

# Adequately Prepared? A Study Using an Innovative Computer Application to Measure Clinical Crown Convergence Angles Achieved by Students at a UK Dental School

## Keywords

Convergence Angle  
Dental Student  
Crown

## Authors

**Kenneth James Strain\***  
(BDS, DIP H&T, MFDS RCS (Ed.))

**Janine Tiu<sup>§</sup>**  
(PhD, BDent Tech, PGDipDentTech)

**James Mackie\***  
(Pg Dip Dent Tech)

**Stephen J Bonsor\***  
(BDS, (hons), MSc FHEA, FDS RCPS (Glasg))

**Richard J Ibbetson\***  
(BDS MSc, FDS RCS (Eng.) FDS RCS (Ed.) FFGDP)

## Address for Correspondence

**Kenneth James Strain\***  
Email: [k.strain.12@aberdeen.ac.uk](mailto:k.strain.12@aberdeen.ac.uk)

\* University of Aberdeen, Westburn Drive, AB25 3BZ Aberdeen, United Kingdom

<sup>§</sup> University of Otago

Received: 12.05.2018  
Accepted: 20.11.2018

doi: 10.1922/EJPRD\_01832Strain07

## ABSTRACT

This study examined the total occlusal convergence angles created for full coverage crown preparations by students at a UK dental school. Working casts of 82 clinical crown preparations were scanned using a 3D scanner. Stereolithographic files were uploaded to Preppr, a crown preparation analysis application. Mean bucco-lingual convergence angle were 19.6° (+/-11.7) and mesial-distally 17.8° (+/-11.1). Smallest bucco-lingual convergence angles were achieved for canine teeth with the largest on molar teeth. The smallest mesio-distal values were on canine teeth with the largest on molar teeth. Ideal total convergence angles (4-14°) were achieved in 23% of bucco-lingual preparations and 33% of mesio-distal preparation. Results for clinically acceptable angles (10-20°) were 30% and 40% respectively. There were no statistically significant differences between tooth types for mean bucco-lingual values. ( $p=0.623$ ), mesio-distal mean values were statistically different by tooth type ( $p=0.003$ ). Mean values for mandibular molars were significantly higher than for maxillary incisors ( $p=0.001$ ) and mandibular molars had significantly higher values than maxillary canines ( $p=0.045$ ). Results in this study were comparable to those of other students and qualified clinicians, with a minority of preparation achieving ideal values.

## INTRODUCTION

The effects of different total occlusal convergence angles (TOC) or tapers on the clinical success of full coverage crowns have been extensively investigated both in vivo and *in vitro*. The angle formed by the opposing walls of a crown preparation when viewed in a given plane forms the total convergence angle.<sup>1</sup> The majority of research examining TOC has been laboratory based with a paucity of research examining the convergence angles achieved by clinicians intra-orally.<sup>2,3</sup> When assessing TOC, two key concepts must be considered, retention and resistance form. Retention is the ability of a crown to resist forces acting to dislodge it along its path of insertion, resistance is the ability of the crown to resist forces acting to dislodge it in a direction other than the path of insertion.<sup>1</sup> Jorgensen found an inverse relationship between TOC angles and retention,<sup>4</sup> TOC has also been shown to be a key determinant of the resistance form of an abutment.<sup>5</sup> The greater the TOC of a crown preparation, the lower the forces needed to dislodge the restoration.<sup>6</sup>

Shillingburg<sup>7</sup> recommends a taper of 2° to 7° for each axial wall, giving an ideal TOC angle of 4° to 14°, Tylman<sup>8</sup> stated that 4° to 10° was ideal. Goodacre *et al.*<sup>9</sup> state that TOC angles of 10-20° are clinically acceptable with other papers in the literature in agreement.<sup>5,10-14</sup> These recommendations must be balanced against the findings of Mack,<sup>10</sup> that a minimum TOC of 12° was needed to be visually certain of avoiding undercuts.

The undergraduate Bachelor of Dental Surgery (BDS) degree at the University of Aberdeen Dental School (ADS) is a 4-year graduate entry programme with students holding a first degree in a subject related to healthcare or biological sciences. Students holding an undergraduate degree before starting their dental studies is the norm in some countries but is unusual within the UK.

This study was a retrospective assessment of TOC angles achieved by undergraduate students preparing full coverage crowns on patients in a clinical environment. All the scanned models within this study had been assessed by a clinical supervisor and deemed suitable for crown fabrication prior to the restoration being placed.

