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RESEARCH AND EDUCATION

Reporting numeric values of complete crowns. Part 1: Clinical preparation parameters

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ABSTRACT

Statement of problem. An implemented objective measuring system for measuring clinical tooth preparations does not exist.

Purpose. The purpose of this study was to compare clinically achieved tooth preparations for ceramic crowns by general dentists with the recommended values in the literature with an objective measuring method.

Material and methods. Two hundred thirty-six stone dies prepared for anterior and posterior complete ceramic crown restorations (IPS e.max Press; Ivoclar Vivadent) were collected from dental laboratories. The dies were scanned and analyzed using the coordinate geometry method. Cross-sectioned images were captured, and the average total occlusal convergence angle, margin width, and abutment height for each preparation was measured and presented with associated 95% confidence intervals.

Results. The average total occlusal convergence angles for each tooth type was above the recommended values reported in the literature. The average margin widths (0.40 to 0.83 mm) were below the minimum recommended values (1 to 1.5 mm). The tallest preparations were maxillary canines (5.25 mm), while the shortest preparations were mandibular molars (1.87 mm).

Conclusions. Complete crown preparations produced in general practice do not achieve the recommended values found in the literature. However, these recommended values are not based on clinical trials, and the effects of observed shortfalls on the clinical longevity of these restorations are not predictable. (J Prosthet Dent 2015;114:67-74)

Patients routinely receive complete crowns as a fixed restorative treatment. Common practice requires that tooth preparation principles are used before crown placement to promote the retention and resistance of the restoration. But do clinicians routinely create ideal crown preparations? The answer is uncertain. Even if clinicians are willing to measure their work, an implemented system for objectively measuring crown preparations does not exist.

Available today are clinical recommendations derived from the early works of Prothero[1] and Jorgensen.[2] The total occlusal convergence (TOC) angle is a combined angle of 2 opposite axial walls in a given plane.[3] This attribute is considered to have a direct influence on the retention of the crown with a significant reduction in retention after approximately 5 degrees.[2] The recommended values based on in vitro testing have ranged from as low as 2 degrees to 12 degrees for optimal retention and resistance form.[1,2,4-7]

The achievability of recommended values were first reported in 1978.[8] Dies prepared by dental students were found to have TOC values of approximately 20 degrees. These dies were measured by projecting the silhouette of the die and tracing around the shadow, with the axial walls extrapolated to measure the TOC angle. A large number of studies have tested the clinical achievability described with their associated measuring methods, which can be traced to those original investigators.[8-31] In recent years, the measuring methods have evolved from measuring a silhouette of

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Clinical Implications

Clinical trials should report crown preparation parameters by using an objective measuring method to make clinically relevant decisions regarding crown preparations.

a preparation to digital means as described in a recent review.[32] This technology has become a valuable restorative technique and a useful tool in obtaining quantifiable data.

Conventional crown preparation recommendations were originally based on cemented metal-based restorations that considered zinc-based cements as the reference standard. Currently, manufacturer recommendations for ceramic crowns are approximately 12 degrees TOC with a minimum of 1 to 1.5 mm margin width to maintain sufficient ceramic thickness (Ivoclar Vivadent; Vita Zahnfabrik H. Rauter GmbH & Co KG).

Teeth are complex and vary between each other, and a ceramic crown restoration is influenced by multivariate conditions.[33] In terms of geometry, the TOC, margin width, and abutment height are assumed to act and influence each other in maximizing the retention and resistance of the crown. Lacking in the literature are clinical studies that measure all these parameters and a single universal method of testing these parameters for ceramic restorations. To address this need for an objective measuring method, the coordinate geometry method was formulated with a set of rules that have been outlined elsewhere.[34] In this study, a custom program was developed to automate many of the calculations in the methodology in order to apply the method to a large sample size.

With such a tool, a comprehensive analysis of crown preparations is presented in 2 parts by using descriptive statistics. Part 1 reports geometric parameters obtained from complete crown preparations. Part 2 applies commonly accepted retention and resistance form theories for this sample. This study also proposes a guide to future reporting methods on the geometry parameters of crown preparations.

