Influence of Different Cements on the Color Outcomes of Titanium-Based Lithium Disilicate All-Ceramic Crowns and Peri-implant Soft Tissue

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Purpose: To evaluate the influence of different cements on the color outcomes of CAD/CAM lithium-disilicate implant crowns cemented to titanium-base abutments utilizing spectrophotometric analysis. ***Materials and Methods:*** A clinical situation with a missing lateral incisor was mimicked using a maxillary plastic model. Titanium-base–supported monolithic lithium disilicate crowns with identical designs were fabricated using a laboratory CAD/CAM system. The crowns were cemented with three provisional cements and with six definitive cements on both nonsandblasted and sandblasted titanium-base abutments for a total of 15 test groups. As a control group, identical crowns were attached with try-in paste on composite die abutments that duplicated the shape of the titanium-base abutments. The colors of the labial surfaces of the crowns and the peri-implant artificial soft tissue were measured with a spectrophotometer and recorded in CIE L*a*b* parameters. Color differences between the test and control groups were calculated as: $\Delta E = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$. Kruskal-Wallis test was used to compare ΔE values across different groups. ***Results:*** The median ΔE values reported for crowns cemented with different definitive cements on titanium-base abutments ranged from 1.4 to 2.9 for the crown surface and from 1.7 to 1.9 on the peri-implant artificial soft tissue; when the titanium-base abutments were sandblasted, the respective median ΔE values ranged from 0.8 to 4.0 and from 1.4 to 2.2. Ceramic crowns cemented with Multilink HO 0 cement presented significantly ($P < .01$) lower ΔE values than the other cement types for the crown surface independent of sandblasting and for the artificial soft tissue surface when the titanium abutments were sandblasted ($P = .011$). ***Conclusion:*** Within the limitations of this study, Multilink HO 0 (Ivoclar Vivadent) cement showed the most favorable masking ability and the most favorable color outcome among the evaluated definitive cements. Cements of more opaque shades appeared in general to be more favorable in terms of masking the gray color of the titanium-base abutments. *Int J Prosthodont 2020;33:63–73. doi: 10.11607/ijp.6435*

Nowadays, there is a huge variety of prosthetic materials available for implant-supported reconstructions. Decision-making regarding choice of material is mostly based on whether the material will meet both the physical and esthetic requirements for a given patient situation.[1] The use of all-ceramic crowns supported by titanium-base abutments has increased significantly since this treatment option was introduced a few years ago. This combination has shown favorable fracture strength that is comparable to that of customized titanium abutments even when utilized for narrow-diameter implants.[2] However, the esthetic outcome of this combination has yet to be investigated in detail.

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Natural-looking peri-implant soft tissue is of increasing importance for a successful esthetic outcome of implant therapy. Healthy conditions and appropriate volume, color, and contours are all important characteristics of peri-implant soft tissue.[3] Thin peri-implant mucosa often shows an almost translucent appearance, which contributes to a shine-through effect of the underlying structures.[4] And when metal implant abutments are utilized, a grayish shade could alter the clinical appearance of the all-ceramic reconstructions and the peri-implant soft tissue.[1,4,5] The influence of different abutment materials on the color outcome of the peri-implant soft tissue has been documented in several studies. It has been reported that, in contrast to other kinds of abutments, titanium abutments are more likely to cause a change in color appearance of the peri-implant mucosa, especially in a clinical situation with a mucosa thickness of 2 mm or less.[1,6–8]

Besides the influence of abutment material and peri-implant soft tissue, it has been documented that along with abutment color and ceramic thickness, the cement color also influences the color outcome of CAD/CAM glass-ceramic lithium disilicate crowns.[9] It seems reasonable to speculate that the cement bonding a CAD/CAM glass-ceramic lithium disilicate reconstruction to a titanium-base abutment could also contribute to the color outcome of the reconstruction and the peri-implant soft tissue. However, it remains unclear to what extent the color outcomes of the implant-supported reconstruction and peri-implant soft tissue would be influenced by different cements and cementation protocols.

To objectively assess color in dentistry, colorimetric, or spectrophotometric, analysis has been documented to be a feasible method. Compared to shade matching with the human eye, spectrophotometry has been found to detect smaller color differences,[10] and the reproducibility achieved by spectrophotometric color assessment was superior to other techniques.[10–13] For spectrophotometric analysis in dentistry, the color is usually measured using the CIE L*a*b* scale, which was recommended by the CIE (Commission Internationale de l'Eclairage). The color is defined by L*, a*, and b* values in the scale, where the L* value indicates the lightness, the a* value indicates the green-red chromatic coordinate, and the b* value indicates the blue-yellow chromatic coordinate. The color difference between different measurement sites or different reconstructions is calculated[10] as $\Delta E = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$. In this equation, ΔL^*, Δa^*, and Δb^* stand for the difference of each value between the two measurement sites.[14]

The aim of the current study was to evaluate, utilizing spectrophotometric analysis, the influence of different cements on the color outcome of titanium-base–supported CAD/CAM lithium-disilicate crowns and the color of the peri-implant soft tissue. The null hypothesis was that no influence of the cements on the color outcomes of the ceramic crowns cemented to titanium-base abutments would be found.