This paper utilized a computer application called Prepr which was developed at the University of Otago, New Zealand for the measurement of crown preparations as part of a study on the use of technology in dental teaching. The software has been used in a number of studies,<sup>15-18</sup> to analyse crown preparations but has not been used in the UK before. Although designed as a tool for teaching, the application can be used in any clinical environment where scanners are available and which are able to produce an STL file.

Studying the TOC angles produced by students served a number of purposes. It provided feedback on teaching outcomes and quality assurance for the programme. The study also allowed for comparison with students at other dental schools and the results achieved by qualified clinicians. The clinical success of a crown is influenced by the quality of the preparation; therefore, it is important to know the adequacy of crown preparations made by students. Whilst there are a number of requirements for a clinically adequate crown preparation, the total convergence angle provides a good indicator of the manual skills of the clinician.

## MATERIALS AND METHODS

This study examined 82 full coverage crown preparations made in a clinical setting during the academic year 2014/2015. Preparations were carried out by a total of 59 3rd, 4th and 5th year students. This represented all the crown preparations carried out during this period and reduced the risk of selection bias.

Impressions were taken in Vinyl Polysiloxane (VPS) (Coletene Affinis). VPS impression materials have been shown to have greater dimensional stability than other elastomeric impression materials at 1, 6 and 24 hours after the impression has

been made.<sup>19</sup> At Aberdeen, students are required to cast their impression on the day it is made. A type 4 dental stone (Fuji Rock EP) was used to create the working cast. This stone has a low expansion rate, less than 0.08% on setting.<sup>20</sup> Working casts are then stored in a designated area away from any sources of moisture that may affect the dimensional stability of the working cast. The dental laboratory at ADS works on a two-week production cycle. Working casts of crowns included in the study were collected after completion of the treatment and scanned on a weekly basis.

To assess the TOC of the crown preparation, a code number was assigned to each working cast to blind the assessor to the student who made the preparation. Casts were then scanned in a desktop 3D scanner (Amann Girrbach Ceramil Map300). The scanner was a 4 axis, blue strip light scanner with an accuracy of less than 20 micrometres.<sup>21</sup> The software created a stereolithographic (STL) file which was exported to Prepr for assessment of the TOC.

Figure 1 shows the output from the application. 3D crown models can be rotated until perpendicular planes in the mesio-distal [MD] and bucco-lingual [BL] are in the desired position for measurement. Prepr then sectioned the 3D scan in the MD and BL planes to create cross sectional outlines. The researcher placed measurement circles on the finish lines, the cervical portion and occlusal aspects of the preparation. Prepr uses a Bezier polynomial equation to isolate fixed points within the measurement circles and then calculates the angles between the points to generate the measurement for the TOC.<sup>22</sup> Measurement data were then recorded in a spreadsheet. The co-ordinates used for measurement were recorded by the software to allow for reproducibility. Tiu *et al.*<sup>15,17</sup> describe, in more detail, the processes used when calculating preparation parameters and the underlying design of the application.

Samples were grouped by tooth type and by arch, maxillary or mandibular. Data were entered into a statistical analysis programme (SPSS V.24). Descriptive statistics were used to determine mean total convergence angles for the bucco-lingual [BL] and mesio-distal [MD] planes with the range, standard deviation and 95% confidence interval for each tooth type.

Inspection of boxplots revealed the data to be normally distributed as assessed by Shapiro-Wilk's test ( $p > 0.05$ ) with no outliers. There was equality of variance using Levene's test for equality of variance (BL  $p = .192$ , MD  $p = .220$ ). One-way ANOVA with Tukey's *post hoc* analysis was used to test for differences in mean TOC angles between tooth types.

## RESULTS

There were 82 clinical crown preparations within the study. The sample consisted of 29 premolars, 28 molars, 20 incisors and 5 canine tooth preparations. Table 1 shows the mean, standard deviation, range, and 95% confidence interval for all 82 preparations with data given by tooth type and arch.