MATERIAL AND METHODS

Two hundred sixty-two second-poured complete crown preparations prepared for ceramic restorations (IPS e.max Press; Ivoclar Vivadent) were collected from dental laboratories located in towns and cities in efforts to represent the population of New Zealand. The period of collection was at each laboratory's discretion, and all 262 specimens were pooled to eliminate any laboratory identifiers. Excluded from the pool were 26 specimens that displayed a negative or flat abutment height. These were deemed unconventional and eliminated after examination by an experienced specialist (B.A.).

A single technician (J.T.) prepared each specimen by exposing the finish lines, and each specimen was scanned in 3 dimensions (3D) (CeraMill map400; AmannGirrbach). Stereolithography (STL) data sets were extracted from the software and inserted into a general purpose 3D viewer (3D-Tool-Free; http://www.3d-tool-usa.com). Two cross-sectional images from each preparation were captured (faciolingual view [FL] and mesiodistal view [MD]) with the 2 planes 90 degrees around the assumption of a central axis. The images were uploaded into the custom computer software which tracked the outlines into x- and y-coordinates. By using prewritten formulae, the software was able to select specific points from which the geometric parameters were calculated.[34]

The software output the values for the geometric parameters, and the values were grouped according to tooth type.[35] This study used descriptive statistics to display the average TOC angle for 2 cross sections (FL and MD), margin width for 4 sides (facial, lingual, mesial, and distal), and abutment height for 4 sides (facial, lingual, mesial, and distal) with their associated confidence intervals.

RESULTS

The number of maxillary specimens (n=185) was greater than the number of mandibular specimens (n=51). The greatest number of preparations was for the maxillary left central incisor (n=30), and the least number collected was for the mandibular central incisors, mandibular right lateral incisor, mandibular canines, mandibular left premolars, and right second molar teeth (n=1).

Mean TOC and 95% confidence intervals for each tooth are displayed in Table 1 with pooled TOC values by type of tooth, as seen in Figure 1. All mean TOC values are greater than the values recommended by Shillingburg et al[36] and the recommendations provided by manufacturers.

The mean TOC values for both FL and MD views on maxillary premolars were similar, except for the MD view the maxillary right first premolar (TOC=43.89 degrees). The greatest mean TOC value was found on the maxillary left second molar (TOC=74.49 degrees, n=4). Maxillary posterior preparations had larger confidence intervals compared to maxillary anterior preparations. Mean TOC values were lower for mandibular posterior preparations compared to maxillary preparations.

The marginal width with their associated confidence intervals for each tooth is displayed in Table 2 with pooled values as seen in Figure 2. The lingual aspect of the maxillary left second molar and the distal aspect of the left mandibular third molar had mean margin widths of 1.29 mm and 1.11 mm. All other mean margin widths were below 1 mm.

Table 1. Total occlusal convergence angles for each tooth prepared by general dentists

Tooth Type	Molars		Premolars		Canines	Incisors		Incisors		Canines	Premolars		Molars		
Maxilla															
Tooth	17	16	15	14	13	12	11	21	22	23	24	25	26	27	
n	5	5	16	9	13	21	29	30	15	9	8	7	15	4	
FL															
Mean	51.28	30.19	29.90	28.54	46.08	38.74	43.60	42.83	36.92	46.17	23.53	33.83	37.68	74.49	
SD[a]	32.05	9.66	14.24	11.02	7.86	8.48	7.94	9.55	6.13	6.59	11.02	9.35	15.88	27.57	
95% CI	±28.10	±8.47	±6.98	±7.20	±4.27	±3.63	±2.85	±3.42	±3.10	±4.30	±7.64	±6.93	±8.04	±27.02	
MD															
Mean	52.30	52.35	28.87	43.89	26.30	22.89	29.47	27.68	23.13	20.93	26.91	28.36	38.92	53.09	
SD[a]	28.14	11.17	13.88	17.23	14.57	9.43	10.15	10.40	7.80	10.62	15.44	11.68	17.34	27.46	
95% CI	±24.67	±9.79	±6.80	±11.25	±7.92	±4.03	±3.70	±3.72	±3.95	±6.94	±10.70	±8.65	±8.78	±26.91	
Mandible															
Tooth	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
n	1	7	6	3	1	1	1	1	2	1	1	1	12	11	2
FL															
Mean	37.44	42.12	48.20	56.69	36.17	40.21	37.01	22.83	28.61	47.96	15.85	35.81	49.85	48.54	60.53
SD[a]		25.44	36.58	20.63					7.79				23.41	18.43	24.34
95% CI		±18.84	±29.27	±23.34					±10.80				±13.25	±10.89	±33.73
MD															
Mean	48.06	51.73	34.43	48.35	27.55	20.63	22.87	15.09	21.74	23.92	18.17	58.78	48.08	46.34	68.30
SD[a]		15.93	15.59	5.67					13.43				17.19	18.89	11.72
95% CI		±11.80	±12.48	±6.41					±18.61				±9.73	±11.16	±16.25

