Convergence angles for full veneer crown preparation completed by undergraduate students in a dental teaching hospital

S. S. Virdee,*[1] L.D. Addy,[2] P.J. Milward[3] and C.D Lynch[4]

Key points

- Make readers aware of ideal ranges of taper for full veneer/coverage crowns (FVC) preparations.
- Make educators aware of the current competency of dental students when preparing FVCs in relation to their international counterparts.
- Highlight strategies to help improve clinical competency of undergraduate dental students.
- Highlights the need to support the clinical skills development in this important aspect of student education.

Objectives To determine the degree of taper and the average angle of convergence (AOC) accomplished for full veneer/coverage crowns (FVC) by supervised undergraduate students at a dental teaching hospital. **Methods** One hundred and twenty-five stone dies of FVC preparations (25 full-metal [FMCs] and 100 metal-ceramic [MCCs]), prepared by dental students were included in this study. To measure AOC, standardised buccal and mesial photographs were taken when dies were mounted onto a custom silicone jig after careful positioning. 2D digital analysis software (ImageJ) was used to calculate the average mesio-distal (MD), bucco-lingual (BL) and overall AOC for each die. Differences between groups were tested for significance at 95% confidence using t-tests and analysis of variance (ANOVA). Findings were compared to the recommended 6°–15° range. **Results** The average AOC was 24.2° ± 11.95°. As few as one-in-four preparations (26.4%, n = 33) complied with the recommended standards. The MD plane (24.7° ± 15.53°) was more tapered than the BL plane (23.0° ± 13.84°) ($p > 0.05$) and FMCs preparations (34.7° ± 15.10°) more than MCCs (21.6° ± 9.38°) ($p < 0.001$). Molars (31.6° ± 12.56°) had the greatest AOC, followed by premolars (20.7° ± 7.81°), canines (19.4° ± 6.37°) and incisors (17.0° ± 9.62°) ($p < 0.001$). Additionally, mandibular teeth (28.8° ± 13.76°) exhibited a greater AOC than those in the maxilla (21.7° ± 10.08°) ($p < 0.05$). **Conclusion** The findings of this study suggest that within a dental school teaching environment, crown preparations completed by undergraduate students are over-tapered. Tooth type, inter and intra-arch position and crown material significantly impact taper, with mandibular molar FMCs displaying the greatest AOC. Contemporary dental school teaching should help support students in this important aspect of their clinical training.

Introduction

Full veneer/coverage crowns (FVC) are a common procedure provided in general practice with over 800–1,000 extra-coronal restorations delivered to NHS patients in England between 2015–2016.[1] The most recent UK Adult Dental Health Survey (2009) revealed that 37% of the adult population have crowns, with each adult having, on average, three crowns each.[2] This treatment forms an integral part of the undergraduate curriculum as there is a need for dentists to develop optimal skills during their training to meet the need for this treatment.[3] This is particularly relevant to newly qualifying dentists who are expected to manage the more complex restorative needs of an ageing, but increasingly dentate population.[2]

One fundamental aspect of tooth preparation is achieving an adequate taper or, as it is more accurately known, angle of convergence (AOC).[4] This is the angle formed between two opposing axial walls of a tooth prepared for a FVC and is a feature that directly influences the longevity of the final restoration.[4] Over-tapered abutments often result in reduced retention,[5] cement failure[6] and pulp devitalisation[7] whereas those that are under-tapered compromise structural durability, aesthetics and the patient's existing occlusion.[8] To prevent these complications from occurring various tapers have been suggested throughout the literature ranging between 4°–20°; however, a 6°–15° AOC is advised by staff to the dental students at the Cardiff Dental Hospital.[4,8,9] This range accounts for the inherent taper within crown preparation burs when held parallel to the long axis of the tooth,[8] allows the abutment to have adequate resistance and retention form,[5] permits tolerable seating and casting of the final restoration,[4] and prevents stress propagating throughout the cement.[6]

