3.1237

3.5 Colour change over time

Graphs have been used to show the colour distance ($\Delta E^{*}_{ab}$) trends in this study. The Spearman’s rank correlation coefficient was set at a significance of p<0.01 to evaluate colour change ($\Delta E^{*}_{ab}$) in the restorations over three time intervals (immediate restoration, 24 hours and two weeks).
Each set of three graphs are all laid out the same way (Figure 13-15, 16-18, 19-20, 21-23, 24-26, 27-29, 30-33, 34-36). The first graph compares colour distance ($\Delta E_{ab}$) differences between immediate restoration and 24 hours. The second graph compares colour distance ($\Delta E_{ab}$) differences between immediate restoration and 2 weeks. The third graph compares colour distance ($\Delta E_{ab}$) differences between 24 hour restoration and 2 weeks.

The lower the values of the plots on the graph the closer the restoration is to the natural tooth colour. The higher the values of the plots, the further away the colour of the restoration is from the natural tooth colour. The final observation to be made is how close the plots are to the dissecting line. The closer the plots are to the dissecting line, the higher probability that the colours will stay the same over time.

The colour distances ($\Delta E_{ab}$) of CeramX Duo (Dentsply) A3 colour at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 13, 14 and 15. The colour comparison resulted in a strong relationship for the colour distance immediate versus 24 hours ($p=0.005$). However, the opposite result was found for immediate versus 2 weeks ($p=0.604$) and 24 hours versus 2 weeks ($p=0.647$).

The colour distances ($\Delta E_{ab}$) of Filtek Supreme XTE™ (3M, ESPE) A3 colour at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 16 to 18. A strong relationship was found for the colour distance comparison between all three time intervals: immediate versus 24 hours
(p=0.00002), immediate versus 2 weeks (p=0.0003) and 24 hours versus 2 weeks (p=0.001).

The colour distances ($\Delta E^*_{ab}$) of CeramX Duo (Dentsply) B3 colour at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 19 to 21. A weak relationship (p=0.019) was found for the colour distance when the colour of the immediate restoration was compared to the 24 hour colour (Figure 19). The comparison of the colour distance change between immediate restoration and the 2 weeks colour did result in a strong relationship (p=0.001) (Figure 20). This was also the case (p=0.0005) for the colour distance 24 hours versus the 2 weeks colour (Figure 21).

The colour distances ($\Delta E^*_{ab}$) of Filtek Supreme XTE™ (3M, ESPE) B3 colour at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 22 to 24. The comparison of the colour distance between all three time comparisons did not result in weak relationship: immediate versus 24 hours (p=0.109), immediate versus 2 weeks (p=0.793) and 24 hours versus 2 weeks (p=0.691).

The colour distances ($\Delta E^*_{ab}$) of CeramX Duo (Dentsply) C3 colour at the interval immediate restoration, 24 hours and 2 weeks are presented in Figures 25 to 27. A strong relationship (p=0.000006) was found between the colour distance ($\Delta E^*_{ab}$) of the immediate and 24 hour colour (Figure 25). The colour distance ($\Delta E^*_{ab}$) between the immediate and 2 week colours (Figure 26) did also produced a strong relationship (p=0.000004). The colour distance comparison between 24 hour and 2
week colours (Figure 27) resulted in a very strong relationship and correlated very closely (p< 0.01).

The colour distances \( (\Delta E^*_{ab}) \) of Filtek Supreme XTE™ (3M, ESPE) C3 at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 28 to 30. A strong relationship was found through the comparison of the three time intervals: immediate versus 24 hours (p=0.0002), immediate versus 2 weeks (p=0.007) and 24 hours versus 2 weeks (p=0.002).

The colour distances \( (\Delta E^*_{ab}) \) of CeramX Duo (Dentsply) D2 colour at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 31 to 33. A weak relationship (p=0.012) was found for the comparison of colour distance between the immediate and 24 hour colour (Figure 31). This trend continued for the comparison immediate and 2 week colour (p=0.144) (Figure 32) and also for 24 hours and 2 week colour (p=0.038) (Figure 33). However on a significant level of five percent a relationship was found for the time intervals: immediate restoration versus 24 hours and the time interval 24 hours versus 2 weeks.