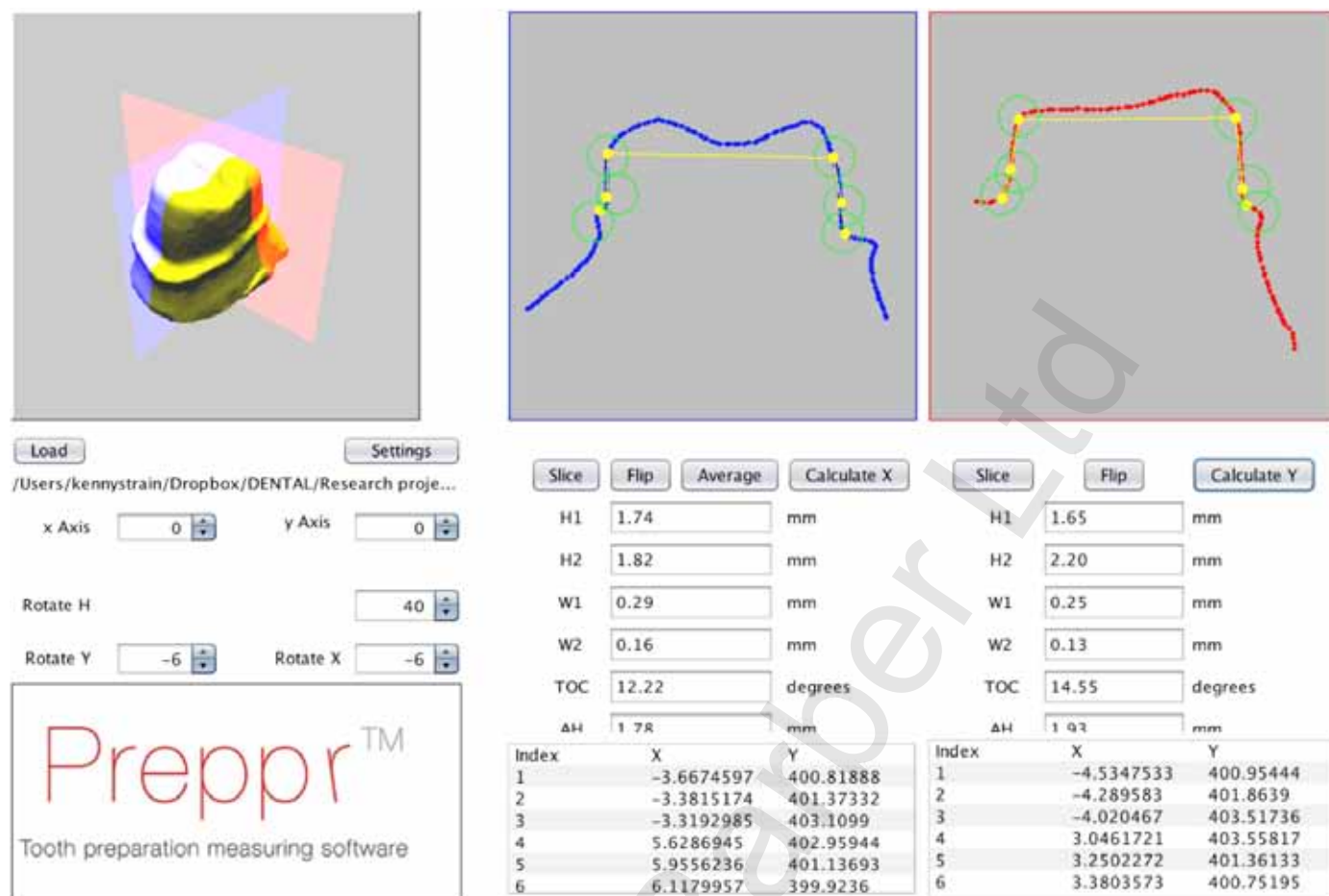


Figure 1: Preppr data output screen with TOC values given in the BL (12.2°) and MD planes (14.6°).

Incisor, canine and premolar preparations had mean values for both BL and MD planes that were within a clinically acceptable range of 10-20°. Only the MD convergence angles of incisors and canines were within the ideal range of 4-14° as described in the literature.<sup>7,8</sup> Within this sample, the percentage of preparations within this ideal range was 23% for BL and 33% for the MD plane. The percentage of preparations with a clinically acceptable TOC was 30% for BL and 40% for MD convergence angles.

The tooth type with the smallest mean MD total convergence angle was the canine (9.7° +/-11) and that with the largest was the molar preparation (23.5° +/-12.1). The smallest mean BL total convergence angles were found on canines (15.9° +/- 6.6) with the largest mean BL values found on molar teeth (21.3° +/-12.1). Bucco-lingual mean total convergence angles were higher for incisors and canines with mesio-distal TOC being higher for premolars and molars. Molar preparations had the highest mean values with both BL and MD being greater than 20°.

