The capacity to change the lightness of discolored tooth substrates by means of minimal-invasive restorations: perception by dentists, dental technicians and laypersons

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Submitted August 5, 2020; accepted March 7, 2021
Abstract

Purpose: To evaluate the minimal ceramic thickness needed to increase the lightness by one value by means of glass-ceramic restorations perceived by dental technicians, dentists, and laypersons. Material and Methods: A total of 15 assessment pairs (reference and test samples) were formed using glass-ceramic blocks in four different colors. Each assessment pair was comprised of two underground blocks differing in one value of lightness. On top of the underground blocks, glass-ceramic platelets were cemented in five different thicknesses (0.1 to 0.5 mm) and in the same color as the reference. Dental technicians, dentists, and laypersons (n = 41/group) were asked to determine the presence of a color difference between the two samples under standardized lighting conditions. The threshold ceramic thickness was defined as the thickness at which ≥ 50% of the evaluators were not able to perceive a difference within an assessment pair. The thresholds were analyzed, and groups were compared by applying chi-square test (P < .05). Results: The majority of dentists and dental technicians (> 50%) detected a lightness difference between the test and reference samples up to a ceramic thickness of 0.5 mm. The majority of laypersons (≥ 50%) did not perceive a lightness difference with ceramic thickness of 0.5 mm. If separated by the different color changes, the threshold ceramic thickness started at 0.4 mm and varied within the groups of evaluators and by the lightness of the assessed color. Conclusion: A considerable number of evaluators perceived a lightness difference when minimally invasive ceramic restorations of 0.5-mm thickness were applied. The threshold ceramic thickness, however, was reduced when the lightness of the substrate was lower. Int J Prosthodont 2021. doi: 10.11607/ijp.7287
1. Introduction

Minimally invasive restorations are indicated to correct the shape and/or the color of a tooth (1). The advantage of ceramic restorations is that they can be manufactured in very thin layers of 0.5 mm (2, 3). This allows the clinician to limit or omit the extent of tooth preparation and consequently preserves healthy tooth substance.

Ideally, minimal invasive preparations are guided by a diagnostic plan that visualizes the final shape of the tooth to be restored (4). The minimal clearance is defined by the material properties of the chosen ceramic material. This clearance can be easily controlled by means of a silicone key or a mock-up taken from the diagnostic set-up (4, 5). The clearance to adjust the color, however, cannot be controlled by this means.

In case of a discolored tooth, it might be challenging to correct the shade by means of a minimal invasive restoration (1). Typically, this scenario is found in anterior teeth suffering from a discoloration as a consequence of trauma (6). The type and extent of these discolorations are heterogenous (6, 7). Gray discolorations are often the result of a pulpal necrosis and ask for a root canal treatment, whereas a yellow-opaque discoloration may derive from an obliteration as a vital reaction of the pulp (6). Regular tooth bleaching or internal bleaching may improve the color of the tooth substrate (7). If indicated, a ceramic restoration can further help to mask the darkened appearance of an abutment tooth. The degree of discoloration, however, influences the extent of tooth preparation and thus increases the invasiveness of the restorative treatment (1).

Clinically, it would be advantageous to know the color change capacity of minimally invasive ceramic restorations in order to individually determine the extent of tooth
preparation. In a case report it has been stated that a change of 1 to 2 tones in the shade tabs can be obtained with a ceramic thickness of 0.3 mm (8). In contrast, an in vitro study suggested that a ceramic thickness of 2.0 mm was needed to mask the color of a tooth substrate (9). Hence, evidence is limited regarding the capacity of color changes by means of ceramic restorations. In addition, the ability for the perception of a color difference may be limited and may vary among dental technicians, dentists and laypersons (10, 11).

The aim of the present study was therefore to determine the minimal ceramic thickness of a glass-ceramic restoration at which the majority (> 50%) of the evaluators (dental technicians, dentists and laypersons) was not able to detect a color difference.

Materials and Methods

2.1 Evaluators and test settings

Three groups of evaluators were formed each consisting of 41 dental technicians, 41 dentists and 41 laypersons. Evaluators were blinded to the aim and design of the study. Each assessment pair consisted of a reference and a test sample (Figure 1). Evaluators were randomly presented the assessment pairs (n=21) to determine the presence of a color difference: 15 test pairs, 3 negative control pairs, and 3 positive control pairs.