Currently, there are very few UK-based studies investigating the undergraduate compliance to these guidelines[10] with most reports being conducted in North American, European and Asian dental institutes. Such information

[1]Clinical Lecturer & Honorary Speciality Registrar in Restorative Dentistry Department of Restorative Dentistry, Birmingham Dental Hospital, Mill Pool Way, Birmingham, B5 7EG; [2]Consultant in Restorative Dentistry, Department of Restorative Dentistry, Cardiff Dental Hospital, Heath Park, Cardiff, CF14 4XY; [3]Senior Lecturer in Dental Technology and Biomaterial Sciences, Dental Education, Scholarship and Innovation, School of Dentistry, Cardiff University, Heath Park, Cardiff, CF14 4XY; [4]Professor of Restorative Dentistry, University Dental School & Hospital, University College Cork, Wilton, Cork, Ireland
*Correspondence to: Satnam Singh Virdee
Email: S.S.Virdee.1@bham.ac.uk

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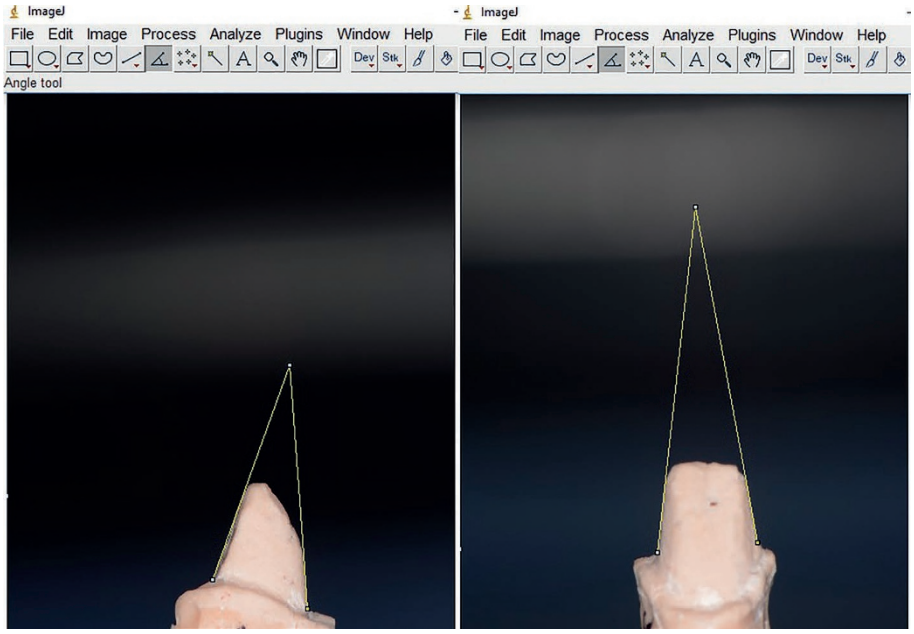

Fig. 1 Measuring the buccolingual and mesiodistal angles of convergence using the angle tool in ImageJ software

would provide valuable insight to educators of the standard and competency of local dental students, in relation to their international counterparts who often over-taper preparations,[11–13] in addition to evaluating outcomes of current teaching strategies. This could then be used for quality assurance, curricular development and to identify strategies educators could use to improve undergraduate compliance to the recommended range of taper.

Therefore primary aim of this study was to identify the average AOC accomplished by clinically supervised undergraduate dental students at the Cardiff Dental Hospital and the overall compliance to the guidelines. Secondly, to establish if the type of tooth, its intra and inter arch position or the final crown material had any significant impact on the overall AOC produced. The accepted standard was that the overall AOC/taper would fall within the recommended 6°–15° range.

Materials and methods

This study was conducted as an audit within the University Dental School & Hospital, Cardiff, and registered with the Dental Hospital Audit Committee. All information was collected anonymously. No identifying information in relation to the patient or student operator was recorded.

