Avicenna J Dent Res. 2017 June; 9(2):e13106. doi: 10.5812/ajdr.13106.

Published online 2017 June 20. **Research Article**

Convergence Angles of Clinical Tooth Preparations for Metal Ceramic Restorations Among Dental Students and General Practitioners

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Received 2016 July 16; **Revised** 2016 December 18; **Accepted** 2017 February 12.

Abstract

Background: Numerous studies showed that the convergence angle (CA) of prepared teeth for fixed prosthodontics in the clinical practice is greater than the recommended values.
Objectives: This cross-sectional study aimed to compare the total occlusal convergence (TOC) angles of metal ceramic fixed prosthodontics among dental students [final-year undergraduate (UG) and Master Prosthodontics (MS) students] and general practitioners (GP) in their private clinics with the recommended value ($\leq$ 12 degrees).
Methods: The buccolingual (BL) and mesiodistal (MD) TOC of 114, 90, and 111 stone dies referred to UG, MS, and GP, respectively, were measured. These dies included incisors, premolars, and molars. One sample Wilcoxon signed rank test, Mann-Whitney U test, Kruskal-Wallis, and Fisher exact test were used for statistical analysis.
Results: Mean values of TOC for UG were 27.8 degrees BL and 20.9 degrees MD, whereas they were 30.6 degrees BL and 18.2 degrees MD for MS. GP had TOC of 35.5 degrees BL and 24 degrees MD. GP had significantly higher TOC values than the other groups ($0.001 > P$ value ≤ 0.007). In each group, TOC did not differ when calculated for partial fixed prosthodontic and single crown abutments ($0.117 \leq P$ value ≤ 0.797). Molars in general had the highest TOC values. Only 0.9%, 3.3%, and 0.9% of UG, MS, and GP, respectively, respected the TOC $\leq$ 12 degrees.
Conclusions: In all the groups, tooth preparations were inconsistent with the recommended TOC values, even among specialists in fixed prosthodontics. These results support the existing literature that the recommended values were rarely achieved and may require reconsideration.
Clinical Significance: Clinically, the CA values of prepared teeth for fixed prosthodontics exceed the recommended values in most cases, not only among general practitioners, but also among students in academic institutes. Thus, the effects of teeth preparations with CA greater than the recommended values on the longevity of the prosthodontics should be further investigated.

Keywords: Convergence Angle, Crowns, Partial Fixed Prosthodontic, Taper, Total Occlusal Convergence

1. Background

Metal ceramic fixed prosthodontics are commonly indicated for the restoration of extensively damaged teeth or compensation for limited teeth loss. Retention and stability are very important requirements for fixed prosthodontics. They both can be achieved by providing a geometrical shape for the prepared tooth with minimum occlusal convergence angles. The total occlusal convergence (TOC) angle is the combined angle made by opposing axial walls when measured against the vertical long axis of the tooth (1). Some studies refer to TOC as convergence angle. This is different from "taper", which is the angle between one axial wall of the preparation and the long axis of the prepared tooth (2). A recent review has shown that TOC was the most important preparation parameter (3). Other less important factors than TOC include height of preparations of the abutment and margin designs and angles.3 However, there is no agreement in the literature concerning the recommended values of TOC.

Textbook guidelines on the TOC during tooth preparation vary from 4 to 20 degrees (4-6). Other researchers have recommended TOC between 10 degrees and 16 on the basis of laboratory studies (7-14). Goodacre et al. (15, 16) proposed that the total TOC should range between 10 degrees and 20 degrees. In general, TOC ranging from 2 to 5.5 degrees is considered optimal, while TOC ranging 6 - 24 degrees is considered acceptable (17-19). Anyhow, tooth preparation with a TOC greater than 25 degrees is statistically less retentive than tooth preparation with the optimum convergence (20). Mack (21) observed that a minimal taper of 12 degrees was necessary to ensure the absence of undercuts. The widely recommended 12° TOC has been

shown to be difficult to achieve for many dental students (22-24).

