Fracture Resistance of Provisional Crowns Fabricated with CAD/CAM Process and Conventional Process after Aging in Simulated Oral Condition

ความต้านทานต่อการแตกหักของครอบฟันชั่วคราวที่ผลิตจากกระบวนการแคดแคม และกระบวนการปกติหลังผ่านสภาพช่องปากจำลอง

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ABSTRACT

The study was to investigate difference in fracture resistance of provisional single crowns fabricated from three different provisional resins namely auto-polymerized PMMA (Unifast Trad - UF), auto-polymerized Bis-acryl (Protemp4 - PT), and CAD/CAM PMMA block (Brylic S - BS) after simulated oral condition. Eight crowns were fabricated for each group using conventional direct technique for the first two groups, and CAD/CAM technique for the last. All crowns were cemented and put through 5,000 cycles of 5°C and and 100,000 cycles of 100N occlusal force before tested for maximum force at fracture in universal testing machine. One-way ANOVA showed that UF has significantly lower fracture resistance at 655.88±75.58N (p<0.05) while no significant difference between PT (1112.42±183.98N) and BS (960.83±84.40N). It can be summarized that UF is inferior to PT and BS in terms of fracture resistance.

บทคัดย่อ

วัตถุประสงค์ของการศึกษาคือการหาความแตกต่างในการต้านทานการแตกหักของครอบฟันชั่วคราวที่ทำจากวัสดุสามชนิด (พีเอ็มเอ็มเอ และ บิสเอคริลชนิดบ่มด้วยตัวเอง และ ก้อนพีเอ็มเอ็มเอสำหรับแคดแคม) หลังผ่านช่องปากจำลอง ครอบฟันกลุ่มละแปดชิ้นในสองกลุ่มแรกถูกสร้างโดยตรงบนฟันเรซินด้วยวิธีปกติ ส่วนกลุ่มที่สามถูกสร้างด้วยวิธีแคดแคม จากนั้นทำการยึดกับฟันเรซิน และผ่านน้ำอุณหภูมิระหว่าง 5°C และ 55°C 5,000ครั้ง รับแรงเคี้ยว 100 นิวตัน 4 ครั้งต่อนาที 100,00 รอบ แล้วทดสอบเพื่อหาแรงสูงสุดที่รับได้ก่อนแตกหัก สถิติการวิเคราะห์ความแปรปรวนแบบทางเดียวพบว่าครอบในกลุ่มพีเอ็มเอ็มเอชนิดบ่มด้วยตัวเอง มีความแข็งแรงต่ำกว่าอีกสองกลุ่มที่ระดับนัยสำคัญ 0.05 ขณะที่อีกสองกลุ่มไม่แตกต่างกัน สามารถสรุปได้ว่า ครอบฟันชั่วคราวจากพีเอ็มเอ็มเอ ชนิดบ่มด้วยตัวเอง มีความแข็งแรงต่ำกว่า บิสเอคริล และ ก้อนพีเอ็มเอ็มเอสำหรับแคดแคม

Keywords: Provisional crowns, Fracture resistance

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Introduction

Provisional restorations are vital and inevitable part in fixed prosthodontics treatment. It provides protection to prepared abutment, promotes gingival health, enhances aesthetics, and preserves occlusal function during fabrication of final prosthesis (Gegauff & Holloway, 2006; Gratton & Aquilino, 2004). In many cases, provisional restorations were used as a diagnostic tool to evaluate new occlusal scheme and aesthetics. That information would be transferred to the technician to help fabricates final restorations (Derbabian et al., 2000). This process often required a considerably long duration of intra-oral service. During such times, fracture or failure of provisional restorations may cause unexpected appointment, additional expense and treatment time, or unnecessary discomfort.

Acrylic resins have been introduced as a material for fabrication of provisional restorations for decades due to its ease of fabrication, availability, and physical properties. Methyl methacrylate, a linear polymer, is one of the first to be used and still being used widely at present thanks to its excellent handling properties, reparability, and reasonably good mechanical properties. Dimethacrylates or bis-acryl was introduced later as an attempt to improve mechanical properties, reduce polymerization shrinkage, improve colour stability, and lower heat exerted during polymerization (Anusavice et al., 2013; Nejatidanesh et al., 2009). Methyl methacrylate was provided to be used as a powder-liquid mixture while bis-acryl material was manufactured as an auto-mix syringe.

