Selecting VITA Classical Shades with the VITA 3D-Master Shade Guide

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Purpose: Although the VITA 3D-Master (3D) shade guide offers improved shade-matching performance, many dental materials are only available in VITA Classical (VC) shades. This study aimed to clarify whether it is possible to convert 3D shades determined by observers into VC shades (indirect method) without adding a clinically significant error in comparison with direct shade determination using the VC shade guide. ***Materials and Methods:*** Forty ceramic specimens were fabricated. L*a*b* values were recorded using a spectroradiometer. Sixty participants (35 dentists, 15 technicians, and 10 students) were recruited and asked to determine the shades of specimens using the VC and 3D shade guides under standardized conditions. Conversion tables were constructed by allocating the closest VC shade tab to every matched 3D shade and by use of an optimization algorithm (indirect methods). Differences between ΔE values for VC matches and for the indirect methods were evaluated using *t* tests. ***Results:*** A mean ΔE (SD) of 4.34 (2.00) for VC and 4.22 (2.21) for 3D was observed (P = .040). Compared with direct shade matching using VC, the indirect method with the optimized tables resulted in a mean ΔE of 4.32 (1.96), which was not significantly different (P = .586). ***Conclusions:*** Within the limitations of this study, the conversion tables were suitable for the determination of tooth color using the 3D shade guide followed by conversion into VC shades without adding a clinically significant error. *Int J Prosthodont 2014;27:376–382. doi: 10.11607/ijp.3770*

Recently, the demand for tooth-colored materials (eg, ceramics or composite resins) for use in dental restorations has increased substantially. Accurate shade determination is a key aspect of esthetically successful restorations and a challenge to both dentists and technicians. Shade determination is routinely performed with the aid of shade guides.[1] The most popular shade guides are VITA Classical (VC; VITA Zahnfabrik) and 3-D Master (3D; VITA Zahnfabrik). Introduced in 1998, the 3D shade guide is a more systematically arranged system that features a guided approach in three steps: determination of lightness (L*), chroma (c*), and hue (h*).[2] This sequence is in accordance with the Munsell color order system.[3] These values also can be described in terms of Commission Internationale de l'Eclairage L* (lightness), a* (red/green), and b* (yellow/blue) values, which enable calculation of differences between two colors (ΔE).[4] Several studies have been performed to evaluate and/or compare the matching performance of the VC and 3D shade guides. Hammad found the reliability of the 3D guide to be superior to that of VC among general dentists, although the two systems showed equal reliability among prosthodontists.[5] Other studies have reported that the 3D guide offers more systematic arrangement of the shade tabs and more uniform spacing of the included shades.[6,7] It has also been reported that the 3D guide provides better coverage of natural tooth colors.[8,9] A laboratory investigation tested the matching quality of the VC and 3D guides and found that color differences were smaller for 3D.[10] A clinical study revealed that if shades for restorations were determined using the 3D guide, fewer shade corrections were required than when restorations were matched with VC.[11] In general, the literature indicates that use of the 3D guide results in superior matching. However, some tooth-colored dental materials are available only as VC shades.[12] A recent theoretical study described

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optimized tables suitable for conversion of 3D shades into VC shades[13]; therefore, it was of interest to review the performance of these conversion approaches within a standardized setting with human observers. Thus, this study aimed to clarify whether it is possible to convert 3D shades determined by observers into VC shades (indirect method) without adding a clinically significant error in comparison with direct shade determination using VC.

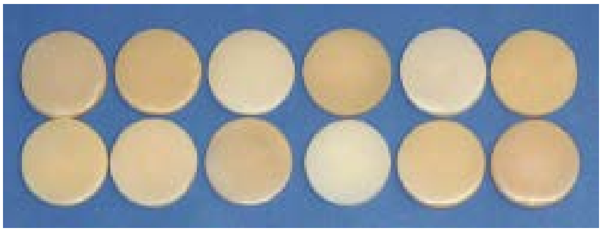

Fig 1 An assortment of completed specimens.

