ORIGINAL ARTICLE

A Novel Methodology of Convergence Angle Assessment Using Professional Computer-Aided Design Software

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Abstract

Background: Convergence angle (CA) is a key determinant of tooth preparation quality, yet its ideal range is difficult to achieve and accurately measure in clinical settings. Existing research mainly reports CA within single experience groups and rarely evaluates operator or tooth related factors. This study introduces a novel 3D scanned methodology to assess CA in actual patient preparations, addressing gaps in previous literature. **Purpose of the study:** The purpose of the study is to evaluate the CA of coronal preparation of actual patients utilizing 3D digitally scanned models and professional computer-aided design (CAD) software. **Materials and Methods:** Dental stone casts were randomly collected from dental schools, dental laboratories, and general practices. Twenty ($n = 20$) preparations were randomly selected from the collected stone casts of each group of dental professionals (students, general practitioners, and restorative specialists). The stone casts were 3D scanned, digitized, and saved in standard tessellation language format, which was then imported into CAD software for evaluation by one operator to measure the CA in the digital model. Descriptive statistics, factorial multivariate analysis of covariance, and one-way analysis of covariance analyses were conducted on the data. **Results:** Adjusting for years of experience as a covariate, no significant difference was found in the main effect between levels of education regarding mesiodistal CA (MDCA), $P = 0.639$ and buccolingual CA (BLCA), $P = 0.156$ or in operators' sex in MDCA, $P = 0.898$ and BLCA, $P= 0.094$. The interactions between levels of education and operators' sex showed no significant difference in MDCA $P = 0.125$ and BLCA $P = 0.685$. There was a significant difference in the main effect between maxillary and mandibular teeth in MDCA ($P < 0.001$), while no difference was observed between maxillary and mandibular teeth in BLCA ($P = 0.115$). There was a significant difference in the main effect between the types of practices, MDCA ($P < 0.001$) and BLCA ($P < 0.001$). There was a significant difference in MDCA among the intended restoration materials ($P < 0.05$). However, no significant difference in BLCA was observed ($P = 0.416$) among the intended restoration materials. The Scheffe *post hoc* test indicated that zirconia differed from PFM but not from Emax ($P = 0.782$), and that PFM was not significantly different from Emax ($P = 0.132$). **Conclusion:** Educational level did not influence CA in teeth preparation performed by various levels of dental professionals. Years of experience as a covariate affected only BLCA. Premolars demonstrated the least CA, while molars showed the highest CA. Other factors, such as tooth type and operators' sex, did not affect CA. The intended restoration material and the type of clinical practice were found to influence the convergence angle (CA). **Clinical Significance:** Clinical accessibility and location in the mouth are the most critical factors for achieving optimal CA, regardless of educational level. Therefore, utilizing the described 3D digital technique will enhance visibility and accessibility, which are crucial for achieving the required and optimal CA.

Key words: 3D scan, restoration's materials, tooth preparation

INTRODUCTION

Convergence angle (CA) is one of the most important features of tooth preparation. They are sometimes known as the degree of taper of the walls of the prepared teeth. While dentists care about undercuts in their preparations, they sometimes over-taper the CA. Mechanical retention and resistance forms are affected by the CA.[1] Measurement of

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CA clinically in a patient's mouth is challenging without the proper tools and may not be that accurate. Optimal CA range between 2° and 5.5°.[2-5] The achievable range is between 6° and 24°.[6-10] Ideal CA is not easily achievable by dentists in the clinic. A more realistic range of achievable CA is 11–22°.[11] Among the methods of measuring the CA are photocopy machines, overhead projectors, goniometric microscopes, 3-D laser scanners, and diamond burs.[12-20] More recently, in literature, the mean CA was measured using digital methods or computer-aided design (CAD) software.[13,21-28]

Most literature reports the CA produced by one group or level of experiences, such as dental students,[12,14,19,21,24,27,29-31] general dentists,[15,23,32] or residents and specialists.[22,33] Few studies compared CA in two groups of experience levels.[13,16-18,20,22,34] Most of the comparisons were using traditional techniques for measuring CA. Several studies utilized 3D and CAD/computer-aided manufacturing methodology to evaluate the CA.[11,21,24,26,29,35,36] None of that literature compared CA with the operator's factors, such as experience level, years of experience, operator's sex, and type of practice. None of that literature compared the CA with operated tooth factors, such as tooth types. None yet compared CA in the intended prostheses types. Most of professional dental preparation evaluation software measured CA and compared them to ideal preparation in typodonts, comparing it to a model preparation.[24] The current study proposes a novel methodology and approach for processing and measuring the CA in scanned 3D models of actual patients' teeth preparations.