Sample selection

The aim of this project was to examine/audit the angle of convergence achieved by supervised undergraduate students on crown preparations from their own patients. At this point, all students included in this audit would have successfully completed a pre-clinical course in crowns, as well as an assessment which includes a crown preparation, before being allowed to provide patients with this treatment. Impressions were recorded using polyvinylsiloxane and a stock tray. The impressions were recorded by students who were treating their own patient. No special instructions, preparatory material or training, which would differ from that of the routine education of the dental programme, was provided to either supervising staff or students before the commencement of this study. The impressions were sent to the laboratory, disinfected and poured in ISO Type IV die stone. The dies were trimmed/sectioned by the staff in the in-house production laboratory, according to their in-house production protocol.

The stone dies of teeth prepared for FVCs were collected from the on-site laboratory at the Cardiff Dental Hospital. Any maxillary and mandibular teeth receiving full-metal (FMC), metal-ceramic (MCC) or full-ceramic (FCC) crowns between July and December 2016 were selected at random. Indirect post-core restorations and partial coverage crowns were excluded.

Measuring angle of convergence

The stone dies of FVCs were marked at the base in the mid most mesial, distal, buccal and lingual aspect and then mounted into a single 4 cm × 4 cm × 2 cm custom jig made from Aquasil Regular Set Silicone Putty (Dentsply, UK). Once stabilised, the markings were used to accurately rotate the models within the jig in the correct mesio-distal (MD) and bucco-lingual (BL) plane at a set distance (5 cm) away from the lens of a Nikon D7100 digital camera equipped with a MICRO NIKKOR 105 mm lens and Sigma ring flash (Nikon Imaging, UK). For each die a 'buccal and mesial' photograph was captured[14], under standardised settings (ISO100, 1/200, F25) and then uploaded onto the publically available ImageJ computer software system (National Institutes of Health, USA).

Using the 'angle tool' feature, straight lines were drawn on the outer- and mid-most aspect of opposing axial walls with each line extended coronally from the margin and eventually intersecting at a point above the occlusal surface (Fig. 1). The exact angle, subsequently created at this crossing, was automatically displayed in the user interface and recorded as the AOC into a piloted data capture form. Where there was more than one plane of reduction, the most gingival aspect was used and the software allowed the lines to extend and bisect past the confines of the

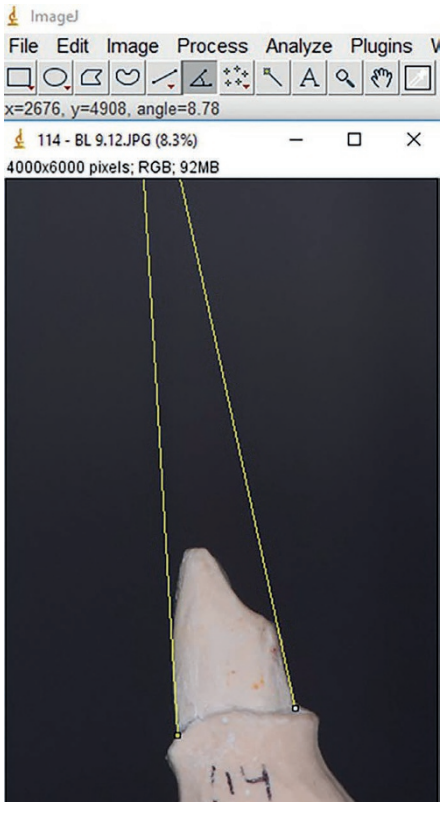

Fig. 2 Measuring the angle of convergence in preparations with two planes of reduction

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image which was particularly useful when measuring abutments with significantly small convergence angles (Fig. 2). Initially, the tapers created by the MD and BL axial walls were calculated, using the buccal and mesial images respectively[10–12,14,15] and then from these values, the overall AOC for each preparation was determined to the nearest single decimal point.