Materials and Methods

Fabrication of Porcelain Disks

Forty bilayer specimens (dentin/enamel) of VITA VM 13 ceramic powders (VITA Zahnfabrik) were fabricated in accordance with a standardized procedure.[14,15] Equal dimensions (14 × 3 mm) were achieved for all disks by pouring the ceramic powders into a steel mold, grinding them with a few drops of distilled water, and then compacting them using a glass plate. After firing of the 2.5-mm dentin layer in a ceramic furnace (VITA Vaccumat 6000, VITA Zahnfabrik), a 0.5-mm layer of enamel was applied and firing was repeated. A metallographic polishing system was used to eliminate inaccuracies in surface texture (up to 1,000 grit). Finally, the intended total thickness of the disks (3 mm) was tested with a digital caliper. Variations in the thickness were limited to 50 μm. Completed specimens were cleaned in an ultrasonic bath. The shades selected for this study were the 10 most popular VC shades, 10 most popular 3D shades, and 10 mixtures each of VC and 3D shades in different ratios (1:1, 1:2, 1:4), for a total of 40 specimens. Shade reproduction for the pure VC and 3D shade specimens was performed using Easyshade Advance in reproduction mode (VITA Zahnfabrik). A two-star match was defined as acceptable reproduction of the intended shade. Figure 1 shows an assortment of completed specimens.

*Assessment of L*a*b* Values*

To obtain L*a*b* values, the 40 specimens and VC and 3D shade tabs were measured five times with a spectroradiometer (SR; PR670, Photo Research). An integrating sphere (Labsphere) with 35-watt tungsten illumination (IHLS 100-35, Labsphere) equipped with a lamp power supply (LPS-100-037, Labsphere) was used to standardize measurements. A 2-degree observer angle was selected for readings; the aperture was set to 1 degree. Specimens were embedded in a custom alumina adapter using gray impression material (Lab Putty, Detax). During measurements, specimens were placed behind the integrating sphere (distance between specimens and SR = 40 cm). Before the readings, the SR was calibrated using a diffuse reflectance standard (USRS-99-010, Labsphere). Mean L*a*b* values from five measurements were used for further calculations. To ensure reliable measurements, repeatability and reproducibility were studied via the Wyble and Rich procedure.[16] A mean ΔE of less than 0.1 was observed among approximately 1,200 readings.

Participants

The study protocol was approved by the local review board of the University of Heidelberg, Heidelberg, Germany (S-155/2011). Residents (dentist and technicians) and students of the Department of Prosthodontics were asked to participate. A study information event was held in order to recruit participants. This event was announced within the department, and all members and clinical students were invited. Inclusion criteria were a successfully passed Ishihara color test and a signed informed consent form. Participants under 18 years of age were excluded. Three candidates (one woman [1.6%] and two men [3.2%]) failed the Ishihara test and were therefore excluded. An agreement was reached that all participants who met the inclusion criteria could be included in the study. The study population (N = 60) consisted of 35 dentists, 15 technicians, and 10 clinical students (43.3% women). The mean age of participants (SD) was 31.1 (7.9) years, with a range of 22 to 56 years. In the dentist group, the mean age of participants was 30.6 (5.5) years, with a range of 24 to 53 years (54.3% women). In the technician group, the mean age was 36.1 (11.2) years, with a range of 25 to 56 years (26.7% women). In the student group, the mean age was 25 (3.4) years, with a range 22 to 32 years (20.0% women). To ensure comparable knowledge among the study population regarding the nature of color and the use of both shade guides, all participants were required to attend a 45-minute lecture.

Randomization

Stratified randomization with regard to participants' profession (dentist, technician, or student) was applied. Randomization was performed by lot using

Fig 2 Setup for color determination by the participants.

