Premolar Axial Wall Height Effect on CAD/CAM Crown Retention Based

On Preparations With Advanced Total Occlusal Convergence

Matthew S. Miller

Uniformed Services University of the Health Sciences
Manuscript/Presentation Approval or Clearance

Initiator

1. USU Principal Author (Last, First, Middle Initial) Miller, Matthew, S

2. Academic Title AEGD-2 Resident

3. School/Department/Center Kessler Dental Clinic

4. Phone 228-376-5118 | 5. Email matthew.miller.108@us.af.mil

6. Clearance ☑ Paper ☑ Article ☐ Book ☑ Presentation ☐ Other

7. Title Premolar Axial Wall Height Effect on CAD/CAM Crown Retention

8. Intended Publication/Meeting International Association for Dental Research

9. Required by 22 Mar 2017 | 10. Date of Submission 4 Jan 2017

**Note: It is DoD policy that clearance of information or material shall be granted if classified areas are not jeopardized, and the author accurately portrays official policy, even if the author takes issue with that policy. Material officially representing the view or position of the University, DoD, or the Government is subject to editing or modification by the appropriate approving authority.

☑ Neither I nor any member of my family have a financial arrangement or affiliation with any corporate organization offering financial support or grant monies for this research, nor do I have a financial interest in any commercial product(s) or service(s) I will discuss in the presentation or publication.

☑ **The following statement is included in the presentation or publication:** The opinions or assertions contained herein are the private ones of the author(s) and are not to be construed as official or reflecting the view of the DoD or the USUHS.

☑ **The following items have been included in the presentation and/or publication:** Student and/or faculty USU affiliation. Examples: 1) LCDR Jane Doe, DMD, Resident, Naval Postgraduate Dental School and Uniformed Services University of the Health Sciences Postgraduate Dental College. 2) COL John Doe, DDS, Endodontics Program Director, Fort Bragg, NC and Associate Professor of Endodontics, Uniformed Services University of the Health Sciences Postgraduate Dental College. 3) USUHS logo included on title slide and/or poster

Chair/Department Head Approval**

Name (Last, First, Middle Initial) Wajdowicz, Michael, N

Signature [redacted]

Commander Approval** (if applicable)

Name (Last, First, Middle Initial)

School

Higher approval clearance required (for University- DoD, or US Gov't-level policy, communications systems or weapons review

Signature

Uniformed Services University of the Health Sciences
Manuscript/Presentation Approval or Clearance

Service Dean Approval**	
Name (Last, First, Middle Initial) Fallis, Drew, W	
School Air Force Postgraduate Dental School	
Higher approval clearance required (for University-, DoD, or US Gov't-level policy, communications systems or weapons review)	
Signature	
Executive Dean Approval**	
Name (Last, First, Middle Initial)	
Higher approval clearance required (for University-, DoD, or US Gov't-level policy, communications systems or weapons review)	
Signature	
Vice President for External Affairs Action	
Name (Last, First, Middle Initial)	
☐ USU Approved	☐ DoD Approval Clearance Required
☐ Submitted to DoD (Health Affairs) on	
☐ Submitted to DoD (Public Affairs) on	
☐ DoD Approved/Cleared (as written)	☐ DoD Approved/Cleared (with changes)
DoD Clearance Date	DoD Disapproval Date
Signature	

The author hereby certifies that the use of any copyrighted material in the thesis/dissertation manuscript entitled:

"Premolar Axial wall Height effect on CAD/CAM Crown Retention Based on Preparations with Advanced Total Occlusal Convergence"

is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyrighted owner.

[redacted]

Matthew S. Miller
AEGD 24 Month Residency Program
Air Force Postgraduate Dental School
Uniformed Services University
7 July 2017

Distribution Statement

Distribution A: Public Release.

Premolar Axial Wall Height Effect on CAD/CAM Crown Retention

Major Matthew S. Miller

APPROVED:

[redacted]

Colonel Michael N. Wajdowicz

[redacted]

Major James J. Renda

[redacted]

Lt. Colonel John A. Brewster (Chairman)

6 JUL 2017

Date

APPROVED:

Col Drew W. Fallis

Dean, Air Force Postgraduate Dental School

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Premolar Axial Wall Height Effect on CAD/CAM Crown Retention Based On Preparations With Advanced Total Occlusal Convergence

is appropriately acknowledged and beyond brief excerpts, is with the permission of the copyright owner.