2. Objectives

This study aimed to compare the TOC of metal ceramic fixed prosthodontics among final-year undergraduate dental students (UG), Master prosthodontics students (MS), and general practitioners (GP) with the recommended values ($\leq$ 12 degrees). In addition, factors such as the specialization of the dentist, the presence of supervision, tooth type and the effect of single crown versus partial fixed prosthodontic (PFP) abutment preparations on the TOC of prepared teeth were assessed.

3. Methods

The sample: The total sample of this cross-sectional study consisted of 315 stone dies collected from UG (114), MS (90), and GP in their private dental clinics in Damascus, Syria (111), during the academic year 2014 - 2015.

Measuring the TOC: The indirect method, described previously by Weed (9), for measuring TOC using the millimetric paper and protractor was used in the current study (Figure 1). Briefly, the buccal surface is faced (Figure 1A) for measuring the mesiodistal (MD) TOC. The width of the buccal surface from the mesiobuccal to the distobuccal edges at the finishing line and occlusal end of the surface was measured by a caliber (Figure 1B). The height of the surface (the distance between the finishing line and occlusal end of the surface) was also measured. These dimensions were transferred to a millimetric paper (Figure 1C). The angle formed by the intersection of the coronal extension of the mesial and distal lines was measured with a protractor (Figure 1D). The same procedures were repeated for the measurement of the buccolingual (BL) TOC after facing the mesial surface.

The MD, BL, and the mean TOC [(MD+BL)/2] of each die were recorded.

Reproducibility of the measurements: The principal investigator (S.H) repeated the measurement of the TOC for 20% (63) of the dies. Interclass correlation coefficient was 0.95, indicating excellent reproducibility.

Statistical analysis: IBM SPSS version 21 (IBM, Armonk, NY, USA) was used for the statistical analysis. Shapiro-Wilk test showed that the data were not normally distributed. Subsequently, one sample Wilcoxon signed rank test was used to compare the mean of each group with the recommended TOC (12 degrees). Kruskal-Wallis test with post-hoc comparisons was performed to test the significance of the TOC differences between the groups. Mann-Whitney U was used for the comparison of means between two sets of data. Finally, Fisher exact test was used to test the relationship between the groups and the adherence to the ideal TOC preparations. P values $\leq$ 0.05 were considered significant.

3. Results

In the current study, the mean BL, MD, and general TOC [(BL + MD)/2] of the whole sample were 31.3 degrees, 21.2 degrees, and 26.3 degrees, respectively. The maximum recorded TOC was 73 degrees, which was a BL TOC related to a general practitioner, whereas, the minimum recorded value was an MD TOC of an MS (6 degrees). In general, the TOC values were higher in the GP group than the other groups (Tables 1 and 2). One sample Wilcoxon signed rank test showed a statistically significant difference between TOC achieved in this study and the recommended values ($\leq$ 12 degrees) in all the groups and dimensions (P values $<$ 0.001). Furthermore, the BL TOC was higher than the MD TOC in all the groups (P values of Wilcoxon signed ranks test were $<$ 0.001).

Table 1. Mean (Standard Deviation) BL, MD TOC, and General Convergence for UG, MS, and GP

Total Occlusal Convergence	UG (N = 114)	MS (N = 90)	GP (N = 111)
BL	27.8 (12.3)	30.6 (11.5)	35.5 (14.8)
MD	20.9 (8.2)	18.2 (8.1)	24 (8)
General convergence [(BL + MD)/2]	24.3 (8.1)	24.4 (6.9)	29.8 (8.9)

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.

