Evaluation of the Quality of Undergraduate Full Veneer Crown Preparations at a UK Dental Teaching Hospital

Keywords

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ABSTRACT

Objectives: To determine the quality of full veneer crown preparations produced by supervised undergraduate students at a UK dental teaching hospital. Methods: One hundred and eighty-five scanned digital dies between October 2019 and March 2021 were obtained. Using cross-sections in four planes, the total angle of convergence, abutment height, margin design and margin depth were evaluated. Statistical comparisons were made by plane, location, material-type, tooth-type, and inter- and intra-arch positions. Results: Across all preparations the mean total angle of convergence was 24.8° ± 11.7°. and mean abutment height was 3.6 mm ± 1.0 mm. Mandibular and molar teeth were significantly more tapered (P <0.001) and exhibited significantly shorter abutment heights (P <0.001). Chamfer margins were the most frequently observed and mean margin depths ranged from 0.49-1.06 mm. The compliance to recommended taught parameters were 28.1%, 42.7%, 34.1% and 6.5% for total angle of convergence, abutment height, margin design and margin depth, respectively. Conclusions: The findings from this study suggest that compliance to taught parameters is poor, especially for molar teeth, and demonstrates the use of digital software in guiding future research and teaching.

INTRODUCTION

In 2019-2020, approximately 700 000 full veneer crowns (FVC) were cemented within the United Kingdom's National Health Service.[1,2] This demonstrates that, despite the advances in materials and promotion of minimally invasive techniques which maintain natural tooth structure and delay the restorative cycle, conventional preparation of teeth for FVCs still remains a common scenario.[3] The principles of FVC preparation can be broadly grouped into (i) biologic, (ii) aesthetic, and (iii) mechanical.[4] Biologic principles aim to conserve tooth structure, maintain pulp vitality, and produce restorations which favour the surrounding periodontium; aesthetic principles focus on minimising display of metal substructure and replicate natural anatomy; and mechanical principles prevent restoration failure and can be further subcategorised into retention and resistance form.[4,5] The former is defined as features of the preparation which resist displacing forces along the path of insertion or long axis, whereas the latter refers to the those features that resist displacing forces in directions other than the path of insertion and/or long axis.[6]

Several key characteristics of prepared teeth have been identified to significantly contribute to the resistance and retention form of FVCs, such as total occlusal convergence (TOC) and abutment height.[4] The TOC, also referred to as taper, describes the angle formed between two opposing axial walls.[4,6] A 10° – 20° TOC is considered the optimum range in order to avoid producing undercuts at lower ranges and, conversely, reduce the risk of debonding from the greater tensile stresses exhibited on the cement at higher angles.[4,7-10] The occluso-cervical distance is recommended to be a minimum of 3 mm, except in molars which require a minimum of 4 mm due to an inherently unfavourable height to width ratio.[4] Where these guidelines cannot be satisfied, such as oval or heavily restored teeth, the use of auxiliary retention and resistance features, and adhesive cementation, is recommended. Other features of prepared teeth include margin design and margin depth, which represent the morphological form created at the junction of prepared and unprepared tooth structure.[6]

The aforementioned principles of FVC preparation are first introduced to dentists in their undergraduate curriculum. Numerous studies indicate that crown preparations produced by this cohort range anywhere between 14° – 27° (*Table 1*). Unfortunately, other features such as abutment height and margin type and depth tend to be severely underreported making it difficult to comment on the standard of preparations with respect to these parameters.[11-19] Furthermore, various methods are often used to assess the crown preparation parameters, ranging from manual methods of hand-drawing on silhouettes of stone dies, through to analysis of digital three-dimensional scans.[19] The use of digital techniques allows for more objective geometry selection, greater standardisation, and reduces the potential for bias.[15,19,20]

The primary aim of this cross-sectional study was to assess the compliance achieved by supervised undergraduate dental students to the recommended TOC, abutment height, margin design and depth in their FVC preparations. The secondary aim of this study was to explore if the average TOC or abutment heights were significantly affected by plane, location, material type, tooth type and intra- and inter-arch positions. The prevalence and compliance of various margin designs and average margin depths was also assessed.