Conventionally, fabrication of provisional restoration can be done in clinical setting by making outer surface form pre-preparation of the tooth or from diagnostic waxing using a matrix, after finishing preparation, apply mixture of provisional material on to the matrix and place directly on prepared abutment which acts as an inner surface template (Gratton & Aquilino, 2004). As CAD/CAM technology was introduced for dental uses, new techniques and materials for provisional crowns fabrications are available. In contrast with conventional provisional crowns materials and fabrication methods mentioned earlier, CAD/CAM provisional crowns materials was pre-polymerized as a resin block which is then installed in to a milling machine. Since the polymerization process took place in a controlled industrial condition by the manufacturer, it is possible to obtain higher density without flaw, void, or contamination (Giordano, 2006).

Fracture resistance and flexural toughness of both conventionally fabricated and CAD/CAM fabricated provisional restorations were examined in a numbers of studies which shows tendency of better result for CAD/CAM groups (Abdullah et al., 2016; Alt et al., 2011; Karaokutan et al., 2015; Rayyan et al., 2015; Stawarczyk et al., 2012; Yao et al., 2014). However, most of these studies test materials under thermal stress or no aging regimen at all while effect of repeated occlusal load on provisional restorations was rarely described.

Objective of the study

The aim of this study was to evaluate fracture resistance of provisional crowns fabricated from different materials after receiving thermocycling and cyclic loading to simulate intra-oral condition

Materials and methods

Resin die preparation

Upper first molar ivorine tooth (Nissin dental product inc., Kyoto, Japan) was embedded in 1/2"poly vinyl chloride tube with chemical-cured poly methyl methacrylate at the center of the tube in perpendicular axis. Three indexes were inscribed in resin base adjacent to buccal, mesial, and distal surface before polyvinyl siloxane (PVS) (Provil, Kulzer, Frankfurt, Germany) matrix was fabricated surrounding tooth surface and incorporating all resin base index to help re-positioning of the matrix. Preparation for all-ceramic crown was done on the tooth with 1 mm deep chamfer margin using high speed diamond round-ended taper bur and polished with fine grit bur of the same size (Diaswiss, Nyon, Switzerland – Burr no. 314SG856018 and 341FSG856018). Prepared teeth along with its resin base were boxed and poured with mold forming polyvinyl siloxane and was left to complete polymerization for 24 hours. This mold was used to duplicate prepared abutment with alumina reinforced epoxy resin (Aditya Birla chemicals ltd., Bangkok, Thailand) and used as experimental dies to make provisional crowns on. After careful inspection under 2.5 x magnifications loupes (HR, HEINE Optotechnik, Herrsching, Germany) to exclude dies with defect, discontinuation of margin or voids, twenty four dies were randomly distributed into three experimental groups for different provisional crowns materials and fabrication methods (8 dies for each groups) as shown in table 1.

Table 1 Provisional crowns material and fabrication method for each experimental group

Group	Material	Composition	Technique of fabrication	Manufacturer
1	Unifast Trad	Methyl-ethyl metacrylate polymer, PMMA, MMA monomer,	Conventional Direct	GC chemicals, Tokyo, Japan
2	Protemp 4	Bis-Diacetate, Silane treated silica, Benzyl-Phenyl- Barbituric acid	Conventional Direct	3M espe, Seefeld, Germany
3	Bicryl Solid	Highly polymerized PMMA	CAD/CAM milling	Sagemax bioceramics, WA, USA

Sample size calculation

Standard deviation was obtained from calculation using mean and standard deviation data from the least difference group of Karaokutan et al., 2015 which has similar design but without cyclic loading of specimens using equation as followed.

$$N\ per\ group = \frac{(\sigma 1^2 + \sigma 2^2)(Z\alpha + Z\beta)^2}{(\mu 1 - \mu 2)^2}$$

Amount of specimens that needed to achieve desired power and significant level (0.9 power and α = 0.05) was 5.43 samples per group. To compensate for possible accident and loss of specimens, sample size was set at eight per group.