Objective of the study

This study aims to measure and compare the CA of coronal preparation of actual patients made by dental students, general practitioners, and restoratives' specialists in Jeddah, Saudi Arabia, utilizing 3D digitally scanned models and professional CAD software. It also seeks to determine which factors may influence the CA in clinical tooth preparation.

MATERIALS AND METHODS

This study was a cross-sectional observational retrospective study. Dental stone casts were collected randomly from dental schools, dental laboratories, and general and private practices in the Jeddah areas, for patients treated by students, general practitioners, and restoratives' specialists. Damaged casts were excluded from the study. Casts that had no identification of the operators' level of education who made the preparation were also excluded. The collected casts were further randomly selected so that a total of 20 crown preparations were selected for each level of education ($n = 20$). Years of operator's experience, level of education, operators' sex, practice type, tooth type, and intended type of prosthesis were noted for each tooth preparation.

The sample comprised a total of sixty preparations. The number of preparations for each factor is shown in Tables 1 and 2. Stone casts were die trimmed, ditched, 3D scanned, digitized, and saved in standard tessellation language (STL) format, using 3D cast scanner (Arctica, KAVO Dental).

The scanned models' STL files were then imported to the (MeshMixer, Autodesk Inc.,), where the mesh was segmented, cleaned, made as solid objects, and then reduced to the required facet size. A video that shows how the STL file was processed in MeshMixer is presented in the attached. Then, the mesh is imported into (Fusion360, AutoDesk Inc.,) where it is measured by one operator for CA on mesiodistal (MDCA) and buccolingual (BLCA) directions. A video shows how the mesh file was processed and angles were measured in Fusion360 is presented in the attached. Descriptive statistics, factorial multivariate analysis of covariance (MANCOVA), and analysis of covariance (ANCOVA) statistical analyses of the data were performed using the Statistical Package for the Social Sciences 25 software package, IBM. Years of experience were used as a covariate in the MANCOVA and ANCOVA analyses.

RESULTS

While controlling for years of experience as a covariate, the following results were reported.

Tables 1 and 2 show the mean, standard deviation, adjusted mean, and minimum and maximum of BLCA and MDCA in different factors.

Table 3 shows no significant difference in MDCA and BLCA in the main effect between levels of education $P = 0.639$, $P = 0.156$, operators' sex $P = 0.898$, $P = 0.094$. However, years of operators' experience as a covariate were not significant on MDCA, $P = 0.816$ and were significant in BLCA, $P = 0.022$. There were significant differences in the main effect between the type of practices, MDCA, $P < 0.001$ and BLCA, $P < 0.001$.

The interactions of the levels of education and the operators' sex showed no significant differences in MDCA $P = 0.125$, BLCA $P = 0.685$ Table 4. No significant differences for the main effect were found in MDCA and BLCA between tooth type, $P = 0.232$, $P = 0.199$ [Table 5].

There was a significant difference in MDCA between intended restoration materials $P = 0.006$. There was no significant difference in BLCA $P = 0.416$ between intended restoration materials [Table 6].

In Table 7, Scheffe *post hoc* test showed that zirconia was different from PFM but was not different from pressable

Table 1: Count, mean, and adjusted mean of mesiodistal convergence angles in various factors

Factor	Mesiodistal convergence angle	*n*	Mean	SD	Adjusted mean†	Minimum	Maximum
Operator's factors							
Level of education	Students	20	22.39	12.15	23.92	4.8	54.3
	General practitioners	20	26.32	15.99	30.16	−0.3.7	63.2
	Specialists	20	20.26	11.20	16.20	0.5	40.4
Operator's sex	Male	33	22.21	13.44	25.85	−3.7	63.2
	Female	27	23.95	13.3	20.87	0.5	54.3
Type of practice	Government	39	19.78	9.39	17.77	−3.7	41.7
	Private	21	28.95	17.22	32.69	6.5	63.2
Tooth's factors							
Tooth type	Central incisors	14	19.557	8.15	19.46	9.2	33.9
	Lateral incisors	12	23.96	10.75	23.91	0.5	40.4
	Canine	11	21.46	13.27	30.82	−3.7	42.1
	1st Premolar	6	17.70	10.13	21.67	4.8	30.3
	2nd Premolar	8	21.09	16.37	28.57	6.5	54.3
	1st Molar	6	30.92	16.37	35.35	12.1	57.4
	2nd Molar	3	40.53	23.49	35.04	16.3	63.2
Maxillary or mandibular	Maxillary	52	19.61	9.77	18.67	−3.7	40.4
	Mandibular	8	44.96	12.50	43.11	27	63.2
Intended restoration	E max	42	20.44	9.82	20.52	−3.7	40.4
	Zirconia	14	32.57	18.52	32.51	4.8	63.2
	PFM	4	16.28	9.44	15.61	7.7	28.5