2.2 Fabrication of the substrate

The substrate consisted of a 15 mm thick ceramic block that was fabricated out of glass-ceramic blocks (Vitablocs Mark II, I10, Vita Zahnfabrik) of four different shades (1M2, 2M2, 3M2, 4M2). The 1M2-, 2M2- and 3M2-colored blocks served as
the substrates of the reference samples, whereas the 2M2-, 3M2- and 4M2-colored blocks served as the substrates for the test samples.

2.3 Fabrication of the ceramic platelets

Glass-ceramic blocks (Vitablocs Mark II, I10, Vita Zahnfabrik, Bad Säckingen, Germany) of three different colors (1M2, 2M2, 3M2) were cut into platelets of 0.7 - 0.8 mm in thickness (Accutom-50; Struers GmbH, Germany). Thereafter, standardized thicknesses of 0.1, 0.2, 0.3, 0.4 and 0.5 mm were manually customized by means of a grinding and polishing machine (LaboPol-21; Struers, Ballerup, Denmark) and using SiC water coolant papers (450 to 2400 grit). The final thickness (± 0.01 mm) of each specimen was verified at five standardized measuring points using a digital micrometer (Mitutoyo AG, Kawasaki, Japan).

2.4 Preparation of the assessment pairs

Within the assessment pairs, the substrate of the test and the reference samples differed in one value of lightness (Figure 2). Glass-ceramic platelets, mimicking minimal-invasive restorations, with the same shade as used for the substrate of the reference sample were cemented on top of the test and the reference sample in different thicknesses (0.1, 0.2, 0.3, 0.4, 0.5 mm). The bonding surfaces of the substrate and the ceramic restoration were etched according to the manufacturer’s instructions using a hydrofluoric acid (Vita Adiva Cera-Etch; Vita Zahnfabrik). Thereafter, a bonding agent (Vita Adiva C-Prime, Vita Zahnfabrik) and a transparent light-curing composite cement (RelyX Veneer; 3M ESPE, Seefeld, Germany) were used for the adhesive cementation (40 s, 1‘200 mW/cm² with Bluephase PowerCure; Ivoclar Vivadent).
2.5 Preparation of the negative and positive control pairs

A positive control pair presented the same color for the reference and test sample (1M2, 2M2, 3M2), whereas a negative control pair showed a color difference between the reference and test sample (1M2 versus 2M2, 2M2 versus 3M2, 3M2 versus 4M2). These control pairs solely consisted of reference and test sample without a glass-ceramic platelet cemented on top of the block.

2.6 Evaluation of the assessment pairs

The assessment pairs as well as the negative and positive control pairs were randomly allocated in a 3D printed specimen holder (Figure 2) and presented to the blinded evaluators. The holders were placed on a table and assessed by the evaluators in an approximate distance of 45-50 cm to the holders. During the assessment, the environmental light conditions were standardized by using a daylight lamp (Smile Lite; 5’500ºK; Smile Line SA, Saint-Imier, Switzerland). The ambiance light was not standardized. Each assessment pair was evaluated separately and the evaluators were asked if they could detect a color difference between the two presented samples. The evaluators were able to take as much time as they needed for an evaluation.

2.7 Statistical analysis

The threshold ceramic thickness was defined as the thickness at which 50% or more of the evaluators were not able to perceive a color difference between the reference and test samples. The number of evaluators was determined in advance to detect a color difference with a probability higher than 71% versus 50% or lower in a group of evaluators. The power for the comparison of the three groups of evaluators using a
Chi-square test with exact derivation is 85.5% for detecting a moderate Cohen effect size of 0.3.

The measured outcomes were coded in a software program (Microsoft Excel; Redmond, WA, USA). The data were analyzed descriptively with a statistical software (SAS 9.4; SAS Institute, Cary, NC, USA). The ceramic thickness for each group to increase the lightness by one value in the 3D master system (Vita Zahnfabrik) depending on the underlying color was calculated. The level of statistical significance was set at $p < 0.05$. No corrections for the multiple testing of the several thickness and color changes is applied.

