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SYSTEMATIC REVIEW

Clinical tooth preparations and associated measuring methods: A systematic review

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ABSTRACT

Statement of problem. The geometries of tooth preparations are important features that aid in the retention and resistance of cemented complete crowns. The clinically relevant values and the methods used to measure these are not clear.

Purpose. The purpose of this systematic review was to retrieve, organize, and critically appraise studies measuring clinical tooth preparation parameters, specifically the methodology used to measure the preparation geometry.

Material and methods. A database search was performed in Scopus, PubMed, and ScienceDirect with an additional hand search on December 5, 2013. The articles were screened for inclusion and exclusion criteria and information regarding the total occlusal convergence (TOC) angle, margin design, and associated measuring methods were extracted. The values and associated measuring methods were tabulated.

Results. A total of 1006 publications were initially retrieved. After removing duplicates and filtering by using exclusion and inclusion criteria, 983 articles were excluded. Twenty-three articles reported clinical tooth preparation values. Twenty articles reported the TOC, 4 articles reported margin designs, 4 articles reported margin angles, and 3 articles reported the abutment height of preparations. A variety of methods were used to measure these parameters.

Conclusions. TOC values seem to be the most important preparation parameter. Recommended TOC values have increased over the past 4 decades from an unachievable 2- to 5-degree taper to a more realistic 10 to 22 degrees. Recommended values are more likely to be achieved under experimental conditions if crown preparations are performed outside of the mouth. We recommend that a standardized measurement method based on the cross sections of crown preparations and standardized reporting be developed for future studies analyzing preparation geometry. (J Prosthet Dent 2015;113:175-184)

The basic principles surrounding the clinical longevity of indirect fixed prostheses have been extensively researched. The plethora of literature available, dating back to the early 1900s, has contributed to dedicated chapters in dental textbooks on the principles of tooth preparations.[1,2]

The review by Goodacre et al[3] considered preparation features for fixed prostheses, together with their historical basis. The primary recommendation was to maximize the retention and resistance forms of the prepared abutments to improve the clinical serviceability of restorations. Retention prevents an indirect restoration from being dislodged along the path of placement, whilst resistance prevents a restoration from being dislodged along any other axis.[4] These geometric forms predict whether the cement at the tooth-restoration interfaces in a given area is subjected to tensile, shear, or compressive forces.

The total occlusal convergence angle (TOC) has been investigated for its influence on retention and resistance;[3,5-7] TOC has been defined as the converging angle of 2 opposite axial walls in a given plane, and is generally nonmaterial specific.[4] Theoretically, parallel axial walls provide maximum retention and resistance, whilst highly converging walls have the least. Jorgensen[5] showed that as the TOC increased, the retention (g/mm^2) decreased in a hyperbolic relationship, with significant reduction in retention as half the TOC exceeded 5 degrees. Optimal

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Clinical Implications

Clinical trials using objective, standardized measuring criteria are needed to determine the significance of the total occlusal convergence angle on the clinical success of single crowns.

TOC angles have ranged from 2 degrees to 5.5 degrees.[8-11] Clinically achievable TOC recommendations range from 6 degrees to 24 degrees and have been quoted in textbooks as being ideal.[1,2,12-14]

In the past, cross-sectional margin configurations have included feather edges[15] and bevels,[16-18] whereas chamfers and shoulders are more common today.[19-24] A finite element analysis showed higher stresses associated with bevel and chamfer designs compared with shoulder margins.[25] Marginal widths are material specific with minimal thicknesses described for metal crowns (0.3-0.5 mm),[26] metal ceramic (0.5 mm), and ceramic crowns (1-1.5 mm).[3]

The aim of this study was to systematically retrieve, organize, and critically appraise the literature on clinically achieved crown preparation parameters and the methods used to measure these parameters.

MATERIAL AND METHODS

The study conformed to the PRISMA study protocol (Fig. 1). A database search was performed in PubMed/Medline, ScienceDirect, and Scopus by using the search terms shown in Table 1. Two investigators, J.T. and B.A., screened the titles and abstracts. The studies were included if the tooth preparations were single complete crowns carried out intraorally or extraorally by a clinician, if the TOC and/or margin width and/or margin angle and/or abutment height were measured, if the study clearly detailed the measuring methods and reported the actual values, and if the studies were published in the English language.