FL, faciolingual; MD, mesiodistal; CI, confidence interval.
[a]Standard deviation for total occlusal convergence angle is shown for comparative purposes with previous studies.

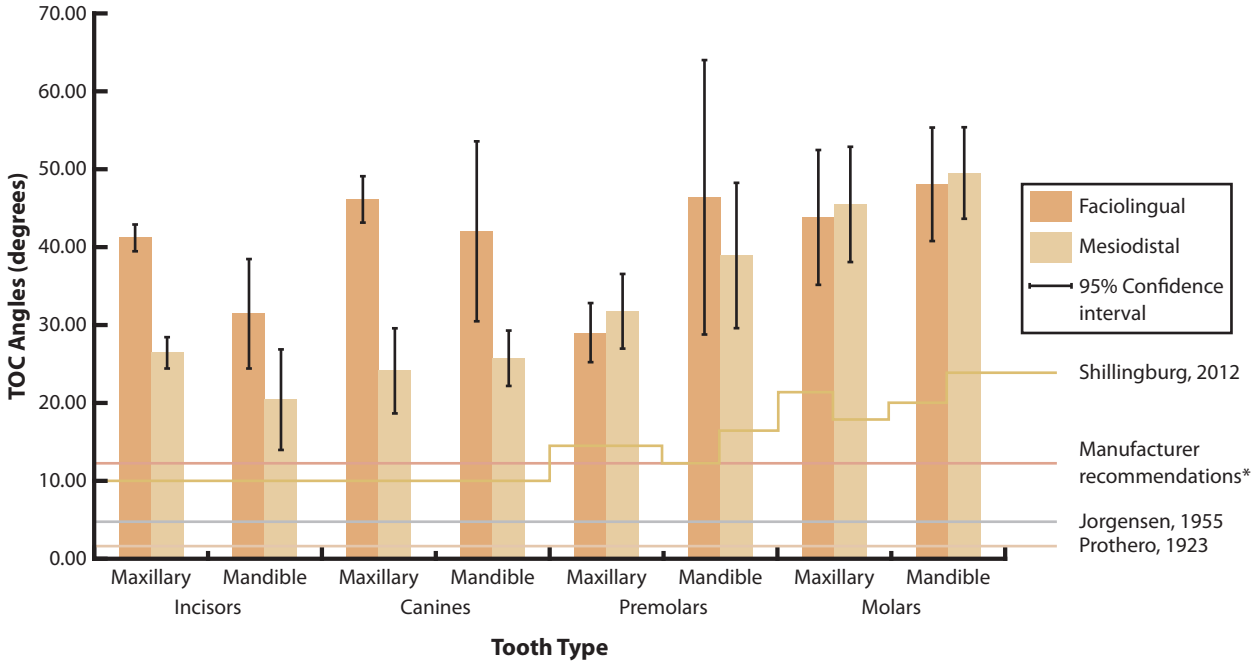

Figure 1. Mean total occlusal convergence angles with 95% confidence intervals grouped into type of teeth and compared to recommended values found in literature. *All-ceramic (Ivoclar Vivident).

The height of preparations and associated confidence intervals for each tooth is provided in Table 3, with pooled values as seen in Figure 3. Maxillary canines had the highest mean height (5.25 mm), with mandibular molar preparations displaying the shortest mean height (1.87 mm). The facial aspect of every tooth had the highest mean abutment height compared to the other views (lingual, mesial, and distal). The mean abutment