**Results**

The pooled data of assessment pairs showed that most evaluators (> 50%) were able to detect a color difference for all tested thicknesses of ceramic platelets. If the groups of evaluators were analyzed separately, the threshold ceramic thickness was 0.5 mm for laypersons, whereas the majority of dental technicians and dentists was still able to distinguish the color difference (Figure 3).

**3.1 Threshold ceramic thickness to change color from 2M2 to 1M2**

The majority of all evaluators was able to detect the color difference between test and reference samples when the color change from 2M2 to 1M2 was assessed (Figure 4a). Statistically significant differences were found in the perception ability between dental technicians, dentists and laypersons showing that laypersons were significantly less perceptive compared to dental technicians ($p < 0.05$) and dentists ($p < 0.05$) (0.2, 0.4, 0.5 mm).
The negative control (difference between reference and test block) showed that 98% of the dentist and laypersons and 100% of the dental technicians were able to detect the difference. Regarding the positive control (no difference between reference and test block), 20% of the dental technicians, 10% of the dentist and 5% of the laypersons did falsely see a color difference.

3.2 Threshold ceramic thickness to change color from 3M2 to 2M2
For the measured color change from 3M2 to 2M2 the threshold ceramic thickness was reached at 0.5 mm for all evaluator groups (Figure 4b). Laypersons were significantly less perceptive to color differences in comparison to the group of dental technicians (p < 0.05) (0.3, 0.4, 0.5 mm).
In the negative control, 100% of the dental technicians, 98% of the dentists and 93% of the laypersons did see the color difference, while the positive control showed values of 15%, 10% and 10% for the respective groups.

3.3 Threshold ceramic thickness to change color from 4M2 to 3M2
The color change from 4M2 to 3M2 revealed a threshold ceramic thickness of 0.4 mm for the dentists and laypersons, while the threshold ceramic thickness was reached at 0.5 mm for the dental technicians. Laypersons were significantly less perceptive to color differences than dental technicians and dentists (p < 0.05) (0.1, 0.2, 0.3, 0.4 mm).
In the negative control, 80% of the dental technicians, 73% of the dentist and 59% of the laypersons did see a color difference between the two test samples. The respective groups showed percentages of 22%, 24% and 27% for the positive control.
Discussion

The threshold ceramic thickness to camouflage a darkened tooth substrate varies depending on the group-affiliation and on the lightness of the substrate. The threshold is lower for laypersons compared to dentists and dental technicians. The higher the lightness of the tooth substrate, the thicker the ceramic restoration to diminish the color difference. A considerable number of evaluators, however, was able to perceive a color difference above the tested ceramic thicknesses.

The present study indicates that a minimal ceramic thickness of 0.4 to 0.5 mm might be enough to mask a one lightness-value darker tooth. Contrarily, another study suggested that a ceramic thickness of 2.0 mm is needed to mask the darkened substrate color (9). The dissimilar material and methods to the current investigation, might explain the substantial discrepancy to the present outcomes. The masking ability was tested with glass ceramic discs in various thicknesses (1.0, 1.5, 2.0 mm) placed on differently colored post materials. Hence, the study used a different set-up regarding the darkened substrate with greater variations between the substrate and the ceramic disc. In the present study, the color differences between the substrate color and the finally assessed color did vary only to a small amount and in standardized steps of one lightness value. Furthermore, the colorimetric measurements were performed using a spectrophotometer and not by the human eye. A study comparing the shade selection reliability of a spectrophotometer and the conventional visual method showed that digital methods are more accurate (12). Accordingly, another study using spectrophotometry to determine the masking ability of feldspathic veneers also stated higher threshold values compared to the present findings. Their results showed that a ceramic thickness of 1 mm was needed to fully mask 1M2- or 2M2-colored substrates when the color 1M1 was used as a reference.
In a case report it was stated that a ceramic thickness of 0.3 mm is sufficient to achieve a color change of one to two tones (8), which could not be confirmed with the present outcomes. Since the statement was based on clinical experience rather than scientific data, it can be assumed that there are further factors which have an impact on the overall appearance. These factors might include the characterization and the texture of the restorative surface as well as the opacity of the used ceramic. Further, the cement-layer is an additional influencing parameter on the final color appearance (14). Especially for thin restorations, the color of the cement seems to play a pivotal role (15). To exclude for this confounding factor, a translucent cement was used in the present study.