MATERIALS AND METHODS

A clinical case from the dental clinic of the University of Geneva with a bone-level implant (Narrow CrossFit [NC], 3.3 × 10 mm, Straumann) supporting a screw-retained single crown in the position of the maxillary left lateral incisor was chosen as the initial situation. The morphology of the peri-implant soft tissue was duplicated from the main cast and reconstructed using artificial gingiva (Gingifast Elastic, Zhermack) on a plastic model with a composite dentition. The lateral incisor was replaced by an NC 3.3-mm replica (Straumann). A scan body (Scanbodies for Bluecam, S, Dentsply Sirona) was attached to the replica after the artificial gingiva was sprayed with titanium oxide scan spray (Helling 3D laser scanning anti-reflection spray, Laser Design). The model was then scanned with a laboratory scanner (inEos X5, Dentsply Sirona) for the 3D digital model. The 3D digital data were inserted into a design software (Cerec inLab 16.1, Dentsply Sirona), and a monolithic lithium-disilicate ceramic crown was virtually designed by an experienced technician (V.F.). A total of 48 low-translucency (LT) monolithic lithium-disilicate crowns (IPS e.max CAD, LT A2, Ivoclar Vivadent) were milled in an identical design using a laboratory milling machine (Sirona InLab MC XL, Dentsply Sirona). All the crowns were then sintered and glazed following the manufacturer's instructions. The test groups were restored with 45 titanium-base abutments (Variobase C, NC, Gingival Height [GH] 1 mm, Straumann). The 45 crowns were cemented with different cements onto the titanium-base abutments into 15 test groups, with 3 samples for each group. The details of each group are shown in Table 1. In groups A1 to A3 and B1 to B6, the titanium abutments went through no surface modification before cementation, while in groups C1 to C6, all the titanium abutments were sandblasted prior to cementation.

Three additional abutments were made using a laboratory composite die material (IPS Natural Die Material, ND1, Ivoclar Vivadent). These abutments were duplicated in the exact shape of the titanium abutment. Three crowns were seated with a try-in paste (Variolink Esthetic try-in paste, light, Ivoclar Vivadent) on the composite die abutments as a control group.

Each sample was screw retained on the replica in the model. A mark was made on the artificial gingiva 1 mm apical to the test site, and two other dots were made on the adjacent canine, indicating 1 mm incisal to the gingival margin and the middle of the crown, respectively, to standardize the location of subsequent color measurements (Fig 1). The thickness of the ceramic at

Table 1 Overview of Abutments and Cements for the Control and Test Groups

Group	Abutment	Cement
Control	IPS Natural Die Material (ND1, Ivoclar)	Variolink Esthetic try-in paste (Light, Ivoclar Vivadent)
A1	Titanium abutments (NC Straumann Variobase C)	Variolink Esthetic try-in paste (Light, Ivoclar Vivadent)
A2	Titanium abutments (NC Straumann Variobase C)	Translucent glue
A3	Titanium abutments (NC Straumann Variobase C)	Zinc oxide temporary cement (Rely X, 3M ESPE)
B1	Titanium abutments (NC Straumann Variobase C)	Self-curing resin-based cement (HO 0, Multilink Hybrid Abutment, Ivoclar Vivadent)
B2	Titanium abutments (NC Straumann Variobase C)	Self-adhesive universal resin cement (A2, RelyX Unicem, 3M ESPE)
B3	Titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (Clear, Panavia V5, Kuraray)
B4	Titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (A2, Panavia V5, Kuraray)
B5	Titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (White, Panavia V5, Kuraray)
B6	Titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (Opaque, Panavia V5, Kuraray)
C1	Sandblasted titanium abutments (NC Straumann Variobase C)	Self-curing resin-based cement (HO 0, Multilink Hybrid Abutment, Ivoclar Vivadent)
C2	Sandblasted titanium abutments (NC Straumann Variobase C)	Self-adhesive universal resin cement (A2, RelyX Unicem, 3M ESPE)
C3	Sandblasted titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (Clear, Panavia V5, Kuraray)
C4	Sandblasted titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (A2, Panavia V5, Kuraray)
C5	Sandblasted titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (White, Panavia V5, Kuraray)
C6	Sandblasted titanium abutments (NC Straumann Variobase C)	Dual-cure resin cement (Opaque, Panavia V5, Kuraray)

the test points was measured in the designing software. The thicknesses of the ceramic material on the cervical and middle test sites were 2.55 mm and 2.67 mm, respectively—slightly thicker than 2.5 mm, which has been documented to cause minimal ΔE in a previous study.[9] The transmucosal area of the ceramic crown was designed as it should be in a clinical situation, and the thickness of the ceramic material at the soft tissue measurement site was measured to be 1.52 mm. The thickness of the artificial soft tissue material at the test site was set at 2.0 mm to mimic a clinical situation in which the underlying titanium abutment would influence the color appearance of peri-implant soft tissue significantly according to previous studies.[1,6–8] The thickness was confirmed using an ISO #20 K file after the set of the artificial soft tissue, as described in previous clinical studies.[1,15]

A spectrophotometer (SpectroShade Micro, MHT) was utilized to measure the color of each reconstruction three times. According to the manufacturer's suggestion, all the tests were done in a room without a window, and during the procedure, the door was closed and the illumination diminished. The spectrophotometer took an image of the reconstruction and recorded the image after each measurement. Both the device and the sample were kept in a black box until the measurement was finished. All the images were downloaded from the device onto a laptop using SpectroShade Database (V1.1.1.0, MHT). Each image was then analyzed in the SpectroShade Analysis program (V1.1.1.0, MHT). For each image, the test sites were as follows: middle of the reconstruction; 1 mm incisal to the soft tissue margin on the reconstruction; and 1 mm apical to the soft tissue margin on the artificial soft tissue. The measurement sites were standardized by the marks on the model as previously described. The cursor was set as square, size 30, as the default setting. The readings with CIE L*a*b* color scale of the three defined measurement sites of each sample were recorded.