†Adjusted means by covariate: Years of experience=6.52 years. Minus (−) sign indicates divergent angles. SD: Standard deviation

Table 2: Count, mean, and adjusted mean of buccolingual convergence angles in various factors

Factor	Buccolingual convergence angle	*n*	Mean	SD	Adjusted mean†	Minimum	Maximum
Operator's factors							
Level of education	Students	20	23.24	9.56	38.39	6.7	42.3
	General practitioners	20	28.75	22.56	34.40	−7.8	65.9
	Specialists	20	27.71	12.66	12.44	2.6	53.4
Operator's sex	Male	33	23.02	16.46	27.49	−7.8	65.9
	Female	27	30.89	14.15	26.84	−0.6	61.2
Type of practice	Government	39	21.26	13.81	17.08	−7.8	61.2
	Private	21	36.42	14.85	43.97	9.2	65.9
Tooth's factors							
Tooth type	Central incisors	14	27.40	15.76	27.05	−0.9	52.3
	Lateral incisors	12	29.24	18.1	29.08	−7.8	61.2
	Canine	11	22.11	11.87	30.61	6.4	40.5
	1st Premolar	6	14.07	11.12	9.07	−0.6	30.3
	2nd Premolar	8	31.30	11.86	32.26	14.4	51.0
	1st Molar	6	28.67	19.48	31.93	8.4	65.7
	2nd Molar	3	36.47	25.55	37.33	20.0	65.9
Maxillary or mandibular	Maxillary	52	25.18	13.95	23.76	−7.8	61.2
	Mandibular	8	35.56	24.27	33.24	−0.6	65.9
Intended restoration	E max	42	25.29	15.08	25.02	−7.8	61.2
	Zirconia	14	31.34	19.03	31.54	−0.6	65.9
	PFM	4	23.20	10.48	25.44	9.2	32.1

†Adjusted means by covariate: Years of experience=6.52 years. Minus (−) sign indicates divergent angles. SD: Standard deviation

Table 3: MANCOVA of operator's factors while controlling for years of experience as covariate

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared	Noncent. parameter	Observed power[c]
Corrected model	Convergence angle MD	3949.482[a]	8	493.685	3.889	0.001	0.379	31.109	0.978
	Convergence angles BL	8478.408[b]	8	1059.801	8.554	0.000	0.573	68.429	1.000
Intercept	Convergence angle MD	486.491	1	486.491	3.832	0.056	0.070	3.832	0.484
	Convergence angles BL	12.618	1	12.618	0.102	0.751	0.002	0.102	0.061
Years of experience	Convergence angle MD	6.973	1	6.973	0.055	0.816	0.001	0.055	0.056
	Convergence angles BL	689.422	1	689.422	5.564	0.022	0.098	5.564	0.638
Level of education	Convergence angle MD	114.630	2	57.315	0.451	0.639	0.017	0.903	0.120
	Convergence angles BL	477.036	2	238.518	1.925	0.156	0.070	3.850	0.381
Operator sex	Convergence angle MD	2.109	1	2.109	0.017	0.898	0.000	0.017	0.052
	Convergence Angles BL	359.921	1	359.921	2.905	0.094	0.054	2.905	0.387
Clinic type	Convergence angle MD	2354.902	1	2354.902	18.549	0.000	0.267	18.549	0.988
	Convergence angles BL	4695.441	1	4695.441	37.897	0.000	0.426	37.897	1.000
Level of education *operator sex	Convergence angle MD	308.234	1	308.234	2.428	0.125	0.045	2.428	0.333
	Convergence angles BL	20.557	1	20.557	0.166	0.685	0.003	0.166	0.068
Error	Convergence angle MD	6474.672	51	126.954					
	Convergence Angles BL	6318.968	51	123.901					
Total	Convergence Angle MD	42136.560	60						
	Convergence angles BL	57139.330	60						
Corrected total	Convergence angle MD	10424.154	59						
	Convergence angles BL	14797.376	59						

[a]R Squared=0.379 (Adjusted R squared=0.281). [b]R Squared=0.573 (Adjusted R squared=0.506). [c]Computed using alpha=0.05. Non-relevant interactions between subjects' tests were truncated for table to fit the page. BL: Buccolingual, MD: Mesiodistal, MANCOVA: Multivariate analysis of covariance. *The significant value is to show if there is significant difference between the result among male/ female.