Table 2. Margin width (mm) for each tooth prepared by general dentists

Tooth Type	Molars		Premolars		Canines	Incisors		Incisors		Canines	Premolars		Molars		
Maxilla															
Tooth	17	16	15	14	13	12	11	21	22	23	24	25	26	27	
n	5	5	16	9	13	21	29	30	15	9	8	7	15	4	
F															
Mean	0.62	0.81	0.54	0.65	0.52	0.45	0.54	0.49	0.51	0.62	0.52	0.49	0.53	0.69	
95% CI	±0.24	±0.55	±0.10	±0.19	±0.14	±0.09	±0.09	±0.09	±0.10	±0.14	±0.19	±0.17	±0.10	±0.34	
L															
Mean	0.70	0.47	0.55	0.47	0.55	0.56	0.64	0.74	0.70	0.59	0.40	0.53	0.63	1.29	
95% CI	±0.21	±0.13	±0.08	±0.13	±0.12	±0.08	±0.07	±0.15	±0.13	±0.24	±0.15	±0.16	±0.19	±0.79	
D															
Mean	0.79	0.54	0.49	0.58	0.49	0.50	0.60	0.59	0.49	0.50	0.63	0.82	0.68	0.38	
95% CI	±0.16	±0.25	±0.07	±0.23	±0.11	±0.09	±0.12	±0.10	±0.08	±0.24	±0.13	±0.28	±0.18	±0.15	
M															
Mean	0.57	0.56	0.62	0.65	0.50	0.46	0.62	0.67	0.61	0.48	0.61	0.82	0.76	0.97	
95% CI	±0.18	±0.23	±0.13	±0.17	±0.07	±0.08	±0.11	±0.11	±0.12	±0.10	±0.22	±0.39	±0.24	±0.76	
Overall mean	0.67	0.60	0.55	0.59	0.52	0.49	0.62	0.62	0.58	0.55	0.54	0.67	0.65	0.83	
Mandible															
Tooth	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
n	1	7	6	3	1	1	1	1	2	1	1	1	12	11	2
F															
Mean	0.73	0.69	0.66	0.71	0.78	0.62	0.18	0.47	0.48	0.74	0.57	0.51	0.64	0.67	0.73
95% CI		±0.18	±0.30	±0.31					±0.01				±0.15	±0.32	±0.54
L															
Mean	0.48	0.67	0.65	0.72	0.39	0.33	0.56	0.18	0.33	0.50	0.54	0.36	0.60	0.57	0.37
95% CI	±0.32	±0.29	±0.14						±0.32				±0.15	±0.18	±0.26
D															
Mean	0.82	0.81	0.79	0.66	0.22	0.33	0.45	0.42	0.71	0.66	0.40	0.51	0.86	0.80	1.11
95% CI		±0.31	±0.22	±0.12					±0.42				±0.13	±0.20	±0.72
M															
Mean	0.61	0.77	0.82	0.65	0.77	0.58	0.40	0.58	0.60	0.88	0.47	0.39	0.73	0.89	0.64
95% CI		±0.17	±0.30	±0.06					±0.10				±0.22	±0.40	±0.52
Overall mean	0.66	0.74	0.73	0.69	0.54	0.47	0.40	0.41	0.53	0.70	0.50	0.44	0.71	0.69	0.71

F, facial; L, lingual; D, distal; M, mesial; CI, confidence interval.

heights for the mesial and distal aspects for each tooth are lower than those of the facial and lingual aspects.

DISCUSSION

This study presents the results of TOC, margin width, and abutment height measurements made from clinically produced preparations for lithium disilicate-based ceramic complete crowns. The values show a significant discrepancy between the clinical situations and recommended values.

The average TOC values were above the manufacturer recommended values of 12 degrees. It was evident the FL cross sections of maxillary incisors were naturally shaped in a way that prevented the 12 degrees TOC from being achieved. A preparation following the natural taper of an incisor would produce a corresponding greater TOC angle. Results confirm this inspection, showing that all maxillary anterior specimens had an average FL cross section with higher TOC values compared to the average MD cross-sectional TOC values. Premolars and molars for both maxillary and mandibular preparations displayed similar average TOC values between the 2 cross-sectional views. Posterior teeth appear to be more uniform and cubelike in both views compared to anterior teeth, which appear flatter. Mandibular incisors show a wider confidence interval; however, only 5 dies were included in this sample as opposed to the maxillary incisors (n= 94). The greatest mean TOC was for the right maxillary second molar (74.49 degrees, 95% confidence interval=27.02, n=4). Teeth with low number of specimens are not representative of the respective preparations by dentists in New Zealand.