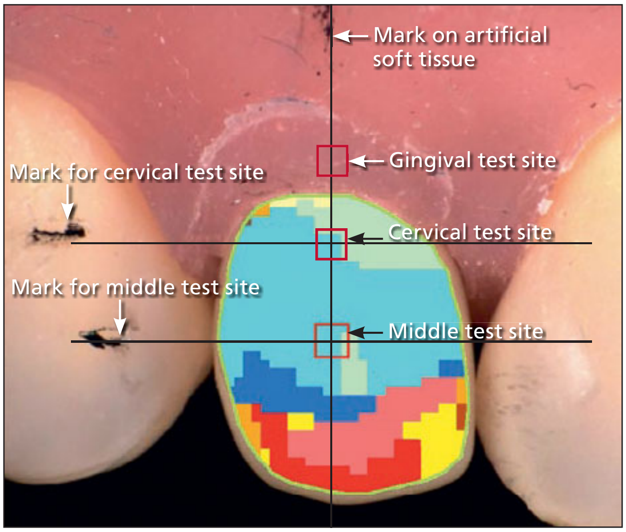

Fig 1 Illustration of a spectrophotometric measurement showing the marks made on the adjacent canine and the artificial soft tissue to standardize the measured sites.

Table 2 Overall Median and 25th and 75th Percentile Values of L*, a*, b*, and ΔE Values for the Spectrophotometric Measurements of the Reconstruction

Test groups	L*			a*			b*			ΔE		
	Median	P25	P75	Median	P25	P75	Median	P25	P75	Median	P25	P75
A1[a]	70.725	70.255	71.23	1.715	1.04	2.57	15.925	15.18	16.70	2.615	2.35	3.05
A2[a]	72.55	72.305	73.40	2.15	1.42	3.10	16.335	15.95	16.73	1.745	1.45	2.17
A3[a]	73.005	72.62	73.155	2.43	1.68	3.34	17.94	17.29	18.385	1.055	0.695	1.41
B1[b]	73.425	72.76	73.62	2.69	1.82	3.455	17.845	17.58	18.115	1.365	0.74	1.58
B2	71.045	70.67	72.46	1.715	1.16	2.585	15.995	15.27	16.53	2.445	2.08	2.82
B3	70.52	69.165	71.025	1.76	1.11	2.36	16.145	15.74	16.98	2.92	2.48	3.51
B4	71.27	69.96	72.06	2.145	1.36	2.85	17.265	16.645	17.60	1.63	1.205	2.36
B5	71.585	71.32	72.31	1.865	1.18	2.63	16.19	15.54	16.74	1.99	1.865	2.40
B6	72.935	72.43	73.36	1.87	1.255	2.62	16.75	16.09	17.22	1.92	1.59	2.12
C1[b]	72.465	71.99	72.715	2.375	1.63	3.125	17.72	17.39	18.10	0.825	0.505	1.20
C2	71.32	70.59	71.765	1.155	0.52	1.72	14.79	13.88	15.58	3.705	3.20	4.23
C3	69.805	69.58	69.96	1.155	0.705	1.95	15.245	14.36	16.05	3.96	3.425	4.45
C4	70.34	70.125	71.145	1.39	0.80	2.02	15.69	14.455	16.295	3.08	2.74	4.00
C5	71.785	71.365	72.595	1.215	0.77	1.885	15.795	15.385	16.56	2.605	2.23	3.135
C6	72.65	72.40	72.92	1.625	1.02	2.47	16.185	15.94	16.81	2.06	1.845	2.275

[a]Temporary cements.
[b]Group with the lowest ΔE value ($P < .05$).

The color difference between different test groups and the control group (ΔE) were calculated according to the formula: $\Delta E = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$. ΔL*, Δa*, and Δb* in the formula indicate the difference between the test group and control group for L*, a*, and b* values, respectively.[10]

Statistical Methodology

The null hypothesis was that ΔE values would not differ between the different cement types, test sites, or surface preparations of the titanium abutments. The data were analyzed using nonparametric tests, as the distribution of the data was not Gaussian according to a Kolmogorov-Smirnov test. The significance level was set at $P < .05$.

The differences between nonsandblasted and sandblasted titanium abutments were tested using Wilcoxon signed ranks test separately for each cement group. Differences between cement groups and test sites were analyzed using Kruskal-Wallis test. As there were significant differences ($P < .05$) between surface preparations, Kruskal-Wallis tests were run separately for nonsandblasted and sandblasted titanium abutments. In order to explore the detailed color shifts, the same statistical scheme was used while substituting the outcome ΔE for each component of the CIE (L*, a*, b*, ΔL*, Δa*, and Δb*). To investigate the influence of various parameters on the color performance at the restoration surface and artificial peri-implant soft tissue, color parameters measured at the middle site and cervical site were pooled together to represent the overall color performance of the restoration surface.

The statistical analysis was performed with IBM SPSS statistics, version 25.

RESULTS

Within the groups where the reconstructions were cemented provisionally with try-in paste (Group A1), transparent glue (Group A2), or temporary cement (Group A3), significantly ($P = .001$) lower median ΔE values were measured for the reconstruction surfaces of the RelyX temp group (A3) (1.1) (Table 2). When measured for the peri-implant artificial soft tissue, the RelyX temp group (A3) also showed the lowest median ΔE value (2.0), although the color difference between the groups for the soft tissue was not statistically significant ($P = .875$) (Table 3).

For the reconstructions cemented on nonsandblasted titanium abutments with definitive cement, the median ΔE values for the different test groups ranged from 1.4 to 2.9, with the lowest median value reported for the reconstruction surfaces of Group B1 (Multilink HO 0) (Table 2, Fig 2). The color difference for the nonsandblasted abutments reached a significant statistical difference ($P < .001$). Measuring the artificial peri-implant soft tissue for the respective nonsandblasted test groups, the median ΔE values ranged from 1.7 to 1.9, with the lowest value reported for Group B4 (Panavia A2) (Table 3, Fig 3). However, the difference among the test groups for the artificial soft tissue was not statistically significant ($P = .281$).