Conventionally fabricated provisional restorations – PMMA resin

Special tray from PMMA resin (Formatray, Kerr dental, CA, USA) along with previously fabricated PVS matrix made from un-prepared ivorine tooth was used as an outer surface template. A thin layer of petroleum jelly was applied on surface of epoxy resin die before chemical-cured PMMA provisional crowns resin (Unifast Trad, GC chemicals, Tokyo, Japan) was mixed according to manufacturer's recommendation and place inside the tray-supported matrix. After polymerization took place into sandy stage, special tray was positioned on epoxy resin die and kept still by applying constant pressure. After 2.5 minutes to allowed complete polymerization, provisional crown was removed from die, checked for defects or voids using 2.5 x microscopes. If quality evaluation was satisfied, provisional crows was finished by removing excess and polishing.

Conventionally fabricated provisional restorations – Bis-acryl resin

PVS putty matrix along with special tray was used as an external form in the same manners as conventionally fabricated PMMA group. Thin layer of petroleum jelly was applied on each individual die before auto-mixed resin (Protemp 4, 3M espe, Seefeld, Germany) was dispersed using manufacturer's tool in PVS matrix and repositioned on epoxy resin die and allowed to initially polymerized for 2.5 minutes and left in matrix to fully polymerize for 5 minutes. Same finishing and quality inspection protocol with previous group was applied.

CAD/CAM fabricated provisional restorations – Solid PMMA block

To make an exact replication of pre-preparation outer form, conventional technique was applied to fabricated provisional crowns on all eight dies of CAD/CAM group. Pre-preparation scan was obtained from scanning of conventionally fabricated provisional crowns before crowns were removed and abutment was scanned as working model using lab scan (E2, 3Shape, Copenhagen, Denmark). To make exact replication of contour and external surface, provisional restorations was designed according to pre-preparation scan using CAD software (dental design, 3Shape, Copenhagen, Denmark) before data was sent to 5-axis milling unit (CoreiTEC 250, imes-icore GmbH, Eiterfeld, Germany). Solid PMMA block (Brylic S, Sagemax bioceramics, WA, USA) was used as to milled provisional restorations of this group.

Cementation of provisional restorations

Cementation of provisional restorations was done with temporary cement (Tempbond NE, Kerr dental, CA, USA) which disperse equally from base and catalyst using digital scale. Cement was mixed within 30 seconds and loaded in to provisional crowns before seating on dies using 5 kg constant pressure from metal pendulum during 6 minutes interval to allow complete set of temporary cement. Excess cement was removed with dental explorer.

Thermocycling and Occlusal fatigue loading

Five thousands cycles of 5-55°C with dwell times of 6 seconds and transfer times of 15 seconds was selected to represent 6 months of oral environment (Gale & Darvell, 1999). This process was done with thermocycling machine (TC-301, KMIT, Bangkok, Thailand). Repeated occlusal load was done similar to testing of ceramic restoration protocol proposed by Heintze et al., 2008 (Heintze, Cavalleri, Zellweger, Büchler, & Zappini, 2008). Occlusal load of 100N at 4Hz frequency was applied via stainless steel ball 5 mm diameter mounted on dynamic testing instrument (Electroplus TM E1000, Instron, Maine, USA) at the central pit along the long axis of each tooth. Six months duration was simulated by 100,000 cycle of occlusion. Loading was done in a 37ºC electric water bath representing oral condition.

Fracture resistance measurement

Fracture test was conducted on universal testing machine (Lloyd LR10K, Ametek, FL, USA) using cross head speed of 1 mm/min with 30kN load cells. Load was applied through metal ball diameter 5 mm at central pit parallel to long axis of the tooth. Force at fracture point and type of failure was recorded.

Data analysis

SPSS v.20 (IBM, NY, USA) was used to analyze all measurements. Maximum force at fracture of each group was tested for normality and homogeneity of varience. Mean and standard deviation of fractural resistance in each group was calculated and compared using one-way ANOVA with Turkey post hoc test. All statistical tests conducted at 0.05 significance level and 0.20 power.