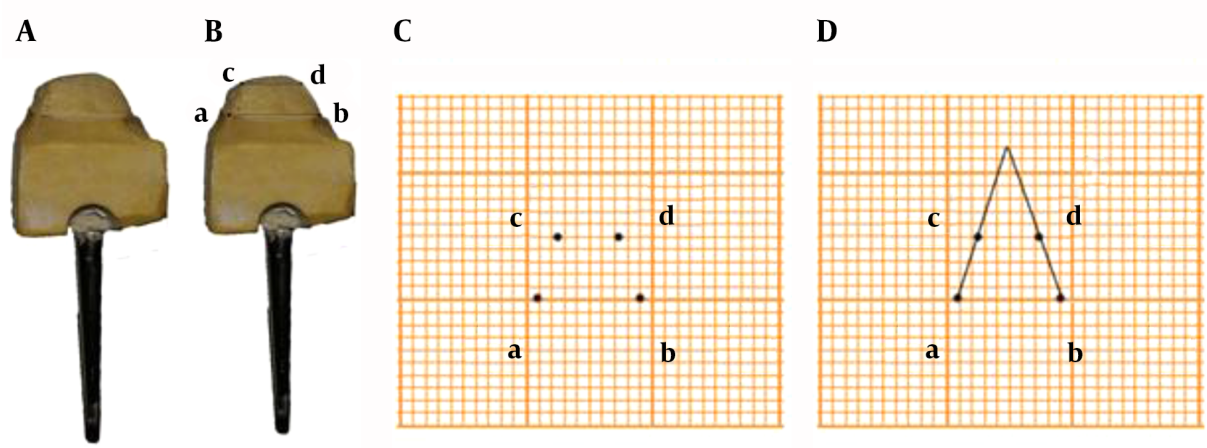
Table 2. P-values of Pairwise Post-Hoc Comparisons of BL and MD TOC Between UG, MS, and GP[a]

Total Occlusal Convergence	UG/MS	UG/GP	MS/GP
BL	0.129	< 0.001	< 0.001
MD	0.084	0.007	< 0.001
General convergence [(BL + MD)/2]	0.999	< 0.001	< 0.001

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.
[a] Pairwise post-hoc comparisons as per Kruskal-Wallis test.

In each group, the BL and MD TOC values were not statistically different between single crown abutments and PFP abutments (P values of Mann-Whitney U test ranged from 0.117 to 0.797). On the other hand, GP had always the largest TOC in both dimensions (BL and MD) in comparison with the UG and/or MS students (Tables 3 and 4). UG

Figure 1. Measuring the Mesiodistal (MD) Convergence Angle of a Molar Belonging to a General Practitioner



A, Facing the buccal surface of the molar; B, drawing a line at the finishing-line of the preparation (from point-a to point-b) and the line of the occlusal end of the surface (from point-c to point-d); C, the lengths of these two lines and the distance between them were transferred by a caliber to a mellimetric paper; D, the angle that is formed by the interaction of the coronal extension of the A - C line and the B - D line was measured and considered as the MD convergence angle of this tooth.

and MS students' preparations were generally comparable. The jaw to which the tooth belonged did not affect BL and MD TOC in each group separately (P values of Mann-Whitney U test ranged from 0.105 to 0.981). In both jaws, GP preparations had greater TOC values than the other groups (Tables 5 and 6).

The effect of the type of teeth (incisor, premolar, and molar) showed that GP reported the biggest TOC than the UG and/or MS students for all types of teeth in BL and MD dimensions (Tables 7 and 8). When each group was analyzed separately, TOC of molars reported the biggest values in general (Tables 9 and 10). Remarkably, the mean BL TOC of the incisors of MS was higher than their molars BL TOC.

Finally, 14.9%, 25.6%, and 8.1% of UG, MS, and GP, respectively, adhered to the ideal preparation in the MD dimension ($\leq$ 12), whereas, 5.3%, 2.2%, and 3.6% of them, respectively, did adhere to the ideal preparation in the BL dimension. When the mean TOC was considered, only 0.9%, 3.3%, and 0.9% of the UG, MS and GP, respectively, respected the TOC $\leq$ 12 degrees. Fisher exact test showed that MS adhered to the ideal preparation in higher percentage in the MD dimension than the other groups (P value = 0.003), whereas there were no differences in the other dimensions between the groups (P value = 0.579 in the BL dimension and P value = 0.446 for the mean TOC).