____

Signature

____

Printed Name

____

Program and Program Location

Uniformed Services

University

Acknowledgements

Special thanks to Col Howard Roberts, Lt Col Nicholas DuVall, Maj Ashley Harris, and Col Michael Wajdowicz.

ABSTRACT

Objectives: To evaluate bicuspid axial wall height effect on retention of adhesively-luted, all-ceramic CAD/CAM crowns with a 20-degree total occlusal convergence (TOC).

Methods: Recently-extracted premolars were randomly divided into 4 groups (n=12) with all-ceramic crown preparations accomplished using a high speed handpiece inserted into a milling device. Preparations contained a 20-degree TOC with each group consisting of axial wall heights of 0, 1, 2, and 3 millimeters, respectively. Completed preparation surface area was determined and preparation features confirmed using a digital measuring microscope. Scanned preparations (CEREC) were fitted with milled and crystallized lithium disilicate full coverage restorations and luted with a self-etching adhesive resin cement after hydrofluoric acid etching and silanation. All manufacturer recommendations were followed. Specimens were stored at 37C/98% humidity for 24hours and tested to failure at a 45-degree angle on a universal testing machine. Failure load was converted in MPa using the available bonding surface area with mean data analyzed using Kruskal-Wallis/Dunn's (p=0.05)

Results: The 3mm preparation height samples displayed significantly stronger failure load than the 0mm and 1mm samples and was statistically similar to the 2mm samples. The 0mm and 1mm samples all failed adhesively while the 2mm and 3mm samples failed largely due to tooth fracture.

Conclusions: Further evidence is provided that CAD/CAM adhesive techniques may compensate for less than ideal preparation features. Bicuspid preparations with a 20 degree TOC restored with adhesively-luted, CAD/CAM e.max CAD crowns require at least 2mm of axial wall height for adequate retention.

Table of Contents

List of Tables

List of Figures

INTRODUCTION

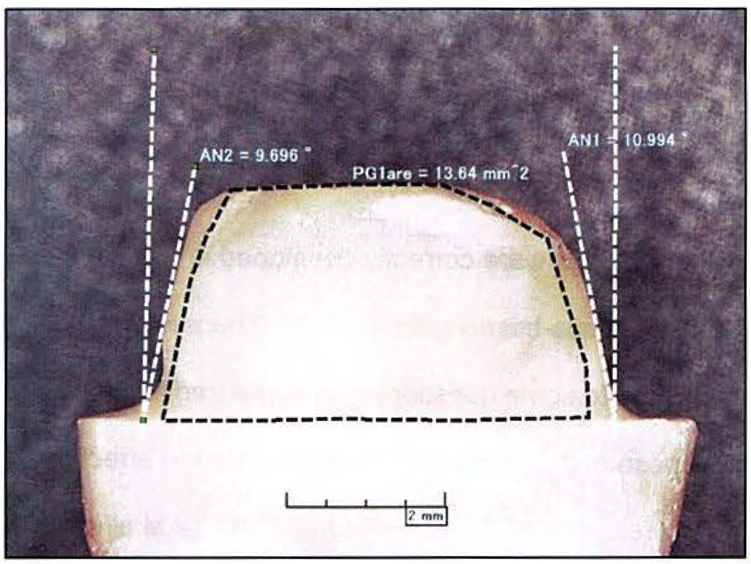
The popularization of full-coverage restorations as the choice treatment for teeth with significant coronal tooth structure loss occurred around the onset of the 20th century. [1] Various philosophies in full-coverage restoration techniques prompted research that led to the establishment of preparation design recommendations to maximize the resistance and retention of full-coverage restorations. Some of these recommendations stated that a two-to-five degree total occlusal convergence (TOC) was the ideal preparation taper, [1] which has been reinforced in the scientific literature. [1,2] However, this preparation taper is rarely achieved in the clinical setting, [5,6,7] and other preparation features may compensate. For instance, greater preparation axial wall height has been proposed to compensate with bicuspids in situations of increased TOC. [1]

The traditional preparation design recommendations were correctly developed in the era of cast metal restorations that were cemented with aqueous-based luting agents. The advent of CAD/CAM coupled with adhesive technology has led to some questioning of some traditional preparation recommendations. [4] The purpose of this study was to investigate the effect of bicuspid preparation axial wall height on the retention of adhesively-luted CAD/CAM all ceramic crowns based on a preparation containing an advanced 20 degree TOC. The null hypothesis is that there will be no difference in the failure force between preparations of zero, one, two, and three millimeters.