Result

Mean maximum force at fracture of provisional restorations in each group along with standard deviation and highest/lowest value was shown in table2. Mean of each groups were compared using ANOVA with Turkey post hoc test and group with significant difference were shown in lower case superscript above mean.

Mean force at fracture of conventionally fabricated PMMA group was significantly lower than other two groups at 655.88 ± 75.58 N (p = 0.000). Conventionally fabricated Bis-acryl has highest mean at 1112.42 ± 183.98 N and CAD/CAM fabricated PMMA was slightly lower at 960.83 ± 64.40 N but not significantly different (p = 0.051). Figure 1 presents mean and standard deviation with significant level in bar chart.

Table 2 Mean maximum force at fracture, standard deviation, highest-lowest value and 95% confidence interval.

Group	Force at fracture					
	Mean (N)	SD	Min (N)	Max (N)	95% CI Lower bound	95% CI Upper bound
Conventional PMMA	655.88^{a}	75.58	540.20	742.36	592.69	719.07
Conventional Bis-acryl	1112.42^{b}	183.98	783.778	1338.51	958.54	1266.16
CAD/CAM PMMA	960.83^{b}	64.40	873.17	1084.46	906.99	1014.67

Same lowercase superscript indicated no significance difference after testing with ANOVA with Turkey post hoc.

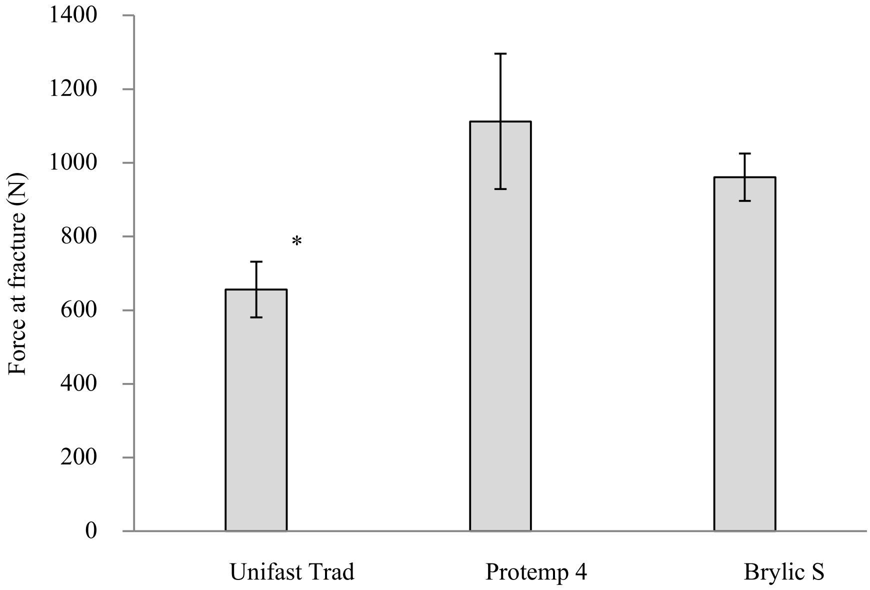

Figure 1 Mean and Standard deviation of maximum force at fracture

* indicates significance difference among experimental groups at $p < 0.05$

Discussion

Intention of this study is to evaluate fracture resistance of provisional restorations of different materials after cementation to experimental dies and underwent cyclic thermal and mechanical stress which was design to simulated 6 months of intra-oral function. Conclusion can be drawn from results of this study that fracture resistance of provisional crowns that conventionally fabricated from provisional PMMA resin was lowest among all experimental groups while those fabricated from Bis-acryl resin with same technique has mean fracture resistance similar to that of CAD/CAM fabricated counterpart.