Studies were excluded if they reported a combined buccolingual and mesiodistal average for TOC or if they

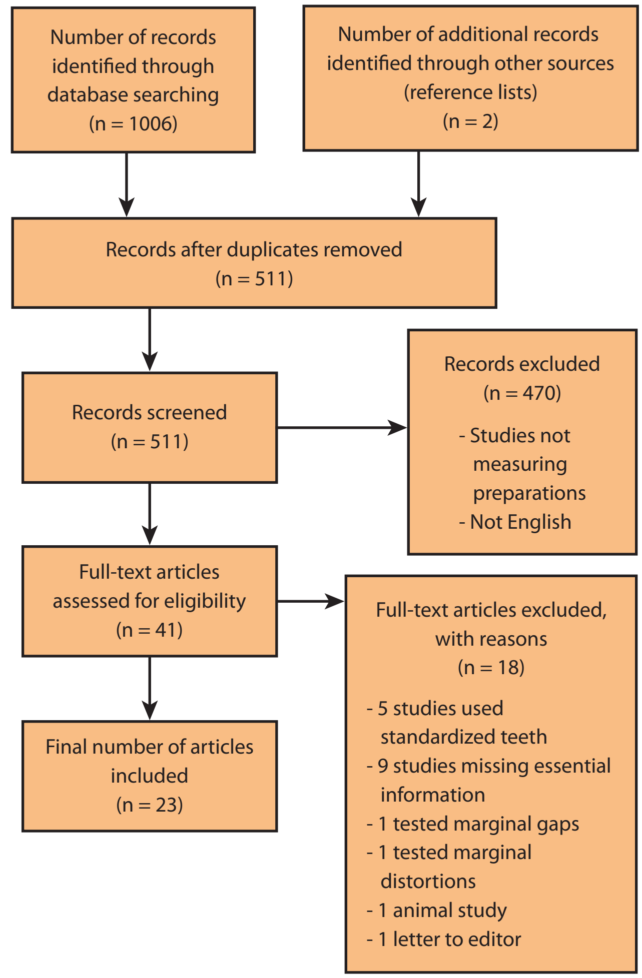


Figure 1. PRISMA flow diagram for identification of studies to be included in review.

Table 1. Search strategy used for databases

Database	Date Accessed	Keywords	No. of Articles
PubMed/Medline	December 5, 2013	Total occlusal convergence AND crown preparation	27
		Taper AND crown preparation	125
		Angles AND crown preparation	70
		Abutment height AND crown preparation	11
		Margin design AND crown preparation	137
ScienceDirect	December 5, 2013	Total occlusal convergence AND crown preparation	10
		Taper AND crown preparation	23
		Angles AND crown preparation	42
		Abutment height AND crown preparation	1
		Margin design AND crown preparation	15
Scopus	December 5, 2013	Total occlusal convergence AND crown preparation	28
		Taper AND crown preparation	124
		Angles AND crown preparation	200
		Abutment height AND crown preparation	14
		Margin design AND crown preparation	179

Table 2. Summary of average total occlusal convergence angles (degrees) found in literature