Data analysis

Initially the overall taper, variation and compliance was analysed for the whole sample. Stone dies were divided into several categories to compare the impact axial planes (MD versus BL), tooth morphology (incisor, canine, premolar & molar), crown material (FMC, PFM and FCC) and intra-arch (anterior versus posterior) and inter-arch position (maxilla versus mandible) of teeth had on the accomplished AOC. Differences between groups were tested for statistical significance at a 5% level of confidence.

Results

Sample characteristics

The total sample consisted of 125 preparations (100 MCCs, 25 FMCs). Molars (n = 50) were most commonly prepared teeth, followed by premolars (n = 39), incisors (n = 28) and canines (n = 8), with 81 of these teeth located in the maxilla and 44 in the mandible. Eighty-nine of the 125 preparations were of posterior teeth, while the remaining 36 were situated in anterior regions. The distribution of all preparations examined are summarised in Table 1.

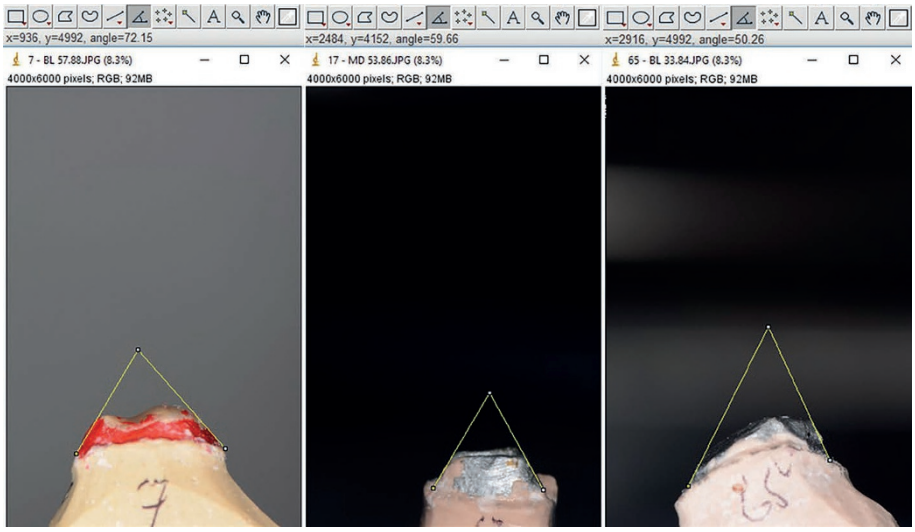

Fig. 3 Examples of over-tapered mandibular molars

Angle of convergence

Only 26.4% (n = 33) of all preparations included in this study fell within the recommended range of taper with the average AOC being 24.2° ± 11.95° and ranging between 5°–83°. The BL axial walls (23.0° ± 13.84°) were often found to be slightly less tapered than the MD walls (24.7° ± 15.53°) however, this difference was not considered to be statistically significant (p >0.05). On the other hand, the tooth type significantly (p <0.001) impacted the convergence angle produced with molars (31.6° ± 12.56°) displaying the greatest tapers and least compliance of all groups (8%), followed by premolars (20.7° ± 7.81°), canines (19.4° ± 6.37°) and then finally incisors (17.0° ± 9.62°). Additionally, teeth positioned in the mandible (28.8° ± 13.76°) and in posterior regions of the mouth (26.7° ± 12.00°) were significantly more tapered (p <0.05) than those located in the maxilla (21.7° ± 10.08°) and anteriorly (17.5° ± 9.00°). Full metal crown preparations (34.7° ± 15.10°), of which displayed the greatest mean taper, had significantly greater convergence angles than MCCs (21.6° ± 9.38°) (p <0.001). The results for all AOC comparisons can be found in Table 1.