Table 4: Interaction of Level of Education with Operator's Sex

5. Level of education *Operator's sex

Dependent variable	Level of education	Operator sex	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Convergence angle MD	Student	Male	21.564[a,b]	7.416	6.675	36.453
		Female	26.264[a,b]	7.416	11.375	41.153
	General Practitioner	Male	31.974[a]	3.824	24.297	39.651
		Female	26.524[a,b]	4.379	17.732	35.315
	Specialist	Male	17.887[a,b]	10.219	−2.628	38.402
		Female	15.353[a]	5.989	3.330	27.377
Convergence angles BL	Student	Male	35.947[a,b]	7.327	21.239	50.656
		Female	40.837[a,b]	7.327	26.129	55.546
	General Practitioner	Male	37.424[a]	3.778	29.841	45.008
		Female	28.362[a,b]	4.326	19.676	37.047
	Specialist	Male	−0.850[a,b]	10.095	−21.116	19.417
		Female	19.086[a]	5.917	7.208	30.964

[a]Covariates appearing in the model are evaluated at the following values: Years of Education=6.5167. [b]Based on modified population marginal mean. Minus (-) sign indicates divergent angles.

Table 5: MANCOVA of tooth's factors while controlling for years of experience as covariate

Source	Dependent variable	Type III Sum of squares	df	Mean square	F	Significance	Partial Eta squared	Noncent. parameter	Observed power[c]
Corrected model	Convergence angle MD	5509.049[a]	12	459.087	4.390	0.000	0.528	52.680	0.998
	Convergence angles BL	3867.583[b]	12	322.299	1.386	0.206	0.261	16.631	0.667
Intercept	Convergence angle MD	8322.943	1	8322.943	79.587	0.000	0.629	79.587	1.000
	Convergence angles BL	5582.613	1	5582.613	24.006	0.000	0.338	24.006	0.998
Years of experience	Convergence angle MD	23.176	1	23.176	0.222	0.640	0.005	0.222	0.075
	Convergence angles BL	283.500	1	283.500	1.219	0.275	0.025	1.219	0.191
Tooth type	Convergence Angle MD	882.167	6	147.028	1.406	0.232	0.152	8.436	0.494
	Convergence angles BL	2091.148	6	348.525	1.499	0.199	0.161	8.992	0.524
Maxillary or mandibular	Convergence angle MD	3138.279	1	3138.279	30.009	0.000	0.390	30.009	1.000
	Convergence angles BL	598.516	1	598.516	2.574	0.115	0.052	2.574	0.349
Tooth type *maxillary or mandibular	Convergence angle MD	297.291	4	74.323	0.711	0.589	0.057	2.843	0.213
	Convergence angles BL	1317.008	4	329.252	1.416	0.243	0.108	5.663	0.406
Error	Convergence angle MD	4915.105	47	104.577					
	Convergence angles BL	10929.793	47	232.549					
Total	Convergence angle MD	42136.560	60						
	Convergence angles BL	57139.330	60						
Corrected total	Convergence angle MD	10424.154	59						
	Convergence angles BL	14797.376	59						

[a]R Squared=0.528 (Adjusted R squared=0.408). [b]R squared=0.261 (Adjusted R squared=0.073). [c]Computed using alpha=0.05.
BL: Buccolingual, MD: Mesiodistal, MANCOVA: Multivariate analysis of covariance. *The significant value is to show if there is significant difference between the result among mandibular / maxillary tooth.

Table 6: ANCOVA of intended prosthesis type factor while controlling for years of experience as covariate

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Significance	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Corrected model	Convergence angle MD	1760.283[a]	3	586.761	3.793	0.015	0.169	11.378	0.788
	Convergence angles BL	667.200[b]	3	222.400	0.881	0.456	0.045	2.644	0.230
Intercept	Convergence angle MD	6575.470	1	6575.470	42.501	0.000	0.431	42.501	1.000
	Convergence angles BL	6081.564	1	6081.564	24.102	0.000	0.301	24.102	0.998
Years of experience	Convergence angle MD	20.642	1	20.642	0.133	0.716	0.002	0.133	0.065
	Convergence angles BL	234.346	1	234.346	0.929	0.339	0.016	0.929	0.157
Intended prosthesis	Convergence angle MD	1743.909	2	871.954	5.636	0.006	0.168	11.272	0.841
	Convergence angles BL	449.949	2	224.975	0.892	0.416	0.031	1.783	0.196
Error	Convergence angle MD	8663.871	56	154.712					
	Convergence angles BL	14130.177	56	252.325					
Total	Convergence angle MD	42136.560	60						
	Convergence angles BL	57139.330	60						
Corrected total	Convergence angle MD	10424.154	59						
	Convergence angles BL	14797.376	59						