Study	Year	Intraoral/ Extraoral	n*	Tooth Type	Total Occlusal Convergence in Degrees (SD)		Operator	Measuring Classification
					Buccolingual	Mesiodistal		
Ohm[31]	1978	Intraoral	50	Mandible and maxillary incisors, cuspids, premolars	23.00 (1.01)	19.20 (0.89)	Final year students	Silhouette/Manual
Leempoel[32]	1987	Intraoral	16	Maxillary premolars	17.50 (4.50)	14.60 (5.00)	One dentist	Silhouette/Manual
			18	Maxillary molars	21.60 (6.10)	21.40 (4.10)		
			8	Mandible premolars	14.30 (6.80)	16.70 (3.70)		
			19	Mandible molars	24.30 (8.10)	24.60 (7.00)		
			24	Maxillary premolars	17.50 (6.30)	20.40 (7.90)	One dentist	
			14	Maxillary molars	20.00 (6.60)	23.40 (6.00)		
			14	Mandible premolars	15.10 (6.20)	16.50 (4.30)		
			19	Mandible molars	31.30 (8.40)	29.20 (7.00)		
Kent[33]	1988	Intraoral	23	Maxillary posteriors	20.70 (6.70)	16.00 (5.40)	One experienced operator	Silhouette/Manual
			88	Mandible posteriors	20.30 (7.60)	24.20 (9.90)		
Nordlander[34]	1988	Intraoral	115	Maxillary anteriors	19.00	14.30	Dentists and specialists attempting 4-10 degrees	Silhouette/Manual
				Maxillary premolars	14.60	16.60		
				Maxillary molars	23.40	22.40		
			94	Mandible anteriors	23.10	17.80		
				Mandible premolars	17.70	17.00		
				Mandible molars	26.60	28.00		
Long[35]	1988	Extraoral	27	Molars	27.90 (16.40)	25.80 (10.20)	House surgeons, general dentists, specialists	Cross section/Manual
Noonan[36]	1991	Intraoral	775	unspecified	20.10 (9.70)	19.30 (9.90)	Students	Silhouette/Manual
			134	unspecified	15.80 (5.10)	15.50 (6.00)		
Sato[37]	1998	Intraoral	9	Maxillary premolars	8.00 (3.30)	7.10 (4.20)	Students attempting 2-5 degrees	Silhouette/Manual
			21	Maxillary molars	12.60 (5.40)	9.40 (3.70)		
			7	Mandible premolars	7.40 (2.10)	9.20 (2.40)		
			26	Mandible molars	7.90 (4.20)	10.80 (4.30)		
Smith[38]	1999	Extraoral	71	Maxillary posteriors	12.27 (5.20)	13.09 (6.70)	Students attempting 6 degrees	Silhouette/Manual
			56	Mandible posteriors	14.09 (7.20)	19.32 (6.70)		
			64	Mandible anteriors	14.94 (8.70)	13.17 (6.60)		
			130	Mandible posteriors	12.92 (4.90)	18.22 (7.40)	Students attempting 12 degrees	
Poon[39]	2001	Intraoral	66/61	Incisors	19.45 (17.06)	12.52 (10.67)	Students and dentists	Cross section/Manual
			12/11	Canines	22.42 (15.26)	10.55 (7.19)		
			38/39	Premolars	15.26 (8.86)	19.69 (13.00)		
			28/27	Molars	21.32 (11.51)	26.11 (12.95)		
Al-Omari[40]	2004	Intraoral	29	Maxillary anteriors	19.00 (9.60)	15.60 (7.50)	Final year students attempting 10-20 degrees	Silhouette/Manual
			37	Maxillary premolars	20.80 (7.20)	17.20 (6.90)		
			27	Maxillary molars	35.70 (19.70)	28.50 (16.00)		
			17	Mandible anteriors	24.10 (7.20)	17.70 (5.10)		
			25	Mandible premolars	22.70 (12.40)	21.70 (11.30)		
			22	Mandible molars	32.50 (10.80)	37.20 (13.50)		
Begazo[27]	2004	Intraoral	1376	Maxillary incisors	Half TOC values in degrees (SD)		General practitioners	Cross section/Digital
					Buccal Lingual	Mesial Distal		
					6.6 (4.5) 9.8 (7.1)	6.0 (4.6) 6.1 (4.3)		
				Mandible incisors	5.1 (3.3) 11.1 (7.6)	5.2 (4.3) 5.2 (4.3)		
			199	Maxillary canines	7.5 (4.2) 10.9 (6.8)	7.2 (4.4) 6.4 (3.2)		
				Mandible canines	6.7 (5.3) 10.0 (9.4)	3.9 (2.2) 4.4 (2.4)		
			819	Maxillary premolars	6.0 (4.6) 7.0 (5.2)	7.4 (6.5) 7.6 (6.0)		
				Mandible premolars	7.1 (5.1) 8.0 (6.2)	7.8 (6.3) 8.2 (6.1)		
			1052	Maxillary molars	10.2 (6.2) 10.5 (7.5)	10.7 (6.5) 11.0 (6.8)		
				Mandible Molars	10.7 (7.8) 12.7 (12.3)	14.4 (10.4) 15.1 (9.8)		
Ayad[41]	2005	Extraoral	262	Molars	17.30 (5.90)	15.20 (4.60)	First year students	Silhouette/Manual

(*continued on next page*)

Table 2. Summary of average total occlusal convergence angles (degrees) found in literature (*continued*)

