COMPARATIVE STUDY OF DIRECT AND INDIRECT COMPOSITE VENEERS IN TERMS OF MARGINAL GAP AND MICROLEAKAGE

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DISSERTATION SUBMITTED IN PARTIAL FULLFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF CLINICAL DENTISTRY(RESTORATIVE)

FACULTY OF DENTISTRY

DEPARTMENT OF RESTORATIVE DENTISTRY

UNIVERSITY OF MALAYA

KUALA LUMPUR

2019

UNIVERSITY OF MALAYA

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Matric No: **DGI160002**

Name of Degree: **Master in Clinical Dentistry (Conservative)**

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ABSTRACT

Objectives

To evaluate the microleakage and marginal gap at cervical and incisal margin of direct and indirect composite veneers.

Materials and method:

Forty-four extracted human maxillary central incisors (n=44) used for the study were chosen based on the inclusion and exclusion criteria. They were randomly divided into two groups. Group 1: Shofu Beautifil™ direct composite (Shofu Inc. Kyoto, Japan) and Group 2: Shofu Ceramage™ indirect composite (Shofu Inc. Kyoto, Japan). Putty index for each tooth was taken before it was subjected to preparation for veneer restorations. The manufacturer's instructions for handling and application procedures for both materials were strictly followed. All the samples were stored under water for 24 hours at 37 ° C, then subjected to thermo-cycling (500 cycles at the temperature between 5° and 55° C for 60 seconds in water baths (according to ISO 11450).

Upon completion of artificial ageing, the entire external surface of the restoration and the supporting crown and root excluding the margins of the veneers were coated with two layers of nail varnish before being immersed in 2% basic fuschine dye for 24 hours. All the specimens were mounted in acrylic resin and sectioned labio-palatally at the middle of the restorations. Each half of the sectioned specimens for both direct and indirect composite veneers were observed under a stereomicroscope (×40 magnifications) and the degrees of dye penetration at the cervical and incisal margins were measured in micrometers (µm). Marginal gaps were measured at the cervical and incisal areas by viewing the specimens under stereomicroscope OLYMPUS™ (40X) for both the groups and the reading were measured in micrometers (µm) by one assessor. To control the

reproducibility of the scoring system and the intra-examiner performance, the samples (n=44) were measured again one month after initial measurement. The reproducibility was tested using intraclass correlation coefficient. Mann-Whitney Test was used to determine any significant differences in microleakage and marginal gap of direct and indirect composite veneer. Wilcoxon Signed Rank test was used to evaluate intragroup differences for microleakage and marginal gap at the cervical and incisal margins for both the groups. Spearman's correlation test was used to correlate the association of microleakage and marginal gap at the cervical and incisal margins of direct and indirect composite veneers ($p>0.05$).

Results

Mann-Whitney U test revealed that direct composite veneers demonstrated significantly lower microleakage and marginal gap at cervical and incisal area when compared to indirect composite veneers ($p< 0.001$). Wilcoxon signed rank test showed that there were no significant intragroup differences for microleakage and marginal gap at cervical and incisal margins for both direct and indirect composite veneers ($p< 0.05$). Spearman correlation test revealed that there was a positive correlation between marginal gap and microleakage at the cervical and incisal portion of the direct and indirect composite veneers and the tooth structures ($p< 0.001$).

Conclusion:

Within the limitation of this study, direct composite veneers Beautifil™ (Shofu Inc. Kyoto, Japan) shown to be superior than the indirect composite veneers, Ceramage™ (Shofu Inc. Kyoto, Japan) by means of less marginal gaps and microleakage. There was a direct correlation between the existence of marginal gaps and microleakage, when there

was less marginal gap between tooth-restoration interface there was less microleakage.

Key words: composite veneer, microleakage, marginal gap.

ABSTRAK

Objektif

Untuk mengenal pasti kebocoran mikro dan jarak jurang pada margin servikal dan insisor venir komposit langsung dan tidak langsung.

Bahan dan kaedah

Empat puluh empat (n=44) gigi insisor rahang atas yang dicabut atas sebab penyakit gusi telah dikumpulkan dan dipilih berdasarkan kriteria inklusi dan ekslusi. Sampel gigi dibahagikan secara rawak kepada dua kumpulan (n=22) iaitu Kumpulan 1: Shofu™ Beautifil™ komposit langsung (Shofu Inc. Kyoto, Japan) dan Kumpulan 2: Shofu Ceramage™ komposit tak langsung (Shofu Inc. Kyoto, Japan) dengan menggunakan kaedah balingan duit syiling. Indeks putty telah diambil untuk setiap sampel gigi sebelum menyediakan venir. Arahan daripada pengilang mengenai tatacara pengguna untuk setiap produk diikuti dengan sewajarnya. Setiap spesimen akan disimpan dalam inkubator pada suhu 37 darjah Celsius. Seterusnya, semua spesimen itu melalui proses kitaran terma 500 kitaran dalam masa 60 saat dalam basin air bersuhu 5 hingga 55 darjah Celcius. (ISO 11450). Selepas itu, varnis kuku disapu pada permukaan akar gigi dan restorasi kecuali di margin servikal dan insisor restorasi. Seterusnya, spesimen gigi direndam dalam 2% pewarna asas fuschine selama 24 jam dan kemudian ditanam (keseluruhan akar gigi kecuali bahagian servikal) dalam resin akrilik dan dipotong setengah untuk dikaji bawah stereomicroskop OLYMPUS™ dengan magnifikasi 40X untuk megirakan kebocoran mikro pewarna asas fuschine. Untuk memastikan kebarangkalian ukuran kebocoran mikro pewarna asas fuschine dan jarak jurang marginal dapat diukur dengan tepat, ukuran kedua untuk sampel sama diukur selepas sebulan (Khng *et al*., 2019). Ujian Mann Whitney digunakan untuk menganalisis hipotesis nol kajian ini. Ujian Wilcoxon Signed Rank digunakan untuk membandingkan kebocoran mikro dan jarak jurang marginal pada

margin servikal dan insisor venir komposit untuk samples dari kumpulan yang sama. Ujian Spearman's digunakan untuk meneroka sebarang hubung kait di antara kebocoran mikro dan jarak jurang marginal pada margin servikal dan insisor venir komposit langsung dan tidak langsung ($p>0.05$).

Keputusan:

Keputusan ujian Mann- Whitney telah membuktikan bahawa venir komposit langsung menunjukkan kebocoran mikro dan jarak jurang marginal yang signifikant lebih rendah bila dibandingkan dengan venir komposit tidak langsung($p<0.001$). Wilcoxon Signed Rank test tidak menunjukkan perbezaan yang signifikan antara kebocoran mikro dam jarak jurang marginal pada margin servikal dan insisor venir komposit langsung dan tidak langsung. Dengan menggunakan ujian Spearman's correlation antara venir komposit langsung dan tidak langsung, ia telah menunjukkan bahawa terdapat hubung kait yang nyata di antara kebocoran mikro dan jarak jurang marginal pada margin servikal dan insisor venir komposit langsung dan tidak langsung ($p< 0.05$).

Kesimpulan:

Dalam batasan kajian ini, kami dapat membuat kesimpulan bahawa venir komposit langsung (Beautifil™, Shofu Inc. Kyoto, Japan) adalah lebih baik dari segi jurang marginal dan kebocoran mikro berbandingkan dengan venir komposit tak langsung (Ceramage™, Shofu Inc. Kyoto, Japan). Kajian ini telah membuktikan perhubungan kadar langsung antara jurang marginal dan kebocoran mikro antara margin servikal dan insisor venir komposit langsung dan tidak langsung.

Kata kunci: venir komposit, kebocoran micro, jurang marginal.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisors Associate Professor Dr Norasmatul Akma binti Ahmad, Associate Professor Dr Eshamsul bin Sulaiman, Dr Mohideen Salihu Farook for their guidance, encouragement and knowledge in the process of me completing this dissertation. They relentlessly go through my work even when they are so busy just so I can complete my work without any delay. Whenever I encounter any queries regarding my research, I can always approach the all of them.

To my respected mentor Associate Professor Dr Hadijah binti Abdullah and Ybhg. Prof. Dato' Dr Abdul Aziz Abdul Razak for all their guidance before their retirement from the Restorative Department Faculty of Dentistry University of Malaya, Kuala Lumpur.

To my parents, thank you for always be there to check whether everything is alright for me. I promised to repay you when I am successful in life.

To my husband, Diong Shein Hin thank you so much in supporting me throughout my Mclindent Journey.

To my sisters, Lim Yee Lian and Lim Yee Shan thank you for being the best sisters in the world. Your achievement in life is my greatest motivation.

To the hardworking laboratory assistants, Puan Zarina Idris and Encik Anwar thank you so much for your help and assistant on the different types of machine needed for my research.

Lastly, thank you to all my family members and friends who had made a great impact in my life.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

C	:	Cervical margin
I	:	Incisal margin
CI	:	Cervical incisal
CAD - CAM	:	Computer-aided design/computer-aided manufacturing
CEJ	:	Cementoenamel junction
SEM	:	Stereomicroscope eletron microscope
Bis-GMA	:	bisphenol A-glycidyl methacrylate
VE	:	Vita Enamic
CM	:	Ceramage
MTBS	:	Microtensile bond strength
SD	:	Standard Deviation
IQR	:	Interquartile range
Z	:	Standard test statistic
PLS	:	Periodic Level Shifting
CCD	:	Charge-coupled device
MOD	:	Mesial -occlusal -distal
UDMA	:	Urethane Dimethacrylate
TEDGMA	:	Tri-ethylene-glycol-dimethacrylate

PFS : Progressive fine structure

S-PRG : Surface pre-reacted glass ionomer

OCT : Optical Coherence Tomography

GPT-9 : The Glossary of Prosthodontic Terms, 9th Edition

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

Aesthetic dentistry is a growing field in dentistry. Most individuals were found to be concerned with the aesthetic of their smile which usually display the maxillary upper central incisors (Tjan *et al*., 1984). Aesthetic is defined as pertaining to the study of beauty and the sense of beautiful, objectifies beauty and attractiveness (GPT-9).

There are many situations when a patient might require aesthetic dentistry related treatment whether it is a crown, veneers or bleaching of the natural tooth. Patients with tooth discolouration, congenital hypodontia and diastemas were usually prescribed with dental veneers. An early literature by Stuart (1975) stated veneers as one of the popular choices for aesthetic correction of anterior teeth.

In the present day many clinicians are still opting for direct or indirect resin composite or ceramic veneers (Meijering *et al*., 1995). Dental veneers are a thin sheet of material usually used as facing (GPT-9). It is considered as a conservative treatment for unaesthetic teeth (Pini *et al.,* 2012).

Ferrari *et al*. (1992) reported that for fabrication of feldspathic porcelain veneer only 0.5 – 0.7mm of tooth reduction is needed. Therefore, it is considered as more conservative in comparison to tooth preparation for a crown. Before veneer, many cases of unaesthetic anterior teeth have been crowned to ensure most durable and aesthetic outcomes (Peumans *et al*., 2000).

The types of dental veneers that are available in the market are the feldspathic porcelain veneers, glass based ceramic veneers (Pini *et al*., 2012), indirect composite veneers and direct composite veneers (Kruelen *et al*., 1998). Feldspathic porcelain veneer has the longest track record for dental veneer. It was introduced as early as 1983. The feldspathic porcelain veneers are made of silicon dioxide (60-64%) also referred as quartz or silica and aluminum oxide (20-23%) which was modified in a sequence of process to create a glass that is suitable to be used for dental restorations (Conrad *et al*., 2007; McLaren & Cao, 2009). A systematic review done by Watt *et al*. (2013) reported the success rate of feldspathic porcelain veneer for 10 years was as high as 95%. The porcelain laminate veneer shows the best survival rate of 94% in 2.5 years interim evaluation of the restorations. (Meijering *et al*., 1998). A meta-analysis with the available clinical information was done by Kreulen *et al*. (1998) showing survival ratio of 92% and 74% in 3 years for porcelain veneer and acrylic veneers respectively.

With the advancement in composite resins, its usage in the fabrication of dental veneers has been increasing. With the advantages such as lower cost and comparable aesthetic qualities, indirect composite veneer is a fast- growing technique used to restore upper anterior aesthetic. It is relatively a new material used to overcome some disadvantages of direct composite and also porcelain laminate veneers. Although resin composite is frequently used as direct posterior restorative materials due to good aesthetics, biological, physical and mechanical properties (Opdam *et al*., 2014; Vidhawan *et al*., 2015), there are still some proven disadvantages of resin composite like the polymerisation shrinkage, discolouration due to the present of resin in the material, shrinkage stress and depth of cure (Ornaghi *et al*., 2014). Peumans *et al*. (2000) also reported that composites are still inferior in comparison to porcelain veneer based on discolouration of the material, wear and marginal fracture. According to Rucker (1990), 20% of the resin veneers had failed, whereas all of the porcelain veneers remained in 2 years. Regarding aesthetics, Goldstein & Lancaster (1984) found that 41% of patient would like to change their smile and of those patients having teeth bonded with composite materials, 97% said they were satisfied to extremely satisfied with the outcome of the treatment.