For reconstructions cemented on sandblasted titanium-base abutments with definitive cement, the

Table 3 Overall Median, Minimum, and Maximum Values of L*, a*, b*, and ΔE Values for the Spectrophotometric Measurements of the Peri-Implant Artificial Soft Tissue

Test groups	L*			a*			b*			ΔE		
	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum
A1[a]	61.32	60.91	62.13	14.30	13.74	14.77	9.63	9.34	10.20	2.42	1.74	2.87
A2[a]	63.52	63.39	63.83	15.74	15.40	15.93	10.66	10.58	10.74	2.31	1.90	2.33
A3[a]	63.79	63.69	64.11	15.49	15.40	15.93	11.01	10.95	11.10	1.97	1.87	2.49
B1	63.79	63.78	63.97	15.41	15.30	15.46	11.17	10.68	11.28	1.92	1.87	2.01
B2	62.37	62.34	63.06	14.83	14.50	15.06	9.90	9.81	10.17	1.80	1.75	2.00
B3	62.37	62.23	62.97	14.92	14.60	15.29	9.83	9.70	10.24	1.91	1.90	2.12
B4	62.01	61.89	62.57	14.42	14.37	14.83	10.18	10.03	10.50	1.69	1.43	1.75
B5	62.22	62.10	62.77	14.40	14.30	14.68	9.93	9.45	9.99	1.71	1.69	2.21
B6	63.53	63.47	64.07	14.74	14.53	15.21	10.31	10.00	10.58	1.83	1.46	2.04
C1[b]	63.08	63.03	63.35	14.74	14.67	14.84	10.37	10.29	10.84	1.43	1.29	1.45
C2	63.11	62.58	63.16	14.69	14.40	14.96	9.55	9.53	9.84	1.99	1.99	2.11
C3	62.18	62.02	62.34	14.24	13.65	14.32	9.55	9.03	9.64	2.05	1.93	2.54
C4	61.94	61.35	62.06	14.42	14.06	14.56	9.50	9.36	9.66	2.18	2.14	2.58
C5	63.17	62.77	63.19	14.13	14.05	14.39	9.58	9.50	10.11	1.86	1.47	1.97
C6	63.74	63.00	63.85	14.44	14.35	14.62	10.10	9.77	10.24	1.75	1.69	1.76

[a]Temporary cements.
[b]Group with the lowest ΔE value ($P < .05$).

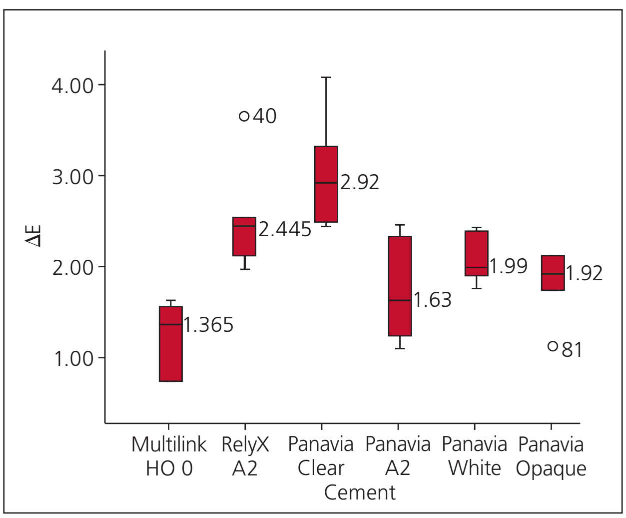

Fig 2 Comparison of ΔE values for reconstruction surfaces across different definitive cement groups for reconstructions supported by nonsandblasted titanium abutments.

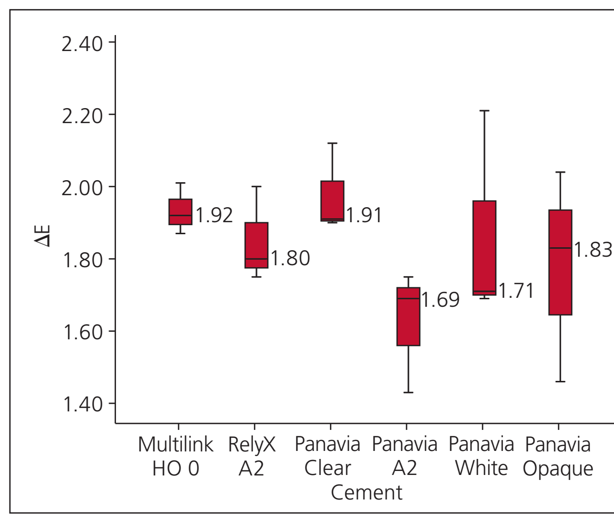

Fig 3 Comparison of ΔE values for artificial peri-implant soft tissue surfaces across different definitive cement groups for reconstructions supported by nonsandblasted titanium abutments.

median ΔE values ranged from 0.8 to 4.0 with significantly ($P < .001$) lower ΔE values measured on the reconstruction surfaces of Group C1 (Multilink HO 0) (0.8 ± 0.4) (Table 2, Fig 4). Measuring the peri-implant artificial soft tissue for the sandblasted test groups, the median ΔE values ranged from 1.4 to 2.2, with the lowest ΔE value again reported for Group C1 (Multilink HO 0) (Table 3, Fig 5). The difference in ΔE values for the soft tissue measurement reached significance ($P = .011$).

The color difference was further analyzed to explore the detailed color shift. For the reconstruction surfaces that were cemented to nonsandblasted titanium-base abutments, the a* and b* values were reduced (Fig 6), indicating a color shift toward green and blue. Further analyzing the color shift of the peri-implant artificial soft tissue for the respected test groups, the a* values were increased, but the b* values were reduced, indicating a color shift toward red and blue (Fig 7). A similar color shift pattern was also seen for reconstructions cemented to sandblasted titanium-base abutments.