Study	Year	Intraoral/ Extraoral	n*	Tooth Type	Total Occlusal Convergence in Degrees (SD) Buccolingual	Mesiodistal	Operator	Measuring Classification
			200	Molars	19.80 (10.00)	19.40 (9.10)	Third year students	
			37	Molars	15.60 (4.80)	14.10 (3.80)	Fourth year students	
Patel[42]	2005	Intraoral	60	Mandible and maxillary	24.23 (11.23)	27.03 (15.00)	Fourth year students	Cross section/Manual
			60	premolars/molars	14.67 (5.04)	16.33 (5.82)	Fifth year students	
			60		14.33 (7.02)	14.88 (7.39)	GDPs	
			60		17.08 (10.39)	16.77 (6.98)	Clinical staff	
Okuyama[43]	2005	Extraoral	46/54	Maxillary molars	34.20	20.70	Students attempting 2-5 degrees	Cross section/Digital
Rafeek[44]	2010	Extraoral	49	Incisors	26.70 (14.10)	14.90 (7.70)	Fourth year students	Cross section/Digital
			50	Molars	18.20 (7.10)	14.20 (5.00)		
		Intraoral	20	Incisors	31.60 (18.80)	16.80 (15.90)	Fifth year students	
			20	Molars	16.80 (12.30)	22.40 (12.80)		
Ghafoor[45]	2011	Intraoral	25	Anteriors	Not reported	18.76 (6.95)	Postgrads and specialists	Silhouettes/Digital
			25	Premolars		20.24 (9.37)		
			25	Molars		29.16 (10.90)		
Ghafoor[46]	2012	Intraoral	110	Premolars	24.32 (9.28)	20.03 (6.49)	Postgrads and specialists	Silhouettes/Digital
			87	Molars	30.44 (10.61)	29.51 (8.97)		
Alhazmi[47]	2013	Intraoral	11	Maxillary premolars	20.80 (7.05)	16.00 (6.80)	Final year students	Cross section/Digital
			22	Maxillary molars	24.80 (8.07)	19.80 (6.40)		
			14	Mandible premolars	23.50 (7.10)	19.60 (7.60)		
			44	Mandible molars	25.00 (8.70)	26.40 (8.20)		
Aleisa[48]	2013	Intraoral	355	Unspecified	20.45 (11.05)	16.66 (10.07)	Students	Cross section/Manual
Guth[30]	2013	Intraoral	75	Maxillary molars	18.60 (8.70)	17.30 (6.20)	General dentists	Cross section/Digital

*Where n has 2 numbers, the first is the buccolingual value and the second is the mesiodistal value.

Table 3. Summary of average abutment heights (mm) found in literature

Study	Year	Intraoral/Extraoral	n	Tooth Type	Abutment Height (mm) (SD)		Operator	Measuring Method
Sato[28]	1998	Intraoral	1	Maxillary first premolar	6.90 (0.00)		Students	Silhouette/manual
			8	Maxillary second premolars	6.60 (1.10)			
			11	Maxillary first molars	5.80 (1.20)			
			10	Maxillary second molars	5.50 (1.40)			
			2	Mandible first premolars	6.40 (1.60)			
			5	Mandible second premolars	5.80 (0.80)			
			18	Mandible first molars	5.70 (1.20)			
			7	Mandible second molars	4.80 (0.70)			
			1	Mandible third molar	5.60 (0.00)			
Etemadi[29]	1999	Intraoral	15	Premolars	Mesial (SD)	Distal (SD)	Two prosthodontists	Cross section/manual
					2.30 (0.50)	2.60 (0.50)		
				Molars	2.70 (0.80)	3.40 (0.90)		
Guth[30]	2013	Intraoral	75	Maxillary Molars	4.10 (0.74)		General dentists	Cross section/digital

were reviews, case reports, letters to the editor, animal studies, or studies on onlays/inlays, partial fixed dental prostheses, or implants.

Title and abstracts were shortlisted; full-text articles were then collected and the same criteria applied. Any disagreements between reviewers were resolved through discussions with the third author.

Data were collected by recording the authors of the study, the year of the study, whether intraorally or extraorally prepared, the number of specimens in the study, the type of tooth, the buccolingual and mesiodistal TOC values and/or abutment height and/or margin design with standard deviations, the operators who performed the crown preparations, and the method used to measure the values collected.

RESULTS

There were 23 studies that satisfied the inclusion criteria, of which 20 reported TOC angles. The studies reporting