A current material known as Ceramage™ (Shofu Inc. Kyoto, Japan) is an indirect composite containing 73% zirconium silicate fillers which improve the aesthetic, flexural and compressive strength of the material. Multiple studies showed that the material with more homogeneous flaw distribution throughout the entire volume resulted in higher structural reliability and lower failure probability, they have concluded that Ceramage™, Lava Ultimate™ and Z100™ have similar Weibull modulus but Vita Enamic™ which is a CAD/CAM composites have highest Weibull modulus (Kelly *et al*., 1995; Ornaghi *et al*., 2002; Quinn *et al*., 2010). Weibull modulus (m) is a dimensionless material-specific parameter, which explains the variation in the strength or asymmetric strength distribution as a result of flaws within the microstructure. Another study had demonstrated that Ceramage™ has significantly higher microtensile bond strengths (MTBSs) compared to SR Nexco™ which had undergone different surface treatments (Visuttiwattanakorn *et al*., 2017). Based on the studies above, it could be concluded that Ceramage™ is able to serve as one of the treatment options in aesthetic cases of anteriors (Kelly ,1995; Ornaghi *et al*., 2014; Quin, 2010). However, there are limited long term studies on Ceramage™. Therefore, more studies should be done on Ceramage™ as it is a relatively new material.

Marginal gap and microleakage extent of restoration play an important role in the success of a restoration. Composite resin has disadvantages of polymerisation shrinkage, staining, poor wear resistance (Abduo & Lyons 2012). Therefore, we decided to perform a laboratory- based research to evaluate advantages of Ceramage™ as composite veneer. As a result of limited research regarding the comparison between direct and indirect composite veneers, it is thus justifiable to venture into this material. It will provide a better understanding to the clinician on the material and which material is suitable in daily practice. Furthermore, in the literature most of the researches were towards the laboratory fabricated porcelain veneers either machinable or pressable porcelain veneers. Hence, this research intended to explore if there are any significant advantages on indirect composite veneers in terms of marginal gap and microleakage of the composite veneer as they cost more compared to direct composite veneers.

Due to the fact that there is limited literature based on marginal gap and microleakage of indirect composite, Ceramage™, it is an advantage to provide evidence- based findings that can be presented to the patient and assisting them on making the best decision in the treatment plan proposed by the clinicians.

CHAPTER 2: AIM & OBJECTIVES

2.1 Aim

To evaluate the microleakage and marginal gap at cervical and incisal margin of direct and indirect composite veneers.

2.2 Objectives

1. To determine the microleakage at the cervical and incisal margins of direct and indirect composite veneers.
2. To determine the marginal gap at the cervical and incisal margins of direct and indirect composite veneers.
3. To compare the microleakage and marginal gap at the cervical and incisal margins of direct and indirect composite veneers.
4. To explore any association between microleakage and marginal gap at the cervical and incisal margins of direct and indirect composite veneers.

2.3 Null hypothesis

There is no difference in microleakage and marginal gap for direct and indirect composite veneer.

CHAPTER 3: LITERATURE REVIEW

3.1 Aesthetic dentistry

Aesthetic dentistry has rapidly gained popularity in the recent years as people are more aware on the shape, size, colour and arrangement of their teeth when they smile. Most of them are obsessed with the "Hollywood smile" which often displayed by male and female actors. A nice smile can be an important role for one's self confidence. A study by Davis *et al.* (1998) showed that a good restoration which will improve patient's aesthetic appearance will also have positive impact on patient self- esteem and their quality of life. Colour, shape, structural and position abnormalities of anterior teeth will directly lead to important aesthetic problems for patients.

Tooth discolouration can be a major concern for most of the population. Discoloured teeth can be overcome by different restorative approaches such as bleaching, ceramic veneer, ceramic crown and composite veneer (Meyenberg, 2013). Before improvements of adhesive technology, the technique that is frequently preferred by clinician is to cover the teeth with dental crowns. (Manhart *et al.,* 2004). The trend of dental veneer is heading towards CAD-CAM fabrication of porcelain dental veneer (Vafiadis & Goldstein, 2011; Schmitter, 2012; Cunha *et al*., 2015). It was reported that these CAD-CAM porcelain veneers are able to be completed within a single visit thus greatly reduce the number of clinical appointments and chairside time (Ojeda *et al*., 2017).

3.2 Conditions affecting dental aesthetics

Aesthetic cases usually involve anterior teeth that demands advanced restorative technique and biomimetic materials in regaining patient's aesthetically pleasing and healthy smile (Venâncio *et al*., 2014).

Table 3.1 Different indications of aesthetic (Bahadir *et al.*, 2018)

Indications for dental aesthetic treatment	Subcategory
1. Tooth discolouration	a. External tooth discolouration b. Internal tooth discolouration
2. Developmental defect of enamel	a. Hypocalcification b. Hypoplasia
3. Surface irregularities	
4. Dental fluorosis	
5. Turner's hypoplasia	

Tooth discolouration is the main complaint of patient when it comes to anterior aesthetic (Muñoz *et al*., 2013). Tooth discolouration is divided into intrinsic and extrinsic.

The causes for extrinsic tooth discolouration are

a. food colouring
b. smoking
c. tabacco chewing
d. chlorhexidine mouthwash
e. dental plaque and calculus (Sherry *et al*., 2014)

Whereas the intrinsic tooth discolouration includes

a. tetracycline staining
b. dental caries
c. dental fluorosis
d. trauma causing pulp necrosis (Muñoz *et al*., 2013)
e. Genetic disorder such as amelogenesis imperfecta, congenital erythropoietic porphyria (Gunther disease), dentinogenesis imperfecta (Barron *et al*., 2008) and hyperbilirubinemia (Barberio *et al*., 2018).

Developmental defects of enamel are categorised into two main groups. One is hypocalcemia where qualitative developmental defect of the enamel caused by incomplete enamel mineralisation and maturation below the enamel surface that is intact at the time of eruption which will cause the tooth to looked slight yellowish - brown in clinical appearances. Hypoplasia is another group that is marked by the decreased thickness of the enamel which includes mild discolourations to defective surface irregularities of enamel (Mahoney *et al.,* 2004).

Mascarenhas (2000), reported another type of discolouration namely the enamel fluorosis that is seen as symmetrically distributed white spots, brown stains, white opaque lines or striations, or a white parchment-like appearance of the tooth surface. It is a chronic fluoride-induced condition where the enamel development is disrupted, and the enamel becomes hypo-mineralised thus appears as white spots.

Trauma can also cause tooth discolouration. Turner's hypoplasia which is a defect of the permanent tooth caused by trauma or periapical infections of deciduous teeth commonly affects patient's dental aesthetic. Clinically, Turner's hypoplasia presented as light brown to dark brown discolouration and usually seen in maxillary incisors and all the molar teeth (Lavania & Lavania, 2015). Dental trauma also causes greyish black discolouration due to pulp necrosis. Yellowish appearance of the traumatised teeth is caused by increase deposition of dentine.

3.3 Dental veneer

In 1937, the "invention" of veneering anterior teeth was introduced by Dr. Charles Pincus. It then became more popular in the mid-seventies, commonly proposed as three different treatment options that is direct bonding using resin composites, prefabricated composite veneers and indirect custom-made porcelain veneers (Faunce & Meyes, 1976). In the early 1980s, Rochette (1975) did further investigation of ceramic etching and bonding to improve the bonding of porcelain veneers to the prepared tooth surface. It is accepted that for dental veneer, only 0.5mm labial incisor tooth structure is needed to be removed.

However, prep-less tooth preparation has been introduced recently so that no sound tooth structure will be removed in the process of restoring the anterior teeth with dental veneers (Malcmacher, 2005). There are two types of dental veneers available in the market namely the direct and indirect dental veneer. The direct dental veneer is done by using composite materials at the chair side to directly restore the tooth to its anatomical appearance. In contrary, indirect dental veneers are made of ceramic or composite materials fabricated in the laboratory and cemented in the patient's teeth with an adhesive resin. (Korkut *et al*., 2013).

Throughout the years, the use of indirect porcelain veneer has been the choice of treatment for restoring the aesthetics of the anterior teeth (Nasedkin, 1988). This is because indirect porcelain veneers have many advantages such as excellent aesthetic, colour stability, high wear resistance, less invasive compared to full crown preparation. The advantages of porcelain veneers are proven in a prospective ten years clinical trial of porcelain veneers by Peumans and colleagues (2004). They stated that porcelain veneers have a good track record in maintaining their aesthetic appearance even after 10 years of clinical service. Although the percentage of restorations that remained "clinically acceptable" (without need for intervention) significantly decreased from an average of 92% (95 CI: 90% to 94%) at 5 years to 64% (95 CI: 51% to 77%) at 10 years, none of the veneers were lost. Fractures of porcelain and large marginal defects were reported as the main reason for failure. The same study reported, most of the restorations that present one or more "clinically unacceptable" problems were repairable and only 4% of the restorations needed to be replaced at the 10-year recall.

Dental veneer restorations are often believed to be a simple aesthetic procedure whereas in reality, excellent restored porcelain veneer restorations require high level of technical skill and accuracy by both the dentist and dental technician (McLean, 1988). Neglection of the iatrogenic factor on the gingiva during tooth preparation which will cause alteration of the biological width (Aristidis *et al.*, 2002) and will contribute to a less favourable outcome. In addition, patients may encounter tooth hypersensitivity as the removal of the enamel layer, will result in dentinal tubules be exposed and causing the tooth to be vulnerable in the oral environment. Layton & Clarke (2013), reported that the high cost of indirect dental veneer is due to the laboratory fees and this may affect the treatment as an option for certain group of patients.

3.4 Direct Composite veneers

Due to the high cost of porcelain veneer fabrication and technique sensitive tooth preparation, composite restorations started to act as an alternative choice for porcelain veneer. According to Meijering *et al.* (1998), there was no significant difference in survival rate in teeth restored with either porcelain veneers or composite veneers. Composite veneer can be further divided into direct and indirect composite veneer. Direct composite veneer is placed directly on the tooth preparation after the tooth surface is conditioned and bonding agent is applied. This step is followed by meticulous finishing and polishing procedure to ensure the surface of the direct composite veneer is smooth to prevent secondary caries and discolouration. Direct composite veneers are viewed as more convenient, with less discrepancy, less technique sensitive, cheaper and easily available. However, the disadvantages of the direct composite veneers are they are prone to discolouration and exhibit lack of resistant to fracture (Hemmings *et al.*, 2000).

The main disadvantages of all the composite restorations regardless of direct or indirect types are the discolouration, polymerisation shrinkage and decrease fracture resistance. It is inevitable that many companies invested large amount of money in research and development to reduce the polymerisation shrinkage and increase the fracture resistance for their product. As an example, Kerr™ introduced the Sonic fill which is claimed to have polymerisation shrinkage of 0.53% if compared to the traditional composite which exhibited 2-3% polymerisation shrinkage (Garcia, 2014). Polymerisation shrinkage is important as it cause microleakage in between the restoration and tooth interface. This microleakage will then weaken the cementation bond which will result in dislodgement of the restoration, increase risk of secondary caries and discolouration at the interface.

3.5 Indirect composite veneer

Indirect composite veneer comprised of prefabricated composite veneer and laboratory fabricated composite veneer. Edelweiss composite veneer system by Ultradent™ is an example of a prefabricated veneer. It is a laser sintered composite veneers. In addition, Shofu™ (Japan) also produce Ceramage™ which is also an indirect composite veneer which is fabricated in the laboratory like the porcelain veneer but less technique sensitive and with less procedural steps. According to Gresnigt *et al.* (2013), there was no statistically difference between survival rate of indirect composite veneer and ceramic veneer in the duration of 36 months. However, indirect composite veneers were shown to require more surface maintenance over time.

A study by Gargari *et al.* (2013), stated the advantages of indirect fabrication over direct fabrication such as:

i) Dimensional and chromatic stability over time
ii) Superior aesthetic results
iii) Adequate abrasion resistance
iv) Biocompatibility with soft tissue due to good finishing margin.

Although the content of direct composite is almost the same with indirect composite, it differs in method of additional polymerisation (Egli, 2010). In the past decades, continuation of improvements of indirect composite veneers have transformed it to be a predictable treatment option. It provides clinician with an alternative choice with less aggressive removal of natural tooth structures (Shetty *et al.*, 2001).

3.6 Composite Resin

Composite is founded by Bowen (1962) by combining dimethacrylates in the form of as a highly cross-linked polymeric material reinforced by a dispersion of amorphous silica, glass, crystalline, or organic resin filler particles and/or short fibers bonded to the matrix by a coupling agent (GPT-9). Nowadays, there are many types of different composite produced by rapid evolving development to overcome the shortcomings and to improve the qualities of composite.

Composite are made up of three main components the organic matrix (monomer), inorganic phase (fillers) and coupling agent (organosilane). The organic phase considered to be the main frame in composite resin, the monomer that is most used is the Bis-GMA. It is a highly viscous material therefore to improve the handling properties, they often combine with lower viscosity monomer such as UDMA and TEGDMA (Holter *et al*., 1997). Inorganic phase in a composite resin is the fillers which normally determines the physical and mechanical properties of the composite material. The uses of fillers are to reduce thermal expansion coefficient and overall curing shrinkage, provides radio-opacity, improves handling and improves the aesthetic results (Labella *et al*., 1999). Fillers that are often used are silicone dioxide, boron silicates and lithium aluminium silicates. Lutz & Philip (1983) classified composite based on the filler particles. Macro-filled composite when the filler size is more than >10µm, micro-filled composite is when the filler size is between 0.01-0.1 µm and lastly micro-filled based complex which have three different types: 1) splintered pre-polymerized micro-filled complexes, 2) spherical polymer based micro-filled complexes and 3) agglomerated micro-filled complexes. The recent development in fillers is the nanotechnology where nano-particles are used and the size of the nanoparticles are approximately 25 nm and the nanoaggregates of approximately 75 nm. The nanofillers used are zirconium/silica or nano-silica particles. The aggregates are treated with silane to increase their binding to the resin. The distribution of the filler (nanoaggregates and nanoparticles) increases the load, up to 79.5% (Geraldi *et al*., 2003).