MATERIALS AND METHODS

Full ethical approval from the University of Birmingham's Research Ethics Committee was obtained for this study (Ref: ERN_21-0666). The recommended parameters for FVC tooth preparation taught at the Birmingham Dental Hospital (BDH) are listed in Table 2.

SAMPLE SIZE CALCULATION

Sample size calculations were conducted using data from previous work carried out by Virdee *et al* (2018).[13] In order to predict enrolment ratios, a pilot sample of 100 randomly drawn crown preparations were taken and the findings were a 4:1 ratio of FMC:MCC crowns, a 1:1 ratio of crowns in the mandible:maxilla, and a 1:13 ratio of anterior:posterior crowns. Therefore, a sample size of 39 was required to compare crown materials (31 FMC / 8 MCC), 94 to compare inter-arch position (47 maxilla / 47 mandible), and 154 to compare intra-arch position (11 anterior / 143 posterior). To account for potential deviations from these predicted ratios,

Table 1. Previous studies assessing clinical TOC achieved by dental students

Study	Year	Operator level	Sample size	Mean TOC, ° (SD)		
				Overall	M-D plane	B-L plane
Strain *et al*[15]	2019	3rd, 4th & 5th year students	82	-	19.6 (11.7)	17.8 (11.1)
Virdee *et al*[13]	2018	Dental students	125	24.2 (11.95)	24.7 (15.53)	23.0 (13.84)
Aleisa *et al*[11]	2013	Final year students	355	18.56 (-)	16.66 (10.07)	20.45 (11.05)
Alhazmi *et al*[14]	2013	Final year students	91	-	22.5 (8.4)	23.5 (7.7)
Rafeek *et al*[18]	2006	Dental students	25	-	20.3 (11.3)	18.3 (8.5)
Patel *et al*[12]	2005	4th year students	60	-	27.03 (15.00)	24.23 (11.23)
		5th year students	60	-	16.33 (5.82)	14.67 (5.04)
Noonan *et al*[17]	1991	Dental students	909	19.1 (9.4)	18.5 (9.5)	19.5 (9.3)

'-' indicates data was not given

Table 2. Recommended crown preparation parameter standards taught at BDH.

Parameter	Recommended Taught Standard
TOC	10-20°
Abutment height	Minimum 3 mm for incisor, canine and premolar teeth Minimum 4 mm for molar teeth
Margin design	Metal interface: Chamfer margin Ceramic interface: Shoulder margin
Margin depth	Metal interface: 0.5 – 0.7 mm Ceramic interface: 1.0 – 1.5 mm

and unsuitability of some crown preparations, a target sample size 20% greater than the minimum of 154 was aimed for. This gave a final sample size of 185, in order to provide 80% power at $\alpha = 0.05$.

SAMPLE SELECTION

All FVC preparations carried out by student operators from October 2019 to March 2021 were consecutively selected until a sample size of 185 was obtained. All students must have satisfied the requirements of a pre-clinical laboratory course and completed relevant competency tests prior to undertaking FVC preparations on live patients. Preparations were identified within the computer-aided design software used in the on-site laboratory. Exclusion criteria were: preparations for fixed partial dentures (bridges), post-core restorations, and partial-coverage crowns (e.g., inlays and onlays). The material type of the crowns was categorised into all-ceramic, metal-ceramic, and full-metal crowns.