All preparations showed a large range due to the presence of some undercuts and over tapered preparations. Within the sample, 15% (n=12) of preparations were found to have undercuts but this had not prevented crowns from being fabricated and placed. Premolars (n=7) were the most undercut

tooth type. Table 2 gives details on these specimens. Values for undercuts ranged from -2.4° to -4.6° BL and -0.5° to -8.8° MD.

For premolars and molars, mandibular mean total convergence angles in both BL and MD planes were higher than maxillary values. For canines, the MD TOC was higher for mandibular preparations and the BL higher on the maxillary. There were no mandibular incisor preparations within the study. Mandibular premolar and molar preparations had the highest mean total convergence angles. The BL plane for mandibular premolars had the highest mean value within the study with 39.5° (+/-14.3), mandibular molars had the second highest with 25.6° (+/-11.9) in the MD plane. The lowest mean values were for the MD aspects of maxillary canines (6.2° +/-5.6) and maxillary incisors (11.6° +/-6.8).

Mesio-distal mean TOC angles were statistically different for the different tooth types, [F(6,75) = 3.759, p=0.003]. Mean MD TOC angles for mandibular molars were significantly higher than for maxillary incisors (p=0.001) and mandibular molars had a significantly higher MD TOC than maxillary canines (p = .045). There were no statistically significant differences between tooth types for mean bucco-lingual TOC angles. [F(6,75)=0.735, p=0.623].

**Table 1.** Mean TOC, range, standard deviation and 95% confidence interval by tooth type and arch.

	PLANE	MEAN	SD	RANGE	95% C/I [+/-]
<b>ALL TEETH [N = 82]</b>	BL	19.6	11.7	51.6	2.6
	MD	17.8	11.1	58.2	2.4
<b>Maxillary [N = 48]</b>	BL	19.5	9.7	46.2	2.8
	MD	14.8	9.5	52.8	2.8
<b>Mandibular [N = 34]</b>	BL	19.6	14.0	51.6	4.9
	MD	22.0	11.8	52.6	4.1
<b>INCISORS [N = 20]</b>	BL	20.1	9.2	36.6	4.3
	MD	11.6	6.8	28.3	3.2
<b>Maxillary [N = 20]</b>	BL	20.1	9.2	36.6	4.3
	MD	11.6	6.8	28.3	3.2
<b>Mandibular [N = 0]</b>	BL	-	-	-	-
	MD	-	-	-	-
<b>CANINES [N = 5]</b>	BL	15.9	6.6	15.2	8.3
	MD	9.7	11.0	31.2	13.7
<b>Maxillary [N = 3]</b>	BL	17.6	6.7	14.7	16.7
	MD	6.2	5.6	31.2	13.9
<b>Mandibular [N = 2]</b>	BL	13.2	5.6	11.2	50.3
	MD	14.9	3.7	7.4	33.2
<b>PREMOLARS [N = 29]</b>	BL	18.1	13.0	45.0	4.9
	MD	17.9	9.2	42.2	3.5
<b>Maxillary [N = 15]</b>	BL	20.4	11.1	44.9	6.2
	MD	17.5	7.6	29.3	4.2
<b>Mandibular [N = 14]</b>	BL	39.5	14.3	44.1	8.3
	MD	18.4	10.7	42.2	6.2
<b>MOLARS [N = 28]</b>	BL	21.3	12.1	49.4	4.7
	MD	23.5	12.1	49.8	4.7
<b>Maxillary [N = 10]</b>	BL	17.6	8.6	27.7	6.2
	MD	19.8	11.4	44.4	8.1
<b>Mandibular [N = 18]</b>	BL	23.4	13.3	49.4	6.6
	MD	25.6	11.9	44.7	5.9

**Table 2. Undercuts by tooth type and plane.**

Undercut by tooth type & plane	BL	MD
Incisor [N = 2]	-	2
Canine [N = 1]	-	1
Premolar [N = 7]	5	2
Molar [N = 2]	1	1

## DISCUSSION

This retrospective study examined the clinical total convergence angles achieved by dental students. There is evidence in the literature that students produce lower values of taper during clinical competency examinations (when they know they are being observed) than those prepared clinically.<sup>23-25</sup> By carrying out a retrospective study, this effect was avoided and a more accurate indication gained of the total convergence angles prepared.