Table 1 Distribution, average AOC, standard deviation and compliance of sample with statistical significance of subgroup comparisons

Groups		Sample(n)	Angle of convergence			
			Mean	Standard deviation	Compliance % (n)	Statistical significance
Total sample		125	24.2	11.95	26.4 (33)	N/A
Axial plane	M-D	125	24.7	15.53	28.8 (36)	P >0.05
	B-L	125	23.0	13.84	30.4 (38)	
Crown material	MCC	100	21.6	9.38	31.0 (31)	P <0.001
	FMC	25	34.7	15.10	8.0 (2)	
Tooth type	Incisors	28	17.0	9.62	57.1 (16)	P <0.001
	Canines	8	19.4	6.37	37.5 (3)	
	Pre-molars	39	20.7	7.81	25.6 (10)	
	Molars	50	31.6	12.56	8.0 (4)	
Inter-arch position	Mandible	44	28.8	13.76	11.4 (5)	P <0.05
	Maxilla	81	21.7	10.08	34.6 (28)	
Intra-arch position	Anterior	36	17.5	9.00	52.8 (19)	P <0.001
	Posterior	89	26.7	12.00	15.7 (14)	

Discussion

The mean taper in this study was found to be 24.2° ± 11.95°, demonstrating that a substantial proportion of FVCs prepared by undergraduate dentists in a clinically supervised setting, are often over-tapered and considerably varied. This is markedly greater than the 3°–14° range of taper recommended in fixed prosthodontics textbooks,[4] the 10°–20° suggested by Goodacre[9] and the 6°–15° taught at Cardiff Dental Hospital and therefore the standard was not met. Nevertheless, the results do correspond closely to other studies that have investigated convergence angles in similar cohorts. For instance, Noonan[12] who analysed 909 FVC

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abutments at the University of Colorado found an average AOC of 19.7°, while Aleisa[11] discovered this to be 18.4° at the University in Saudi Arabia. Additionally, Refeek[15] and colleagues at the University of West Indies reported tapers of 21.9° with considerable variation around the mean. Taking these findings into account, it is evident teeth prepared by dental students studying at dental institutes in the UK are comparable; if not slightly more over-tapered, to those prepared by their international peers. This notion is supported by Patel *et al.*[10] who conducted a similar study at the University of Sheffield, albeit almost 15 years ago, and reported an average AOC of 20.6° among undergraduate dentists.

In this study, molar teeth were shown to have the greatest AOC (31.6° ± 12.56°) ($p < 0.001$) and least compliance to the guidelines (8.0%), particularly those in the mandible (28.8° ± 13.76°) ($p < 0.05$) (Fig. 3). Strikingly similar results have been reported in the literature where Ghafoor found average tapers of 29.2° ± 10.90° in molars, 20.2 ± 8.37° in premolars and 18.8° ± 6.95° in anterior teeth.[16] Additionally, Kent concluded mandibular molars had the greatest convergence angles in contrast to maxillary anterior teeth.[17] This anterior to posterior trend of increasing AOC strongly correlates to the operator's ability to directly visualise and position the bur next to the teeth. Furthermore, the bulbosity of molars, their lingual inclination in the lower arch and the additional retraction required for the tongue could all be contributing reasons as to why mandibular teeth specifically are so frequently over-tapered and varied in quality.[18] These issues, predominately associated with access, could be overcome by ergonomic positioning of both the patient and operator.[19] Training students to use different seating positions could help them tackle problems related to tooth position and morphology during FVC preparation.

The lack of operator experience is often a common reason used to explain why undergraduate dentists over-taper teeth. However, the literature investigating this factor has found the average AOC of general dental practitioners (GDPs), and sometimes even specialists, to fall within a similar range. For example, Patel concluded there was no statistical significance between the convergence angles of fifth year dental students and GDPs who had in excess of 20 years' experience.[10] Similarly, Ghafoor[16] stated tapers of 22.7° from specialists in operative dentistry and there have even been reports of practitioners producing average convergence angles of up to 40.0°.[23] These findings suggest that past a certain level, experience may not be a crucial factor and that many of the operative skills required for such work may predominantly be attained throughout undergraduate training, emphasising the need for high quality education throughout this critical period. Conventional methods of pre-clinical teaching of preparation techniques include interactive television, didactic lectures, pre-recorded videos and multimedia live distant learning. However, Robinson & Lee[24] found undergraduates taught with real-time video magnification, via surgical microscope, produced mean tapers significantly lower ($p < 0.001$) for their first FVC preparation than any other group where this method was absent. This reinforces the need for educators to use more contemporary equipment to enhance the quality of education, particularly at a pre-clinical level where most operative skills are learnt.