Over the years, new and improved dental composite with lower polymerisation shrinkage, water sorption, better surface polishability, reduction of uncured monomer after curing by soft curing technique has been developed from clinical evaluations (Bernardo *et al*., 2007) and laboratory-based studies focused on composite durability (Drummond, 2008). This is caused by an increase application of dental composite in clinical practice. A study by Sadowsky (2006) stated that more than half of posterior restorations now rely on composite. He concluded that the increase usage of dental composite even in stress bearing area is due to the ability of the improved dental composite to withstand the masticatory forces at the posterior region.

3.6.1 Macro-filled composite

Macro-filled composite is defined as when the filler size is more than >10µm. The major advantage for this composite is the good physical properties that enable it to be used at posterior restorations example at stress bearing site like in class II or class IV. However due to its large filler particles size, this composite has poor polishability hence the rough surface will increase the plaque accumulation on the restoration (Lutz & Philips, 1983). Due to its poor wear resistance, the exposed rough surface of the filler caused staining and discolouration of restoration.

3.6.2 Hybrid composite

Hybrid composite is derived by reinforcing organic matrix with micro-fillers to reduce the differences in properties between the inorganic macro-fillers and the unfilled organic matrix. Normally the micro-filler size is between 0.6 - 1 µm and contained 0.04 µm colloidal filler. The recent hybrid composite has many advantages over conventional composites. Some of the advantages of hybrid composites are its wide range of colours and ability to mimic the dental structure, less curing shrinkage, low water absorption, excellent polishing and texturing properties, abrasion and wear rate that is very similar to that of natural tooth structures, similar thermal expansion coefficient to that of teeth, can be used for both the anterior and posterior tooth, different degrees of opaqueness and translucency in different tones and fluorescence (Hemmings *et al*., 2000 ; Gracia *et al*., 2014). This characteristic of hybrid composite has successfully reduced the polymerisation shrinkage which is one of the major disadvantages of dental composite compared to other restorative materials (García, 2006). Although there is improved wear resistance compared to the macro-filled composite the surface morphology of the hybrid composite is still inferior compared to the micro-filled composite. Therefore, it is still not considered as ideal to be used as an anterior restoration (Lutz & Philip, 1983).

3.6.3 Micro-filled composite veneer

Micro-filled composite has the best polishability and surface morphology due to its small fillers size (0.01 to 0.04 µm). Therefore, it is only indicated for the anterior restoration where aesthetic is the crucial aspect. However, their tensile strength is low, they are brittle and should not be used in Class IV stress bearing areas (Wei *et al*., 1994). Germain *et al*. (1985) studied two series of composite resins with a light-cured urethane dimethacrylate matrix to which varying amounts of two types of silanated silica particles. Group one contained volume fractions ranging from 15.8 to 28.8% silica particles of 20nm in diameter (Type I filler) and group two contained series volume fractions of from 24 to 49.4% of an agglomerated silica particle of 40nm in diameter (Type II filler). Germain *et al*. (1985) concluded that increased filler levels result in trends for increased depth of cure, colour stability, hardness, compressive strength, and stiffness, while water sorption and resistance to both toothbrush abrasion and wear by opposing tooth were reduced.

3.6.4 Nano composite

Most of the recent composite that is being introduced mainly focusing on nanotechnology. Nanocomposite reflects the inorganic fillers in an organic/inorganic composite that is nanosized (Chen *et al.*, 2010). The extremely small filler size normally between 0.1-100nm will have a dimension below the wavelength, which is 0.4-0.8µm. This will make them unable to absorb visible light. This characteristic of nanocomposites causes it to have very good optical properties. The major advantage of nanocomposite is they contain 90-95% of filler weight. As the polymerisation shrinkage of composite is normally due to the amount of organic resin matrix present in a composite, increasing the filler amount and reducing the organic resin matrix, can successfully reduce the polymerisation shrinkage.

Although with the reduction of fillers particles size, the mechanical properties of nanocomposite are suitable for both anterior and posterior restorations. Meyer (2003) stated that nanotechnology not only can reduce the polymerisation shrinkage, but it can also lessen the cusp wall deflection thus less micro-fissures developed at the enamel edges which can reduces the microleakage, discolouration, bacteria penetration and post-operative sensitivity.

3.6.5 Ormocers

Ormocers is a new packable composite known for its organically modified ceramic technology (Cunha *et al*., 2003). It is developed to overcome some limitations in the traditional composite material. The main difference of ormocers is it contains inorganic-organic co-polymers with the addition of inorganic silanated filler particles. It is synthesised through a solution and gelation process (sol-gel process) from multifunctional urethane and thioether(meth)acrylate alkoxysilanes. Ormocers contains ceramic polysiloxane which has lower shrinkage when compared to the usual organic dimethacrylate monomer such as Bis-GMA which present in most of the composite. The lower polymerisation shrinkage of Ormocers is because the polysiloxane chain which are longer than Bis-GMA in traditional composite materials (Kalra *et al*., 2012). Volumetric shrinkage of Ormocers depends on the filler content. Ormocers containing fillers has 1-3% volumetric shrinkage where else ormocers without fillers has 2-8% of volumetric shrinkage. The size of the filler particles is 1–1.5 µm.

The polymerisation opportunity of ormocers has resulted in double conversion of monomer thus eliminating the residual monomer that is usually found after curing of composite which will improve the physical properties and reduces the probability of discolouration (Hickel, 1998). In 2003, Civelek *et al*. studied the polymerisation shrinkage and microleakage in class II cavities of various resin composites and found that Ormocer showed lesser microleakage than the ion-releasing and hybrid composites lined only with bonding agent at the cemento–enamel junction (CEJ).

In 2008, Siso *et al*. studied the diametral strength, depth of cure, flexural strength and compressive strength of Ormocer, a hybrid composite and a packable composite, and concluded that the Ormocer showed greater depth of cure and flexural strength as compared to the other two. Its flexural strength was between the packable composite and the hybrid composite while its compressive strength was lesser than the composite materials.

3.6.6 Compomer

Compomers were introduced in early 1990s by combining of composite and glass ionomer cement. As a result, it contains the aesthetic properties of traditional composite resins with fluoride releasing properties of glass ionomer cements. It is a polyacid-modified composite resin. Therefore, compomers have the advantages of composite and glass ionomers cement. Compomers contain a bifunctional monomer, which enable it to react with the pendant methacrylate groups of other monomers, as well as with the cations produced by the glass particles (Meyer *et al.*, 1998).

The mechanical properties of compomers are still inferior when compared to the traditional composite. In a study done by Yap *et al*. (2004) they compared three different compomers with three conventional types of composites using single-edged notched specimens to determine the fracture toughness, after a week storage in water. They reported that the fracture toughness of composites ranges from 1.75–1.92 MPam1/2, whereas for compomers it ranges 0.97–1.23 MPam1/2. Based on the result, they suggested that compomers should not be indicated in stress bearing areas due to its low fracture resistance.

One of the advantages of compomers is its fluoride releasing properties in acceptable clinical amount. It would be released when the reactive glass fillers are subjected to acid environment and causes water uptake. Fluoride releasing properties of this material increase its popularity in pedodontics restorations as it can prevent caries formation by serving as pit and fissures sealants (Croll *et al*., 2004).

3.7 Tooth preparation for direct and indirect composite veneers

A conservative approach in tooth preparation should be implied for direct and indirect composite veneer as bonding on enamel is more predictable compared to bonding on dentine. In 2012, Gresnigt *et al*. performed a randomised split mouth trial on two different types of micro-hybrid composite resin in fabricating direct composite veneers. It was reported that the tooth preparation was 0.1-0.3mm on the cervical and 0.3-0.6mm at the incisal with 1mm incisal overlapped, it also extended to the interproximal region of the tooth. The incisal overlapped is to produce a veneer with good translucency and enough bulk of material to prevent chipping of veneer.

Chai *et al*. (2018) did a critical review paper on different types of incisal preparation for ceramic veneers. The preparations were classified into two main types, overlapped and non-overlapped. The four common preparation designs under this category are window (intra-enamel), butt joint (incisal bevel), feathered edge and palatal chamfer. Window and feathered edge belong to the non-overlapped preparation, whereas the butt joint and palatal chamfer are under the overlapped preparation. They concluded that the butt joint and feathered edge preparation are ideal preparation for ceramic veneers.

3.8 Microleakage

Microleakage may be defined as the clinically undetectable passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material (Eick, 1986). Microleakage is usually tested in vitro by using bacterial, chemical or radioisotope tracers. Colour dye penetration studies are the most commonly used techniques in the literature.

The causes of microleakage are dimensional changes of materials due to polymerisation shrinkage, thermal contraction, absorption of water, mechanical stress and dimensional changes in tooth structure (Staninec, 1986). The polymerisation shrinkage of a composite resin can create contraction forces causing disruption of the bond to the cavity walls, leading to marginal failure and subsequently microleakage (Davidson *et al*., 1984). The other contributing factor for microleakage will be the coefficient of thermal expansion. The coefficient of thermal expansion of composite resin (25 to 60 ppm°C-1) is several times larger than that of enamel (11,4 ppm°C-1) and dentine (8 ppm°C-1) (McCabe,1998) thus can contribute to microleakage.

3.8.1 Assessment of microleakage of dental veneers

3.8.1.1 Direct observation

This is the most simple and direct method to check for any catch or gap between the restorations and the natural tooth structure. The clinician can use an explorer to probe the marginal integrity and assumed there is a leakage depending on their tactile sensation. However, this method is not mentioned in any literature as the results is not quantifiable. Interestingly, a study by Gonzalez *et al.* (1997), suggested that the direct observation to be used with the adjunct of photographic observation.

3.8.2 Photographic observation

Panduric *et al.* (2007) detect deformations and fractures in dental hard tissues or in composite material from internal stresses using double-exposure holographic interferometry. The samples were illuminated using a helium-neon laser beam, and the holograms of samples were recorded using Agfa 10E75 photographic plates. Hologram reconstructions were captured with an 8-bit monochrome CCD camera and qualitatively analysed. Deformations and fractures appeared as fringe patterns on all interferograms, where the distribution of fringes provided location information, while the density of fringes gave the amplitude information. This is an example where photographic observation is used to check for the microfractures in the tooth structure and composite materials. The drawbacks of this method are there will be differences of results between different examiners as some microfractures may be missed out and this will directly affect the results that will be reported at the end of the experiment.

3.8.3 Dye penetration test

The dye penetration test is the most common test used to detect the microleakage at the space between tooth structure and the restored materials. By introducing the dye tracers, one can clearly see the extent of the dye with the help of either a stereomicroscope or scanning electron microscope (SEM).

According to Gonzalez *et al*. (1997), the dye tracers that can be used are as follow;

a. Organic dyes
b. Fluorescent dyes
c. Radioisotopes
d. Silver nitrate techniques
e. Calcium hydroxide techniques

Organic dyes are the oldest tracer that is most frequently used. Some of the organic dyes used include basic fuchsine which was used by Fuks *et al*. (1992) to evaluate the microleakage of class 2 glass-ionomer-silver restorations in primary molar. Prati *et al.*

(1991) uses methylene blue to test microleakage of dentine bonding systems. Based on the literature, basic fuchsin dye is one of the most commonly used dyes (Jia *et al*., 2017; Aboushelib *et al*., 2012; Patel *et al.*, 2015). Aboushelib *et al*. (2012) compared internal adaptation, marginal accuracy and microleakage of a pressable versus a machinable ceramic laminate veneers. He assessed dye penetration extent, internal cement film thickness, vertical and horizontal marginal gaps at the incisal and cervical regions. As defective marginal seal will result in seepage of saliva bacteria penetration that will cause secondary caries and post restoration sensitivity. Therefore, many researches regarding the microleakage extent of a restoration have been carried out. The most popular method to evaluate the sealing ability of the restoration is by dye penetration test. Many different types of dye have been used for the dye penetration test such as, methylene blue, sliver nitrate with developer, india ink and basic fuchsine dye.

3.8.4 Consequences of microleakage

Microleakage of composite restoration can be directly linked to marginal integrity (Ferrari & Garcia, 2002). Marginal gap is due to the shrinkage of resin composite during polymerisation (Lai & Johnson, 1993). The main reason for replacement of resin composite restorations is secondary caries, which accounts for 40–70% of the cases (Mjör, 1997; Al-Negrish, 2002). Few studies, stated the effects of microleakage as pulpal irritation, marginal discolouration and secondary caries (Bergenholtz *et al.*, 1982; Brännström, 1986; Kidd *et al*., 1992).

3.9 Advancement in the direct and indirect composite veneers

A review by Klapdohr & Moszner in 2005, focused on the inorganic filler component of dental composites and related filler composition, morphology, and loading content with properties conveyed to composites. Ceramage ™ (Shofu Inc, Kyoto, Japan) is an indirect composite containing 73% zirconium silicate fillers which is normally found in ceramic veneers improve the aesthetic, flexural and compressive strength of the material. In 2016, Lim did a study to measure the Weibull distribution of a restorative materials such as direct composite [Z100 (ZO), 3M-ESPE], an indirect laboratory composite [Ceramage™ (CM), Shofu Inc, Kyoto, Japan], and two CAD/CAM composites [Lava Ultimate™ (LU), 3M ESPE™; Vita Enamic™ (VE), Vita Zahnfabrik™ (VZ)] restorations.