Table 4. Summary of average margin widths (mm) found in literature

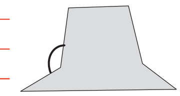
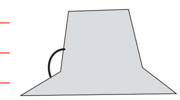
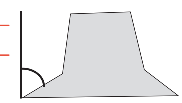
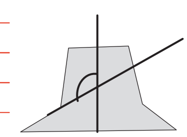
Study	Year	Intraoral/ Extraoral	n	Crown Type/ Goal Thickness	Tooth Type	Margin Width (mm) (SD)				Operator	Measuring Method
Seymour[49]	1996	Extraoral	4	Metal ceramic/ 0.8-1.5 mm	Maxillary right canines	0.85 (0.17)				Three dentists	Cross section/ Digital
			4		Maxillary right first premolars	0.91 (0.19)					
			3		Maxillary right second premolars	0.77 (0.16)					
			2		Maxillary left canines	0.83 (0.01)					
			3		Maxillary left first premolars	0.63 (0.08)					
			1		Maxillary left second premolar	0.58					
			2		Mandibular left canines	0.75 (0.02)					
			2		Mandibular left first premolars	0.77 (0.18)					
			2		Mandibular left second premolars	0.50 (0.05)					
			1		Mandibular right canine	0.53					
Poon[39]	2001	Intraoral	68	Metal ceramic/ 1.0-1.5 mm	Incisors	0.77 (0.27)				Students and dentists	Cross section/ manual
			10		Canines	0.91 (0.28)					
			31		Premolars	0.71 (0.28)					
			9		Molars	0.83 (0.32)					
Begazo[27]	2004	Intraoral	1376	All-ceramic/ 0.7-1.2 mm	Maxillary incisors	**Buccal (SD)**	**Lingual (SD)**	**Mesial (SD)**	**Distal (SD)**	General practitioners	Cross section/ digital
						0.9 (0.3)	0.9 (0.3)	0.9 (0.3)	0.9 (0.3)		
					Mandible incisors	0.7 (0.3)	0.8 (0.3)	0.6 (0.3)	0.7 (0.3)		
			199		Maxilla canines	0.9 (0.3)	0.9 (0.3)	0.8 (0.3)	0.9 (0.3)		
					Mandible canines	0.8 (0.3)	0.8 (0.3)	0.7 (0.3)	0.8 (0.2)		
			819		Maxillary premolars	0.9 (0.3)	0.9 (0.3)	0.8 (0.3)	0.9 (0.4)		
					Mandible premolars	0.9 (0.3)	0.8 (0.3)	0.8 (0.3)	0.8 (0.3)		
			1052		Maxillary molars	1.0 (0.3)	1.0 (0.3)	0.8 (0.3)	1.0 (0.3)		
					Mandible molars	0.9 (0.3)	1.0 (0.5)	1.0 (0.3)	0.9 (0.3)		
Al-Omari[40]	2004	Intraoral	29	Metal ceramic/ shoulder (1-1.5 mm)	Maxillary anteriors	1.00 (0.29)	0.88 (0.32)	0.81 (0.24)	0.81 (0.17)	Final year students	Silhouette/ manual
			37	chamfer (0.3-0.5 mm)	Maxillary premolars	0.88 (0.23)	0.78 (0.25)	0.72 (0.20)	0.62 (0.25)		
			27		Maxillary molars	0.92 (0.30)	0.74 (0.25)	0.62 (0.18)	0.57 (0.20)		
			17		Mandible anteriors	0.45 (0.09)	0.49 (0.16)	0.51 (0.28)	0.63 (0.20)		
			25		Mandible premolars	0.85 (0.22)	0.64 (0.25)	0.79 (0.23)	0.66 (0.21)		
			22		Mandible molars	0.87 (0.32)	0.80 (0.53)	0.70 (0.33)	0.61 (0.23)		

the TOC angles are chronologically summarized in Table 2. One study reported half the TOC angles in sufficient detail to be included.[27] In 15 studies, the crown preparations were carried out intraorally, and 5 studies had preparations performed extraorally. The mean TOC angles reported for the buccolingual dimension ranged from 7.4 degrees to 35.7 degrees, while the mean TOC angles for the mesiodistal dimension were between 7.1 degrees and 37.2 degrees.

Overall, 7295 preparations were evaluated over a period of 35 years. Approximately half (47%, n=3446) were from the same study.[27] Of the 23 articles included in this review, 51% (n=3713) measured TOC values performed by dentists or general practitioners, 38% (n=2758) by students, and 1% (n=60) by clinical staff. The remaining studies failed to specify the operators, with 4% (n=272) carried out by postgraduates and specialists, 3% (n=236) by dentists and specialists, 2% (n=145) by students and dentists, and 2% (n=111) by a skilled operator.

Three studies reported the abutment heights of natural teeth.[28-30] The values are tabulated in Table 3. One study reported the distal and mesial abutment heights,[29] while the other 2 reported an average value for each abutment.[28,30] All studies were performed intraorally, and the operators included students, general dentists, and prosthodontists.