For reconstructions supported by nonsandblasted titanium abutments, the overall median ΔE value differences at the middle part and the cervical part of the reconstructions and the artificial soft tissue did not

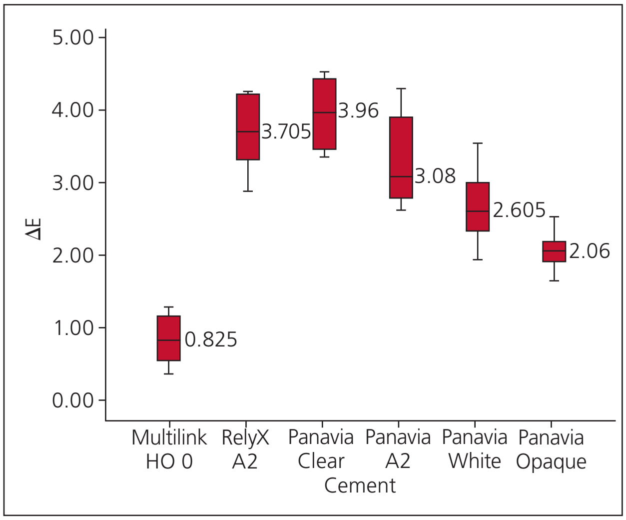

Fig 4 Comparison of ΔE values for reconstruction surfaces across different definitive cement groups for reconstructions supported by sandblasted titanium abutments.

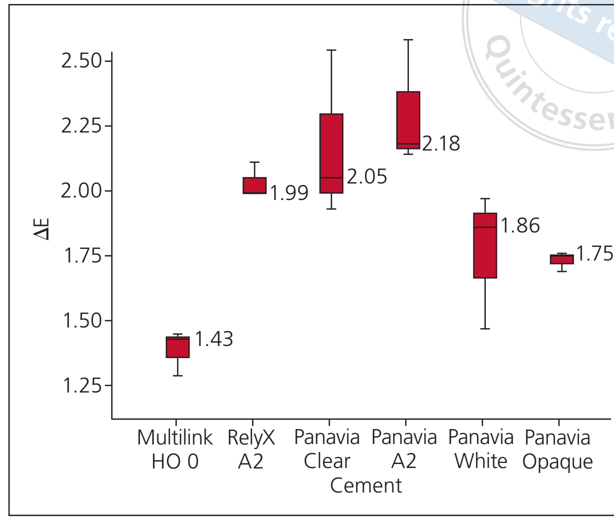

Fig 5 Comparison of ΔE values for peri-implant artificial soft tissue surfaces across different definitive cement groups for reconstructions supported by sandblasted titanium abutments.

reach statistical significance (P = .321) (Fig 8). On the other hand, for reconstructions supported by sandblasted titanium abutments, the difference of the respective median ΔE values reached statistical significance (P = .004), indicating a stronger color influence at the reconstruction surface compared to the peri-implant artificial soft tissue (Fig 8). The influence of sandblasting the abutments on the color outcome was investigated by comparing the median ΔL*, Δa*, Δb*, and ΔE values for reconstructions supported with sandblasted vs nonsandblasted titanium-base abutments. For the reconstruction surfaces, there was a statistically significant difference for all four color values (P < .05), but for the peri-implant artificial soft tissue, the color difference reached statistical significance (P < .05) only for the median Δa* and Δb* values. The influence of sandblasting the abutments on the surface color outcome of the reconstructions was different between different cements, with Groups C1 (Multilink HO 0) and C6 (Panavia opaque) leading to the smallest color difference (Figs 9 and 10).

DISCUSSION

The present in vitro study showed that color outcomes of the all-ceramic, lithium disilicate implant crowns cemented to titanium-base abutments were influenced by different types of cement. More opaque cements led to less discoloration, both with nonsandblasted and sandblasted abutments. The discoloration was induced by a color shift of the ceramic crowns to a more greenish/bluish color after cementation. Furthermore, cements also influenced the color outcome of the peri-implant soft tissue at the all-ceramic crowns, but to a less pronounced degree. The null hypothesis was hence rejected for reconstructions supported by both sandblasted and nonsandblasted titanium-base abutments.

The importance of the cements on the color of the crowns was already observed at the temporary cements tested in the present study. The outcomes demonstrate that within the temporary cements, RelyX induced the smallest color change with a median ΔE value of 1.1, which was below the threshold value of visible color differences (ΔE 1.815). The comparison of the light try-in paste, the translucent glue, and the temporary cement may not seem relevant for the final clinical outcome, but the comparison between the temporary and definitive cements showed that on both the reconstruction surfaces and the peri-implant soft tissue surfaces, the differences in ΔE values—and in ΔL*, Δa*, and Δb* values—caused by the cements were statistically significant. This implies that using try-in paste or cementing an all-ceramic reconstruction to the titanium abutment with temporary cement might be inaccurate for predicting the final color outcome of the reconstruction, both for the reconstruction surface and for the peri-implant soft tissue.

Among the definitive cement groups, when nonsandblasted titanium abutments were used, the lowest median ΔE values were observed in Groups B1 (Multilink HO 0) and B4 (Panavia A2), with ΔE values of 1.4 and 1.6, respectively. Other cement groups showed ΔE values above the threshold value for color differences detected by the human eye (ΔE 1.8).[16] The findings of the present study are in agreement with previous studies showing that opaque cements are better suited to masking the dark color of metal substructures.[5,9,17]