The Weibull modulus (m) is a dimensionless material-specific parameter that explains the variation in the strength or asymmetric strength distribution as a result of flaws within the microstructure. A higher Weibull modulus indicates that the particular material has a more homogeneous flaw distribution throughout the entire volume, which results in higher structural reliability and lower failure probability (Kelly *et al.,* 1995; Ornaghi *et al*., 2014; Quin *et al.,* 2010). They have concluded that Ceramage™, Lava Ultimate™ and Z100™ have similar Weibull modules but Vita Enamic™ (VE) which is a CAD/CAM composites have the highest Weibull module. s. Visuttiwattanakorn *et al*. (2017) did a study and microtensile bond strengths (MTBSs) of 2 different types of indirect composite with surface treatment and concluded that Ceramage™ (CM) has the microtensile bond strengths (MTBSs) and is able to serve as one of the treatment options in aesthetic cases of anteriors. However, there are limited long term studies on Ceramage™.

CHAPTER 4: MATERIALS AND METHODS

4.1 Study design

This is a laboratory based experimental study.

4.2 Sample size calculation

The sample size was calculated using a G power version 3.1: sample size calculator. The following input parameters were chosen for the sample size calculation: large effect size of 0.8, $\alpha = 0.05$ and the power of 0.80 (80%) (Appendix 1). This resulted in the sample size of 21 per group. However, in this study the sample size was added to 22 samples per group to have a higher precision of measurements (Gandolfi *et al.*, 2012).

4.3 Pilot study

The pilot study was performed on 2 samples from each group to assess the effect of dye penetration on the extracted natural tooth and the ability to observe the extent of the penetrated dye in the marginal gap between the composite veneer and the natural tooth structure using light stereomicroscope. It was observed that in all cases, the extent of the dye and the marginal gap can be clearly observed with the light microscope using 40X magnification (Boening *et al.,* 2000). Problem encountered during the pilot study was the acrylic resin used to mount the natural tooth was unable to set even after 3 days. This could be due to the contamination of the acrylic mixture by its remnants on the mixing syringe that has been used to measure the monomer A and base B. Therefore, after using a new syringe for each measurement, the acrylic resin had set successfully after 8 hours as what has been described by the manufacturer.

4.4 Ethics approval

This study was approved by the Medical Ethics Committee, Faculty of Dentistry, University of Malaya on 1st November 2017 (Reference number - DF RD1712/0051(P).

4.5 Collection and preparation of teeth

Forty-four sound maxillary central incisors (n=44) extracted from patients due to periodontal reasons were used in this research.

These teeth were collected from three different private dental clinics. All the teeth were cleaned thoroughly to remove the soft tissue, calculus and later stored in 1% Chloramine- T solution (molecular formula: $C_7H_7ClNO_2SNa$) for 7 days for disinfectant purpose. Subsequently, the teeth were rinsed in distilled water and stored in the incubator at 37°C before being used for the test.

4.6 Selection of sample

The teeth with similar dimensions (10.5$\pm$0.1 mm cervico-incisal height, 8.5$\pm$0.1 mm mesio-distal width and 13.0$\pm$0.1 mm root length) were selected based on the standard sizes proposed by Wheeler's in 1963 (Figure 4.1) and measured with a Renfert caliper No. 11190000 (Table 4.3, No. 1). This is to standardise the surface areas of each sample. Tooth with slight discrepancy (< 0.5mm) on its different areas were included in the sample. Teeth with enamel hypoplasia, cracks, gross irregularities or other developmental defects of the enamel structure were excluded from the study.

4.7 Materials and instruments used in the study

List of materials and instruments used in the study were presented in Table 4.2 and 4.3.

Table 4.1 Exclusion and inclusion criteria

Inclusion criteria	Exclusion criteria
1. Tooth with dimensions 10.5mm Cervico-Incisal height, 8.5mm Mesio-Distal width and 13mm root length ±0.1mm (Wheeler's, 1963)	1. Do not meet the standardised measurement
2. Tooth which are intact (non-carious and without any fractures)	2. Tooth which are not intact (carious, fractured enamels, cracks, hypoplastic and hypomineralised enamel)

Average measurements for maxillary central incisor (Fig 4.1)

The selected tooth measures 10.5mm cervico-incisal height, 8.5mm mesio-distal width and 13mm root length based on the standard sizes proposed by Wheeler's (1963).

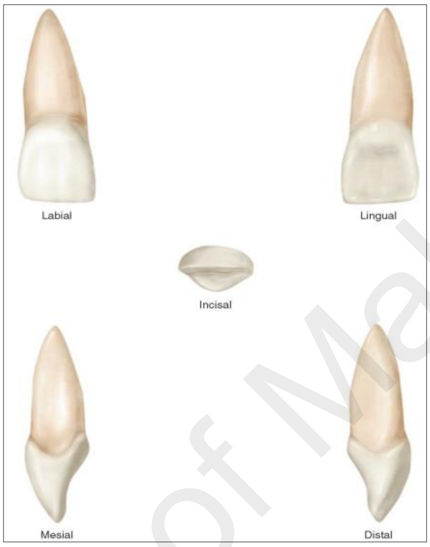


Figure 4.1 Different surface views of maxillary central incisors (Courtesy of Wheeler's dental anatomy 10th edition, 2014)

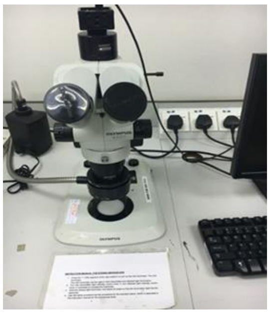
Table 4.2 Lists of materials used for this study

Types of materials	Brand name	Ingredients	Manufacturer	Product number
1. Direct composite, group 1 	Beautifil™	S-PRG (Surface Pre-reacted Glass Ionomer)83% wt, 69% volume)	Shofu Inc, Kyoto, Japan	PN1775
2. Luting cement 	Beauticem™	Paste A: Urethane dimethacrylate (UDMA), Fluoroboro-aluminosilicate glass, Surface Pre-reacted Glass Ionomer (S-PRG) Paste B: Urethane dimethacrylate (UDMA), 2-hydroxyethyl methacrylate (HEMA), Phosphonic acid,	Shofu Inc, Kyoto, Japan	PN3214

		Carboxylic acid monomer, zirconium silicate. polymerisation initiator.		
3. Bonding agent  	Beautibond™	Phosphonic acid and carboxylic acid monomer	Shofu Inc, Kyoto, Japan	PN1782
4. Indirect composite, group 2  	Ceramage™	73% by weight micro-fine ceramic particles embedded in an organic polymer matrix.	Shofu Inc, Kyoto, Japan	PN1806

Table 4.3 Lists of instruments used for this study

Types of instruments	**Manufacturer**	**Product number**
1. Caliper 	Renfert, Germany	No. 11190000
2. Diamond burs 	Shofu Inc, Kyoto, Japan	No 0897-1, ISO552/036, No.845X1 ISO 289/016
3. Ceramage polishing kit 	Shofu Inc, Kyoto, Japan	PN 033
4.Metkon microcut 125 	Metkon,bursa, Turkey.	No.06 125

5.Stereo electron microscope 	Olympus, Tokyo Japan.	SZX7

4.8 Randomisation of samples

Forty- four samples (n=44) are divided randomly into 2 groups, Group 1(n=22) and Group 2 (n=22). Each sample were numbered from 1 to 44. Even numbered samples were assigned under group 1 and odd numbers for group 2. Flip coin method was used to choose the groups for direct and indirect composite veneers. Based on the method, direct composite veneer was assigned in group 1 and the indirect composite veneer in group 2.

4.9 Tooth preparation

Putty index impression was taken for all the forty-four samples (n=44) before commencement of the tooth preparation for veneers. These putty index impressions were sectioned into half vertically to serve as a guide for the tooth reduction to ensure a uniform removal of tooth structure for every samples.

All the teeth were prepared for anterior veneers. The facial reduction was between 0.5 – 0.7mm, following the contour of the tooth extending until the proximal contact area. The incisal edge was reduced by 1.0mm and the incisal overlap design was prepared on the palatal surface.

The chamfer cervical margin was positioned 1.0mm incisal to cemento-enamel junction (CEJ). Each tooth was prepared free hand using the depth gauge diamond burs (Table 4.3, No 2). The depth cuts were marked with pencil to avoid over preparation of the tooth. The tooth was prepared using a straight cylinder round end coarse diamond bur (Table 4.3, No 2) for all the reductions and to create a chamfer margin. To ensure standardised even tooth reduction, sectioned putty index was used. In addition to the putty index, a Renfert caliper No. 11190000 (Table 4.3, No 1) was used to counter measure the reduction on each surface to ensure standardised tooth preparation.

4.9.1 Direct composite veneers

For this type of restoration, 22 prepared teeth (n=22) were randomly selected. The surface of each prepared tooth was washed and air dried. The bonding agent, (Beautibond™, Shofu Inc, Kyoto, Japan) (Table 4.2, No 3) was applied using a micro-brush tip and left undisturbed for 10 seconds. Air dried with gentle air for about 3 seconds and polymerised for 5 seconds according to manufacturer's instructions. The area was light polymerised with a calibrated light curing unit (Demi™ Plus, Kerr, USA) irradiation wave length: 400-500nm for 10 seconds also according to manufacturer's instructions. A resin filled direct composite resin (Beautifil™, Shofu Inc, Kyoto, Japan) (Table 4.2, No 1) was adapted to the silicone index of the prepared tooth surface and pressed against the prepared tooth surface to prevent voids and then light polymerised for 20 seconds. Once the silicone mold was removed, the veneer was cured again for another 20 seconds to ensure complete polymerisation. During the finishing phase, the composite veneers was contoured to appropriate size and shape. The sectional putty impression and Renfert caliper No. 11190000 (Table 4.3, No 1) were used to control the thickness of the restoration, excess material was reduced during this stage.

Finally, the restorations were polished with rubber cups and discs in the composite polishing kit by Shofu Inc, Kyoto, Japan (Table 4.3, No 3) with polishing paste (DURA-POLISH™, Shofu, Japan) for 5 minutes and a timer was used to standardise the polishing time for each veneer.

4.9.2 Indirect composite veneers

For this type of restoration, 22 prepared teeth (n=22) were randomly selected. Twenty-two impressions for the group 2 veneer preparation was taken using Impregum (3M ESPE™, Seefeld, Germany) with maxillary stock tray in which 5 crown portions of the prepared samples were captured in a single impression. Die stones were poured using Type IV dental stone (Pastel Rock™ Die Stone, Kerr,USA) to prepare the working die. Then a sinter disc was used to separate the working die from the base. The veneer preparation was exposed using a round bur. The outline of the preparation on the die was marked using a carbon marker. Two coats of die spacer were applied on all the surfaces except for the cervical margins and air dried. A thin layer of separating media was also applied on the dies for easy veneer removal. Indirect composite veneer was built up using dentine body shade and enamel incisal shade based on manufacturer's instructions. After each incremental layer, the resin was polymerised using light curing laboratory machine (Solidilite V™, Shofu Inc, Kyoto, Japan) for 3 minutes. Sectioned index and Renfert caliper No. 11190000 (Table 4.3 No 1) were used to standardised the thickness of the veneer. A total of 5 minutes was allocated to polish the veneer with (DURA-POLISH™, Shofu Inc, Kyoto, Japan). Subsequently, the veneer was detached from the die and the spacer removed.

4.9.3 Cementation of indirect composite veneer

Bonding agent (Beautibond™, Shofu Inc, Kyoto, Japan) (Table 4.2, No 3) was applied on the prepared surface of the tooth and light polymerised for 5 seconds. The fitting surface of the veneer was sandblasted using approx. 0.1 – 0.2 MPa (approx. 1 – 2 bar) air pressure to increase micro-retention of the restoration. Further, Bonding agent (Beautibond™, Shofu Inc, Kyoto, Japan) (Table 4.2, No 3) was also applied on the fitting surfaces of the veneer, air dried for 3 seconds and polymerised for 10 seconds. A freshly mixed resin luting cement (Beauticem™, Shofu Inc, Kyoto, Japan) (Table 4.2, No 2) was applied on the fitting surface of the veneer which was then cemented with a constant index finger pressure at the middle of the veneer while the wrist of the hand was rested on the table. Excess cement was removed and the resin cement was polymerised on all the surfaces for 10 seconds.

4.9.4 Thermocycling Procedure

After cementation of the veneers in both groups, all the specimens were stored in distilled water at 37° C in 100% humidity in an incubator for 24 hours to mimic the temperature in the oral environment. Then samples from both groups were subjected to 500 cycles of thermocycling between 5° and 55° C for 60s in water bath (according to ISO 11450). The temperatures of both the baths were checked regularly using two separate thermometers respectively.

4.9.5 Microleakage Evaluation

4.9.5.1 Preparation Prior to Immersion in Dye Solution

At the end of thermocycling, the apices of the restored tooth roots were sealed with a pattern wax. Other areas of the tooth excluding cervical and incisal veneer margins were coated with two layers of nail varnish and allow to dry for 4 hours. This is to prevent dye penetration into other areas through any micro cracks.

4.9.5.2 Microleakage Test

The specimens were immersed in 2% fuchsine methylene blue dye for 24 hours. After 24 hours, the specimens were washed under running tap water for few minutes and dried. Afterwards the teeth were embedded in acrylic resin and sectioned vertically in labio-palatal direction from the middle of restoration using low speed precision saw (Table 4.3, No 4).