STUDY DESIGN

Following a completed preparation, students recorded impressions with addition polyvinylsiloxane (Aquasil, Dentsply Sirona, North Carolina, US) in plastic stock trays (Polytrays, Dentsply Sirona, North Carolina, US) and placed temporary FVC restorations between preparation and fit visits. The laboratory technicians poured the impressions in type IV die stone (SHERA, Lemförde, Germany) and sectioned the casts according to their in-house production protocol. Dies were then converted into digital stereolithography files using an extra-oral scanner (Renishaw Plc, Gloucestershire, United Kingdom) and imported into a computer-aided design programme (exocad GmbH, Darmstadt, Germany), before being outsourced for manufacture. The digital models were obtained retrospectively such that no students or supervising clinical staff received additional instructions outside of the dental training course.

OUTCOME MEASURES

Cross sections of each preparation were extracted from the software in four planes: bucco-lingual (B-L), mesio-distal (M-D), mesiobuccal-distolingual (MB-DL) and distobuccal-mesiolingual (DB-ML) (*Figure 1*). Each section was imported into ImageJ (National Institute of Health, Maryland, US) and calibrated within the software. TOC was measured for 740 cross-sections, as per Virdee *et al* (2018), as each preparation yielded four values. The 'angle tool' feature was used to determine the TOC between straight lines extending from each axial wall of the preparation (*Figure 2a*).

Abutment height was calculated at 1480 sites as per Güth *et al* (2013). Briefly, values were recorded in millimetres at mesial (M), distal (D), buccal (B), lingual (L), MB, DL, DB and ML points. The 'straight line' feature was used to determine the vertical preparation height from the margin finishing line to the highest cuspal tip at each site (*Figure 2*b). Each cross-section had margin design and depth evaluated and were classified into chamfer, deep chamfer, shoulder, bevelled shoulder and knife edge.[8] An additional 'indefinable' category was added for preparations failing to exhibit any of the stated margin designs.

Margin depth was evaluated as per Tiu *et al* (2014) and was defined as the horizontal distance from the margin finishing line to the start of the axial wall (*Figure 2c*). A depth greater than 0.8mm was used to differentiate between chamfer and deep chamfer margin designs.[7,8] Margin depths were not calculated for those preparations which were categorised as knife-edged or indefinable. Prevalence of margin design and depth was assessed at the 8 separate locations, as described for abutment height calculation but compliance to taught standards was calculated at the B and L locations only, due to the various combinations of ceramic and metal coverage for metal-ceramic crowns.[8]

For each preparation, a panel of two clinicians (first author and second author) determined the path of insertion and centre of rotation, prior to manual construction of the four cross-sectional planes (M-D, B-L, MB-DL and DB-ML). For each parameter, inter and intra-rater reliability analysis was