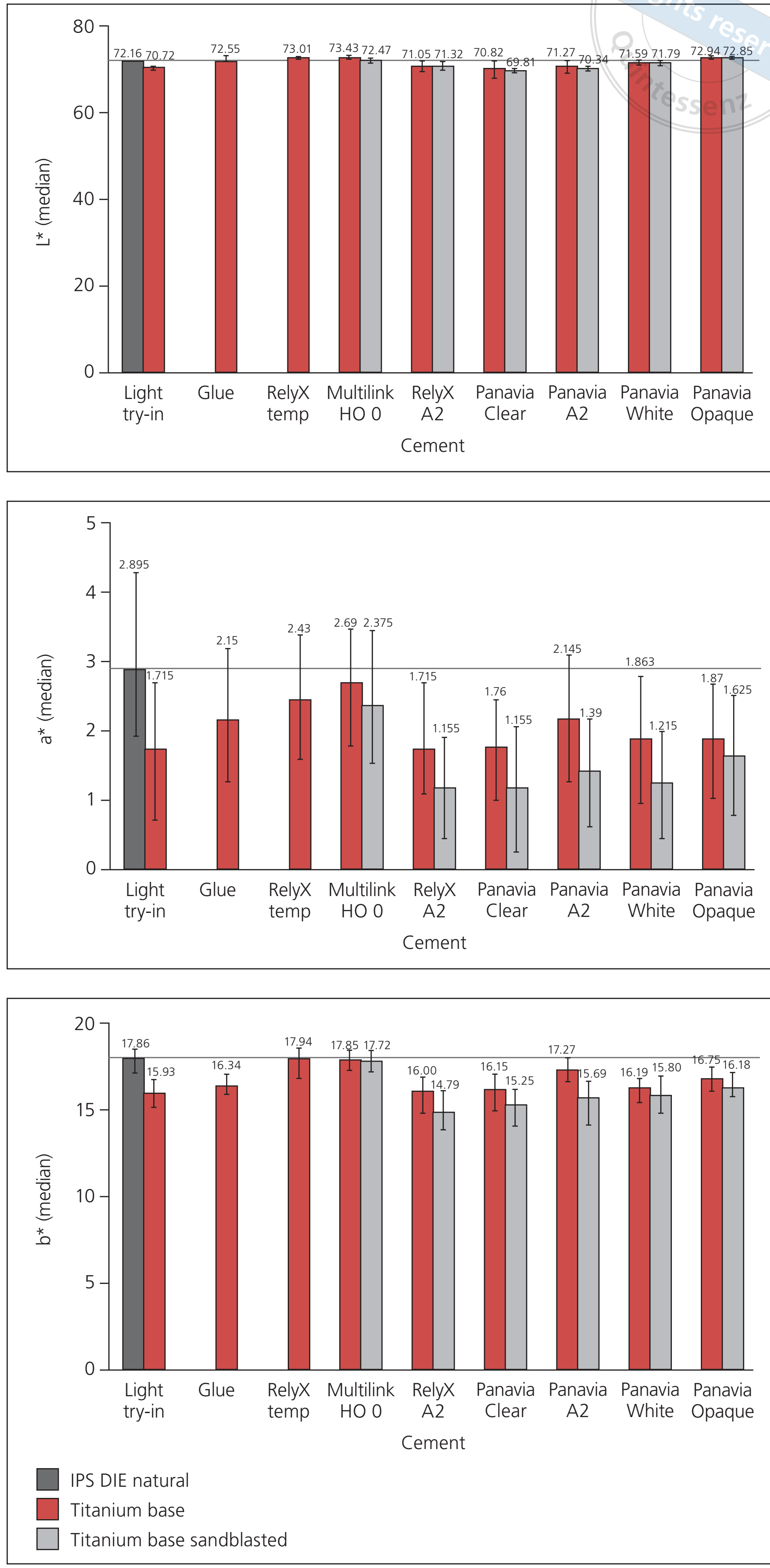

Fig 6 Overall comparison between the control group and the different cementation groups for L*, a*, and b* values at the reconstruction surfaces.