Either half of the equally sectioned tooth (n=44) was observed under a stereomicroscope ×40 magnifications (Table 4.3, No.5) and scored as 1st reading accordingly based on the degree of dye penetration at the incisal and cervical margins of the restored veneer. The samples (n=44) were measured again one month after initial measurement by the same examiner and recorded as 2nd reading. Mean of two readings (1st and 2nd) were taken as the final measurement. The measurements were scored using the microleakage scoring system (Table 4.4).

Table 4.4 Microleakage scoring system (modified Silveira 2006 scoring)

Score	Dye penetration extent(µm)
0	No dye penetration
1	≤ 999.00
2	≤ 1999.00
3	≤ 3000.00

4.9.5.3 Marginal gap evaluation

Either half of the equally sectioned tooth (n=44) was observed under a stereomicroscope ×40 magnifications (Table 4.3, No.5) and the marginal gap between the veneer and tooth at cervical and incisal margins was recorded as the 1st reading. The samples (n=44) were measured again one month after initial measurement by the same examiner and recorded as 2nd reading. Mean of two readings (1st and 2nd) were taken as the final measurement.

The definition of marginal gap is the perpendicular measurement from the internal surface of the casting to the axial wall of the preparation is called the internal gap, and the same measurement at the margin is called the marginal gap (Holmes, 1989). This definition was supported by Groten *et al*. (2000) and they added that marginal gap measurements are frequently used to quantify fit of the restorations to the natural tooth surface (Groten, 2000). The area where the marginal gap is measured under the stereomicroscope is clearly portraited in Figure 4.2.

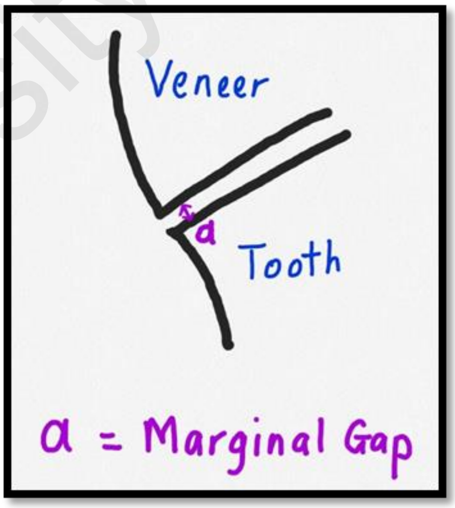


Figure 4.2 Illustration on the marginal gap at the tooth-veneer interface (modified from Holmes 2006).

4.10 Scoring and calibration

The microleakage and marginal gap was measured by a same calibrated examiner under stereomicroscope x 40 magnifications and scored, accordingly based on the degree of dye penetration at the incisal and cervical margins of the restored veneer. To control the reproducibility of the scoring system and the intra-examiner performance, the samples (n=44) were measured again one month after initial measurement (Khng *et al.*, 2015). Reproducibility was evaluated by means of the intraclass correlation coefficient (ICC) (Appendix 2).

44 maxillary central incisor were collected

Inclusion criteria: > Tooth of dimensions 10.5mm CI height, 8.5mm MD width and 13mm root length ±0.1mm (Wheeler's 1963) > Intact (non-carious, no fracture)	Exclusion criteria:> doesn't meet the standardised measurements> tooth not intact (carious, fracture, cracks, hypomineralised)

Facial reduction between 0.5 – 0.7mm, The incisal edge was reduced 1.0mm with incisal overlap1mm palatal surface.

Putty index impressions for every samples were taken to serve as a guide for the tooth reduction.

Group 1: Direct composite veneer (n=22)	Group 2: Indirect composite veneer (n=22)

Group 1:

(Beautibond™, Shofu Inc, Kyoto, Japan) applied and left undisturbed for 10sec. gentle air for about 3 sec and polymerised for 5 seconds.

Layering technique used to adapt composite to the tooth surface with the silicone putty index.

Restorations were polished with Dura-polish™ polishing paste (Shofu Inc, Kyoto,Japan) for 5 minutes.

Group 2:

Impregum (3M ESPE™, Seefeld, Germany) with maxillary stock tray .Die stones working die is prepared using Type IV dental stone (Pastel Rock™ Die Stone, Kerr, USA).

2 coats of die spacer were applied on all the surfaces except for the cervical margins and air dried.

Indirect composite veneer was built up using dentine body shade and enamel incisal shade by layering technique.

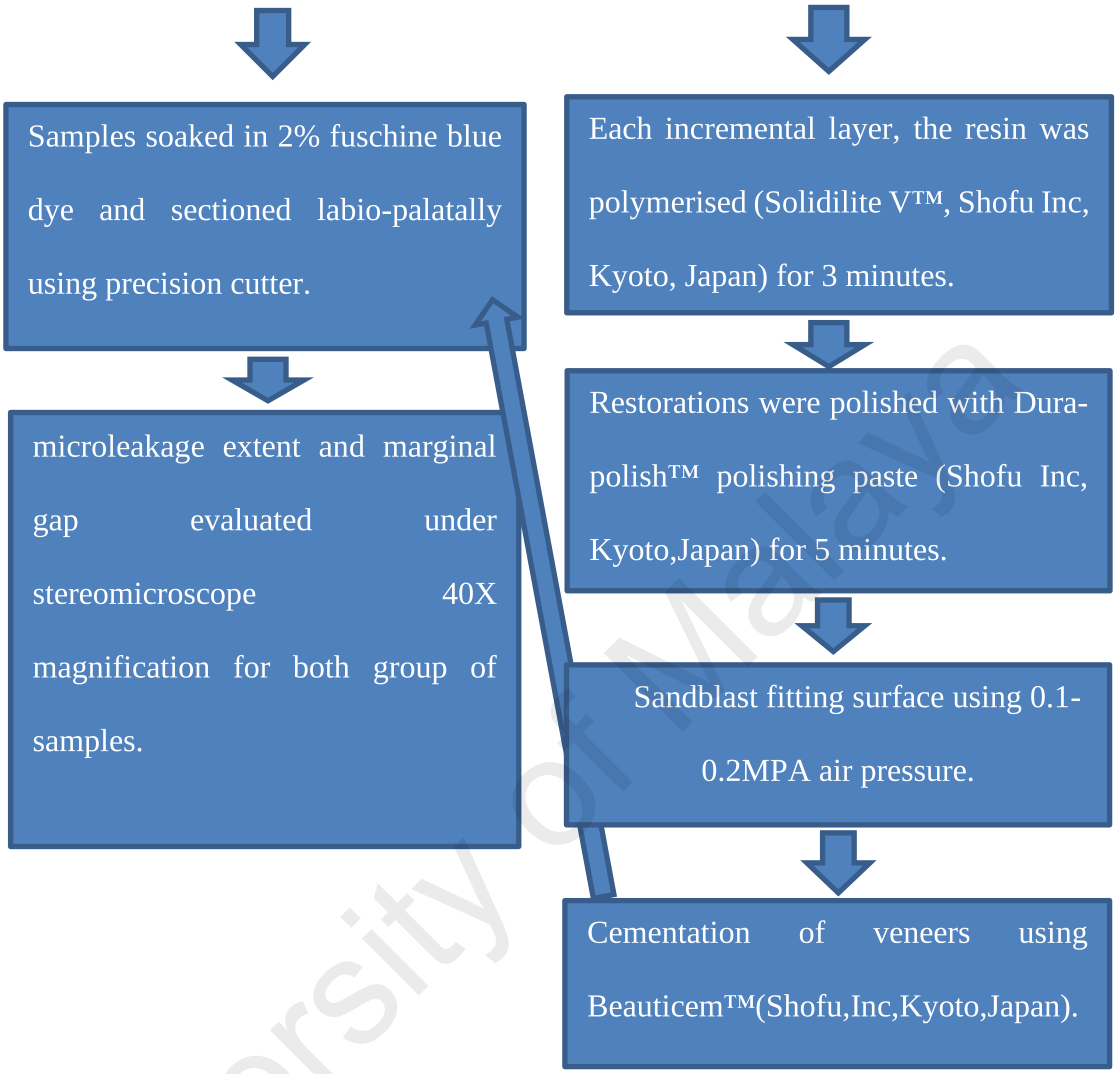


Figure 4.3 Flow chart of research methodology

4.10.1 Data collections and analysis

The data for all the samples (n=44) were collected and tabulated using SPSS version 23 (SPSS Inc., Chicago, USA). The normality of the sample size for this study was analysed using Shapiro-Wilk test was selected because the number of samples for this study is < 50. The results of the normality test were not normally distributed hence the non-parametric Mann-Whitney U test was used to analyse the median microleakage and marginal gaps. Wilcoxon Signed Rank test was used for intragroup comparison for microleakage and marginal gap at cervical and incisal margins. Spearman correlation test was used to evaluate existence of correlation-ship between marginal gap and the microleakage extend at the cervical and incisal region of the composite veneers fabricated from two different methods (direct and indirect).

CHAPTER 5: RESULTS

5.1 Microleakage scoring system

The microleakage scoring system was adapted and modified based on Silveira scoring (Silveira *et al*., 2006) (Figure 5.1).

Figure 5.1: Scores of dye leakage observed for both substrates (Silveira *et al*., 2006)

0 = No dye penetration

1 = Dye penetration up to half of the cavity depth

2 = Dye penetration more than half of the cavity depth

3 = Dye penetration arriving to the cavity floor

The scoring system used in this study is based on the modification of the Silveira scoring system (Table 5.1).

Table 5.1 Microleakage scoring system (modified Silveira *et al.*, 2006 scoring)

Score	Dye penetration extent(μm)
0	No dye penetration
1	≤ 999.00
2	≤ 1999.00
3	≤ 3000.00

The data in Table 5.2 showed direct composite veneer (Beautifil™) having most score of 0 and 1 (91%) and indirect composite veneer (Ceramage™) showed 100% of score 1 and above.

Table 5.2 Microleakage scoring at cervical and incisal margins of direct and indirect composite veneers

Score	**Direct composite veneer (Beautifil™) (n=22)**		**Indirect composite veneer (Ceramage™) (n=22)**	
	Cervical (%) (n)	**Incisal (%)(n)**	**Cervical (%)(n)**	**Incisal (%) (n)**
0	32(7)	41(9)	0(0)	0(0)
1	59(13)	59(13)	46(10)	73(16)
2	9(2)	0(0)	27(6)	18(4)
3	0(0)	0(0)	27(6)	9(2)

5.2 Evaluation of microleakage and marginal gap

5.2.1 Quantitative evaluation of microleakage

The data was analysed for normal distribution. Shapiro-Wilk test was selected because of the sample size which is less than fifty. The results showed that the data for microleakage was normally distributed ($p < 0.005$) for the indirect composite veneers (Appendix 5a). On the other hand, the data for direct composite veneer group was not normally distributed ($p > 0.005$). Therefore, non-parametric independent Mann-Whitney U test was used to test the null hypothesis of the study (Appendix 7a, 7b).

Table 5.3, shows the median and interquartile range of microleakage for direct and indirect composite veneers at the cervical and incisal margins (Appendix 6a, 6b). The median values of microleakage for indirect composite veneers at the cervical and incisal margins (1286.21 µm and 642.83µm) are higher compared to the direct composite veneer (120.18µm and 36.44µm) respectively. The statistical analysis test revealed that there was a significant difference between two groups for microleakage values at the cervical and incisal margins ($p < 0.001$).

Table 5.3 Microleakage of tested veneers at cervical and incisal margins (µm).

	Direct composite veneer (Beautifil™) (n=22)		Indirect composite veneer (Ceramage™) (n=22)			
Location	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Z	p value [a] *
Cervical	305.72 (543.30)	120.18 (±376.61)	1377.54 (1467.27)	1286.21 (±851.07)	4.40	<0.001*
Incisal	125.88 (±201.99)	36.44 (210.84)	899.70 (941.10)	642.83 (±670.98)	4.93	<0.001*

SD= standard deviation

IQR = interquartile range

Z = standard test statistic

p value set at α=0.05

[a] = Mann-Whitney test Sig(2tailed)

* significant difference

Median value of microleakage (μm) of direct and indirect composite veneers at cervical and incisal margins

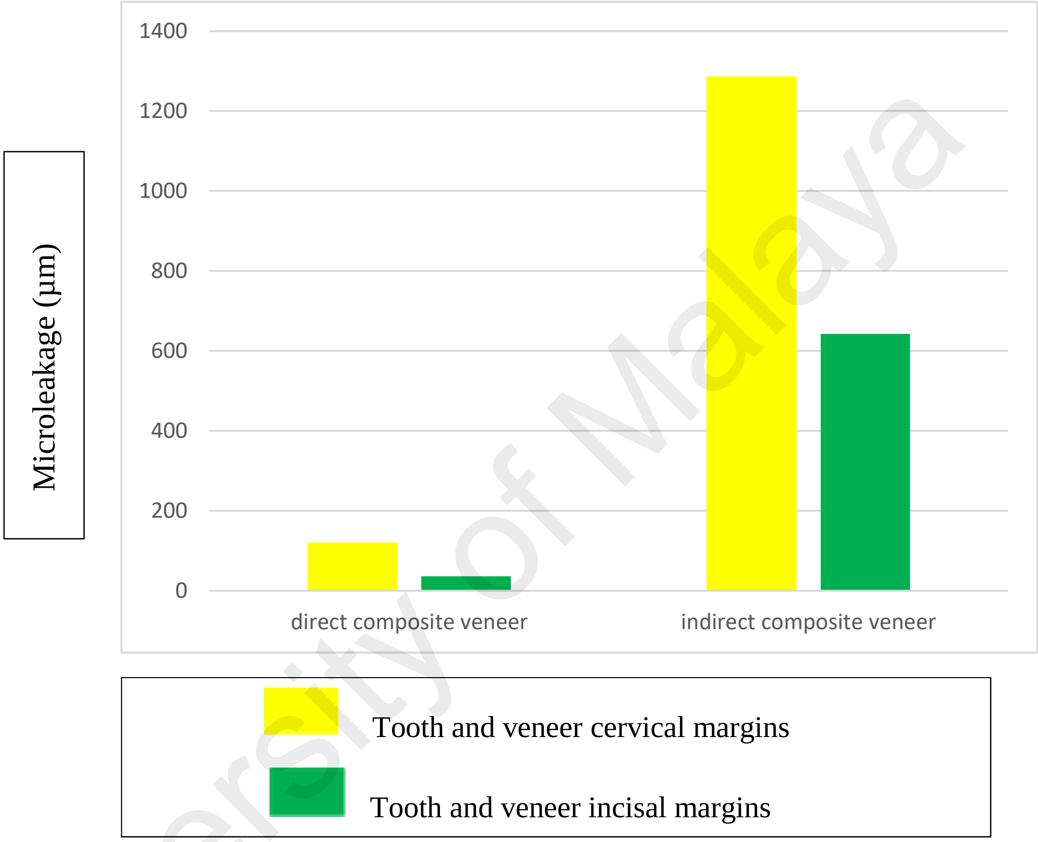


Figure 5.2 Median value(μm) of microleakage of direct and indirect composite veneers at cervical and incisal margins.