METHODS

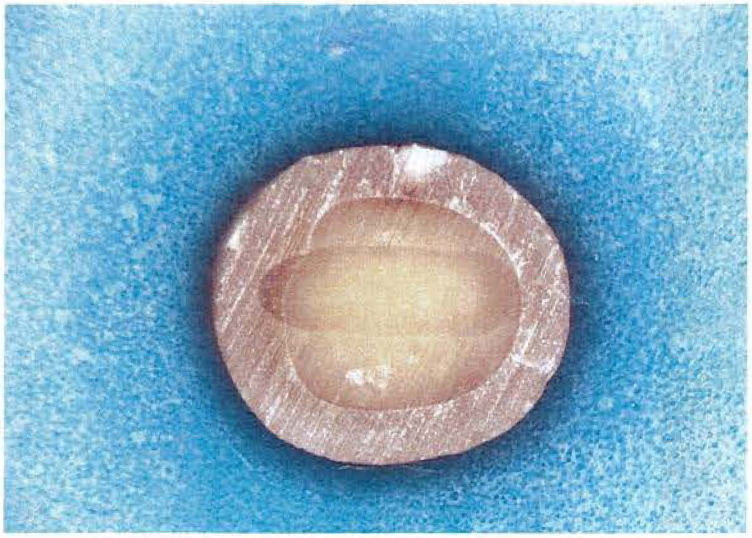
Forty eight recently-extracted premolars were collected in accordance with guidance from the local Institutional Review Board. The occlusal surfaces were reduced to 1mm below the marginal ridges with a slow-speed, water-cooled diamond saw (Buehler, Lake Bluff, IL, USA). The teeth were imbedded in autopolymerizing denture base methacrylate resin (Diamond D, Keystone Industries, Cherry Hill, NJ, USA) and randomly divided into 4 groups (n=12). All-ceramic crown preparations were accomplished per manufacturers recommendations for lithium disilicate crowns using a diamond bur (8845KR.31.025, Brassler USA, Savannah, GA, USA) in a high speed handpiece (EA-51LT, Adec Newburg, OR, USA) inserted into a lathe-type milling arrangement. All preparations contained a 20-degree TOC (Figure 1) with each group consisting of axial wall heights of 0, 1, 2, and 3 millimeters.

Figure 1. Measurement of TOC of preparation



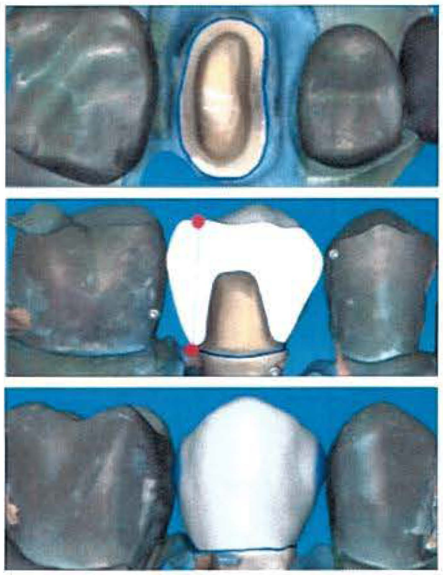
Preparations were refined by a board certified prosthodontist. The 0mm axial wall height group was additionally prepared with a buccal lingual grove feature approximately the width and half of the depth of a #8 round bur in order to allow for orientation of the restoration (Figure 2).

Figure 2. Orientation of groove on 0mm axial wall height preparations



The grove was placed parallel to the direction of planned forces to add only negligible resistance features. Completed preparation surface area was determined and preparation features confirmed using a digital measuring microscope (KH-7700, Hirox USA, Hackensack, NJ, USA). Preparations were then placed in an acrylic template (Figure3), images obtained using a CAD/CAM camera (CEREC AC, Sirona Dental Systems, Charlotte, NC, USA, Software version 4.4.4). Crowns were designed using a biogeneric copy to ensure uniform contours, anatomy, and stable occlusal table.

Figure 3. Standardization with acrylic template



Full coverage, lithium disilicate all-ceramic restorations (IPS e.max CAD, Ivoclar Vivadent, Amherst NY, USA) were milled (Cerec MC XL, Sirona Dental Systems) and then fitted to confirm proper adaptation to the preparation. The crowns were then glazed (IPS e.max CAD Crystall Glaze Spray, Ivoclar-Vivadent) and crystalized using a laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent).