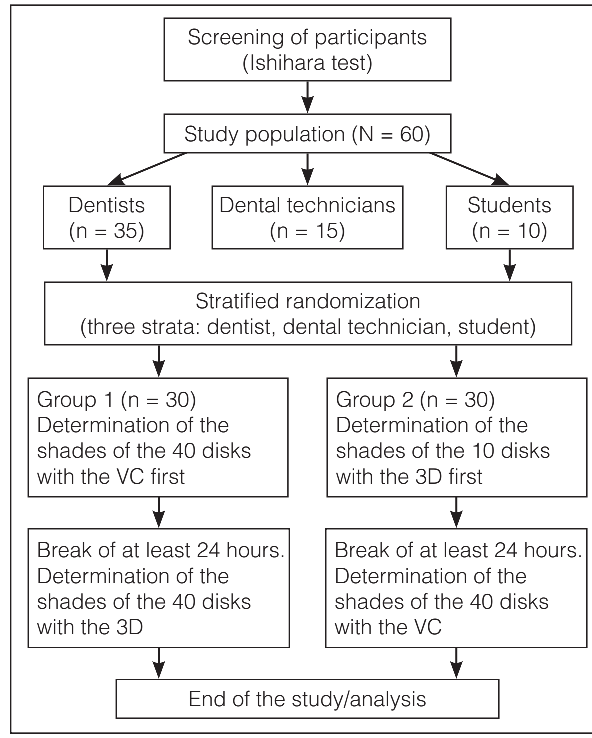

Fig 3 Flowchart of the participants.

three separate lottery wheels for the three strata. Participants were randomly allocated to two groups: determination of specimen shade with VC first (group 1, n = 30) or with 3D first (group 2, n = 30). In addition, the order in which the ceramic disks were presented was randomized.

Study Procedures

Participants were asked to determine the color of all 40 specimens, with either the VC or 3D first and with a break of at least 24 hours before use of the other shade guide, within a standardized environment (neutral gray light booth). To ensure an equal distance of 0.4 meters from the disks to the observers' eyes, an optometrist's frame was used. Disks were illuminated by D65 daylight at an angle of 45 degrees; the observers viewed the disks at 0 degrees.[15] The light booth was the only light source in the room during the investigations; the walls of the testing room were painted with Munsell no. 7 neutral gray (Fig 2). The best possible shade matches by the observers were assessed and documented on case record forms for each disk. A detailed participants' flowchart is displayed in Fig 3.

Designing Conversion Tables (Table 1)

The easiest and most intuitive method to design conversion tables is to assign each of the 26 3D shade tabs the closest (smallest ΔE) of the 16 VC shade tabs (indirect method 1). Additionally, an optimized conversion table was computed (indirect method 2).

For calculation of the optimized table, a color model within the limits of the 3D and VC color space (L*a*b* values as measured by SR) was developed. The color space was discretized in 0.05 steps and contained a total of 21,090,000 grid points. The sum of all grid points (d) was denoted CS_{dis}.

For each grid point (d), the closest 3D shade tab, β(d), was calculated (smallest ΔE). For each β(d), the best possible VC shade tab was assigned. This VC shade tab was termed Δ3D – VC(d). Finally, the minimization problem was separately solved for each 3D shade tab using the following algorithm, which was executed on a standard notebook (enumeration of all possibilities):

$$\sum_{d \in CS_{dis}\, \beta(d)} \Delta_{3D-VC}(d)$$

Testing the Performance of Conversion Tables

α(d) was introduced as a variable for each VC shade tab selected for a certain specimen by an observer, whereas the color distance (ΔE) between the shade tab and specimen was termed $\Delta(d)_{VC}$. Likewise, for 3D shade tabs, the distance between the shade tab and

Table 1 Conversion Tables

	VC shade	
3D shade	Indirect method 1 (smallest ΔE to the respective 3D shade)	Indirect method 2 (optimized table)
1M1	B1	A1
1M2	A2	A1
2L1.5	A2	A2
2L2.5	B3	B3
2M1	D2	D2
2M2	A2	A2
2M3	B3	B3
2R1.5	C1	C1
2R2.5	A3	A2
3L1.5	C2	C2
3L2.5	B4	B4
3M1	D3	D2
3M2	A3	A3
3M3	B4	B4
3R1.5	D3	D3
3R2.5	A3.5	A3.5
4L1.5	C3	C3
4L2.5	A4	A4
4M1	C3	C2
4M2	C3	C3
4M3	A4	A4
4R1.5	C3	C3
4R2.5	A4	A4
5M1	C4	C4
5M2	A4	A4
5M3	A4	A4

specimen was termed $\Delta(d)_{3D}$. The 3D shade tab was converted via tables into the corresponding VC shade (indirect methods 1 and 2).

The procedure was repeated for all 2,400 color determinations with the 3D guide.

The indirect and direct shade matching is visualized in Fig 4.