5.2.2 Quantitative evaluation of marginal gap

The results for the Shapiro-Wilk test for marginal gap showed that the data was not normally distributed for direct and indirect composite veneer ($p < 0.05$) (Appendix 5b).

Therefore, Mann-Whitney U test was used to test the statistical significance (Appendix 8a, 8b).

Table 5.4, shows the median and interquartile range of the marginal gap for the direct and indirect composite veneers at the cervical and incisal margins (Appendix 6c). The median values of marginal gap for indirect composite veneer at the cervical and incisal margins (12.51µm and 15.67µm) are higher compared to the direct composite veneer. Statistical analysis showed that indirect composite veneers were associated with significantly higher marginal gap compared to direct composite veneers ($p < 0.001$).

Table 5.4 Marginal gap of tested veneers at cervical and incisal margins(µm).

	Direct composite veneer (Beautiful™) (n=22)		Indirect composite veneer (Ceramage™)			
Location	**Mean (SD)**	**Median (IQR)**	**Mean (SD)**	**Median (IQR)**	**Z**	**p value [a] ***
Cervical	0(0)	0(0)	12.67 (±8.09)	12.51 (6.43)	5.216	< 0.001*
Incisal	0(0)	0(0)	15.16 (±10.58)	15.67 (9.50)	5.216	< 0.001*

SD= standard deviation

p value set at α= 0.05

IQR = interquartile range

[a] = Mann-Whitney test Sig(2tailed)

Z = standard test statistic

* significant difference

Median value of marginal gap(µm) of direct and indirect composite veneers at cervical and incisal margins

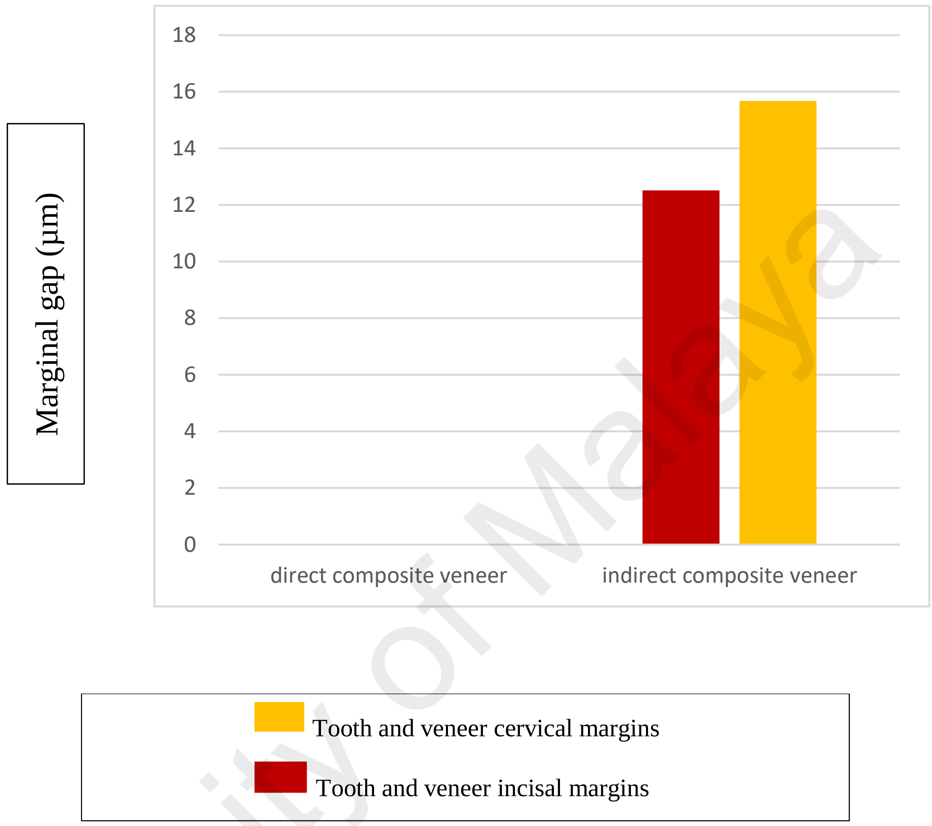
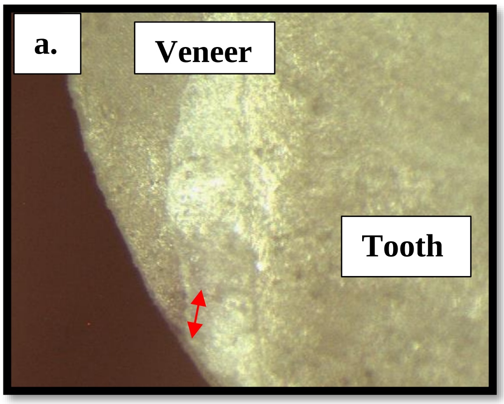


Figure 5.3 Median value of marginal gap(µm) of direct and indirect composite veneers at cervical and incisal margins.

Images of measurement of microleakage (µm) of direct composite veneer (Beautifil)



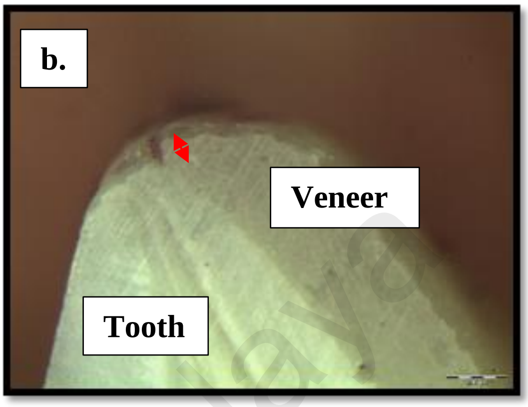
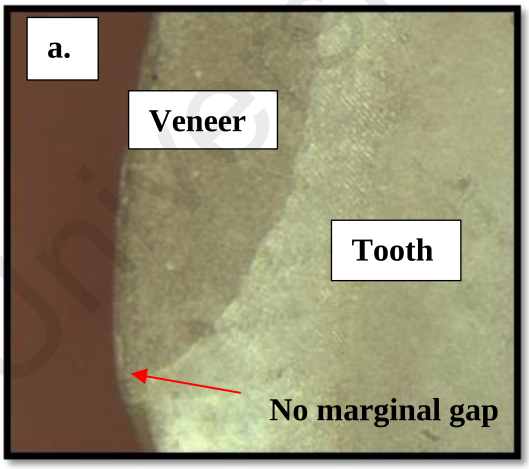


Figure 5.4 a) Microleakage(µm) at tooth and veneer cervical margin.

Figure 5.4 b) Microleakage(µm) at tooth and veneer incisal margin.

↔ Microleakage(µm)

Images of measurement of marginal gap (µm) of direct composite veneer (Beautifil)



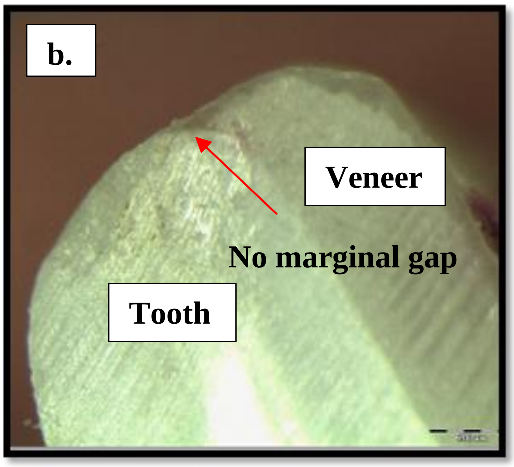


Figure 5.5 a) Marginal gap (µm)at tooth and veneer cervical margin.

Figure 5.5 b) Marginal gap (µm)at tooth and veneer incisal margin.

→ no marginal gap

Images of measurement of microleakage (µm) of indirect composite veneer (Ceramage)

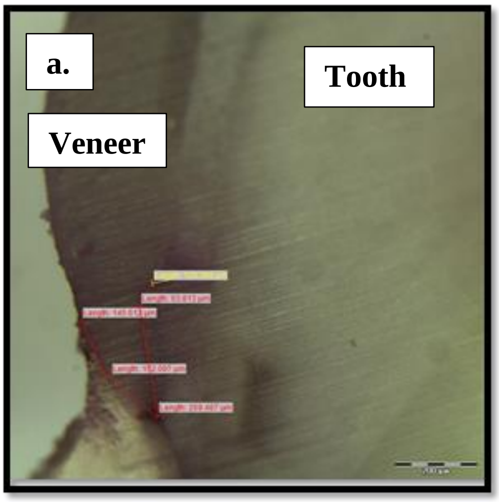


Figure 5.6 a) Microleakage (µm)at tooth and veneer cervical margin.

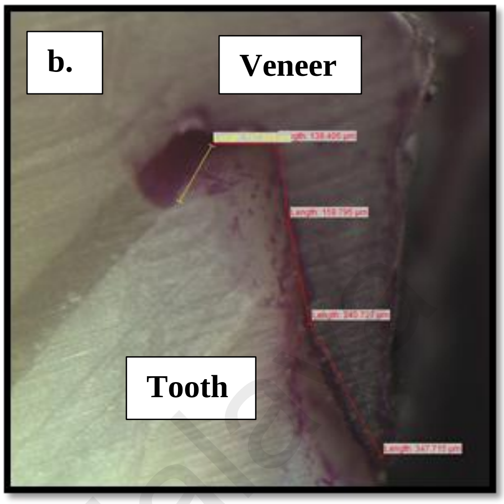


Figure 5.6 b) Microleakage (µm)at tooth and veneer incisal margin.

Microleakage (µm)

Images of measurement of marginal gap (µm) of indirect composite veneer (Ceramage)

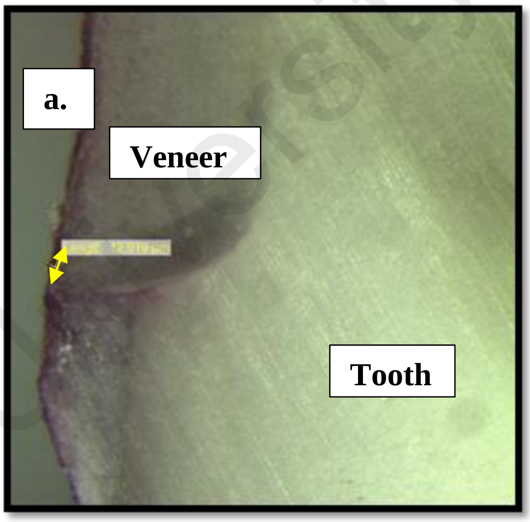


Figure 5.7 a) Marginal gap (µm)at tooth and veneer cervical margin.

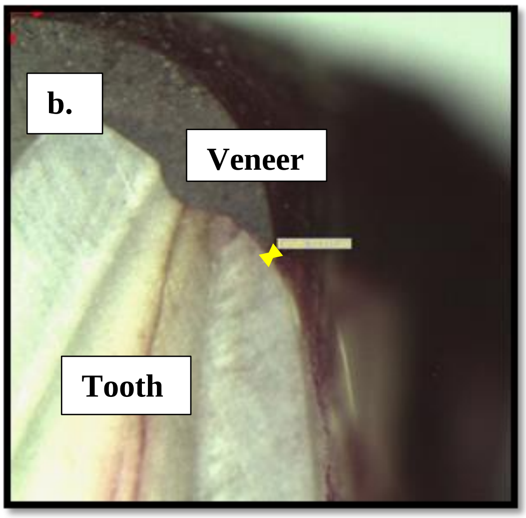


Figure 5.7 b) Marginal gap (µm)at tooth and veneer incisal margin.

Marginal gap (µm)

5.2.3 Intragroup comparison for microleakage and marginal gap at cervical and incisal margins

Wilcoxon Signed Rank test was used to evaluate intragroup differences for microleakage and marginal gap at the cervical and incisal margins for both the groups.

Table 5.5, showed that there was no significant difference within the group in microleakage at the cervical and incisal margins for direct composite veneers ($p > 0.05$) and indirect composite veneers ($p > 0.05$) (Appendix 9a, 9b).