The colour distances \( (\Delta E^*_{ab}) \) of Filtek Supreme XTE™ (3M, ESPE) D2 colour at the intervals of immediate restoration, 24 hours and 2 weeks are presented in Figures 34 to 36. The colour distance comparison between the three different time intervals revealed a strong relationship between the restoration colours: immediate versus 24 hours (p=0.000006) (Figure 34), immediate versus 2 weeks (p=0.0006) (Figure 35) and 24 hours versus 2 weeks (p=0.000004) (Figure 36).
Ceram X Duo (Dentsply) A3 colour

Figure 13: ΔE*ab Immediate versus 24 hours

Figure 14: ΔE*ab Immediate versus 2 weeks

Figure 15: ΔE*ab 24 hours versus 2 weeks

Filtek Supreme XTE™ (3M, ESPE) A3 colour

Figure 16: ΔE*ab Immediate versus 24 hours

Figure 17: ΔE*ab Immediate versus 2 weeks

Figure 18: ΔE*ab 24 hours versus 2 weeks
Figure 19: ΔE*ab Immediate versus 24 hours

Figure 20: ΔE*ab Immediate versus 2 weeks

Figure 21: ΔE*ab 24 hours versus 2 weeks

Figure 22: ΔE*ab Immediate versus 24 hours

Figure 23: ΔE*ab Immediate versus 2 weeks

Figure 24: ΔE*ab 24 hours versus 2 weeks
Ceram X Duo (Dentsply) C3 colour

Figure 25: $\Delta E^{*ab}$ Immediate versus 24 hours

Figure 26: $\Delta E^{*ab}$ Immediate versus 2 weeks

Figure 27: $\Delta E^{*ab}$ 24 hours versus 2 weeks

Filtek Supreme XTE™ (3M, ESPE) C3 colour

Figure 28: $\Delta E^{*ab}$ Immediate versus 24 hours

Figure 29: $\Delta E^{*ab}$ Immediate versus 2 weeks

Figure 30: $\Delta E^{*ab}$ 24 hours versus 2 weeks
**Ceram X Duo (Dentsply) D3 colour**

Figure 31: $\Delta E^{a*b*}$ Immediate versus 24 hours

Figure 32: $\Delta E^{a*b*}$ Immediate versus 2 weeks

Figure 33: $\Delta E^{a*b*}$ 24 hours versus 2 weeks

**Filtek Supreme XTE™ (3M, ESPE) D2 colour**

Figure 34: $\Delta E^{a*b*}$ Immediate versus 24 hours

Figure 35: $\Delta E^{a*b*}$ Immediate versus 2 weeks

Figure 36: $\Delta E^{a*b*}$ 24 hours versus 2 weeks
Chapter 4 Discussion

4.1 General

This *in vitro* study was undertaken to compare the ability of two composite materials [CeramX Duo (Dentsply) and Filtek Supreme XTE™ (3M, ESPE)] to mimic natural tooth structure.

4.2 Restoration colour distance ($\Delta E^*_{ab}$) compared to the natural tooth colour

The median restoration colour distance ($\Delta E^*_{ab}$) for Filtek Supreme XTE™ (3M, ESPE) composite material (section 3.2, 3.3 and 3.4) were markedly far away from the natural tooth colour ($\Delta E^*_{ab} = 0$) and will be discussed in section 4.2.1 to 4.2.4. This study confirmed the results of Magne and So (2008) that Filtek Supreme XTE™ (3M, ESPE) is not the ideal material for the modern two layering concept. Unfortunately, no previous studies were found that tested the layering concept using CeramX Duo (Dentsply).

4.2.1 CeramX Duo (Dentsply) A3 colour versus Filtek Supreme XTE™ (3M, ESPE) A3 colour

The median colour distance ($\Delta E^*_{ab}$) of CeramX Duo (Dentsply) A3 colour was far from the natural tooth A3 colour ($\Delta E^*_{ab} = 0$). This observation was seen at all three time intervals: immediate restoration: 15.7, 24 hours: 16.3 and 2 weeks: 15.9.
The median colour distance ($\Delta E^*_{ab}$) of Filtek Supreme XTE™ (3M, ESPE) A3 colour was also far from the natural tooth A3 colour ($\Delta E^*_{ab} = 0$). This observation was seen at all three time intervals: immediate restoration: 12.8, 24 hours: 11.8 and 2 weeks: 12.4.

The deduction can be made that Filtek Supreme XTE™ (3M, ESPE) was slightly closer to the natural tooth colour at the 2 weeks time interval.

4.2.2 CeramX Duo (Dentsply) B3 colour versus Filtek Supreme XTE™ (3M, ESPE) B3 colour

The median ($\Delta E^*_{ab}$) colour distance of CeramX Duo (Dentsply) B3 colour was far from the natural tooth B3 colour ($\Delta E^*_{ab} = 0$). This observation was seen at all three time intervals: immediate restoration: 14.9, 24 hours: 15.3 and 2 weeks: 15.8.