More studies have been published on the TOC angle than any other parameter, which reflects the emphasis on this parameter for clinical success. Almost all previous

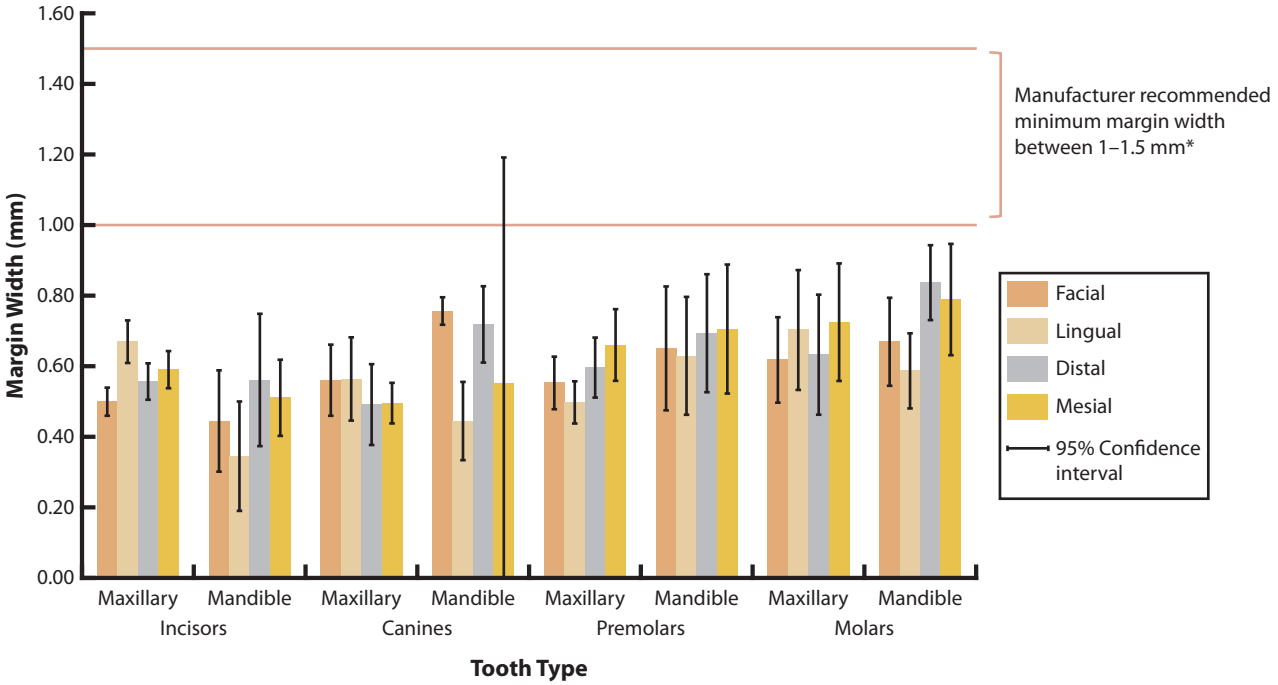

Figure 2. Mean margin width with 95% confidence intervals grouped into type of teeth and compared to current recommendations. *Ceramic (Ivoclar Vivident).

studies published report mean TOC angles above recommendations found in the literature. This report in particular observed high TOC angles for maxillary and mandibular molars. There are previous studies that also provide similar values (27.03 degrees, SD=15.00;[25] 30.44 degrees, SD 10.61;[18] 37.20 degrees, SD=13.50[11]).

The margin width values were below manufacturer recommendations for lithium disilicate ceramic crowns (1.0 to 1.5 mm). Many of the marginal widths fell within a range of 0.4 to 0.6 mm (Fig. 2), a range commonly associated with preparations for complete metal crowns. Although many preparations had margins short of the recommended values, there was a limitation given the size of the original tooth. Mandibular incisors and maxillary lateral incisors are smaller teeth, and a minimum margin of 1 mm would have taken too much existing tooth forms away. Clinicians are apparently conservative when it comes to crown preparation margin widths.