Table 5. Summary of average Margin Angles (degrees) found in literature

Study	Year	Intraoral/Extraoral	n	Tooth type	Definition of Angle/ Angle Goal
Seymour[49]	1996	Extraoral	4	Maxillary right canines	
			4	Maxillary right first premolars	
			3	Maxillary right second premolars	
			2	Maxillary left canines	
			3	Maxillary left first premolars	90-110 degrees
			1	Maxillary left second premolar	
			2	Mandibular left canines	
			2	Mandibular left first premolars	
			2	Mandibular left second premolars	
			1	Mandibular right canine	
Poon[39]	2001	Intraoral	65	Incisors	
			8	Canines	
			28	Premolars	
			9	Molars	90-110 degrees
Dalvit[50]	2004	Intraoral	67	Anteriors	
			19	Premolars	
			13	Molars	Minimum 33 degrees
Begazo[27]	2004	Intraoral	1376	Maxillary incisors	
				Mandibular incisors	
			199	Maxillary canines	
				Mandibular canines	
			819	Maxillary premolars	
				Mandibular premolars	90-130 degrees
			1052	Maxillary molars Mandibular molars	

The studies reporting margin width (n=4) are presented in Table 4. The studies reporting the margin angle (n=4) are presented in Table 5. Meta-analysis was not possible for any of the reported crown preparation parameters because of the differences in the methods used to acquire the measurements.

Considerable heterogeneity was found in the measurement methods used to examine crown preparations. A classification matrix was created in this review for ease of reporting (Fig. 2). It was found that 35% (n=8) of the studies used manual processes to measure the silhouette of dies, 22% (n=5) used manual processes to measure the cross section of dies, 13% (n=3) used digital processes to measure the silhouette of dies, and 26% (n=6) used digital processes to measure the cross section of the die.

DISCUSSION

This review presents the published evidence for geometric parameters associated with clinical crown preparation and the methods used to measure these parameters. The evidence shows a general nonconformity to the values recommended for crown preparation; considerable heterogeneity is also apparent in the measuring methods used in these studies.

Our search methodology coupled the search term "crown preparations" in all searches with geometric parameters. The limitation in this includes other search terms being synonymous with crown preparations, such as tooth preparations, dental preparations, preparations, and single-crown preparations. This initial search retrieved many articles that were not relevant to the review, including in vitro bench fatigue tests, strength tests, finite element analyses, and retention analysis using fixed TOC values of 32 degrees or less.[51-54] Many relevant studies had to be excluded because they reported grouped values or ranges or did not provide enough information. Some of the included articles failed to specify anatomic location (mandible versus maxilla)[29,35,36,39,41,44-46,48,50] or type of tooth (incisor, canine, premolar, or molar),[36,38,50] and 1 article reported only a single cross section.[45]

The TOC angle was the most commonly reported parameter. Several studies had mean TOC values greater than 24 degrees.[32,34,35,39,40,43-47] The lowest range of TOC angles (7.10 to 12.60 degrees)[28] were produced intraorally by students working under the supervision of

Table 5. (Continued) Summary of average Margin Angles (degrees) found in literature

Margin Angle in degrees (SD)	Operator	Measuring Method
10.7.78 (12.82)	Three Dentists	Cross section/digital
104.04 (26.51)		
94.32 (8.28)		
108.45 (9.58)		
118.48 (14.12)		
108.33		
100.25 (1.76)		
126.45 (12.10)		
113.57 (3.63)		
113.5		
108.32 (13.92)	Students and Dentists	Cross section/manual
106.31 (11.31)		
101.99 (11.64)		
108.17 (13.26)		
79.00 (14.00)	Unspecified	Silhouette/digital
72.00 (15.00)		
74.00 (14.00)		

Buccal (SD)	Lingual (SD)	Mesial (SD)	Distal (SD)	General Practitioners	Cross section/digital
120.6 (17.6)	119.5 (16.6)	115.6 (19.3)	117.0 (18.8)		
127.4 (21.4)	125.3 (18.4)	128.0 (20.5)	129.1 (19.6)		
123.6 (17.5)	122.9 (16.6)	120.5 (19.9)	119.6 (19.7)		
120.1 (21.7)	121.4 (18.4)	124.8 (16.3)	122.0 (16.2)		
123.6 (15.5)	121.3 (15.2)	119.2 (17.6)	119.7 (18.2)		
122.8 (16.0)	123.2 (18.9)	118.9 (19.8)	117.0 (18.0)		
118.1 (14.9) 118.6 (19.5)	119.5 (14.9) 118.3 (17.7)	118.5 (17.6) 113.6 (17.8)	118.6 (16.1) 112.8 (18.4)		

prosthodontists, who were aiming for 2 to 5 degrees (conforming to the recommended 6 to 12 degrees). This suggests that attempting very narrow angles may be the key to achieving acceptable values. However, another study with similar experimental design (students attempting a 2- to 5-degree TOC) produced a different result, with TOC angles measuring up to 34 degrees.[43]