Preparations were cleansed with pumice slurry with the crowns luted with a self-adhesive resin cement (RelyX Unicem, 3M ESPE, St Paul, MN, USA) after hydrofluoric acid etching (IPS Ceramic Etching Gel, Ivoclar-Vivadent) and treatment with silane (Clearfil Ceramic Primer, Kuraray America, New York, NY, USA). All manufacturer recommendations were followed. Restored specimens were stored at 37C/98% humidity for 24 hours and were mounted at a 45 degree angle to the long axis of the tooth root on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA). Load was applied to the lingual inclines of the palatal cusp using a stainless steel piston at a rate of 0.5 mm/min until failure. Collected failure load was also converted to stress using the available bonding surface area. Failure mode was evaluated visually at 20x magnification with digital microscope (Hirox) as well as microtomography (MicroCT) (Skyscan 1172, Bruker MicroCT, Kontich, Belgium) at a resolution of 13.6 microns using 100kV energy with a 0.4-degree step size. Individual images were combined into a three dimensional image (Figure 4) using recombination software (nRecon, Bruker MicroCT) and analyzed with a volume-rendering 3D software (CTVox, Bruker MicroCT).

Figure 4. MicroCT scan demonstrating tooth fracture

Data was first subjected to the Shapiro-Wilk and Bartlett's Test which identified an abnormal distribution and variance inhomogeneity, respectively. The Kruskal-Wallis test and Dunn's post hoc test was then used at a 95 percent confidence level (p=0.05) using a computer based statistics program (SPSS, IBM Systems, Chicago, IL).

RESULTS

The results are identified in Table 1 which displays mean failure load, stress, and failure modes for each group. The 3mm preparation axial wall height samples displayed significantly stronger failure load at failure compared to the 0mm and 1mm samples and was statistically similar to the 2mm samples.

Table 1: Mean Failure Load (N) and Stress (MPa) and Failure Modes

Mean Preparation Axial Wall Height (mm)	Failure Load (N)	Failure Stress (MPa)	Failure Modes
0	105 (62) A	2.8 (1.7) A	12 AF
1	200 (157) AB	4.4 (2.7) A	12 AF
2	315 (180) BC	6.7 (3.5) AB	2 AF/10 TF
3	434 (178) C	8.4 (3.4) B	1 AF/11 TF

Groups identified with same capital letter are similar in each column (Dunn's, p=0.05) AF=adhesive failure; CF=cohesive ceramic failure; TF=tooth fracture.

The lowest two axial wall height groups failed entirely adhesively, whereas the highest two axial wall height groups predominantly failed largely by tooth fracture.

DISCUSSION

Currently it is largely understood that the earlier recommended ideal TOC of two to five degrees is practically not clinically achievable with an actual measured clinically attained TOC being in the range of 19 – 27 degrees. [7] Goodacre et al [1] proposed a realistically achievable guideline of 10 to 20 degrees for TOC, which allow for other compensatory preparation factors. Notwithstanding, a three-millimeter minimum axial wall height is recommended for bicuspids. [1] Bowley et al [4] reported the findings of a finite element analysis for bicuspid preparations with increasing degrees of total occlusal convergence. The model was based on a direct frictionless contact between the intaglio crown surface and the tooth preparation, with the result of having the preparation geometry as the sole determinant of the displacement. The results showed an increase in marginal gap formation above 12 degrees TOC, which lead to the conclusion that buccolingual convergences angles greater than 12 degrees reduced the resistance form of the preparation. Additionally there was an even more drastic increase in marginal gap formation between the 24 degrees of convergence and 28 degrees of convergence. [4]

However, recent studies by Tiu et al [5,6] have reported for bicuspid preparation parameters for all-ceramic crowns submitted to a commercial dental laboratory. Although the preparations contained a mean three millimeter axial wall height, the mean TOC was 33 degrees.

Clinically the practitioner often may not have full control over preparation parameters, which may lead to additional treatment such as periodontal surgery and/or intentional endodontic treatment with a post and core to achieve suitable axial wall height. Some proponents of CAD/CAM adhesive dentistry anecdotally claim that adhesive technology may compensate for less than ideal preparation features. In order to evaluate some aspects of these claims this research center started a series of research studies evaluating if adhesive CAD/CAM technology could compensate for loss of axial wall height with increasing TOC.