The clinician has the least control over the height of the preparation. The tooth requiring restoration may have previous damage that must be removed. In consideration of this, a general pattern of longer anterior preparations compared to posterior preparations must be considered. Previous studies measuring preparation height show a range of measurements but cannot be compared because the definition of height has not been adequately addressed.[16,19,28] The methodology in this study allows the height to be differentiated at different areas of the preparations. The height was higher for facial areas compared to mesial, distal, and lingual areas across all types of tooth preparations. The margin angle and abutment width are parameters that may be measured by the coordinate geometry method; however, these parameters were omitted in the current study.

The authors do not know how many dentists contributed to the specimen collection or whether the value constitutes an ideal representation of clinicians. The TOC values presented were far beyond the recommendations presented in the literature and under prepared for margin width. Findings in this study and others confirm that the recommended values for single bonded ceramic crowns may need to be revised.

The software used in this study may be developed for further measurements. If all future studies were performed in such a way, methodological differences would be negligible, allowing for meta-analysis. Currently the articles published have described many different methods, and because of this, the values cannot be easily compared.

The numeric values produced in this study can be used as a base for future studies, including in vitro testing. Many in vitro studies simulate TOC values up to a 32-degree maximum.[37-39] From this study, 32 degrees does not represent the upper limit of TOC values of preparations, which are in reality much higher. What happens to the resulting restoration when TOC is greater is unknown. Moreover, research is needed to test all these parameters together and to test how they influence each other and the resulting survival of the crown.

Table 3. Abutment height (mm) for each tooth prepared by general dentists

Tooth Type	Molars		Premolars		Canines	Incisors		Incisors		Canines	Premolars		Molars		
Maxilla															
Tooth	17	16	15	14	13	12	11	21	22	23	24	25	26	27	
n	5	5	16	9	13	21	29	30	15	9	8	7	15	4	
F															
Mean	3.39	2.58	4.43	4.99	7.08	6.06	6.26	6.20	5.97	6.69	4.51	3.61	4.11	2.69	
95% CI	±1.23	±1.91	±0.74	±1.19	±0.72	±0.48	±0.38	±0.36	±0.38	±0.76	±1.06	±0.61	±0.64	±0.63	
L															
Mean	2.67	4.05	3.01	3.41	5.69	4.39	4.95	4.56	4.52	4.32	3.01	2.79	3.05	2.33	
95% CI	±0.77	±0.61	±0.51	±1.04	±0.64	±0.55	±0.42	±0.73	±0.60	±0.87	±0.70	±0.63	±0.39	±0.51	
D															
Mean	2.79	2.56	2.21	1.85	4.06	4.08	3.74	3.73	3.77	4.06	2.41	2.46	2.64	2.63	
95% CI	±0.67	±0.67	±0.49	±0.49	±0.39	±0.56	±0.44	±0.38	±0.36	±0.56	±0.45	±0.81	±0.55	±0.51	
M															
Mean	1.93	2.86	2.96	2.56	4.18	4.26	3.95	3.71	4.01	3.79	2.34	2.19	2.58	1.82	
95% CI	±0.48	±0.69	±0.73	±0.55	±0.51	±0.56	±0.43	±0.38	±0.39	±0.59	±0.66	±0.59	±0.48	±0.20	
Overall mean	2.70	3.51	3.15	3.20	5.25	4.70	4.73	4.55	4.57	4.72	3.07	2.76	3.10	2.37	
Mandible															
Tooth	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
n	1	7	6	3	1	1	1	1	2	1	1	1	12	11	2
F															
Mean	3.12	3.48	3.52	3.38	6.24	4.37	4.04	3.90	4.74	4.86	5.92	5.57	3.99	3.64	3.20
95% CI		±1.07	±1.16	±0.39					±1.03				±1.16	±0.47	±0.98
L															
Mean	1.72	1.92	2.13	2.61	5.50	4.82	4.06	3.26	3.57	3.87	4.60	1.72	2.85	2.52	2.28
95% CI		±0.74	±0.68	±0.75					±1.72				±0.94	±0.56	±1.66
D															
Mean	0.76	2.76	2.58	3.12	4.85	3.79	3.43	4.12	4.24	2.39	1.98	2.62	2.76	2.15	1.81
95% CI		±0.68	±0.46	±0.32					±0.67				±0.62	±0.49	±0.38
M															
Mean	1.86	2.47	1.69	1.62	2.43	3.55	3.32	2.82	3.98	3.09	3.24	2.00	2.14	2.69	2.26
95% CI		±0.52	±0.51	±0.17					±0.52				±0.48	±0.48	±0.59
Overall mean	1.87	2.66	2.48	2.68	4.76	4.13	3.71	3.53	4.13	3.94	3.94	2.98	2.94	2.75	2.39

F, facial; L, lingual; D, distal; M, mesial; CI, confidence interval.