Regarding the perception-ability among dental technicians, dentists and laypersons, it was found that dental technicians showed the highest capability to detect color differences, followed by dentists and laypersons. A study evaluating the perceptibility and acceptability thresholds for the evaluation of color differences for trainee dental surgeons and laypersons, reported that dentists had lower perceptibility- and acceptability-thresholds compared to laypersons (10). Similar findings were reported in another study comparing these thresholds for dental technicians, dentists, dental nurses and non-dental observers. Dental technicians showed significantly lower thresholds than dental nurses and non-dental observers (11). Surprisingly, a previously published study revealed contradictory outcomes (16). The study aimed to assess the threshold values for the perception of color changes in human teeth, showing dental photographs to dental technicians, dentists and laypersons. Several pictures were prepared modifying the CIE L*a*b* parameters in half of the picture to different amounts (16). The perception ability to detect the color differences did not differ between the groups (16). Another interesting finding of the present results is
that the evaluators seem to be more discriminating when detecting color differences within the brighter colors compared to darker ones. The results of a previous study showed a significant decrease in the visual tooth color matching ability of human observers when evaluating darker colors and thus support the present findings (17). Evaluating the positive and negative controls, there are false-positive and false-negative results in all groups. The dental professionals tended to have more false-positive judgments. Since the study design is based on visual color comparisons and not on spectrophotometric measurements, the collected data are rather subjective and could explain the presence of false-positive or -negative assessments. The higher number of dental professionals with more false-positive ratings could be due to a confirmation bias which describes the tendency to select, determine and interpret information in such a way that it fulfills the expectations which might be higher for the group of professionals. This could lead to a stricter rating of the color differences by these groups. Moreover, in the present study neither the evaluators’ color vision was tested nor were they calibrated in terms of rating color differences, which could be recommended prior to the performance of color assessments (18). Additionally, a study stated that the reproducibility of visual color matching by one observer and between different observers showed high to moderate levels of inconsistencies (17).

This study contributes important findings to the exploration of the masking potential of minimal-invasive ceramic restorations but delivers only one of many needed components to fully understand this complex field of research. It still remains unclear to what extent other parameters might influence the color perception and the masking potential by means of an indirect restoration. This has to be further studied, investigating the influencing parameters on the level of the restoration (e.g. opacity
of restorative material, surface texture, surface characterization), on the level of the cement (e.g. cement color, cement opacity, layer thickness) and on the level of the substrate (e.g. different discolorations).

Conclusions

The needed ceramic thickness to change the perceived lightness by one value starts with 0.4 mm and varies within the groups of evaluators (dental technicians, dentists, laypersons) and the lightness of the assessed color. A certain number of evaluators is capable of perceiving color differences above thicknesses applied in minimally invasive dentistry with significant differences between professionals and laypersons.

Conflict of Interest

This study was financially supported by the Clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland. Materials for this study were provided by Vita Zahnfabrik.

Acknowledgements

The authors express their specials thanks to Marcel Arnold for creating the graphics and Albert Trottmann for his help in the laboratory procedures.
References

Figures

Figure 1 – Graphical illustration of the assessment pairs’ setup
Figure 2 – 3D printed specimen holder for the assessment pairs
Figures 3 – Ceramic thicknesses from 0.1 to 0.5 mm in relation to the percentage of evaluators who detected a color difference grouped by evaluators. The dashed line marks the 50%-threshold.
**Figures 4a-c** – Ceramic thicknesses from 0.1 to 0.5 mm, negative controls (NC) and positive controls (PC) in relation to the percentage of evaluators who detected a color difference grouped by evaluators. The dashed line marks the 50%-threshold.

**Figure 4a** – Color change from 2M2 to 1M2

*sign. differences between groups of evaluators using Chi-square test (p < 0.05)
**Figure 4b** – Color change from 3M2 to 2M2

* sign. differences between groups of evaluators using Chi-square test (p < 0.05)
**Figure 4c** – Color change from 4M2 to 3M2

*sign. differences between groups of evaluators using Chi-square test (p < 0.05)