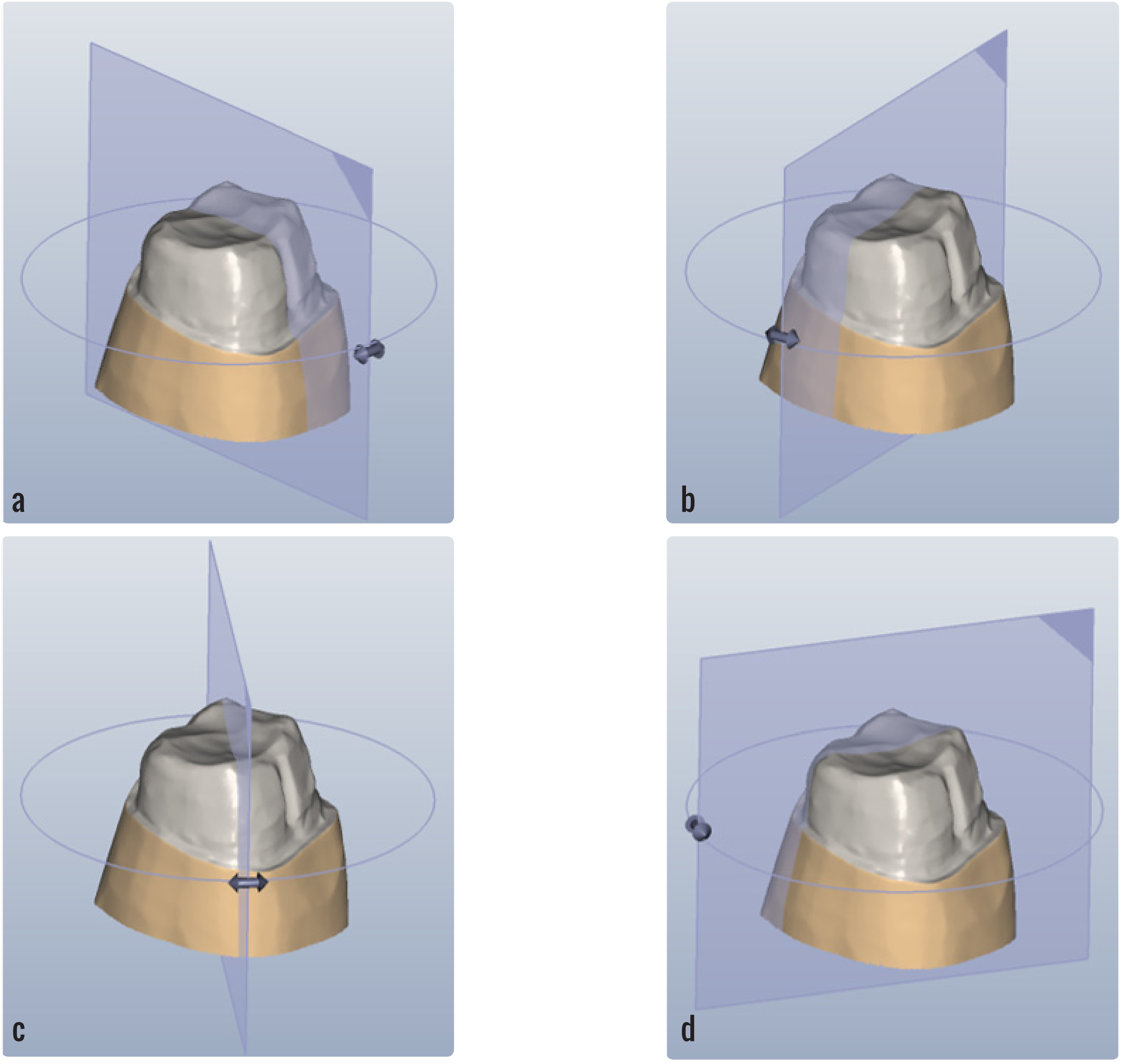

Figure 1: Cross sections of a FVC preparation in the a) bucco-lingual, b) mesio-distal, c) mesiobuccal-distolingual and d) distobuccal-mesiolingual planes.

determined in a pilot study (continuous variables: intra-class correlation coefficient; categorical variables; Cohen's kappa) and calibration was assessed throughout the study at every 20th preparation. Any uncertainties were independently adjudicated by the third author. All data was extracted into piloted spread sheets in Microsoft Excel 2019 (Microsoft Corp, New Mexico, US).

STATISTICAL ANALYSIS

All statistical analyses were programmed in Stata version 16.0 (StataCorp, Texas, US). Statistically significant differences between the primary outcomes (TOC / abutment height) were assessed by plane, location, material type, tooth type, inter- and intra-arch position. The Shapiro-Wilk test revealed a non-normal distribution of primary outcome measures, therefore non-parametric tests were used to test for significant differences; Mann-Whitney U and Kruskal-Wallis with post-hoc Dunn's test (Bonferroni-corrected). All statistical tests were two-sided at $\alpha = 0.05$.

RESULTS

Intra- and inter-rater reliability for all parameters were considered excellent (> 0.75).