4. Discussion

The current study findings support the existing literature that the recommended TOC values are rarely achieved in dental practice (25-27). Accordingly, this might lead us to find answers to these questions; first, what are the effects of the currently achieved TOC on the long-term sustainability of prosthodontics as well as on the prepared teeth? Second, what should be the recommended TOC values for fixed prosthodontics? Third, on what basis these values should be calculated? Sato et al. (28) mentioned that the ideal goal (2 to 5 degrees) should not be changed altough they acknowledged that a 10-degree TOC was more clinically achievable, whereas Smith et al. (12) considered a 6-degree TOC criterion to be unrealistic. Surveys have demonstrated that a TOC of 16 degrees is clinically achievable and it can provide adequate retention (29, 30). A minimal TOC of 12 degrees has been suggested to ensure that there are no undercuts in preparations (21). Long-term clinical studies are necessary to assess the influence of TOC on the longevity of fixed prosthodontics. It should be noted that the obtained values of TOC in the laboratory studies were smaller than the clinical achieved values (9, 24). Then, should the recommended TOC values be raised to about 20 degrees?

Tooth preparation with appropriate TOC is one of many factors directly affecting the overall acceptability of a crown preparation. Recommendations have been made for optimal axial wall taper of tooth preparations for fixed prosthodontics to prevent undercuts, compensate for inaccuracies in fabrication, and permit more complete seating during cementation (20, 31). However, the amount of convergence necessary for proper retention and resistance to dislodgment for fixed prosthodontics is closely related to the shape of the preparation and factors such as length and diameter of the preparation, which may affect the

Table 3. Mean (Standard Deviation) TOC for UG, MS, and GP According to the Abutment Type (Single Crown/PFP Abutment)

Total Occlusal Convergence	Single Crown/PFP	UG	MS	GP
BL	Single crown	27.9 (12.6)	30.9 (13.6)	35.8 (14.8)
		N = 53	N = 51	N = 86
	PFP	27.7 (12.1)	30.2 (8.5)	34.6 (15.1)
		N = 61	N = 39	N = 25
MD	Single crown	19.9 (8.2)	17.9 (7.9)	23.3 (7.9)
	PFP	21.8 (8.2)	18.7 (8.5)	26.4 (8.2)

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; PFP, partial fixed prosthodontics; UG, undergraduate students.

Table 4. P-values of Pairwise Post-Hoc Comparisons of TOC According to the Abutment Type (Single Crown/PFP Abutment) Between UG, MS, and GP[a]

Total Occlusal Convergence	Single Crown/PFP	UG/MS	UG/GP	MS/GP
BL	Single crown	0.510	0.002	0.186
	PFP	> 0.05	> 0.05	> 0.05
MD	Single crown	0.815	0.015	< 0.001
	PFP	0.223	0.087	0.002

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; PFP, partial fixed prosthodontics; UG, undergraduate students.
[a] Pairwise post-hoc comparisons as per Kruskal-Wallis test.

Table 5. Mean (Standard Deviation) TOC for UG, MS, and GP According to the Jaw

Total Occlusal Convergence	Jaw	UG	MS	GP
BL	Maxillary teeth	26.9 (11.4)	30.9 (13.2)	37.3 (14)
		N = 57	N = 45	N = 54
	Mandibular teeth	28.7 (13.2)	30.3 (9.5)	33.8 (15.4)
		N = 57	N = 45	N = 57
MD	Maxillary teeth	20.9 (8)	17.7 (7.1)	22.7 (6.4)
	Mandibular teeth	21 (8.5)	18.3 (9)	25.2 (9.2)

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.

Table 6. P-values of Pairwise Post-Hoc Comparisons of TOC According to the Jaw Between UG, MS, and GP[a]

Total Occlusal Convergence	Jaw	UG/MS	UG/GP	MS/GP
BL	Maxillary teeth	0.334	< 0.001	0.064
	Mandibular teeth	> 0.05	> 0.05	> 0.05
MD	Maxillary teeth	0.178	0.172	0.001
	Mandibular teeth	0.745	0.038	0.001

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.
[a] Pairwise post-hoc comparisons as per Kruskal-Wallis test.

amount of convergence necessary for any given preparation. Furthermore, in light of the considerable additional tooth removal of teeth prepared with increased TOC, there are clear advantages in achieving an adequate tooth prepa-