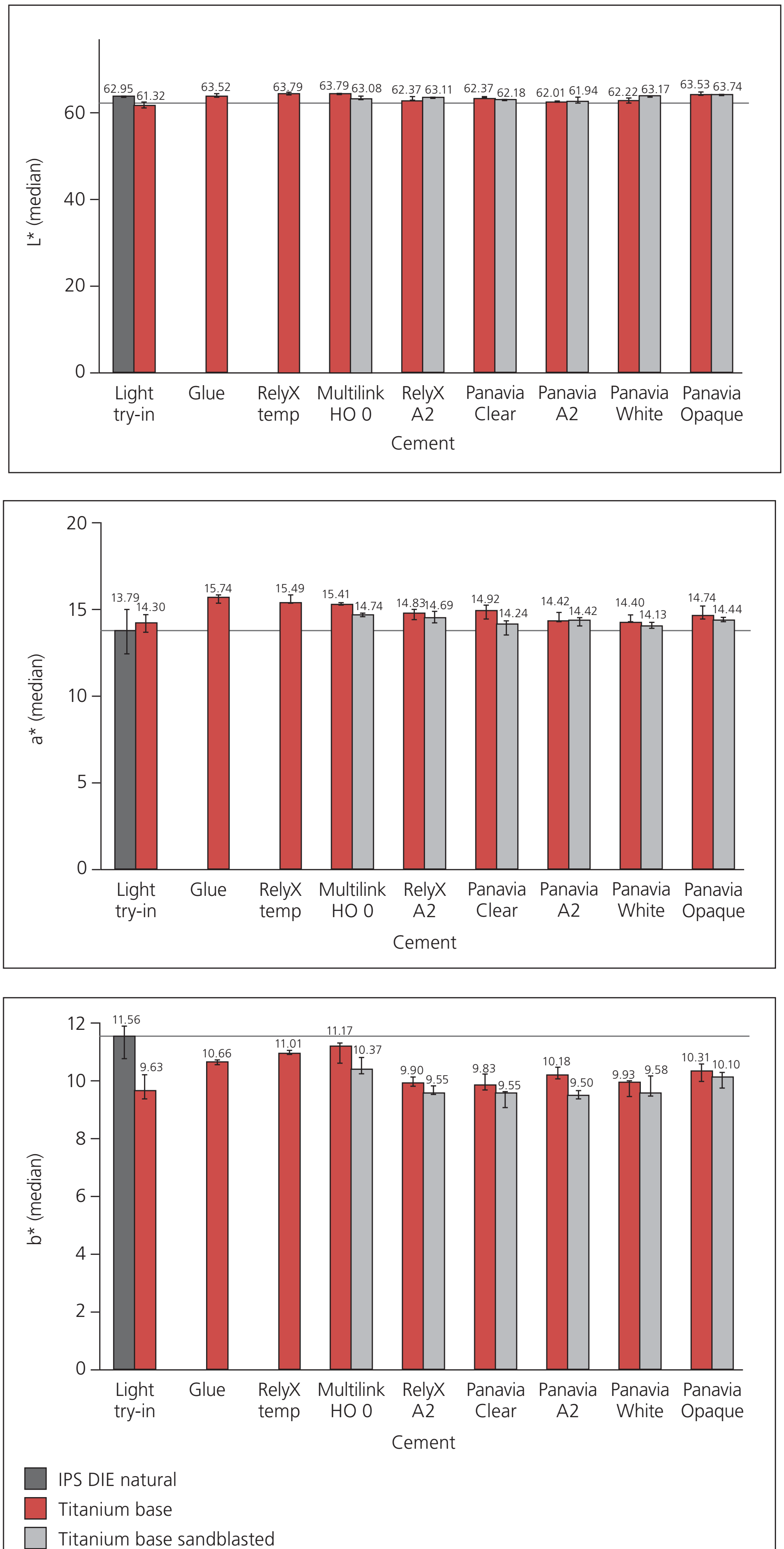

Fig 7 An overall comparison between the control group and the different cementation groups for L*, a*, and b* values at the artificial peri-implant soft tissue.

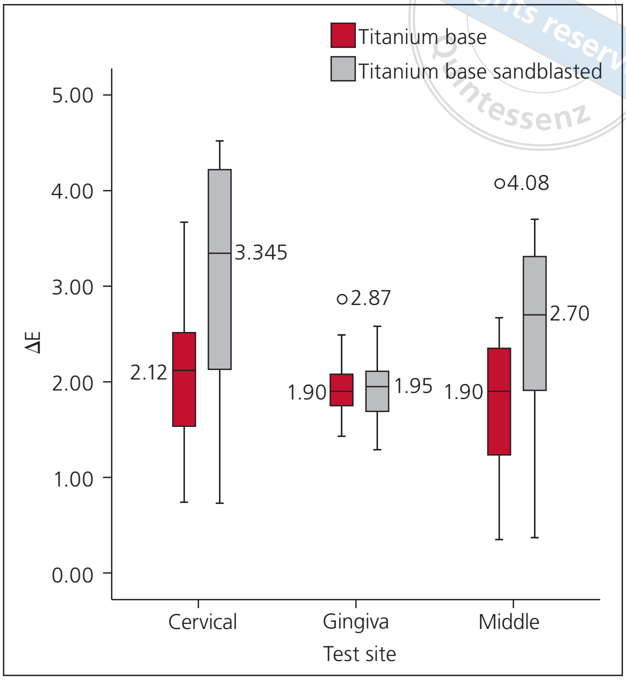

Fig 8 The median ΔE distribution across different measurement sites for reconstructions supported by nonsandblasted vs sandblasted titanium abutments.

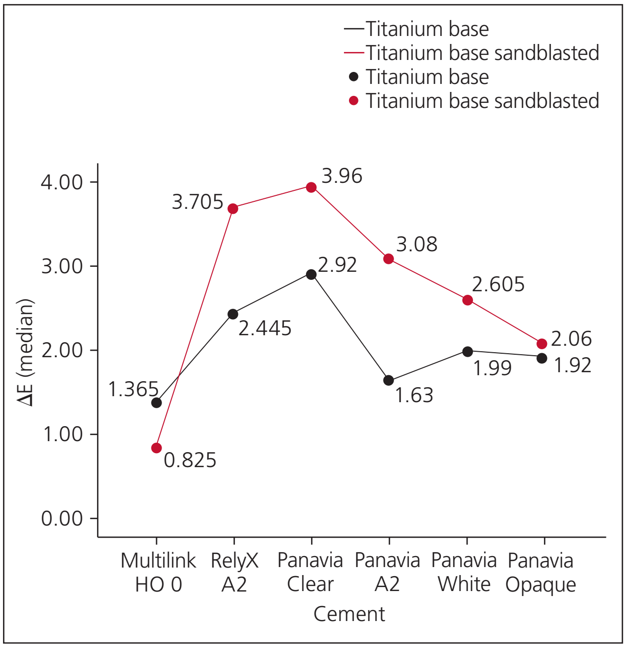

Fig 9 Median ΔE distribution for reconstruction surfaces with different cement groups for reconstructions supported by nonsandblasted vs sandblasted titanium abutments.

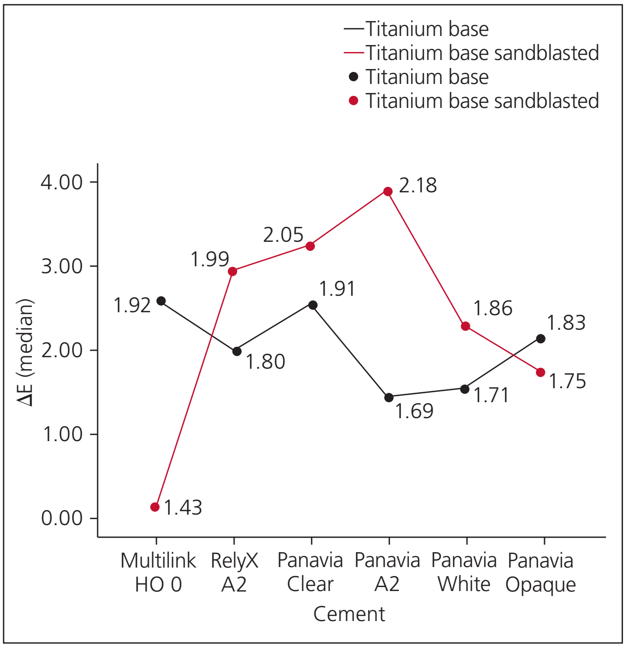

Fig 10 Median ΔE distribution for artificial soft tissue surfaces with different cement groups comparing reconstructions supported by nonsandblasted vs sandblasted titanium abutments.