Similarly, the intragroup differences for marginal gap at cervical and incisal margins was not statistically different for indirect composite veneers ($p > 0.05$) (Table 5.6) (Appendix 10a, 10b).

Table 5.5 Intragroup comparison for microleakage at cervical and incisal margins

Types / location	Mean (µm)	Median (µm)	Z	p- value*
Direct composite veneer (C vs I) (n=22)	C (305.72) I (125.88)	C (120.18) I (36.44)	1.706	0.088
Indirect composite veneer (C vs I) (n=22)	C (1377.54) I (899.70)	C (1286.21) I (642.83)	1.834	0.067

Z = Wilcoxon Signed Rank test statistic value C = Cervical margin

p-value set at α= 0.05 I = Incisal margin

* significant difference

Table 5.6 Intragroup comparison for marginal gap at cervical and incisal margins

Types / location	Mean (µm)	Median (µm)	Z	p- value*
Direct composite veneer (C vs I) (n=22)	C & I (0.00)	C & I (0.00)	NA	NA
Indirect composite veneer (C vs I) (n=22)	C (12.67) I (15.16)	C (12.51) I (15.67)	1.328	0.184

Z = Wilcoxon Signed Rank test statistic value   C = Cervical margin

p- value set at α= 0.05   I = Incisal margin

* significant difference

5.2.4 Relationship between microleakage and marginal gap of direct and indirect composite veneers.

Spearman correlation test was used to evaluate any statistically significant correlation exists between microleakage and the marginal gap at the cervical and incisal margins of the direct and indirect composite veneers. Table 5.7 showed that there was a positive correlation (r =0.574, p <0.001) exists between marginal gap and microleakage at the cervical portion of the veneer and the tooth structure (Appendix 11a). Table 5.7 also showed that there was a positive correlation (r =0.634, p <0.001) exists between marginal gap and microleakage at the incisal margins of the veneer and the tooth structure (Appendix 11b).

Table 5.7 Relationship between microleakage and marginal gap at the cervical and incisal margins

	Microleakage and marginal gap at cervical margins (n=44)	**Microleakage and marginal gap at incisal margins (n=44)**
Spearman's correlation(r)	0.574	0.634
p- value*	< 0.001*	< 0.001*

p- value set at α= 0.05

* significant difference

CHAPTER 6: DISCUSSION

6.1 Study design

Microleakage and marginal gap of direct and indirect composite veneers are evaluated in vitro on extracted maxillary central incisors. Laboratory study was chosen as it is more appropriate within the time allocated if compared to a clinical study. Based on the literature, most of the studies on marginal gap or microleakage of different type of veneers were usually performed as a laboratory study (Celik *et al*., 2002; Korkut *et al*., 2011; Aboushelib *et al*., 2012; Jia *et al*., 2017). For this study, the methodology was adopted from the research done by Jia *et al*. (2017) as its methodology best represented the aim and objectives of this research. A randomised split mouth clinical trial of indirect composite and ceramic veneers by Gresnigt *et al*. (2013) with three years follow- up showed that increase marginal discolouration and fracture seen more frequently in indirect composite veneer group compared to porcelain veneer group but there were no significant differences between the survival rate of both type of veneers (87% indirect composite veneer, 100% ceramic veneers). Another study on the clinical performance of porcelain veneers within five years by Peumans *et al*. (1998) concluded that 25% had mild discolouration and only one had severe discolouration. At five years recall, 99% showed acceptable marginal adaptation of the porcelain veneers to the tooth. Although the condition of in vitro studies is not exactly similar to the oral environment, the results of in vivo (Gresnigt *et al*., 2013) and in vitro (Jia *et al*., 2017) studies stated above proved that there were more marginal discolouration seen in indirect composite veneer when compared to porcelain veneers.

6.2 Materials used

With the increase awareness and knowledge of patients in the field of dentistry, aesthetic factor and the longevity of the treatment provided as an additional need to have a healthy, functional dentition. This is a growing challenge for clinician as they have to provide aesthetically pleasing and long-lasting restorations or prostheses for the patients without compromising the existing dental health.

Over the years, composite veneer has gained popularity and considerable importance in providing increasing aesthetic demand and offered as a treatment option for a patient that favours minimal preparation (Celik *et al*., 2017). Ceramage™ is Shofu's zirconium silicate indirect restorative product that provides excellent aesthetic results for both anterior and posterior restorations. It contains organic polymer matrix and more than 73% filler of progressive fine structure (PFS), a microstructure that resists plaque accumulation. In contrast, Beautifil™, another product by Shofu, Japan, is a universal direct nano-hybrid composite incorporating S-PRG (surface pre-reacted glass ionomer) technology that contains a stable phase of glass-ionomer for aesthetic and long-lasting restorations that release and recharge fluoride. Beautifil™ and Ceramage™ were chosen for this study because indirect composite was only recommended in case reports studies (Gargari *et al*., 2013; Al-Halabi *et al*., 2015). Stronger evidence- based study was needed to prove the clinical advantages and cost effectiveness of indirect composite (Ceramage™) when compared to direct composite (Beautifil™). Futhermore, there are no articles comparing the marginal gap and microleakage of direct composite veneer and indirect composite veneer at cervical and incisal margins.

In addition, Ceramage™ was chosen among various indirect composite in the market because it is a relatively new indirect composite material that is available in this country. Beautifil™ was selected as the direct composite material to avoid bias in this study, both materials are by Shofu Inc. Kyoto, Japan.

6.3 Pilot study

Before the start of the research, a pilot study was done for this experiment to ensure the procedures are achievable and replicable. During the preparation of the samples, the acrylic resin used to mount the specimens failed to set at the first attempt. It was later discovered that contamination of monomer before mixing might have caused the failure of the acrylic resin to be hardened even after 3 days. At the second attempt in preparing the samples, separate new syringes were used to measure monomer A and B before mixing it together resulting with the acrylic resin hardened as planned.

6.4 Samples

In this study, the maxillary central incisors were selected because they were the most commonly indicated for laminate veneers (Calamia, 1983). In addition, extracted human maxillary central incisors were used to simulate the clinical situation in terms of adhesion of composite resin on a natural tooth. This is viewed as a better option when compared to using typodont teeth or a die. Natural tooth is made up of organic and inorganic substances that will influence the adhesion of the composite restoration to the etched and conditioned tooth structure but this condition cannot be appreciated in typodont teeth. Although there are studies where bovine teeth or typodont teeth were used for similar study, it was claimed that is difficult to obtain extracted human teeth (Ateyah, 2004). This study had used forty-four maxillary central incisors to work on collected from three dental centers. It is important to note that intact human tooth that was indicated for extraction due to periodontal reason was used in the attempt to stimulate clinical situation.

6.5 Dye tracer

The use of dyes to evaluate microleakage at tooth and restoration interface is one of the oldest and most used method to date (Ibbara *et al*., 2007). There are many dye tracers in the market. The different dyes are organic dyes, fluorescent dyes, radioisotopes, silver nitrate techniques and calcium hydroxide (Gonzalez *et al*, 1997). Basic fuchsine dye is one of the most commonly used dyes today (Jia *et al*, 2017; Aboushelib *et al*, 2012; Patel, 2015). The percentage concentration that is currently in use ranges from 0.5 to 2.0 percent. Therefore, basic fuchsine dye (2%) was used in this study because of its low cost, ease of application and low molecular weight of the dye, which is smaller than bacteria (Patel, 2015). Samples were soaked for 24 hours in basic fuschine dye (2%) after thermo-ageing of the samples (Jia *et al*., 2017).

6.6 Veneer tooth preparation

Veneer preparation can affect the fitting of both direct and indirect veneer. The possible effect of the tooth preparation of veneers on the degree of microleakage were discussed in few studies (Hekimoglu *et al*., 2004; Celik *et al*., 2017). In these studies, the advantages, disadvantages, indications of incisal reduction, chamfer and shoulder preparation were discussed. Studies by Calamia (1985) and Andreasen (1992), highly supported the incisal reduction as they claimed it to have better retention and aesthetic of the veneer without the abrupt change of colour between natural tooth and veneers. In short, the transition between the dental veneer and natural tooth will be more natural and unnoticeable. In a recent study on the survival rate of porcelain veneer based on the type of veneer tooth preparation proved that window preparation was one of the most conservative type (Chai *et al*., 2018). Incisal coverage was reported to be better than no incisal coverage. The two predictable designs of incisal coverage are the incisal overlap and butt joint. For butt joint preparation, no long-term follow-up studies have been reported as yet. In general, incisal overlap was preferred for healthy normal tooth with sufficient thickness and incisal butt preparation was preferred for worn tooth and fractured teeth (Shetty, 2011). There are many different studies on the types of veneer preparation on the extent of the microleakage but all have contradictory results. Some studies claimed incisal overlap preparation had the best outcome (Stappert *et al*., 2005; Zarone *et al*., 2005), while some claimed butt joint had a better outcome (Castelnuovo *et al*., 2000). Interestingly, Alghazzawi *et al*. (2012) reported that there were no significant differences between both methods.

On the cervical margin preparation, there is a possible relation between cervical margin form (i.e. butt-shoulder versus chamfer) and aesthetic appearance, as the actual cervical preparation form was dependent on the degree of discolouration of the tooth indicated for dental veneers. Furthermore, based on a study on margin preparation forms for crowns it is proven that acceptable cement thickness was achievable for both shoulder and chamfer form (Ateyah, 2004).

6.7 Light cured

In this in vitro study, the light cured machine used was Demi™ Plus Dental Curing Light (KERR, USA). Demi™ Plus employs the power of Periodic Level Shifting, (PLS), shifting output intensity from 1,100 mW/cm2 to a peak of 1,330 mW/ cm2 multiple times throughout the curing cycle with a wavelength of 450 nm to 470 nm. Demetron L.E.D. Radiometer (KERR, USA) was used to precisely measures the radiant energy of each in milliwatts per centimeter squared (mW/cm2). Over time, several factors can reduce the output intensity of a curing light machine including: rough handling, material build-up on light guides, overheating, and bulb degradation. A loss in output can affect the amount of time needed to efficiently cure the material. Hence output density of the light will be tested daily before performing the laboratory procedure to ensure a complete curing of the composite material. The recommended curing time for universal composite, shades A3 and lighter (at 2 mm depth) is five seconds; shades A3.5 and darker is ten seconds; bonding agents, universal luting cements and self-etch, self-adhesive cements is five seconds. The recommended curing time for direct composite restoration used in the study is 20 seconds.

Layering technique was applied for the restoration of direct composite veneer. The layering was constantly checked with the putty index taken prior to tooth preparation to achieve the pre-operative size of the tooth. The composite is cured each side and the putty index removed and the remaining surface of the composite dental veneer was cured again thoroughly (Chandrasekhar *et al*., 2017).

As for the indirect composite veneer, Ceramage™ and Solidilite V™ curing machine (Shofu Inc, Kyoto, Japan) were used in the laboratory. Solidilite V™ indirect light curing machine has four specially designed powerful halogen lamps with a wide wavelength spectrum of 400-550 nm to ensure uniform, optimised light polymerisation.

It contains integrated fan and a protective soft start cure mode to optimise efficient light polymerisation of indirect composites such as Ceramage™. The recommended curing times are listed in the table 6.1, according to manufacturer's instructions.

Table 6.1 Recommendation curing time for indirect composite veneer, Ceramage™.

Light cure	Solidilite EX™
Pre- opaque	1 min
Opaque	3 min
Composite (pre-light-cure)	1 min
Flowable composite (pre-light-cure)	1 min
Pontic	3 min
Final	5 min

6.8 Use of stereomicroscope

Microleakage and marginal gap were evaluated using stereomicroscope in some studies (Boening, 2000; Keshvad, 2011; Aboushelib *et al.*, 2012) while other studies used scanning electron microscope (Soares, 2005; Ibarra *et al.*, 2007). There was one study that used computerised digital image analysis system (Baig *et al.*, 2010). This computerised system consisted of a stereomicroscope (Olympus™ SZCTV; Olympus) attached to a CCD (charge-coupled device) camera (SSCDC58AO; Sony Corp, Tokyo, Japan), which captured and recorded live images obtained through the stereomicroscope and displayed them on a computer monitor using an image capture and processing software (Micro Image, v. 4.0; Olympus Optical Co, Hamburg, Germany).

In the present study, we used stereomicroscope with 40X magnification as suggested by previous studies ((Boening *et al.*, 2000; Keshvad *et al.*, 2011; Aboushelib *et al.*, 2012). This magnification allowed us to observe the extent of the dye penetration and also the marginal gap at cervical and incisal margins clearly.

In addition, there are some studies that uses OCT (Optical Coherence Tomography) (Sinescu *et al*., 2009; Rominu *et al*., 2009) and confocal microscopy (Jacobsen *et al*., 2003; Bakhsh *et al*., 2011) to observe and measure the marginal gap at the tooth and restoration interface.

6.9 Marginal Gap evaluation

Marginal gap and microleakage are few features that can cause restorative failures. In the literature there are several terms used to describe the gap at the margin between the veneer and the natural tooth structure. These terms are marginal discrepancy, vertical marginal discrepancy, horizontal marginal discrepancy and marginal gap (Holmes *et al*.,1992). It is the most frequent method used to measure the adaptation of margin of the restoration and the finish line of the tooth preparation at cervical, incisal and proximal margins (Baig *et al*., 2010; Bindl *et al*., 2005). The marginal gaps in the literature range from 50-200µm (Christensen, 1966; McLean, 1971; Mitchell, 2001; Boening *et al*., 2000). For the longevity of the restoration, a marginal discrepancy of 100µm is accepted (Shiratsuchi *et al*., 2006). There are non- invasive ways to check marginal gap such as scanning electron microscope. However, the invasive method based on sectioning can be more precise than the non-invasive method. The absolute marginal discrepancy appears better defined and easier to determine in a section in comparison to an intact surface (Hung *et al*., 1990; Maleknejad *et al*., 2009). Therefore, the invasive method of evaluating marginal gap was adopted in this study.