The median ($\Delta E^*_{ab}$) colour distance of Filtek Supreme XTE™ (3M, ESPE) B3 colour was also far from the natural tooth B3 colour ($\Delta E^*_{ab} = 0$). This observation was seen at all three time intervals: immediate restoration: 7.50, 24 hours: 6.7 and 2 weeks: 6.1.
The deduction can be made that Filtek Supreme XTE™ (3M, ESPE) was to a large extent closer to the natural tooth colour at all three time intervals.

4.2.3 CeramX Duo (Dentsply) C3 colour versus Filtek Supreme XTE™ (3M, ESPE) C3 colour

The median $\Delta E^*_{ab}$ colour distance of CeramX Duo (Dentsply) C3 colour was far from the natural tooth C3 colour ($\Delta E^*_{ab} = 0$). This observation was seen at all three time intervals: immediate restoration: 12.4, 24 hours: 12.3 and 2 weeks: 13.7.

The median $\Delta E^*_{ab}$ colour distance of Filtek Supreme XTE™ (3M, ESPE) C3 colour was also far from the natural tooth C3 colour ($\Delta E^*_{ab} = 0$). This observation was seen at all three time intervals: immediate restoration: 9.5, 24 hours: 8.7 and 2 weeks: 7.9.

The deduction can be made that Filtek Supreme XTE™ (3M, ESPE) was to a large extent closer to the natural tooth colour at all three time intervals.
4.2.4 CeramX Duo (Dentsply) D2 colour versus Filtek Supreme

XTE™ (3M, ESPE) D2 colour

The median ($\Delta E_{ab}^*$) colour distance of CeramX Duo (Dentsply) D2 colour was far from the natural tooth D2 colour ($\Delta E_{ab}^* = 0$). This observation was seen at all three time intervals: immediate restoration: 7.2, 24 hours: 7.3 and 2 weeks: 6.1.

The median ($\Delta E_{ab}^*$) colour distance of Filtek Supreme XTE™ (3M, ESPE) D2 colour was also far from the natural tooth D2 colour ($\Delta E_{ab}^* = 0$). This observation was seen at all three time intervals: immediate restoration: 6.6, 24 hours: 7.1 and 2 weeks: 7.9.

The deduction can be made that Filtek Supreme XTE™ (3M, ESPE) D2 colour similar to the CeramX Duo (Dentsply) D2 colour. The minimum value (immediate restoration: 6.6, 24 hours: 5.2, 2 weeks: 4.6) of the CeramX Duo (Dentsply) D2 colour was close to the natural tooth colour.

4.3 Restoration colour comparisons ($\Delta E_{ab}^*$)

The Filtek Supreme XTE™ (3M, ESPE) colour restorations (A3, B3 and C3 colours) were closer to the natural tooth colour (all time intervals) when compared to the corresponding restoration colours for CeramX Duo (Dentsply) (Figures 10, 11 and 12). The D2 restoration colour of both
Filtek Supreme XTE™ (3M, ESPE) and CeramX Duo (Dentsply) were very similar. The only visible difference was that the minimum value of CeramX Duo (Dentsply) D2 restoration colour was closer to the natural tooth colour.

The deduction can be made that the Filtek Supreme XTE™ (3M, ESPE) colour restorations (A3, B3 and C3) performed the best in this in vitro study. The D2 restoration colour of both Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) composite materials were similar.

4.4 Composite restoration colour differences over the three time intervals

Figures 13 to 36 represents the individual composite materials used in the study compared at the three time intervals: immediate restoration, 24 hours and 2 weeks. The straight line showed in the graphs represents the ideal situation which means all the values should be on these lines. This is not the case, because of practical faults that may have occurred during the study. This will be discussed in detail in section 4.5. The most important time interval in this study is the 24 hours versus 2 weeks, since 24 hours restoration colour is more accurate than the immediate restoration colour (Nakajima et al., 2012, Magne and So, 2008).
The Filtek Supreme XTE™ (3M, ESPE) restoration colours A3, C3 and D2 remained the same over the three time intervals. Only the Filtek Supreme XTE™ (3M, ESPE) restoration colour B3 did not say consistent over the three time intervals.

The CeramX Duo (Dentsply) restoration colours B3 and C2 remained consistent over the three time intervals. The D2 colour did not remain the same for the three time intervals. Fortunately the colour (D2) was the same over two of the time intervals and was noteworthy on a five percent significant level: immediate restoration versus 24 hours (p= 0.012) and 24 hours versus 2 weeks (p= 0.038). The CeramX restoration A3 colour stayed the same for the time interval: immediate restoration versus 24 hours (p= 0.005), but was different for the other two time intervals.