ΔE Values

Color differences between each specimen and shade tab matched by the observers with VC and 3D were calculated as follows[4]:

$$\Delta E_{ab} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

ΔE values for the simple and optimized method were also calculated.

All calculations were performed with both the conventional ΔE formula above and the ΔE2000 formula[4]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*}{k_H S_H}\right)^2 + \Delta R}$$

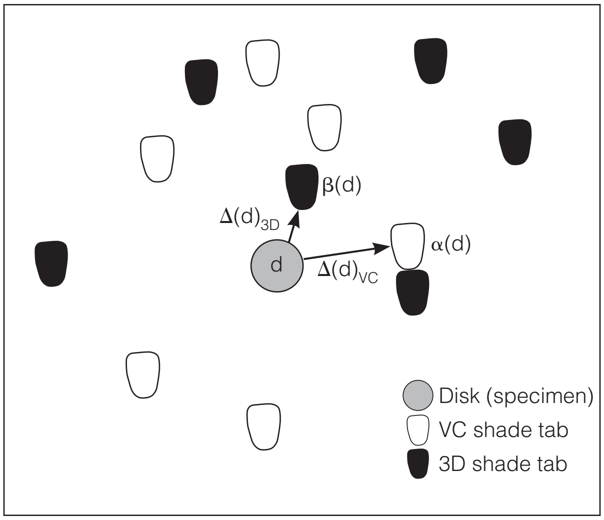

Fig 4 Methods for direct and indirect shade matching.

Statistical Analysis

Descriptive statistics were used to report the distributions of ΔE values for all methods. Differences between shade determinations with VC and indirect shade determinations with the conversion table were analyzed using *t* tests. Univariate analysis was used to evaluate the effect of age, sex, profession, and shade guide on the dependent variable ΔE. Statistics were performed using SPSS 19.0 (IBM). The level of statistical significance was set to $P < .05$.

Results

Conversion Tables

A mean ΔE (SD) of 4.34 (2.00) was observed between all specimens and shade tabs determined using VC. A significantly smaller ($P = .040$) mean ΔE of 4.22 (2.21) was found for the 3D guide. When the conversion tables were used, the nearest-neighbor table (simple table) provided a mean ΔE of 4.45 (1.94), and the optimized table gave a mean ΔE of 4.32 (1.96; Table 2). With the optimized table, the mean ΔE values were comparable with those from direct shade matching with VC ($P = .586$). For 40% of cases, use of the conversion tables gave an additional error; the maximum error was 2.69 ΔE. The mean additional error was 0.11 ΔE (simple table) or –0.02 ΔE (optimized method) compared to the direct shade match (Table 2). The univariate model indicated that both sex and the shade guide used had a significant effect on ΔE, whereas profession ($P > .205$) and age ($P = .617$) had no significant effect (Table 3).

Table 2 Shade Determination (ΔE) with the VC and 3D Guides for All Disks

Percentile	VC guide	3D guide	NN (IM1)	Optimized (IM2)	VC vs NN	VC vs optimized
Mean	4.34	4.22	4.45	4.32	−0.11	0.02
SD	2.00	2.21	1.94	1.96	2.16	2.23
10	2.27	1.51	2.25	2.25	−2.78	−2.69
20	2.60	2.30	2.75	2.63	−1.86	−1.75
30	3.00	2.92	3.26	3.06	−1.07	−0.93
40	3.27	3.54	3.86	3.65	−0.19	−0.19
50	3.94	4.01	4.29	4.07	0	0
60	4.34	4.31	4.45	4.37	0	0
70	5.09	5.14	5.05	4.94	0.37	0.79
80	5.86	5.70	6.07	5.85	1.50	1.69
90	7.36	6.89	6.77	6.75	2.77	2.90

NN = nearest neighbor; IM = indirect method.

Table 3 Univariate Analysis with ΔE as the Dependent Variable

		95% confidence interval		
Factor	Regression	Lower	Upper	*P*
Profession				
Dentist	0.09	−0.08	0.26	.311
Technician	−0.13	−0.34	0.07	.205
Student	0			
Age	0.00	−0.01	0.01	.617
Sex				
Female	−0.22	−0.34	−0.09	.001*
Male	0	–	–	–
Shade guide				
VC	0.12	0.01	0.24	.040*
3D	0	–	–	–

*Statistically significant.