Achieving adequate retention and resistance form requires a complex recipe. This paper has focused on one specific ingredient and should not be seen as undermining the importance of other aspects of crown preparation such as abutment height. The effect of abutment height has been discussed in the literature

with multiple studies<sup>6,26,27</sup> discussing the relationship between abutment height and TOC. Yoon *et al.*<sup>28</sup> demonstrated that the increased abutment height of central incisor teeth allowed for taper angles greater than would be unacceptable in shorter abutments. Additionally, the increased height to base ratio allowed for an increase in taper angles. Woolsey and Match<sup>26</sup> found that a 3 mm occlusion-cervical height gave adequate resistance at a 10° but inadequate resistance at 20°.

This study, along with a number of other studies,<sup>3,9-11,29,30</sup> demonstrates that achieving ideal TOC is clinically difficult even for qualified dentists and restorative / fixed prosthodontic specialists. In the present study, 23% of BL and 33% of MD preparations were found to have ideal total convergence angles with 30% of BL and 40% of MD preparations having clinically acceptable values. This study of student clinical crown preparations found that depending on tooth type between 9% and 35% of the BL surfaces of preparations were in the ideal range with 6.4% to 31.3% of the MD preparation surfaces in the ideal range. The percentage of preparations with TOC angles in the clinically acceptable range is 0.85% to 43% for the BL aspect and 3% to 43% for the MD aspect. Table 3 compared results from the present study with those of other dental students. The percentage of preparations with ideal and acceptable total convergence angles in the present study was comparable to those achieved by dental students at other institutions within the UK and globally.<sup>14,25,29,31-35</sup>

It is useful to compare the results achieved by dental students with those of qualified dentists as, in the UK, dental students are able to practise independently immediately on graduation.

**Table 3. Mean convergence angles within ideal and clinically acceptable ranges**

Study	% of preparations within ideal range 4-14		% within acceptable range 10-20	
	BL	MD	BL	MD
University of Aberdeen	23	33	30	40
Noonan & Goldfogel <sup>24</sup>	-	-	19.5	13.2
Al-Omari <i>et al</i> <sup>25</sup>	9	16	24	34
Patel <i>et al</i> <sup>22</sup>	-	-	13 - 43	3 to 43
Rafeek <i>et al</i> <sup>26</sup>	-	-	20	24
Rafeek <i>et al</i> <sup>15</sup>	20-35	20-30	-	-
Aleisa <i>et al</i> <sup>27</sup>	-	-	38.6	26.5
Sato <i>et al</i> <sup>12</sup>	12.7 - 16.3	6.4 - 31.3	-	-
El - Mubarak <i>et al</i> <sup>28</sup>	-	-	0.85	8.5
- Data not given or unable to be computed				

Patel *et al.*<sup>29</sup> found that clinical staff and general dentists produced mean TOC of 14 to 17°, Nordlander *et al.*<sup>36</sup> showed that general dentists and specialists produced TOC angles of around 19 to 20°: other studies within the literature reveal qualified dentists and specialists produce mean total convergence angles ranging from 15 to 25°. <sup>12,14,37-39</sup> Seen within this context the mean values, 19.6° +/-11.7 BL and 17.8° +/-11.1 MD found within this study were comparable with values achieved by other dental students and qualified dentists.

Mean TOC for incisors, canines and premolars were higher bucco-lingually than mesio-distally, for molar teeth the opposite was found. This finding has previously been reported in the literature.<sup>17</sup> Maxillary incisors and canines had their largest total convergence angles in the BL plane. The short palatal wall of maxillary anterior teeth is easily over tapered and clinicians can also fail to respect the two-plane nature of the labial reduction which can also contribute to increased tapers, this may be especially prevalent with inexperienced clinicians. Multiple studies of student crown preparations have found the BL plane of maxillary anterior teeth to have higher total convergence angles than the MD plane.<sup>25,35</sup>

Posterior tooth preparations teeth tend to have larger TOC angles relative to anterior teeth. There is a number of factors that contribute to this; the increased difficulty of accessing the distal aspect of posterior teeth, the reduced occluso-cervical height of molar abutments and the mesial inclination of these teeth.<sup>9,12,30,36</sup> Mandibular teeth have been found to be more likely to have an increased TOC compared with maxillary teeth,<sup>5,38</sup> with mandibular molars being found to have the highest TOC of any tooth.<sup>8</sup> Within the present study, mandibular premolars had the highest BL TOC and mandibular molars had the highest MD TOC.