4.5 Reasons why values are not all on the ideal line

Composite material differs from the natural tooth structure and the clinician hopes to attain a blending affect between the restoration and the hard tooth structure (Paravina et al., 2008b). The buccal-lingual diameter of teeth used in this in vitro study was different, therefore the layering thickness of the dentine composite needed to be adjusted accordingly (Magne and So, 2008). This is also the case in the clinical scenario. Lastly the layers chosen according to manufacturer’s instruction may not be an
ideal choice for the natural tooth. The CeramX Duo (Dentsply) restoration material utilises the same combination of materials to make an A3 and C3 colour restoration. This is not correct, since the \((\Delta E^{*}_{ab})\) is different for these two colours.
Chapter 5 Conclusion

In this section, the conclusions of the study will be drawn according to the hypothesis presented in section 2.1.

1. Filtek Supreme XTE™ (3M, ESPE) and CeramX™ Duo (Dentsply) is equally efficient in mimicking the natural tooth structure.

The statistical tests cannot provide clear results as to which composite materials is superior, but both composite materials were unable to mimic the colour for the natural teeth. Therefore the hypothesis was rejected.

From the mean values, Filtek Supreme XTE™ (3M, ESPE) A3, B3 and C3 restoration colours were slightly closer to the natural tooth colour. CeramX™ Duo (Dentsply) D2 colour was similar to Filtek Supreme XTE™ (3M, ESPE) D2 colour with slightly lower minimum values.

2. Composite colour will remain stable immediately after the restoration is made, 24 hours to two weeks of storage time.

The hypothesis was accepted for the Filtek Supreme XTE™ (3M, ESPE) restoration colours A3, C3 and D2 and for the CeramX Duo (Dentsply) restoration colours B3, C2 and D2. The Filtek Supreme XTE™ (3M,
ESPE) restoration colour B3 and CeramX Duo (Dentsply) restoration colour A3 did not stay consistent over the three time intervals. Thus the hypothesis for these two colours was rejected.
Chapter 6 Shortcomings of the study and future research

The current study measured the colour distance ($\Delta E^*_{ab}$) of both layers of composite used to make the restorations. The colour distance ($\Delta E^*_{ab}$) of the individual layers could not be measured. Therefore one cannot make any deductions on which one of the layers or both resulted in a restoration that did not mimic the natural tooth structure. Future studies are needed to determine the effect of the individual layers on the outcome of the final restoration colour distance ($\Delta E^*_{ab}$).

Future studies are also needed to determine the effect of different composite layer thickness on colour distances ($\Delta E^*_{ab}$) of the restorations compared to the natural tooth structure.
Chapter 7 References


Lee YK, Lim BS, Kim CW. Difference in the colour and colour change of
dental resin composites by the background. J Oral Rehabil 2005; 32: 227-
233.

Magne P and So WS. Optical integration of incisoproximal restorations

Minolta Co.,Ltd. Radiometric Instruments Operations 3-13, 2-Chome,

Nakajima M, Arimoto A, Prasansuttiporn T, Thanatvarakorn O, Foxton RM,
Tagami J. Light transmission characteristics of dentine and resin

Paravina RD. New shade guide for tooth-whitening monitoring: Visual

Paravina RD, Westland S, Johnston WM, Powers JM. Color Adjustment

Rosenstiel SF, Geguaff AG, McCafferty RJ, Johnston WM. In vitro tooth

Appendix A: Ethics Clearance Certificate

An ethics clearance certificate (12/7/18) was obtained through the HUMAN RESEARCH ETHICS COMMITTEE at the University of the Western Cape for the use of human extracted teeth.

Office of the Deputy Dean
Postgraduate Studies and Research
Faculty of Dentistry & WHO Collaborating Centre for Oral Health

UNIVERSITY OF THE WESTERN CAPE
Private Bag X1, Tygerberg
Cape Town
SOUTH AFRICA

Date: 17th August 2012

For Attention: Dr AA Grundlingh
Restorative Dentistry

Dear Dr Grundlingh

STUDY PROJECT: Colour comparisons of two composite materials to natural tooth structure: an in vitro study

PROJECT REGISTRATION NUMBER: 12/7/18

ETHICS: Approved

At a meeting of the Senate Research Committee held on Friday 17th August 2012 the above project was approved. This project is therefore now registered and you can proceed with the study. Please quote the above-mentioned project title and registration number in all further correspondence. Please carefully read the Standards and Guidance for Researchers below before carrying out your study.

Patients participating in a research project at the Tygerberg and Mitchells Plain Oral Health Centres will not be treated free of charge as the Provincial Administration of the Western Cape does not support research financially.

Due to the heavy workload auxiliary staff of the Oral Health Centres cannot offer assistance with research projects.

Yours sincerely

[Signature]

Professor Sundesh Naidoo