When the titanium abutments were sandblasted, the lowest median ΔE value of 0.8 was observed on the reconstruction surface of Group C1 (Multilink HO 0). All of the other cements showed ΔE values above the threshold level for visible color differences of ΔE 1.815. On the level of the peri-implant soft tissues, no significant differences between the groups were found for the sandblasted abutments. The masking ability of Panavia Opaque remained stable after sandblasting the titanium abutments, while the ΔE value of Multilink HO 0 became even lower after sandblasting. A possible explanation was that the sandblasting might have resulted in a thicker layer of cement. A previous study demonstrated that increasing the cement thicknesses of

Multilink cements affected the color of lithium-disilicate ceramic on silver-palladium abutments.[16] However, when the titanium abutments were sandblasted, the difference of ΔE values for the artificial soft tissue became statistically significant, with Multilink HO 0 group presenting the lowest median value (1.4), followed by Panavia Opaque (1.8). On the contrary, the ΔE value of Panavia A2 shifted from being the lowest ΔE value (1.7) to becoming the highest (2.2) ΔE value when the abutments were sandblasted. It appears that the increase of an ΔE value within the Panavia A2 group was due to the dramatic decrease of the Δb* value, leading to a color shift toward blue.

According to the manufacturer's instructions, the spectrophotometer (SpectroShade Micro) was not only calibrated at the beginning of the measurements, but also during the measurements. The spectrophotometer had a built-in set-up to automatically suggest a calibration after taking several measurements. The number of measurements before a new calibration was not specified in the manufacturer's instructions, but was no more than 10 according to the experience in the current study. During the entire measurement procedure, whenever suggested by the device, a calibration was carried out by the operator according to the manufacturer's instructions. The mouthpiece on the spectrophotometer was placed perpendicularly against a white tile and then a green one, offered by the manufacturer, to make a calibration. The device notified that the calibration was done successfully on the screen once it was calibrated. If the calibration was not successful, the device would automatically suggest a new calibration procedure.

In the present study, all reconstructions of the test groups used titanium abutments of the same size, and all-ceramic crowns were fabricated with the same CAM system using one identical design, so the ceramic crowns therefore most likely exhibited similar translucency.[18] In a previous study, low-translucency CAD/CAM glass-ceramic lithium disilicate–reinforced crowns with a thickness of 2.5 mm were shown not to be influenced by the substrate color. However, the crowns investigated in that study were placed on natural tooth abutments.[9] In the present study, the low-translucency CAD/CAM glass-ceramic lithium disilicate–reinforced crowns were supported by dark and opaque titanium abutments. In another study, lithium-disilicate ceramic discs with a thickness of 1.5 mm were fabricated from medium-opacity and high-translucency ceramic blocks, and the influence of substrate color on the color outcome of the lithium disilicate was evaluated.[19] The authors concluded that due to discoloration, lithium disilicate ceramic reconstructions fixed on titanium abutments can be clinically unacceptable in terms of color performance.[19]

The results of the present study demonstrated that the cements also contributed to the final color outcome of the peri-implant artificial soft tissue at the present thickness of 2.0 mm. These values measured in the present in vitro study were, however, smaller than the ones found in a clinical study.[20] In that study, the mean peri-implant soft tissue thickness was measured to be 1.8 ± 0.4 mm. Another clinical study also reported similar thickness of the peri-implant soft tissue, at 1.7 ± 0.6 mm.[21] The thickness of the peri-implant soft tissue is a crucial factor influencing the color change caused by the titanium substructures, as demonstrated in both in vitro[1] and clinical studies.[7,8]

It has been reported in previous studies that an average threshold value for the visibility of color differences on tooth structures by the naked eye under uncontrolled clinical situations was 3.7.[22,23] In a recent study regarding the color differences on soft tissue, the threshold value of 3.7 has been used as well.[11] However, it has been reported that various factors contribute to whether a color difference is detectable under certain circumstances. Based on a recent study using standardized clinical photos, the overall threshold for the detection of gingival color differences was reported to be 3.1.[24] In standardized situations, a threshold value of 1.8 for intraoral color distinction of reconstructions by the human eye was documented.[7] Since the current study was done under standardized laboratory conditions, a previously determined ΔE value of 1.8 was considered the threshold value for color distinction of reconstructions by the human eye.[16]

Within this threshold level, the present study could demonstrate differences of the cements. Based on these findings, the use of opaque resin cements is recommended for the fixation of lithium disilicate all-ceramic crowns on titanium-base abutments. The color evaluation of the crowns was well standardized under the laboratory conditions. The evaluation of the discoloration of the soft tissues may be questioned, as the gingival mask with one universal color that was used to mimic the peri-implant soft tissues has different light properties than natural soft tissues. The color difference between this material and peri-implant soft tissue in vivo should not be neglected. The median L* values measured on the artificial soft tissue ranged from 61.3 to 63.8, which was much higher than the L* values reported in recent clinical studies.[1,6,21,25–27]

Clinical studies will be needed to further investigate the influence of different cements on the color outcome of peri-implant soft tissue.

CONCLUSIONS

Within the limitations of the current study, the following conclusions could be drawn:

- Cements of different brands and different shades influenced the color outcomes of CAD/CAM lithium disilicate all-ceramic crowns supported by titanium abutments.
- Sandblasting the titanium abutments prior to cementation may influence the color outcomes of CAD/CAM lithium disilicate all-ceramic crowns supported by titanium abutments. The effect of sandblasting on the color outcome was dependent on the cement type utilized.
- For nonsandblasted titanium abutments, the most favorable overall color outcomes were observed for Multilink HO 0, followed by Panavia A2 and Panavia Opaque. When sandblasted titanium abutments were utilized, Multilink HO 0 was the only cement presenting a ΔE value below detection by the human eye.

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