SAMPLE CHARACTERISTICS

One-hundred and eighty-five preparations were identified. Of these, 20 (10.8%) preparations were all-ceramic, 39 (21.1%) PFM and 126 (68.1%) full-metal crowns. The most commonly prepared teeth were molars (64.9%), followed by premolars (26.5%), incisors (7.6%) and canines (1.1%). Eighty-seven (47.0%) preparations were located in the mandible, with 169 (91.4%) posterior and 92 (49.7%) located on the right side *(Table 3)*.

TOTAL OCCLUSAL CONVERGENCE

Of the total sample, 28.1% (n = 52) preparations were compliant to the recommended 10° – 20° standard. The mean TOC was 24.8° ± 11.7, ranging from 3.6° – 66.1°. Significant ($P < 0.05$) differences in TOC were identified by plane, tooth type, material type, and inter-arch position. The greatest tapers were

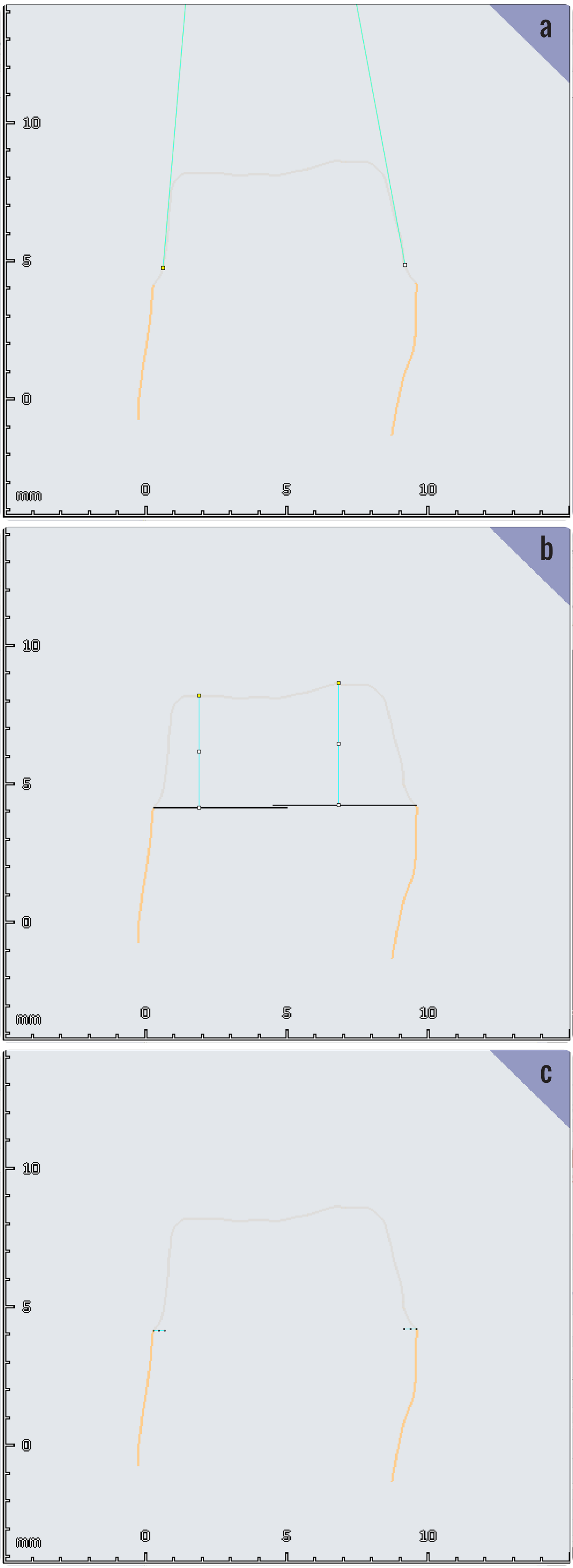

Figure 2: Calculation of: a) TOC; b) abutment height; c) margin depth

identified in the DB-ML plane (26.6° ± 15.0), in posterior teeth (25.8° ± 11.5), particularly molars (28.2° ± 11.5), in preparations for full-metal crowns (26.9° ± 10.9), and preparations in the mandible (28.3° ± 12.3). The mean TOC of teeth situated on the right (26.3° ± 12.1) was not significantly different ($P > 0.05$) from those on the left (23.3° ± 11.2) *(Table 3)*.