Based on the findings of this study, patients undergoing treatment by undergraduate dentists are likely to be provided suboptimal FVCs with high convergence angles. Therefore, auxiliary retention enhancing strategies should be considered to improve clinical outcomes and longevity of the final restoration, especially when preparing mandibular molars. Resin cements in particular have been shown to overcome the retentive issues associated with over-tapered preparations, due to developments in their tensile and adhesive strengths,[25] and therefore should be used to cement FVCs when adequate moisture control can be achieved.[26] Additionally, teeth should be prepared to a minimum clinical crown height of 3 mm and retentive grooves incorporated into the preparation when the remaining tooth tissue permits.[27,28] Retentive pins have largely been superseded by resin cements but again can be used when there is a sufficient bulk of tooth tissue remaining.[8]

At present, significant variation exists within the literature on the methods employed to measure convergence angles due to the lack of a standard research model. In this study, the two-dimensional (2D) digital analysis software ImageJ was used due to its accessibility, ease of use and potential for becoming a valuable educational tool. As such, students at the Cardiff Dental Hospital are encouraged to evaluate their own preparations throughout the undergraduate programme via similar methods, which requires very little training at pre-clinical stages of the course. It is anticipated this will continually reinforce their visual understanding of what an ideal taper looks like and act as a self-reflective tool which will hopefully translate into higher quality FVC preparations.

Similar to the methods employed by Noonan[12] and Norlander,[29] who measured convergence angles using the silhouettes of images produced by overhead projectors and photocopier machines, this approach relies heavily on careful positioning of the die stone. Inaccurate placement could result in capturing an image that displays an AOC non-representative of the preparation. The custom silicone jig and the mid-most markings scribed onto the base of the die stone was designed to overcome this potential issue. However, if the pin of the abutment was placed in an incorrect orientation by the lab, such as not being consistent with the long axis of the tooth, then potential errors could still exist within the data.

One possible solution is using metrology equipment where optical laser probes extract three-dimensional (3D) coordinates on the surface of a sample stone die, and then mathematical formulas transform this data into a computer generated 3D computer image where linear, angular and volumetric measurements can be conducted.[11,15] This method, which was used by Rafeek,[15] is unique in that the software can place the image in a particular alignment within the 3D space to ensure the BL and MD angles can be calculated in the same plane and position for each stone die. This ultimately eliminates the potential errors in angle calculation that occur from misaligning the abutment and results in more accurate readings. However, the use of such an approach does require significant economical investment, specialised equipment, appropriate facilities and IT training than when compared to using 2D image analysis techniques.

Conclusions

Within the limitations of this study, it could be concluded the average AOC produced by undergraduate dentists at UK dental teaching hospitals are often varied and significantly greater than the range recommended within the literature. These findings are consistent with other American, European and Asian studies demonstrating the competence of dental students in the UK is similar to that of their international colleagues. Factors such as tooth type, anterior-posterior and inter-arch

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position and the final crown material were found to significantly impact convergence angles, with FMCs on mandibular molars displaying the greatest taper.

To improve compliance, laboratory teaching should employ contemporary methods of demonstrating preparation techniques, such as real-time video magnification. Additionally, greater emphasis needs to be placed on the teaching of ergonomic patient-operator positioning and the routine use of silicone indices. Auxiliary retentive strategies should be used to improve clinical outcomes for patients receiving FVCs from undergraduate dentists and when possible, further studies should use metrology equipment to attain more accurate measurements of convergence angles.

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