Another consideration is that the current recommendations of a 12-degree TOC and a 1 mm margin may need to be reinvestigated and updated to a more clinically achievable value. Teeth are complex and unique, and no tooth should be subjected to the same recommended values. Each tooth needs its own clinically recommended value that is adjusted to the capacity of the tooth.

The authors recommend that future in vitro and in vivo studies involving the measuring of tooth preparations be prepared and reported in a manner similar to this study. Points to consider include the following: specifying the material and type of crown (in this report, all preparations have been prepared for ceramic lithium disilicate complete crowns); type of cement used; type of tooth (for example, ISO 3950 or FDI system, which specifies the exact tooth and position in arch); number of specimens, reporting the means and confidence intervals; reporting the major parameters of TOC, margin width, abutment height, and abutment width; and reporting for each cross section or side (for example, TOC, both the FL and MD views are specified and reported separately, margin width of mesial, distal, facial, and lingual margins).

Furthermore, future clinical trials should include the recording of preparation parameters for each individual preparation. Bringing this to practice would help standardize survival decisions.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. Software is a useful tool for measuring crown preparation geometries. The TOC angles from preparations produced in general practices have values that are much higher than those recommended in the literature, the average width of

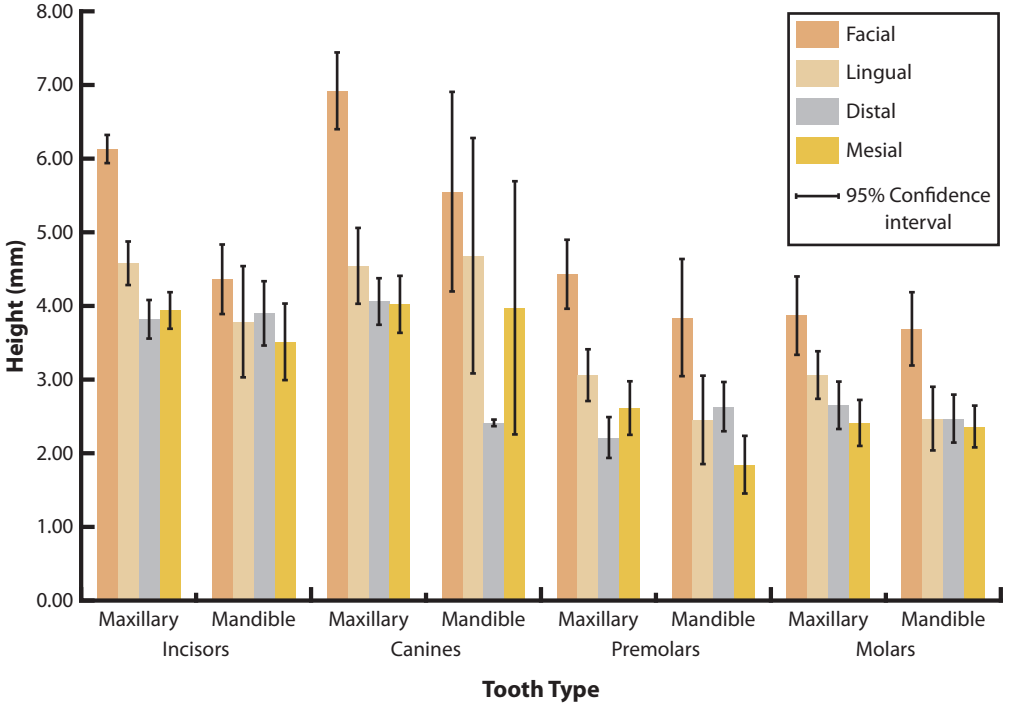

Figure 3. Mean abutment height values with 95% confidence intervals for each tooth.

marginal reduction on all teeth is greatest on facial surfaces, and all margin widths fall short of the minimum recommended 1 to 1.5 mm.

2. Predicting the effects of the observed shortfalls on the clinical longevity of restorations is impossible without clinical trials implementing an objective measuring method.

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