Table 7. Mean (Standard Deviation) TOC for UG, MS, and GP According to the Tooth Type

Total Occlusal Convergence	Tooth Type	UG	MS	GP
BL	Incisor	25.4 (8.8)	36.4 (13.5)	39.7 (15.9)
		N = 30	N = 30	N = 30
	Premolar	27.1 (11.9)	25.8 (9.1)	28.4 (10.5)
		N = 44	N = 30	N = 37
	Molar	30.2 (14.6)	29.6 (8.8)	38.6 (15.3)
		N = 40	N = 30	N = 44
MD	Incisor	17.8 (7)	12.7 (4.7)	20.9 (8)
	Premolar	19.1 (7.3)	18 (7.7)	22.6 (5.9)
	Molar	25.2 (8.3)	24 (7.4)	27.3 (8.5)

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.

Table 8. Pairwise Post-Hoc Comparisons of TOC According to the Tooth Type Between UG, MS, and GP[a]

Total Occlusal Convergence	Tooth Type	UG/MS	UG/GP	MS/GP
BL	Incisor	0.004	< 0.001	0.999
	Premolar	> 0.05	> 0.05	> 0.05
	Molar	0.999	0.008	0.040
MD	Incisor	0.012	0.541	< 0.001
	Premolar	0.999	0.070	0.011
	Molar	> 0.05	> 0.05	> 0.05

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.
[a]Pairwise post-hoc comparisons as per Kruskal-Wallis test.

Table 9. Mean TOC (Standard Deviation) for Incisors, Premolars, and Molars Among UG, MS, and GP

Total Occlusal Convergence	UG/MS/GP	Incisor	Premolar	Molar
BL	UG	25.4 (8.8)	27.1 (11.9)	30.2 (14.6)
		N = 30	N = 44	N = 40
	MS	36.4 (13.5)	25.8 (9.1)	29.6 (8.8)
		N = 30	N = 30	N = 30
	GP	39.7 (15.9)	28.4 (10.5)	38.6 (15.3)
		N = 30	N = 37	N = 44
MD	UG	17.8 (7)	19.1 (7.3)	25.2 (8.3)
	MS	12.7 (4.7)	18 (7.7)	24 (7.4)
	GP	20.9 (8)	22.6 (5.9)	27.3 (8.5)

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.

ration with minimum unnecessary tooth removal (32).

The mean TOC found in the current study was 26.3 degrees that is slightly higher than that measured in other studies (26, 27, 33-35). This disparity in the TOC values might be explained by including dies from GP in this study. Annerstedt et al. (36) revealed that the mean TOC for dental students (19.4 degrees) was less than the convergence created by dentists (22.1 degrees). Nevertheless, several studies reported mean TOC values greater than 24 degrees (14, 25, 37, 38). In the current study, the BL TOC was always big-

Table 10. Pairwise Post-Hoc Comparisons of TOC of Incisors, Premolars, and Molars Among UG, MS, and GP[a]

Total Occlusal Convergence	UG/MS/GP	Incisor-Premolar	Incisor-Molar	Premolar-Molar
BL	UG	> 0.05	> 0.05	> 0.05
	MS	0.002	0.167	0.456
	GP	0.004	0.999	0.004
MD	UG	0.982	< 0.001	0.003
	MS	0.031	< 0.001	0.012
	GP	0.999	0.006	0.021

Abbreviations: BL, buccolingual; GP, general practitioners; MD, mesiodestal; MS, Master prosthodontics students; UG, undergraduate students.
[a] Pairwise post-hoc comparisons as per Kruskal-Wallis test.

ger than MD TOC in all the groups. This is consistent with the majority of the previous studies (24, 25, 34, 39). This may be attributed to the absence of direct visual assessment in the BL dimension. The presence of cheeks, lips, and tongue may also be other probable causes. Although students are taught to align the bur with the axis of the tooth (or the path of insertion) to overcome the excessive BL TOC, more effective methods seem to be necessary. In practice, convergence is estimated by the visual assessment. The latter usually underestimates the actual TOC values with inaccuracy reaching more than 10 degrees (40).