This study was the culmination of three research efforts whose goal was to evaluate the determinate factor of adhesive CAD/CAM axial wall height within the recommended TOC recommend by Goodacre et al. [1] In all three evaluations all specimens were prepared, measured, and tested by the same individual while another researcher oversaw all scanning and milling procedures. This was accomplished in order to be able to hopefully compare the results of all three studies in a reasonable effort. The only difference in these three studies was the work of the first authors, who performed all scanning, milling, crystallization, and luting procedures. To wit, the first study evaluated the same axial wall height parameters under the same conditions at a ten-degree TOC, [8] which was followed by an identical effort at a chosen TOC of 16 degrees. [9] Accordingly, the present study evaluated under the same conditions evaluated at the recommended 20-degree TOC upper limit. The combination of the mean results of all three studies can be seen in Tables Two through Four.

In spite of the planned preparation consistency of these studies, the authors are hesitant to directly statistically compare the failure load/stress results due to the inherent variability between the first authors of these experiments.

First, any normalizing effect of failure stress calculation over the three studies remain inconclusive. While one may be tempted to note that failure stress did appear to normalize the failure load results, the sample size of these studies resulted in calculated power too low to reject the null hypothesis.

It can be observed in Table 2 a generalized decline in failure load is appreciated as the TOC increases. The only puzzling exception was an increase in failure load noted by the 16-degree TOC zero millimeter axial wall height. When the results are considered graphically

The results displayed a significantly greater failure load for the 2mm nd 3mm axial wall height groups then the 0mm and 1mm axial wall height groups. The results demonstrated that at 16 degrees of TOC adhesion may compensate for a reduced axial wall height, but only for an axial wall height of 2mm or greater. [9]

The current study extended the research of Gillette and Martin by examining preparations with a TOC at the maximum value of Goodacre's recommended range at a TOC of 20 degrees.

Table 2: Mean Failure Load (N)

Mean Preparation Axial Wall Height (mm)	10°	16°	20°
0	148.3 (70.1) A	262.8 (86.5) A	105 (62) A
1	374.8 (150.9) B	318.5 (164) A	200 (157) AB
2	499.7 (128.8) BC	512.1 (128.8) B	315 (180) BC
3	622.4 (142.1) C	612.7 (126.4) B	434 (178) C

Groups identified with same capital letter are similar in each column

Table 3: Mean Failure Stress (MPa)

Mean Preparation Axial Wall Height (mm)	10°	16°	20°
0	2.89 (1.1) A	6.03 (1.1) A	2.8 (1.7) A
1	6.35 (2.5) B	6.35 (2.5) A	4.4 (2.7) A
2	7.16 (1.6) B	7.16 (1.6) AB	6.7 (3.5) AB
3	7.52 (1.7) B	7.52 (1.7) B	8.4 (3.4) B

Groups identified with same capital letter are similar in each column

Table 4: Failure Mode

Mean Preparation Axial Wall Height (mm)	10°	16°	20°
0	12 AF	9 AF/3 TF	12 AF
1	12 AF	7 AF/4 TF/1 CF	12 AF
2	2 AF/9 TF/1CF	3 AF/7 TF/2 CF	2 AF/10 TF
3	2 AF/6 TF/4CF	1 AF/9 TF/2CF	1 AF/11 TF

AF=adhesive failure; CF=cohesive ceramic failure; TF=tooth fracture

Tables 2-4 compare the data from the three studies. Overall there was a general decreasing of values for failure load and stress as TOC increased. It is difficult to set a value for failure load or failure stress that indicates a likelihood a crown would be retained in a clinical situation with similar preparation parameters. For bicuspids at a range of 10 to 20 degrees of TOC a generally accepted minimum axial wall height is 3mm. Therefore the data for the 3mm axial wall height groups within each study establish values that can be used as benchmarks for minimally acceptable failure load or stress.

For failure load at 10 degrees of TOC there was a significant difference between the 0mm axial wall height group and all three of the other groups with the 2 and 3mm groups being statistically similar. For failure stress at 10 degrees of TOC the 1-3mm groups clearly surpassed the 0mm axial wall height group. These results indicate that at 10 degrees of TOC the clinical retention of a crown may be similar for preps that are 1mm and greater. At 16 and 20 degrees of TOC the 0mm as well as the 1mm axial wall height groups failed at significantly lower failure loads and failure stress than the 3mm axial wall height groups indicating insufficient retention. For the 2mm axial wall height group with the TOC of 16 degrees the failure load was significantly higher than the 0mm and 1mm axial wall height groups and similar to the 3mm axial wall height group. For the 2mm axial wall height group with the TOC of 20 degrees the failure load was statistically similar to both the 1mm and 2mm axial wall height groups and significantly higher than the 0mm axial wall height group. At 16 and 20 degrees of TOC Failure stress demonstrated a significant difference only between the lower two axial wall groups and the 3mm axial wall height group. These results are inconclusive as to if the 2mm axial wall height group has adequate retention.