ABUTMENT HEIGHT

Of the total sample, 42.7% (n = 79) of preparations were compliant to the recommended standard, with a mean abutment height of 3.6 mm ± 1.0, ranging from 1.5 mm – 6.7 mm. Significant differences were identified by location, tooth type, material type, and inter-arch position ($P < 0.05$). The shortest abutment heights were identified at the mesial aspect of preparations (2.8 mm ± 1.1), in posterior teeth (3.5 mm ± 0.8), particularly molar teeth (3.4 mm ± 0.8), in preparations for all-ceramic (3.4 mm ± 1.3) and full-metal (3.4 mm ± 1.8) crowns, and preparations in the mandible. The mean abutment height of teeth situated on the right (3.4 mm ± 0.9) was not significantly different ($P > 0.05$) from those on the left (3.7 mm ± 1.0) *(Table 4)*.

MARGIN DESIGN

Of the total sample, 34.1% (n = 63) of preparations were compliant to the recommended standard *(Table 5)*. The most prevalent margin designs were chamfer (55.7%), deep chamfer (13.7%), knife-edge (12.5%), shoulder (9.5%), indefinable (6.0%) and bevelled shoulder (2.7%) *(Table 6)*.

MARGIN DEPTH

Of the total sample, 6.5% (n = 12) of preparations were compliant to the recommended standard *(Table 5)*. Where margin depths could be measured, the mean depths were 0.49 mm for chamfer, 1.06 mm for deep chamfer, 0.88 mm for shoulder, and 0.98 mm for bevelled shoulder *(Table 6)*.

DISCUSSION

The results from this study indicate compliance to taught standards of 28.1% for TOC, 42.7% for abutment height, 34.1% for margin design and 6.5% for margin depth. The mean TOC and abutment height were 24.8° ± 11.7 and 3.6 mm ± 1.0 respectively. These parameters varied significantly according to the plane, location, tooth type, material type, and inter-arch position of the preparations. Chamfer margins were most commonly prepared with varying depths.

The findings of this study conform with the existing literature, which suggest similar TOC produced by other undergraduates, both within the UK and internationally.[11,14,16] For example, the two most recent studies presented in Table 1, were based at UK dental institutes and found similar mean convergence angles as displayed in this study.[13,15] In the limited number of studies which have reported on abutment height, values were found

Table 3. Distribution, mean TOC, standard deviations, statistical significance of subgroups and compliance of sample.

Groups		Sample, n	Mean TOC, ° (SD)	*P*-value	Compliance, % (n)
Total sample		185	24.8 (11.7)	-	28.1 (52)
Plane	**B-L**	185	22.4 (12.4)	0.023	27.0 (50)
	M-D		24.4 (17.4)		28.1 (52)
	DB-ML		26.6 (15.0)		24.9 (46)
	MB-DL		25.7 (14.4)		25.6 (48)
Material type	**All-ceramic**	20	24.8 (10.0)	< 0.001	30.0 (6)
	Metal-ceramic	39	18.0 (12.6)		43.6 (17)
	Full-metal	126	26.9 (10.9)		23.0 (29)
Tooth type	**Incisors**	14	13.8 (7.1)	< 0.001	35.7 (5)
	Canines	2	14.7 (10.9)		0
	Premolars	49	19.8 (9.3)		44.9 (22)
	Molars	120	28.2 (11.5)		20.9 (25)
Inter-arch position	**Mandible**	87	28.3 (12.3)	< 0.001	23.0 (20)
	Maxilla	98	20.8 (9.7)		32.7 (32)
Intra-arch position – **A/P**	**Anterior**	16	13.9 (7.2)	< 0.001	31.3 (5)
	Posterior	169	25.8 (11.5)		27.8 (47)
Intra-arch position – **L/R**	**Left**	93	23.3 (11.2)	0.150	30.1 (28)
	Right	92	26.3 (12.1)		26.1 (24)