The effect of clinical experience of the clinician showed a significant difference in TOC values in both BL and MD dimensions. Students' (both UG and MS) preparations were generally closer to the recommended TOC. In our faculty, UG work is constantly checked and corrected by their instructors (MS). Furthermore, students have to prepare limited number of abutments (< 5) and their exercises begin with relatively easy cases. Thus, all their preparations are being evaluated individually. This also may explain the close results between UG and MS in this study. Noonan et al. (13) and Sato et al. (28) measured TOC and taper values of dental students under normal clinical condition and testing condition and found greater values under normal clinical condition compared to testing condition. In Marghalani et al. (41) study, which was conducted under examination conditions, about 80% and 70% of students achieved BL and MD TOC less than 14 degrees. The majority of dental students in New Zealand were able to achieve TOC between 10 and 20 degrees, but some preparations had excessive values (> 60 degrees) (40). One study aimed to achieve TOC of $\leq$ 5 degrees among students working under supervision of prosthodontics. The resulted TOC was 7.1 to 12.6 degrees (28). This may represent a way for achieving acceptable TOC among dental students. In addition, Tiu et al. recently developed a software that seems to be an effective educational tool for dental students in prosthodontics (42). On the other hand, the continuous developing of strong luting cements may be a reason behind the absence of worriedness toward excessive TOC by GP. Should not be overlooked, TOC more than 20 degrees sharply increases the stress on the cement (18), and negatively affects the retention and resistance (43). In Tiu et al. (44) study, when mean BL and MD TOC of the GP were calculated, they were 42.2 degrees and 34.1 degrees, respectively. These values were higher than the values obtained by GP in this study. The presence of supervision among students may also interpret the high values among GP. In addition, GP may increase the TOC to reduce patient's chair-time.

The TOC values of single crowns and PFP abutments were identical in the current study similar to Nordlander et al. (27) study. This is in contrast to Aleisa et al. (33) study finding that TOC values of PFP abutments were higher than single crowns' TOC, and to Ali et al. (45) research reporting that the TOC values for single crowns were higher than those of PFP abutments. In the current study, TOC of the maxillary teeth did not differ from the mandibular teeth' TOC. This is in contrast to Alhazmi et al. (34) and Tiu et al. (44) who found greater TOC in mandibular teeth.

The type of tooth being prepared had an influence on the TOC values. Molars in general had the highest values of the convergence among the other teeth in BL and MD dimensions. This is consistent with Ghafoor et al. (25, 38) Alhazmi et al. (34), and Tiu et al. (44). The presence of cheeks, limited visibility, and the difficulty of access to them were suggested as causal factors (33, 38). However, the BL TOC of the incisors was higher than the molar TOC among MS. This may be attributed to their attempt to increase the esthetics of the final restoration.

In this study, only 3.3% of the MS could prepare teeth with TOC of 12 degrees or less. They were better than the other groups. Notwithstanding, the difference cannot be considered tangible. Anyhow, GP had recorded the highest TOC values. Definitely, specialized training and the pres-

ence of supervision can aid in improving the clinical practices and achieving TOC closer to the recommended values. The message our faculty wanted to deliver to the syndicate - through this research- was that some actions (such as holding lifelong courses or distributing booklets) might be necessary for GP.

There are many techniques for measuring TOC of preparations, such as photocopy machines, tool marker microscope, overhead projectors, goniometric microscopes, and CAD/CAM machines. Although the TOC was measured by the protractor in the current study, this method showed excellent (> 0.8) agreement (46). The interclass correlation value in this study was 0.95.

In conclusion, the current study findings support the existing literature that the recommended TOC values ($\leq$ 12 degrees) are rarely achieved in practice, even among specialists in prosthodontics. TOC measured in the current study, even of MS, was significantly greater than the recommended values. Nevertheless, GP preparations were much far away from the recommended values, which may require some actions from the syndicate.

Acknowledgments

The authors thank Dr. Rami Alsharbaji Almozik and Dr. Manar Alkhalil for their help in collecting the sample. We also extend our appreciation to Fayha Haj Islam for her statistical assistance.

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