Height varied considerably between studies. This is the parameter over which the clinician may have least control because the coronal tooth structure may have previously incurred significant damage or may have received restorations of varying quality.[29]

A general trend was noted for margin widths to fall under 1 mm. Two studies reported that the mean margin widths fell short of the desired minimum value of 0.8 to 1.5 mm[49] or 1 to 1.5 mm.[39] Clinicians tend to be excessively conservative, and this is likely to have both esthetic and structural (marginal failure) repercussions when the restoration is fabricated with thin anteroposterior and buccolingual dimensions.

Two studies had the same definition for margin angles and set a satisfactory range for margin angles, between 90 and 110 degrees.[39,49] Seymour et al[49] concluded that their values fell short of this recommendation, whereas Poon and Smales[39] rated their preparations to be "satisfactory" because their values fell within this range. The definition of angle for marginal angles differed markedly among the included studies. This lack of consensus on the definition alone suggests that universal standardization is needed to better investigate the clinical consequences of the various marginal angles.

Overall, intraoral preparations were more tapered with higher TOC values than extraoral preparations, and

		Process	
		Manual	Digital
Shape	Silhouette	Silhouette/ Manual	Silhouette/ Digital
	Cross-section	Cross-section/ Manual	Cross-section/ Digital

Figure 2. Classification matrix of measuring methods. Image shape-either outline of die when viewed from certain direction (silhouette) or cross-sectional view by means of sectioning or virtual sectioning (cross-section), and process used to measure parameters-hand drawing lines or machines with manual processes (manual) or measured using software on computer (digital).

a clear pattern was observed of increasing TOC angles moving from anterior preparations to posterior preparations. The exception was the maxillary incisors, which not only produced higher TOC angles in the buccolingual view but also always showed higher TOC values in the buccolingual view than in the mesiodistal view.

The heterogeneity in operator experience, working conditions, and ultimately the measurement method means no substantial comparisons can be made on specific values. When the studies are considered chronologically, those published in the 1970s and 1980s had similar values to the more recent studies published in the 2000s and 2010s, with the mean values remaining in a range of approximately 18 to 25 degrees. One particular study had mean TOC values reaching 37.2 degrees.[40] An increase in the TOC angle of crown preparations may have a direct negative effect on the amount of remaining healthy tooth tissue and may therefore compromise the abutment integrity. Little mention has been made in the literature regarding the effect of the TOC on abutment structure or on other preparation parameters. In the meantime, despite advances in technology and education during the past 4 decades, we have observed little change in the analysis and reporting of TOC values.

Methods based on light projection and silhouette tracing were used in 3 studies.[28,34,38] Others used projected photographic negatives,[32,39] photographs,[33] or photocopies of the shadow of dies.[36] Two studies read their TOC values from microscopes.[40,41] Unless the projections are of a 1:1 ratio, these methods are limited to finding values that are unaffected by size. Enlarging the die helps with identifying and calculating the resultant TOC and margin angles but cannot help with measuring height and margin width. Another limitation with earlier studies is that a silhouette of a die is inaccurate in recording opposite sides of axial walls, as the tooth preparation geometry is asymmetric and complex.

Preparing the groundwork for future studies means measuring methodologies need to be addressed and standardized. A certain bias and subjective techniques are found with the different methods in the studies included in this review. Deducing axial walls can be subjective in terms of where exactly on the axial wall is selected for extrapolation and demarcation. Even a slight change in position can change the resultant angle by a noticeable amount, with both the left and right axial walls doubling the error.

A small number of studies attempted to address this issue by objectively evaluating the crown preparation geometry.[55,56] Guth et al[30] presented a study in which data sets were used in a similar manner to the previous studies, where 4 cross sections were used to calculate the TOC value. This study also attempted to set up rules for quantifying the other preparation parameters. However, we consider that the criteria used to delineate the area and calculate the TOC were still vague and subject to different interpretations. Hey et al[57] presented analytical software for quantifying the marginal area with a view to future clinical use; although TOC was not recorded, the margin width was defined as the distance to the axial wall 1 mm above the preparation margin. Recently, a new method has been suggested and validated for objectively measuring crown preparation. The method relies on a mathematical formula to objectively select specific points to measure the geometry.[58] Standardizing the method would improve coherence and enable valid comparisons of future studies.