Within this study, 15% of preparations were found to have undercuts. Studies by Tiu *et al.*<sup>16,17</sup> examining crown preparations of New Zealand dental students found up to 9% of specimens were undercut. A systematic review<sup>2</sup> of student clinical crown TOC angles found that of 12 published studies<sup>11,13,14,25,29,31-35,40,41</sup> on student clinical crown preparations, only one paper.<sup>33</sup> discussed samples with undercuts and these were removed from the results. Rafeek *et al.*<sup>33</sup> found that 12% of the dies available for their study contained an undercut. The remaining papers did not discuss undercut and are potentially at risk of selection bias. Future studies should state clearly if preparations with undercuts were removed from the sample or included.

If a clinician was to prepare a tooth with a greater than ideal TOC, the use of adhesive cements can to a certain extent ameliorate this. Zidan *et al.*<sup>42</sup> and El-Mowfy *et al.*<sup>43</sup> found that the use of adhesive cements provided similar retention and resistance values for crown preparations with large TOC angles when compared to preparations with much lower TOC angles and cemented with a traditional luting cement. Despite the fact that modern adhesives allow for preparations with increased convergence angles, there are still sound biological and mechanical reasons for limiting crown TOC. Crowns experience repetitive dynamic loading during mastication and parafunction which results in compressive, tensile and shear forces being applied to the prosthesis and the cement.<sup>44</sup> By limiting TOC, clinicians not only preserve tooth structure and reduce stress to the pulp but also limit the forces

and loading being transmitted to the luting material.<sup>45</sup> In vitro studies have shown that increasing TOC reduces the retention of a cemented crown.<sup>4,42,46</sup> Clinicians should therefore aim to produce small convergence angles in order to reduce the biological cost to the tooth and limit the stress placed on the cement substrate.

This study has made use of an innovative computer application that provided a simple and quick means to measure TOC measurement and which allowed for reproducibility of measurements. The increasing use of digital technology within dentistry, will make future studies easier to conduct as data collection becomes a routine part of digital workflows. Utilising this data, future research may be able to relate prepared TOC angles to the long term clinical success of fixed prosthetics. This will allow for meta-analysis of data and realistic recommendations for crown convergence angles.

## CONCLUSION

This study examined the clinical total convergence angles produced by students at the University of Dental School by using an innovative crown preparation computer application that had not previously been used in the UK. Crown preparation TOC angles were comparable with those produced by dental students at other institutions and to qualified clinicians. This paper found that for students and qualified clinicians, achieving ideal total convergence angles is clinically challenging with only a minority of preparations achieving ideal total occlusal convergence angles.

## MANUFACTURERS' DETAILS

Affinis Vinyl Polysiloxane, Coletene Whaledent, Feldwiesenstrasse 20, CH-9450 Altstätten, Switzerland; Fuji Rock EP dental stone, GC, 3-2-14 Hongo, Bunkyo-ku, Tokyo 113-0033. Japan; Ceramil Map300 scanner with mindmap 200 software, Amann Girrbach, Herrschaftswiesen 1, 6842 Koblach, Austria; SPSS Version 24, IBM SPSS Statistics for Mac 2016, Version 24. Armonk, NY;

## CONFLICT OF INTEREST DECLARATION:

There are no conflicts of interest with regards to this research.

## REFERENCES

1. Journal of Prosthetic Dentistry. The Glossary of prosthodontic terms 9th Edition. *J Prosthet Dent.* 2017;**94**:E25.
2. Strain KJS, Mackie J, Bonsor SJ, Macfarlane TV. Crown Taper achieved by dental students: A systematic review. *J Dent Educ.* 2018.
3. Tiu. J, Al-Amleh. B, Waddell. JN and Duncan. WJ. Clinical tooth preparations and associated measuring methods: a systematic review. *J Prosthet Dent.* 2015;**113**:175-84.
4. Jorgensen, KD. The relationship between retention and convergence angle in cemented veneer crowns. *Acta Odontol Scand.* 1955;**13**:35-40.
5. Blair. FM, Wassell. RW, and Steele. JG. Crowns and other extra-coronal restorations: Preparations for full veneer crowns. *Br Dent J.* 2002;**192**:561-571.
6. Dodge. WW, Weed. RM, Baez. RJ, Buchanan. RN. The effect of convergence angle on retention and resistance form. *Quintessence Int.* 1985;**16**:191-194.