Pure Shade Specimens

For the pure 3D shades, the mean ΔE (SD) was 4.25 (1.95) for VC and 3.79 (2.03) for 3D ($P < .001$). For the simple and optimized tables, the ΔE values were 4.33 (1.77) and 3.92 (1.84), respectively. Detailed results are presented in Table 4.

For determination of pure VC shades, the mean ΔE was 3.92 (1.81) for VC and 3.69 (1.91) 3D, which was a significant difference ($P < .001$). Use of the optimized table resulted in better mean shade matches than use of direct determination with VC, whereas use of the simple table resulted in comparable color differences (simple table: $P = .263$; optimized table: $P = .004$; Table 5).

Mixed Shade Specimens

For the mixed 3D shades, participants achieved a mean ΔE (SD) of 5.06 (2.24) using VC and 4.87 (2.81) using 3D ($P = .065$). The conversion tables resulted in a mean ΔE of 5.19 (2.58) for the simple method and 5.09 (2.58) for the optimized method. The direct shade matches obtained with VC were not significantly different from those obtained with the conversion tables (simple table: $P = .143$; optimized table: $P = .721$).

For the mixed VC shades, participants achieved a mean ΔE of 4.10 (1.77) with VC and 4.52 (1.70) with 3D ($P = .001$). Conversation tables provided a mean ΔE of 4.43 (1.48) for the simple table and 4.53 (1.38) for the optimized table, both of which were significantly worse than when using direct shade matching with VC ($P < .001$).

ΔE2000 Values

The mean ΔE2000 (SD) for matches between specimens and shade tabs was 3.49 (1.34) for VC and 3.21 (1.57) for 3D. Use of the 3D guide resulted in significantly smaller ΔE2000 values ($P < .001$). Use of the conversion tables resulted in a mean ΔE2000 of 3.65 (simple conversion table) and 3.56 (optimized table), which were slightly but significantly larger than with direct VC matching ($P < .028$).

Discussion

The results of this study reveal the possibility of determining tooth colors with the 3D guide followed by conversion into VC values using conversion tables without adding a clinically significant error in comparison with direct shade matching with VC. Compared with direct shade determinations, use of simply converted 3D shades (NN) resulted in a mean additional error of 0.11 ΔE; if the optimized method is applied the conversion even results in a 0.02 units lower ΔE than the direct shade matching. However, a previous theoretical study found larger color differences

Table 4 Shade Determination (ΔE) for the Pure 3D Shades

Percentile	VC guide	3D guide	NN (IM1)	Optimized (IM2)	VC vs NN	VC vs optimized
Mean	4.25	3.79	4.33	3.92	−0.08	0.33
SD	1.95	2.03	1.77	1.84	2.23	2.36
10	2.19	1.17	2.19	1.79	−3.00	−3.00
20	2.61	1.98	2.63	2.28	−2.11	−1.61
30	2.92	2.05	2.91	2.63	−0.85	−0.39
40	3.14	2.98	3.50	2.79	0	0
50	4.07	3.55	4.34	3.82	0	0
60	4.37	4.72	4.79	4.26	0	0.62
70	5.09	5.14	5.05	4.92	0.28	0.92
80	5.87	5.41	5.85	5.23	2.09	2.58
90	7.82	5.98	6.85	6.61	2.90	3.35

NN = nearest neighbor; IM = indirect method.

Table 5 Shade Determination (ΔE) for the Pure VC Shades

Percentile	VC guide	3D guide	NN (IM1)	Optimized (IM2)	VC vs NN	VC vs optimized
Mean	3.92	3.69	3.83	3.69	0.09	0.23
SD	1.81	1.91	1.45	1.49	2.04	2.03
10	1.97	1.34	1.96	2.00	−2.60	−2.30
20	2.27	1.64	2.27	2.35	−1.53	−1.28
30	2.66	2.53	3.04	2.59	−0.90	−0.65
40	3.07	2.92	3.58	3.21	−0.09	0
50	3.58	3.54	3.86	3.58	0	0
60	4.12	4.15	4.12	4.01	1.87	0.38
70	4.66	4.31	4.57	4.33	0.89	1.13
80	5.42	4.96	4.82	4.75	1.74	1.80
90	6.87	6.30	5.67	5.87	2.6	2.78