[a]R squared=0.169 (Adjusted R squared=0.124). [b]R squared=0.045 (Adjusted R squared=−0.006). [c]Computed using alpha=0.05.
BL: Buccolingual, MD: Mesiodistal, ANCOVA: Analysis of covariance

Table 7: Scheffe's *post hoc* test for intended prosthesis type in mesiodistal convergence angle

Convergence angle MD			
Material of intended prosthesis	n	Subset for alpha=0.05	
		1	2
Scheffe[a,b]			
PFM	4	16.275	
Pressable ceramic (Emax)	42	20.436	20.436
Zirconia	14		32.571
Significance		0.782	0.132

Means for groups in homogeneous subsets are displayed. [a]Uses harmonic mean sample size=8.690. [b]The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed. MD: Mesiodistal

ceramic (Emax), $P = 0.782$; and PFM was not different from pressable ceramic (Emax), $P = 0.132$.

DISCUSSION

The hypothesis was rejected for the operator's factors, operated teeth factors, and intended prostheses' types. The level of education, and operator's sex, each factor alone, did not affect neither MDCA nor BLCA of the tooth preparations, which was in agreement with several studies that compared various experience levels.[13,18,22] Mean CA was similar and within the range recorded by several previous studies of CA by conventional silhouette or protractor methods.[11-13,15-18,33,36] Though, type of practice showed a significant difference in Mesial, Distal convergence angle (MDCA) and Bucca, Lingual convergence angle (BLCA) between private practice and government practice. One study compared CA produced by male and female students and showed no difference between them, which is similar to what is shown by the current study.[29] The ranges of previous studies of the mean CA fall within the range of adjusted means of CA in the current study are 15.61–43.11°.[11,21-23,26,27,29,31]

Although tooth type in its original angle of unprepared surfaces may dictate the CA, there was no significant main effect for tooth type. Another observation is that smaller CA levels are recorded for the first premolars. That could be attributed to the premolars' location, in the corner of the mouth, and their unprepared surface parallelism. The highest recorded CA was for the second molar teeth. That indicates that accessibility and visual accessibility factors like indirect vision and position of operator and tooth location in the mouth may play an important role in CA levels. When operators prepare teeth for zirconia prostheses, they tend to produce significantly higher MDCA than with PFM prostheses. That is understandable since the overall preparations for zirconia are more reduced compared to PFM, where dentists usually tend to prepare PFM conservatively and often become under-reduced preparations with the resultant over-contoured prosthesis. Measurement of scanned tooth preparation using this technique requires about 5–18 min per tooth. There is a learning curve. Once a workflow is established by the operator, the time spent on the measurement will be reduced significantly. To ensure a high-level intra-examiner reliability, only one person measured the same tooth angles twice within 2 weeks. In the current study, dental students, general practitioners, and specialists were included with years of experience ranging from 3 to 13 years. Higher years of experience, more than 13 years, may show a significant difference between levels of experience. Retrospective studies have their limitations, and the current study suggests that it is not sufficient to say the level of education alone did not affect CA; years of experience may be a confounding factor that has not been taken into consideration in previous CA comparative studies in the literature. The location of the tooth in the mouth affects its accessibility of the tooth. Future research may include more samples from other populations, nationally and internationally, and more operators' factors, and other accessibility factors.

CONCLUSION

Within the limitations of this study, it can be concluded that:
1. While controlling for years of experience, level of education alone did not affect CA in teeth preparation made by various dental professionals
2. Premolars had the least CA, whereas molars had the highest CA due to better accessibility
3. MDCA was affected by the accessibility and tooth location in the mouth
4. Other factors like tooth type and operators' sex, alone, did not affect CA
5. The planned or intended prosthesis type affected MDCA but not BLCA
6. Type of practices, government or private affected both MDCA and BLCA.

FUTURE DIRECTION

Further studies to investigate the impact of various techniques and armamentariums on tooth preparation.

ETHICAL APPROVAL

The research proposal was exempted by the Institutional Review Board of King Abdulaziz University, as the study was conducted as an *in vitro* experiment.

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DATA AND MATERIALS AVAILABILITY

All data associated with this study are present in the paper.

*This study followed EQUATOR guidelines.

SOURCE OF SUPPORT

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CONFLICTS OF INTEREST

None declared.

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