Simulated aging which incorporates both cyclic thermal changes and repeated occlusal load has shown to effect fracture resistance of many provisional resins in varying degree. A study by Yao et al. (2014) shown significant changes in flexural strength after bar specimens were put through 5,000 round of thermal cycling. This effect found on both bis-acryl and CAD/CAM PMMA. Mean flexural strength of conventionally fabricated bis-acryl group (Protemp 4) was reduced from 103.13±4.48 MPa to 92.97±7.13 MPa while mean flexural strength another bis-acryl group (Structur 2) was also reduced from 107.85±3.60 MPa to 84.85±10.05 MPa. Tendency of strength reduction was also found in highly polymerized CAD/CAM PMMA block (TelioCAD) which mean flexural strength fell from 124.10±6.45 MPa to 95.39±10.48 MPa. This is also apparent in more clinically relevance configuration such as three-unit bridges. Stawarczyk et al. (2012) found significant reduction of mean maximum force at fracture of CAD/CAM fabricated temporary bridges (TelioCAD) after 120,000 rounds of chewing simulation was significantly reduced from 420±58 N to 365±47 N but CAD/CAM block from other manufacturers (artBlock Temp and ZENO) did not exhibit significant reduction even after 1.2 million cycles. Alt et al. (2011) also investigated effect of thermal aging on three-unit bridges configuration and found that conventionally fabricated bis-acryl (Luxatemp AM) had considerable reduction of fracture force from 561.9±73.1 N to 268.4±101.2 N after 5,000 cycles of thermal changes while conventionally fabricated PMMA (Trim) and CAD/CAM PMMA (Cercon Base) was also effected but not significantly (188.1±50.4 N to 138.5±54.4 N for Trim and 416.9±89.8 N to 325.2±86.4 N for Cercon Base).

Although differed in study design which this study include cementation and loading of single unit provisional crowns as compared to single crown with only thermal aging by Karaokutan et al. (2015) and three-unit bridges with thermal aging by Alt et al. (2011) results were comparable. Manual mixing PMMA resins have clear tendency of lower fracture resistance, especially after aging regimen. This was in accordance with result of fatigue test of various provisional resin published by Lang et al. (2003) which all of conventional PMMA groups did not survive 460,000 cycle of 50N at 1.6 Hz while only few Bis-acryl resins failed. Even with only cyclic thermal changes, hand-mixed PMMA perform significantly poorer than Bis-acryl counterparts in flexural strength testing of bar specimens (Nejatidanesh, Momeni, & Savabi, 2009). This might attributed to molecular structure of PMMA which, having only one acrylate group per monomer, is a linear polymer while Bis-acryl which has two acrylate groups allowed it to form cross-linking easily (Anusavice, Shen, & Rawls, 2013). Moreover, manufacturers of Bis-acryl resin usually add fillers – in this case, 3M espe added silane treated silica to Protemp 4 – which helps improved mechanical properties of their resins. Dispersing and mixing power and liquid manually which was required to fabricate PMMA auto-polymerize resin further risk trapping air bubble or inconsistent mixed causing area prone to crack propagation while auto-mixing syringe of Bis-acryl hugely eliminate such risk. Whereas main component of many CAD/CAM block including the one tested in this study does not differed significantly from auto-polymerizing PMMA, the result was – in accordance with others studies – clearly superior. This possibly is a result of difference polymerization environment. While auto-polymerizing PMMA needed to be handled by clinician in chair-sided setting which can leads to defects as mentioned above, CAD/CAM block was polymerized in highly controlled industrial environment which composition, pressure, and purity can be fully controlled (Güth et al., 2012).

There might be some ambiguities when comparing conventionally fabricated Bis-acryl and CAD/CAM PMMA which might depend on different manufacturers and thus difference in detailed composition of each resins. Some of the CAD/CAM PMMA demonstrated higher fracture toughness or flexural strength in many studies (Abdullah et al., 2016; Karaokutan et al., 2015; Pascutti et al.; Peñate et al., 2015). Interestingly, some researcher found no difference between some conventionally fabricated Bis-acryl and CAD/CAM PMMA (Peñate et al., 2015; Yao et al., 2014). These variations might depend on manufacturer of each manufacturer of both types of resin as demonstrated by many reports (Haselton et al., 2002; Karaokutan et al., 2015; Yilmaz et al., 2018).

Conclusion

Within limit of this study, it can be concluded that after withstanding simulated oral condition, provisional crowns fabricated from auto-polymerizing PMMA resin have lower fracture resistance than auto-polymerizing Bis-acryl and CAD/CAM fabricated PMMA. Therefore, Bis-acryl and CAD/CAM PMMA can be properly used as a long-term provisional restorations.

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