in the range of 2.7 mm ± 0.8 and 3.1 mm ± 0.98 on the mesial aspect of molar crown preparations and 3.4 mm ± 0.9 and 3.6 mm ± 1.07 on the distal aspect.[20,21] These studies evaluated preparations produced by prosthodontists and general dental practitioners and the values of 2.8 mm ± 1.1 (mesial) and 3.5 mm ± 1.2 (distal) found in our present work would indicate that FVC preparations from dental students are comparable. The reason for this is likely due to the limited operator control associated with the height of remaining coronal tooth tissue due to past trauma, caries, or restoration.[21] It would thus be advised to build up molar teeth with core restorations to provide an ideal abutment height, where this is feasible. Furthermore, it appeared that mandibular teeth were particularly prone to challenges during crown preparation, with significantly greater TOC and significantly lower abutment heights relative to maxillary teeth. This may be explained by a combination of two factors: (i) the natural anatomy of mandibular teeth is that they possess a lingual inclination and therefore there is inherent difficulty in orientating the handpiece parallel to the axial walls, especially when considering additional interference from the tongue,[22] and (ii) due to the nature of the TMJ, the maxilla provides a much more stable structure compared to the mandible, which has the potential to move during dental procedures.[13,14] Although pre-clinical teaching accounts for the difficulty associated with tooth inclinations through realistic jaw models, the unpredictable motions of the tongue and mandible are much more challenging to apply into simulation environments.

There is a lack of evidence which supports an ideal margin design or depth for optimum retention and resistance form in FVC preparation. Thus, there is great variation in taught standards for margin design and these vary even more dependent upon the material properties of the final restoration and personal preference of the practitioner.[23] A prime example of this is the variation in school of thought regarding the knife-edge margin design, which is often

Table 4. Distribution, mean abutment height, standard deviations, statistical significance of subgroups and compliance of samples.

Groups			Sample, n	Mean Abutment Height, mm (SD)	*P*-value	Compliance, % (n)
Total sample			185	3.6 (1.0)	-	42.7 (79)
Location		B	185	4.6 (1.3)	< 0.001	67.6 (125)
		L		3.5 (1.2)		40.0 (74)
		M		2.8 (1.1)		24.3 (45)
		D		3.5 (1.2)		40.5 (75)
		DB		4.0 (1.2)		56.2 (104)
		ML		3.1 (1.2)		30.8 (57)
		MB		3.8 (1.1)		49.2 (91)
		DL		3.4 (1.2)		38.4 (71)
Material type		All-ceramic	20	3.4 (1.3)	< 0.001	40.0 (8)
		Metal-ceramic	39	4.1 (1.0)		82.1 (32)
		Full-metal	126	3.4 (0.8)		31.0 (39)
Tooth type		Incisors	14	5.2 (0.9)	< 0.001	100 (14)
		Canines	2	4.0 (1.6)		50.0 (1)
		Premolars	49	3.5 (0.9)		69.4 (34)
		Molars	120	3.4 (0.8)		25.0 (30)
Inter-arch position		Mandible	87	3.3 (0.9)	< 0.001	34.5 (30)
		Maxilla	98	3.9 (0.9)		50.0 (49)
Intra-arch position	A/P	Anterior	16	5.0 (1.0)	< 0.001	93.8 (15)
		Posterior	169	3.5 (0.8)		37.9 (64)
	L/R	Left	93	3.7 (1.0)	0.061	45.2 (42)
		Right	92	3.4 (0.9)		40.2 (37)

Table 5. Compliance of sample to recommend margin design and margin depth.