7. Shillingberg. HT, Hobo. S, Whitsett. L, Jacobi. R and Brackett. SE. Fundamentals of fixed prosthodontics. 3rd ed. Chicago: Quintessence; 1997.
8. Tylman. SD and Malone. WFP. Tylman's Theory and Practice of Fixed Prosthodontics St Louis: C. V. Mosby Co.; 1978.
9. Goodacre C, Campagni W, Aquilino S. Tooth preparations for complete crowns: An are form based on scientific principles. *J Prosthet Dent.* 2001;**85**:363-76.
10. Mack, PJ. A theoretical and clinical investigation into the taper achieved on crown and inlay preparations. *J Oral Rehabil.* 1980; **7**:255-265.
11. Annerstedt. AL, Engstrom. U, Hansson. A, Jansson. T, Karlsson. S, Lli-jhagen. E, et al. Axial wall convergence of full veneer crown preparations. Documented for dental students and general practioners. *Acta Odontol Scand.* 1996;**52**:109-12.
12. Wilson. AH and Chan. DC. The relationship between preparation convergenve and retention of extra-coronal retainers. *J Prosthodont.* 1994;**3**:74-8.
13. Ohm. J, and Silness. E. The convergence angle in teeth prepared for artificial crowns. *Journal of Oral Rehabilitation.* 1978;**5**:371-5.
14. Sato. T, Al Mutawa. N, Okada. D and Hasegawa. S. A clinical study on abutment taper and height of full cast crown preparations. *Journal of Medical and Dental Science.* 1988;**45**:205-10.
15. Tiu J, Wadell JN, Al-Amleh B, Van Wuuren WAJ, Swain MV. Coordinate geometry method for capturing and evaluating crown preparation geometry. *J Prosthet Dent.* 2014;**112**:481-487.
16. Tiu J, Cheng E, Hung TC, Yu CC, Lin T, Schwass D, et al. Effectiveness of Crown Preparation Assessment Software As an Educational Tool in Simulation Clinic: A Pilot Study. *J Dent Educ.* 2016;**80**:1004-1011.
17. Tiu. J, Lin. T, Al-Amleh. B and Waddell. JN. Convergence angles and margin widths of tooth preparations by New Zealand dental students. *J Prosthet Dent.* 2016;**116**:74-79.
18. 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.
19. Bonsor SJ, Pearson GJ. *A clinical guide to applied dental materials.* 1st ed., editor. London: Churchill Livingstone; 2013.
20. GC Europe. Products. [Online]; 2018 [cited 2018 October 5. Available from: <https://www.gceurope.com/products/fujirock>.
21. <http://archadental.com/map300>. Archa Dental - AmannGirrbach Ceramill Map 300 3D Dental Scanners. [Online]; 2018 [cited 2018 February 16. Available from: <http://archadental.com/map300>.
22. Tiu J. Tooth preparation: Measuring, understanding and reporting tooth preparation and its influence on the fracture of all-ceramic crowns [PhD Thesis]. PhD Thesis. Otago: University of Otago, New Zealand, Sir John Walsh Research Institute; 2015.
23. Weed. RM, Suddick. RP and Kleffner. JH. Taper of clinical and tyodont crowns prepared by dental students [abstract]. *J Dent Res.* 1984;**63**:162-345.
24. Curtis. DA, Lind. SL, Brear. S and Finzen. FC. The correlation of student performance in preclinical and clinical prosthodontic assessments. *J Dent Educ.* 2007;**71**:366-72.
25. Rafeek. RN, Smith. WA, Seymour. KG, Zou. LF and Samarawickrama. DY. Taper of full-veneer crown preparations by dental students at the University of the West Indies. *J Prosthodont.* 2010;**19**:580-585.
26. Woolsey GD, Matich JA. The effect of axial grooves on the resistance form of cast restora- tions. *J Am Dent Assoc.* 1978;**97**:978-980.
27. Leong EWJ, Tan KBC, Nicholls JI, Chua EK, Wong KM, Neo JC. The effect of preparation height and luting agent on the resistance form of cemented cast crowns under load fatigue. *J Prosthet Dent.* 2009;**102**:155-164.