Results of the present study demonstrated that the marginal gaps were greater in the indirect composite veneer group (12.51µm at cervical margin and 15.67µm at incisal margin) when compared to direct composite veneer group (0.00µm at cervical and incisal margins). In this study, group 2 (indirect composite veneer) specimens were fabricated on working dies directly produced from impregum impressions of veneer tooth preparations of every samples to ensure a stable and detailed records. In the vertical cut sections, it was possible to precisely measure marginal accuracy in both horizontal and vertical dimensions (Aboushelib *et al*., 2012).

Based on the results, there was a significant difference in marginal gap between direct and indirect composite veneers. This can be caused by the use of luting agent in indirect composite veneers (Jain *et al*., 2015). This is supported by Scheibenbogen-Fuchsbrunner *et al*. (1999), they claimed that the reason of larger marginal gap in indirect composite veneers can be caused by removal of cement flashes with blunt instruments. The other explanation on the increase marginal gap at the tooth and veneer interface in indirect composite veneer may be due to the lack of sufficient cementation pressure during cementation procedure of the indirect composite veneer. De Munk *et al*. (2004) reported an improved adaptation of the cement to the substrate when was applied under pressure due to its thixotropic characteristics. In this study, however, the veneers were cemented under constant finger pressure at the center of the veneer that simulated that applied in the clinical setting. Although gap was not present at the dentine interface, it is seen at the enamel interface. Some studies also concluded that sandblasting on the fitting surface of the veneer causes microdefect on the margin of the veneer which directly causing an ill- fitting veneer (Sinescu *et al*., 2009; Rominu *et al*., 2009). In this study, direct composite veneer showed distinctively less marginal gap when compared with indirect composite veneer because of the restorative technique adopted as it is proven in many studies that layering (Lee *et al*., 2007; Park *et al*., 2008; Soares *et al*., 2013) and soft start curing (Schneider *et al*., 2010) technique successfully reduced the polymerisation shrinkage in composite restorations.

6.10 Microleakage evaluation

Microleakage is one of the major drawbacks of tooth coloured restorations. Dye penetration method was used in this study to assess microleakage under the stereomicroscope. According to Hannig & Friedrichs (2001), the goal of adhesive dentistry will be achieved with a close adaptation of the restoration to the prepared cavity wall to prevent microleakage at the interface. The marginal gap at the tooth – restoration interface will cause dentinal fluid percolation and this will directly cause pulpal sensitivity during functional load and secondary caries (Nedeljkovic, 2015). According to Yüksel & Zaimoğlu (2011), the types of cement and marginal discrepancy had significant effect on microleakage. There was less microleakage in self- adhesive resin cement than with glass ionomer luting cement. Therefore, in our study Beauticem™ (Shofu Inc. Kyoto, Japan), self-etch, self-adhesive dual cure resin cement was chosen. It has multiple indications and one of it is to lute indirect resin composite. With the limited amount of studies comparing microleakage of direct and indirect composite veneers, similar studies in regards to microleakage were taken into account (Aboushelib *et al*., 2012; Jia *et al*., 2017; Haralur, 2018). The results in our study showed increase microleakage extent in indirect composite veneer (cervical 305.72µm, incisal 125.88µm) and indirect composite veneer (cervical 1377.54µm, incisal 899.70µm) which is in agreement with a study conducted by Jia *et al*. (2017) showing that direct composite materials fiber-reinforced composite (0.333mm) showed lesser microleakage when compared to indirect composite materials 3M composites (3M ESPE)

(0.536mm). Results of the study by Jia et al in 2017 indicated a correlation between the materials used and microleakage with less microleakage in direct composite veneers.

6.11 Marginal gap and microleakage at different locations

In this study there was no statistically significant difference between the marginal gap and microleakage at different location (cervical and incisal) within the same group of samples. However, the reading of marginal gap and microleakage at the cervical margin is higher compared to incisal margin. This may due to microleakage tends to be higher in dentine than in enamel (Hasanreıˇsogˇlu *et al*., 1996; Gerdolle *et al*., 2005). Dentine has higher biological variability than enamel, which makes it more difficult substrate to obtain a high bond strength with the adhesive that must resist thermal stresses and the interfacial stresses generated by the polymerisation shrinkage of the composite resin (Manhart *et al*., 2001). This might explain the increase marginal gap seen in the indirect composite veneers compared to direct composite veneers. Jain *et al*. (2015) did an in vivo study comparing marginal adaptation of direct and indirect composite veneers by evaluating qualitatively on epoxy resin dies (obtained from post-restorative impressions) at baseline and at each follow-up under scanning electron microscope (SEM) and concluded that direct composite veneers performed better in terms of marginal adaptation. This is in agreement with the results obtained from this study showing that better marginal adaptation seen in direct composite veneers. In this study, direct composite veneers were fabricated using nano-hybrid composite therefore it may be the reason for better marginal adaptation because there are studies (van Dijken & Hörstedt, 1987; Jain *et al*., 2015) that concluded that micro filled composites have greater polymerization shrinkage when compared to nano- filled and hybrid composites.

6.12 Correlation between marginal gap and microleakage

There were many studies which claimed that indirect restoration has smaller marginal gap hence better marginal integrity. Liberman *et al*. (1997) stated that the indirect procedure resulted in a significantly reduced microleakage when compared to that produced by the semi-direct inlay technique (Liberman,1997). Yüksel & Zaimoğlu (2011) concluded that both marginal discrepancy and cement type had significant effects on microleakage. They recorded lower levels of microleakage with self-adhesive resin cement. Christian *et al*. (2016), performed an in vitro study evaluated the correlation between microleakage and absolute marginal discrepancy in zirconia crowns cemented with four resin luting cements 4 groups are RelyX® (Rx), Multilink® (Mk), PANAVIA 2.1® (P), and Maxcem® (Mx). They found that there was no significant difference among the 4 types of cements in terms of absolute marginal discrepancy and microleakage. Absolute marginal discrepancy is not necessarily related to microleakage and PANAVIA 2.1® has the highest microleakage due to it is more sensitive technique compared to other resin cements (Christian *et al*., 2016). Aboushelib *et al*. (2012) performed a study on internal adaptation, marginal accuracy and microleakage of a pressable versus machinable ceramic veneers. Forty ceramic veneers were fabricated by either milling ceramic blocks using a CAD/CAM system or press-on veneering using lost wax technique. They concluded that pressable ceramic veneers produced higher marginal adaptation, homogenous and thinner cement film thickness, and improved resistance to microleakage compared to machinable ceramic veneer. The study by Aboushelib *et al*. (2012) has almost the same methodology as this research but using ceramic veneers instead of composite veneer. However, their study is able to provide an insight on the microleakage of indirect restorations as the measurements of the indirect ceramic veneers (microleakage 233.512- 831.758 µm) is in consistent with the measurements of indirect composite veneer (microleakage 899.70-1377.54µm) in this study. In a more recent study by Jia *et* *al*. (2017), which compared marginal microleakage of fiber-reinforced composite (FRC) (Everstick NET, Stick Tech), porcelain laminate veneer (PLV) (IPS Empress II (E-Max Press) and 3M composites (3M ESPE). The result of their study was in agreement with this study showing that direct composite materials fiber-reinforced composite (0.333mm) showed lesser microleakage when compared to indirect composite materials 3M composites (0.536mm). In contrast, a clinical study by Duquia *et al*. (2006) compared the cervical microleakage in mesial -occlusal- distal (MOD) restorations between direct and indirect composite and reported lesser microleakage and better sealing ability of indirect composite restorations.

The results obtained from this study are valid to reject the null hypothesis as there was significant correlation between the marginal gap and the microleakage. The higher microleakage observed in group 2 could be attributed to the present of luting cement at the veneer and tooth interface. The luting cement might have absorbed the dye or the polymerisation shrinkage of the luting cement might have contributed the microleakage. In group 1, however, there was direct contact of composite to the tooth structure.

One of the main objectives of the study was to evaluate if there was an interaction between the extent of microleakage and the amount of marginal gap for both direct and indirect composite veneer groups. To date, there is very limited study comparing different fabrication composite veneer instead there are many articles comparing composite veneers to porcelain veneers and even more on different fabrication technique of ceramic veneers (eg, pressable, machinable, CAD-CAM) (Calamia *et al*., 1983; Calamia *et al*., 1985; Holmes, 1992; Meijering *et al*., 1998; Yüksel *et al*., 2011; Shetty *et al*., 2011). For now, with the revolution and improvement of usage of composite material in fabrication of indirect composite veneer, for example Ceramage™ (Shofu), Eldelweiss™ (Ultradent), Sinfony™ (3M) and Premise™ indirect (Kerr), extensive attention has been given on indirect composite veneers. This is due to the fact that indirect composite veneer will require a less aggressive tooth preparation in comparison to porcelain veneers. Porcelain veneers are also more brittle due to the glass phase that require substantial amount of thickness of the veneer to prevent fracture of the veneers. Furthermore, indirect composite veneer has reduced laboratory time and less technique sensitive laboratory procedures in comparison with porcelain veneers. More importantly, is the reduction in cost of the fabrication of indirect composite veneer compared to porcelain veneer. However, based on the results of this study, direct composite veneer shows better adaptation and less microleakage when compared to indirect composite material.

To date, only a few clinical studies have been carried out for indirect composite veneer. Thus, it is essential that more extensive research to be carried out to provide evidence-base regarding the material. In direct composite veneer, composite resin is directly applied on the tooth structure and sculptured to the anatomical shape of the tooth. Although direct composite veneer is much more cost effective compared with indirect composite veneer and porcelain veneer, it has been shown in many studies that direct composite veneers have inferior colour stability, excessive wear and greater polymerisation shrinkage. The longevity of direct composite veneer is 4 to 8 years with the average years is about 4 to 5 years (Albers, 2002). Veiga *et al*. (2016) performed a systematic review and meta-analysis of the longevity of direct and indirect resin composite restorations in posterior teeth. They concluded that there was no significant difference in the overall risk between direct and indirect composite restorations in 3 years follow- up (Veiga *et al*., 2016). The follow up period was too short to be conclusive on the overall risk of direct and indirect composite veneer just based on 3 years follow up, at least 10 years prospective follow up have to be carried out.

One of the factors causing a large difference in marginal gap and microleakage value of the same group in this study might be attributed to the depth of preparation either in enamel or dentine. There are some similar studies that showed that microleakage tends to be higher in dentine than in enamel (Hasanreıˇsogˇlu *et al*., 1996; Gerdolle *et al*., 2005). Dentine has higher biological variability than enamel, which makes it more difficult substrate to obtain a high bond strength with the adhesive that must resist thermal stresses and the interfacial stresses generated by the polymerisation shrinkage of the composite resin (Manhart *et al*., 2001). The results of our study were in agreement with other studies (Aboushelib *et al*., 2002; Kalmowicz *et al*., 2015; Jia *et al*., 2017), which concluded that the microleakage in enamel was significantly lower when compared with dentine, regardless of the material, C-factor, or insertion technique.

CHAPTER 7: CONCLUSION

Within the limitations of the study, the following conclusions were made:

1. Indirect composite veneer exhibited more microleakage when compared to direct composite veneer.
2. Indirect composite veneer exhibited more marginal gap when compared to direct composite veneer.
3. There is no statistical significance in microleakage and marginal gap at the cervical and incisal margins of both direct and indirect composite veneers.
4. There is a strong correlation between the amount of marginal gap and the extent of microleakage at the tooth and veneer interface. The amount of marginal gap is directly proportionate to the extent of microleakage.

CHAPTER 8: LIMITATION

1. The sample size is small due to the difficulty in obtaining maxillary central incisors.

2. Sectioning of the tooth into equal halves might cause chipping of the restorations. Therefore, nowadays some studies using optical coherent tomography (OCT) and confocal microcopy to evaluate marginal gap between tooth and veneer's interface.

CHAPTER 9: RECOMMENDATIONS

A clinical randomised controlled split-mouth clinical trial where patient receive direct composite veneer on one quadrant and indirect composite veneer at another quadrant in a same patient oral environment will have a more clinical significance on the success rate of each treatment as was carried out by Gresnigt *et al*., 2012. It can also be suggested that future research a laboratory- based study can be perform to explore on the exact location of the dye penetration whether is at the restoration and luting cement interface or the luting cement and tooth interface. Other method to increase surface roughness at fitting surface of indirect composite veneer should be considered by manufacturer instead of using sandblasting technique will may cause chipping of thin cervical or incisal margin of the thin shell-like veneers. The study can be further improved by comparing different latest material which is available in the market.

CHAPTER 10: CLINICAL SIGNIFICANCE

Direct composite veneer is still an acceptable option with good clinical performance where conservative tooth preparation is indicated. It is also more cost effective and suitable for patients with financial constraint. Direct composite veneer can serve as a short to mid-term treatment option for anterior aesthetic restoration. This study can serve as a reference for clinician in making decision on clinical application of different materials especially related to direct and indirect composite veneers. We would like to state that within the limitation of this study, direct composite veneer is comparable if not superior to the indirect composite veneer.

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