Although several studies have acknowledged that ideal TOC angles are rarely achieved, it would be interesting to see if ideal values are ever consistently achieved. Sato et al[28] mentioned that the ideal goal of a 2- to 5-degree standard should not be changed but acknowledged that a 10-degree TOC was more clinically achievable, whereas Smith et al[38] considered a 6-degree TOC criterion to be unrealistic.

Emphasis has been placed on education and trying to train preclinical students to create ideal preparations. Many of the studies measured student-performed preparations. In one experiment, experienced prosthodontists supervised every step of the process.[28] Another conducted the study with students using typodonts on bench tops and also on a simulation model.[38] The TOC values from these studies fell short of the recommended values. More recently, digital assistance software has been produced to train students.[59-62] A study used real-time magnification for teaching students and found an improvement in performance.[63] These have been useful in enhancing the learning process of crown preparations for students, but to the authors' knowledge, no studies have suggested that the preparations performed with these systems have significantly improved the quality of preparations in practice.

Perhaps the focus should shift from trying to educate and train students to an unrealistic standard. Although proper training should be given, it may be time to respond to the studies and opinions and revise the current recommendations. If a disparity already exists between recommendations and clinical values, then what are the consequences and where does the threshold lie before a noticeable failure occurs? These questions will remain unanswered unless clinical trials accurately report preparation parameters for each crown instead of just reporting a range.[64,65]

Each tooth in the dental arch has a uniquely complex geometry (size and shape) specific to its function, and teeth vary not only intraarch and interarch but also between persons. The idea that tooth preparation principles with finite values can be applied to all situations in a one-size-fits-all approach belies what is clinically achievable and creates a disparity between recommendations put forth in the literature or by manufacturers and the reality of general practice. Considering that exact specific angles cannot be consistently achieved, clinical recommendations ought to be tooth specific and provide an acceptable range. The methodologies used for measuring values such as TOC and margin geometry on complex dental geometric shapes in the clinical setting are the main problem with these historical numerical recommendations. Currently, no universally accepted standards exist for measuring these key features in crown preparations; as a result, a large amount of bias exists in the literature. Moreover, the vast majority of studies that have dictated these preparation principles are based on in vitro studies and not on sound clinical trials, raising the issue of evidence-based clinical practice. However, a reliance on low-level evidence is not surprising, given the difficulty involved in measuring TOC and margin geometry in clinical trials.

CONCLUSIONS

Within the last few decades, recommendations have increased from 2 to 5 degrees to 10 to 22 degrees to account for clinical achievability. The TOC seems to be the most important preparation parameter as more studies are available on this parameter than on abutment height, margin width, and margin angle. More studies were also conducted intraorally than extraorally, but preparations performed extraorally had values closer to those recommended than those performed intraorally. Also, more studies reported values measured from silhouettes, which do not truly represent opposing axial walls. Future studies should be based on cross sections of crown preparations. Standardized measurement and reporting are needed for future studies that analyze preparation geometry in a simple and objective fashion. Clinical trials are needed to determine the implications of values that exceed those recommended by the literature and the combined effect of all the preparation parameters.

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Noteworthy Abstracts of the Current Literature

Effect of the occlusal profile on the masticatory performance of healthy dentate subjects

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Purpose. The purpose of this study was to examine, on the basis of masticatory performance (MP), total muscle work (TMW), and range of movement (RoM), whether reduction of the profile of the cusps results in loss of the biomechanical effectiveness of chewing by healthy dentate patients.

Methods. Twenty healthy patients (10 female, mean age: 24.1 ± 1.2 years) chewed standardized silicone particles, performing 15 masticatory cycles. Three experimental conditions were investigated: chewing on (1) the natural dentition (ND), (2) splints with structured occlusal profiles simulating the patient's natural dentition (SS), and (3) splints with a plane surface (PS). The expectorated particles were analyzed by a validated scanning procedure. The size distribution of the particles was calculated with the Rosin-Rammler function and the mean particle sizes (X50) were determined for each experimental condition. The target variables of the experimental conditions were compared by repeated measures analysis of variance.

Results. X50 values calculated for MP differed significantly ($P < .002$) between PS and SS, and between ND and SS. Conversely, no significant differences ($P > .05$) were observed between SS and ND. Regarding muscle work the EMG activity of the masseter differed significantly ($P < .001$) between the left and right sides, with higher values for the right (chewing) side. No significant differences ($P > .05$) were observed for TMW and RoM under the three test conditions.

Conclusions. The results confirm the biomechanical significance of structured occlusal surfaces during chewing of brittle test food by young dentate subjects.