28. Yoon SS, Cheong C, Preisser Jr. J, Jun S, Chang BM, Wright RF. Measurement of total occlusal convergence of 3 different tooth preparations in 4 different planes by dental students. *J Prosthet Dent.* 2014;**112**:285-292.
29. Patel. B, Wildgoose. D and Winstanley. R. Comparisons of convergence angles achieved in posterior teeth prepared for full veneer crowns. *Eur J Prosthodont Restor Dent.* 2005;**13**:100-4.
30. Ghafoor R, Siddiqui AA, Rahman M. Assessment of convergence angle of full coverage porcelain fused to metal crowns in clinical practice. *Indian J Dent Res.* 2012;**23**:241-246.
31. Noonan. JE jr, and Goldfogel. MH. Convergence of the axial walls of full veneer crown preparations in a dental school environment. *J Prosthet Dent.* 1991;**66**:706 -708.
32. Al-Omari. WM and Al-Wahadni. AM. Convergence angle, occlusal reduction, and finish line depth of full crown preparations made by dental students. *Quintessence Int.* 2004; **35**:287-93.
33. Rafeek. RN, Marchan. SM, Seymour KG, Zou. LF and Samarawickrama. DY. Abutment taper of full cast crown preparations by dental students in the UWI school of dentistry. *Eur J Prosthodont Restor Dent.* 2006 June;**14**:63-66.
34. Aleisa. K, Al-Dwairi. ZN, Alwazzan. K, Al-Moither. M, Al-Shammari. M, Lynch. E. Convergence angles of clinical tooth preparations achieved by dental students at King Saud University, Saudi Arabia. *J Dent Educ.* 2013;**77**:1154-8.
35. El-Mubarak. N, Abu-Bakr. N, Omer. O and Ibrahim. Y. Assessment of undergraduate students' tooth preparation for full veneer cast restorations. *Open Journal of Stomatology.* 2014;**4**:43-48.
36. Nordlander. J, Wei. D, Stoffer. W, and Ochi. S. The taper of clinical preparations for fixed prosthodontics. *J Prosthet Dent.* 1988;**60**:148-151.
37. Leempoel. PJB, Lemmens. Ph, Snoek. PA, Van't Hof. MA. The convergence angle of tooth preparations for complete crowns. *J Prosthet Dent.* 1987;**58**:414-416.
38. Ghafoor. R, Siddiqi. AA and Rahman. M. Angle Of Prepared Teeth For Full Veneer Metal Ceramic Crowns. *J Coll Physicians Surg Pak.* 2011;**21**:15-18.
39. Eames. WB, O'Neal. SJ, Monteiro. C, Roan. JD Jr, and Cohen. KS. Techniques to improve the seating of castings. *J Am Dent Assoc.* 1978;**96**:432-437.
40. Dorriz. H, Nokar. S, Baghai-Naini. R, and Madadi. A. The convergence angle of full coverage crown preprations made by dental students. *J Dent (Tehran).* 2008;**5**:37-41.
41. Al-Hazmi. M, El-Mowafy. O, Zahran. MH, Uctasli. S, Alkumru. H, Nada. K. Angle of convergence of posterior crown preparations made by pre-doctoral dental students. *J Dent Educ.* 2013;**77**:1118-21.
42. Zidan. O, and Ferguson GC. The retention of complete crowns prepared with three different tapers and luted with four different cements. *J Prosthet Dent.* 2003;**89**:565-71.
43. El-Mowfy. OM, Fenton. AH, and Forrester. N. Retention of metal ceramic crowns cemented with resin cements: Effect of preparation taper and height. *J Prosthet Dent.* 1996;**76**:524 -529.
44. Anselm - Wiskott. H. Fixed prosthodontics: principles and clinics. 1st ed. London: Quintessence; 2011.
45. ShahrbaF. S, Van Noort. R, Mizakouchaki. B and Ghassemieh. E. Effect of the drown design and interface lute parameters on the stress state of a machined crown tooth system: a finite element analysis. *Dent Mater.* 2013;**29**:123-31.
46. El-Ebrashi. MK, Craig. RG, and Peyton. FA. Experimental stress analysis of dental restorations. Part IV. The concept of parallelism of axial walls. *J Prosthet Dent.* 1969;**22**:346-353.