Groups		Sample, n	Margin design compliance, % (n)	Margin depth compliance, % (n)
Total sample		185	34.1 (63)	6.5 (12)
Material type	All-ceramic	20	0	5 (1)
	Metal-ceramic	39	10.3 (4)	2.6 (1)
	Full-metal	126	46.8 (59)	7.9 (10)

Table 6. Margin design type, frequency and mean depths with standard deviations.

Margin type	Total frequency (%)	Mean depth, mm (SD)
Chamfer	824 (55.7)	0.49 (0.2)
Deep chamfer	202 (13.7)	1.06 (0.3)
Shoulder	141 (9.5)	0.88 (0.4)
Bevelled shoulder	40 (2.7)	0.98 (0.4)
Knife edge	185 (12.5)	-
Indefinable	88 (6.0)	-

discouraged due to the fact that lab technicians may find them difficult to detect,[8] but, on the other hand, there exists the principles of conservative vertical crown preparation with maximum preservation of dental tissues.[24] Standardisation of the taught margin designs and depths between tutors on simulation and live patient clinics would aid students to produce more objective preparation targets.

The limitations associated with this study are acknowledged. Firstly, whilst a laboratory protocol for casting and scanning models is present, there will inevitably be variations between technicians in the casting process and subjectively determining the location of the margins, particularly those which were considered indefinable. Whilst this does improve the external validity of the results, this limitation, which is common to most studies in this field,[11-16] can be comprehensively overcome by directly scanning in tooth preparations chairside. There are however significant cost implications associated with this.[25] Furthermore, evaluation of the parameters within the CAD-CAM system and image analysis software were undertaken manually, resulting in the possibility of human error. Purpose-built software such as Preppr (University of Otago, New Zealand), has been developed to make assessment of 3D files more efficient, however it is not widely accessible and still requires a degree of manual selection of measurement points.[26] A more readily accessible alternative may be the use of specialised software integrated within intraoral scanning systems, such as prepCheck (Dentsply Sirona, Bensheim, Germany), and there are dental institutes where these have been incorporated into undergraduate teaching.[27] The automated nature of this software eliminates the variation associated with manual evaluation methods and appears to be the most viable option for dental schools going forwards, however, high initial set-up costs and specialised training may be a deterrent.

The quantity of previous crown preparations completed by a student, and thus level of clinical experience, was not accounted for in this study. Capturing data on the experience of the operator and taking randomised stratified samples may explore the effect of student experience on parameter compliance. It is also difficult to determine the amount of assistance students received by their supervisors whilst preparing teeth. In future studies, this may be gauged through student reflections and tutor feedback. Whilst the sample size in this study was adequately powered for the primary comparisons, more than 185 preparations would have been needed to conduct subgroup analyses. Therefore, larger samples sizes may be needed in future research in order to make valid comparisons. Furthermore, within this sample itself, anterior teeth, all-ceramic, and metal-ceramic preparations were relatively underrepresented, representing 8.6%, 10.8%, and 21.0% of the cohort, respectively. At the same time, however, this may simply reflect the fact that the majority of FVCs provided are for posterior teeth and made solely from metal.

Future studies should therefore:

- Aim to enrol larger sample sizes, stratified to represent varying levels of clinical experience
- Enrol prospective cohorts, with a greater deal of standardisation
- Look to utilise intraoral scanning methods with automated software, where feasible

CONCLUSIONS

Within the limitations of this study, it can be concluded that the overall compliance of crown preparation to taught parameters is poor, with only 28.1%, 42.7%, 34.1% and 6.5% of preparations being within the recommended ranges for TOC, abutment height, margin design and margin depth, respectively. The mean TOC tends to be overtapered, whilst abutment height tends to be below the taught standard for molar teeth. These findings may help to guide future research and teaching in the field, and also demonstrate how digital software may aid in these efforts.

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