The failure mode analysis may provide more insight into the results of this study for the 2mm axial wall height group. For the 10 and 20 degrees of TOC the 0 and 1mm axial wall height groups failed entirely adhesively. For the 16 degrees of TOC these groups were not entirely but

Table 5: Preparation Parameters

Axial Wall Height (mm)	Mean Dentin Surface Area (mm^2)	Mean Total Wall Height (mm)	Mean Total Occlusal Convergence (degrees)
3mm	52.06 (7.03)	3.06 (0.02)	20.9 (0.8)
2mm	47.1 (8.5)	2.03 (0.03)	19.9 (0.7)
1mm	45.6 (10.4)	1.05 (0.04)	20.2 (0.7)
0mm	37.2 (4.3)		

largely adhesive in nature. At 10 degrees of TOC the 1mm axial wall height group failed adhesively at a stress value similar to the 2 and 3mm axial wall height groups. This was not the case for the 16 and 20 degrees of TOC. For all three studies the 2 and 3mm axial wall height groups largely showed fracture of either the crown or tooth with minimal adhesive failures. Umesh et al in 2016 reported bite force for premolars to range from 234N to 464N. Although, the max bite force reported is higher even then the mean failure load of the 3mm axial wall height specimens for the current study, the failure mode indicates that even at 20 degrees of TOC and 2mm axial wall height the preparations had adequate retention as failure forces were transferred to the underlying tooth structure.

Table 5 shows the preparation parameters for each of the axial wall height groups. The small amount of variance in each group for the mean total wall height and mean occlusal convergence indicates the specimens were well standardized. Traditionally studies evaluate failure load. In this study the mean dentin surface area was also measured, which allowed for the calculation of failure stress. With surface area being crucial for adhesive dentistry and the variance in natural dentition this was completed to see if it normalized the data by accounting for the variable of tooth size. The data from this study was inconclusive as to if it did normalize the data and a larger sample size would be needed.

Limitations to this study include that it was an in vitro study and may not represent actual clinical conditions. There was no thermocycling completed, which could degrade the bond over time and a single ceramic primer and cement were tested and may not represent all adhesive possibilities.

CONCLUSION

All failure loads were within the range reported for human function. Under the conditions of this study and based on both failure load/stress and failure modes, bicuspid preparations with a 20 degree TOC restored with adhesively-luted, CAD/CAM e.max CAD crowns require at least 2mm of axial wall height for adequate retention.

BIBLIOGRAPHY

1. Goodacre CJ, Camagni WV, Aquilino SA. Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent 2001; 85:363-76.
2. Gilboe, Dennis B. Fundamentals of extracoronal tooth preparation. Part I. Retention and resistance form. Journal of Prosthetic Dentistry. 94(2):105-7, 2005 Aug.
3. Goodacre, CJ. Designing tooth preparations for optimal success. Dent Clinics NAmerica 2004;48: 359-385.
4. Bowley JF, Ichim IP, Kieser JA, Swain MV. FEA evaluation of the resistance form of a premolar crown. J Prosthodont 2013; 22(4):304-12.
5. Tiu J, Al-Amleh B, Waddell JN, Duncan WJ. Reporting numeric values of complete crowns. Part 1: Clinical preparation parameters. J Prosthet Dent 2015;114:67-74).
6. Tiu J, Al-Amleh B, Waddell JN, Duncan WJ. Reporting numeric values of complete crowns. Part 2:Retention and resistance theories. J Prosthet Dent 2015;114:75-80.
7. Ohm E, Silness J. The convergence angle in teeth prepared for artificial crowns. *J Oral Rehabil* 1978;5:371-5.
8. Gillette C, Buck R, DuVall N, Cushen S, Wajdowicz M, Roberts H. Premolar Axial Wall Height Effect on CAD/CAM Crown Retention. *Operative Dentistry*. 2016;41(6):666-671.
9. Martin C, DuVall N, Harris S, Wajdowicz M, Roberts H. Premolar Axial Wall Height Effect on CAD/CAM Crown Retention. Int J Prosthodont 2017 (in press).
10. Umesh S, Padma S, Asokan S, Srinivas T. Fiber Bragg Grain based bite force measurements. *J Biomech.* 49(13);2877-2881:2016.