NN = nearest neighbor; IM = indirect method.

between converted shades and directly matched VC shades.[13] Two primary factors may explain this discrepancy: First, the theoretical study used virtually generated shades in the VC color space (and no 3D shades); second, the algorithm chose the best possible shade tabs in each case. This approach benefited the VC matches; in fact, the 3D matches could never have been better than the VC matches. In the present study, shades were matched by human observers who did not always select the best possible shade with either shade guide. The coverage error of VC was found to be 2.57 for VC tabs and 2.01 for 3D tabs. In the authors' opinions, this seems realistic because the 3D shade guide contains more tabs, and more equally spaced tabs, than VC. In 60% of cases, however, use of the conversion tables gave equal or better matches than direct matching with VC. A threshold for 50:50 perceptibility of color differences (indicating that 50% of the observers will perceive a mismatch) has been reported to be 1 ΔE[17]; therefore, the conversion error of 0.11 ΔE in this study (simple table) may not be clinically significant.

Other authors have reported thresholds for perceptibility tolerance of 2[18] or 2.6[19] ΔE, and 2.7[20] or 5.5[19] ΔE values have been regarded as 50:50 thresholds for color acceptance. However, the magnitude of color differences for observers' shade determinations in the present study should be noted. Mean ΔE values of 4.34 for direct color matches with VC and 4.22 with 3D were found. Although the thresholds for color perceptibility were exceeded in both approaches, the matches can still be regarded as acceptable. These findings are partially in agreement with those of another laboratory study reporting ΔE values of 4.5 for visual determinations with the 3D guide but distinctly higher values for the VC guide.[10]

The sex of the observers also had an effect on color matching in this study. Female observers achieved better mean color matches than men. In the literature, this association is regarded as controversial. A multi-center study observed an effect of sex on color matching.[21] Other studies reported no effects.[22,23] In the present investigation, no effect of profession or age was detected. This result may be unexpected because these two factors represent, even if weakly, the participants' experience with shade determination. One explanation for this lack of association may be the comprehensive lecture attended by all participants before the experiments; however, it should also be noted that the sex ratio in the technician and student groups was unbalanced, which may have biased the group effects. With regard to the experimental setting, this study used a light booth equipped with D65 daylight illumination at an angle of 45 degrees, and participants observed the specimens at an angle of 0 degrees, as recommended by Wee et al.[15] Further, the ceramic specimens were fabricated using a standardized procedure that has been used successfully in other studies.[14,15] Note that the present study did make one change to the procedures used in those previous studies. In this trial, an enamel ceramic layer was applied to the disks, which the authors' decided was closer to clinical reality.

One possible limitation of the study design was the use of porcelain disks rather than tooth-shaped specimens. However, Barrett et al found no differences in matching reliability between disks and shade tabs.[24]

The spectroradiometric readings of the shade tabs and specimens were the basis of all calculation in this study. Previous studies have found this approach to be the most reliable and accurate.[15,16] Further, various standardizations were used in this study (eg, specific power supply, custom specimen adapters, integrating sphere) and tested to allow repeated measurements with deviations smaller than 0.1 ΔE units.

The ΔE values for determination of pure shade specimens were lower than those for mixed shade specimens for both shade guides. This result was expected because the coverage error of the shade guides limits the shade match. However, pure shade tabs do not replicate clinical reality. It should also be noted that the smaller the $L^*a^*b^*$ values, the better the indirect methods performed. Use of shade data representative of different populations may, however, enable production of a more clinic-specific conversion table.

Conclusions

Within the limitations of this study, the conversion tables used were suitable in most cases for determination of tooth color using the 3D shade guide followed by conversion into VC shades without adding a clinically significant error. The simple conversation table is especially recommended for clinical use because it is not specifically weighted for the shades used in this study, which may be different from natural tooth colors. Clinical studies are needed to verify this outcome; however, to the authors' knowledge, there is currently no gold standard for intraoral measurement of $L^*a^*b^*$ values, which would be necessary to construct clinical conversion tables.

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