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The colour of monolithic zirconia restorations determined by spectrophotometric examination

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ABSTRACT

Objective: The aim of this in vitro study is to examine the optical effects of monolithic zirconia of different translucency and thickness, combined with substrates of different colours. *Materials and methods*: Zirconia specimens of two colours (A2P1, WHITE) were used for the study, three try-in pastes (Variolink Esthetic); substrates were prepared from nine types of materials (six VITA SIMULATE, three metals). Measurements were carried out at the Faculty of Atomic Physics of the Technical University of Budapest with the state-of-the-art PerkinElmer® Lambda 1050 spectrophotometer. *Results*: The colouring of zirconia has a major effect on dE values resulting in different colour perceptibility and acceptability. Try-in pastes, however, have no significant effects overall. *Conclusion*: Applying coloured zirconia is highly eligible for preparing aesthetic crowns as their substrate-covering effect makes it possible to reproduce the desired colour. Uncoloured zirconia nonetheless is unaffected by the substrate material, especially above a certain layer thickness.

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Spectrophotometric analysis; zirconia; colour; reflection; CIEDE2000; monolithic zirconia

Introduction

Colour is one of the most important aesthetic parameters in dentistry. The requirement to achieve natural looking restorations is one of the most challenging aspects of dentistry, and the shade matching of dental restorations with the natural dentition is a difficult task due to the complex optical characteristics of natural teeth [1].

Normally, zirconia crown restorations are chosen for endodontically treated teeth or for broken teeth or teeth with large decay, or simply for aesthetic purposes. In such cases, crowns are prepared based on discoloured dyes. The question occurs whether the satisfactory aesthetic experience is achieved if the same crown is applied to different dyes. Will the metal post and the zirconia abutment be adequately covered by the chosen crown? Will they lose the optical advantage when applied in such combinations? [2–5].

Colour matching of an all-ceramic or zircon restoration is still a key challenge in aesthetic dentistry: numerous factors impact precise colour reproduction, including technician skills and the limitations of existing dental shade guides. For these reasons, the aim of our *in vitro* study is to examine the optical effect of zirconia of different translucency and thickness, combined with substrates of different colours. Such combination can be simulated using the world's most advanced spectrophotometer in order to obtain reproducible, standardisable data.

Material and methods

Zirconia specimens (provided by Erran Tech) of two colours, an uncoloured zirconia with white shade (WHITE or W) and an A2 coloured zirconia (A2P1 or P1), were used for the study with the following parameters: *surface* – 12 × 14 mm, thickness range: 0.5, 1.0, 1.5, 2.0, 2.5 mm. Specimen had been cut from zirconia blocks necessary for CAD/CAM procedures. Surfaces were treated and polished. All samples have a self-glazed surface and a machined surface.

Three try-in pastes (Variolink Esthetic) were used in our *in vitro* study: *warm* (yellowish shade), *neutral* (transparent) light+ (opaque). This paste exists in five different colours, the three aforementioned types proved to be the most commonly used and thus be the most practical for the study. The pastes are glycerin-based and are therefore easy to remove from the surface facilitating the rapid repeatability of the measurements with unlimited combinations. For the simulation of the 100 nm thickness of the paste, an automatic pipette and a metal plate were applied.

In addition to the zirconia specimens and try-in pastes, different dye materials were needed: VITA SIMULATE Preparation Material is a light-curing composite used in the fabrication of artificial dyes to simulate the shade of the prepared tooth. Nine substrates were made of different colours and materials: six types of VITA SIMULATE materials (0M1S, 1M1S, 2M3S, 3M2S, 4M3S, 5M3S) plus one each of

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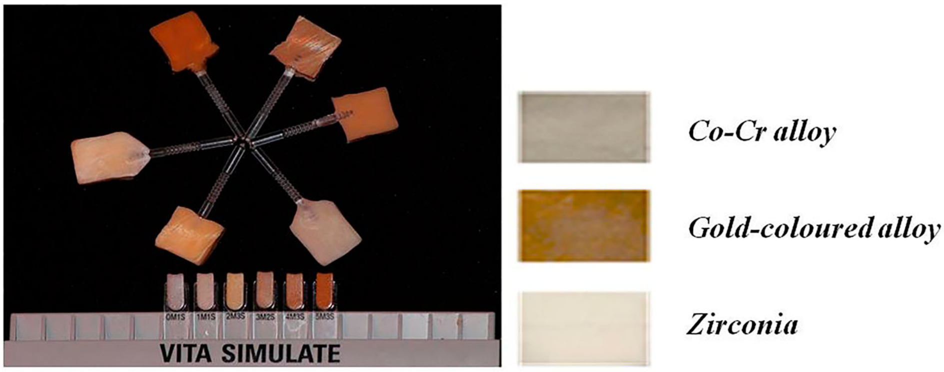

Figure 1. Specimens.

Co-Cr, zirconia, and gold-coloured alloy. The material is used as an aid particularly when fabricating translucent zirconia restorations where the shade effect is strongly influenced by the shade of the stump. As the shade of the restoration can be verified in advance and corrected where required, this product makes it easier for dental technicians to reproduce the tooth shade, and to do so with greater reliability (Figure 1).

Spectroscopic measurements were carried out at the Optic Laboratory of the Faculty of Atomic Physics of Budapest Technical University with the state of the art PerkinElmer® Lambda 1050 UV/Vis/NIR spectrophotometer (Figure 2). Even though the measurement range of the device is between 175 and 3300 nm *(from ultraviolet to near infrared)*, the subject of our analysis was limited to the visible light of the electromagnetic spectrum, 400–700 nm; thus, the range was set between 380 and 780 nm with an interval of 10 nm. Reflection measurements were carried out since the purpose of the analysis was to achieve the most accurate shade definition. For the purpose of standardisation colour temperature was set to 6500 K [6–8].

The shades of realistic zirconia crown were simulated with the zirconia specimens, the try-in pastes and substrates. The metal plate was placed on the substrate and try-in pastes applied with an automatic pipette, and as a final step, the zirconia specimen applied, too. Such three-layer sample combinations were positioned at the aperture of the device, isolated from outer light effects. Three measurements were done for each combination meaning 2 *types of zirconia (A2P1; WHITE)*, 5 levels of layer thickness *(0.5, 1.0, 1.5, 2.0, 2.5 mm)*, *2 types of try-in paste (neutral for A2P1, warm for WHITE)*, *9 types of substrate (0M1S, 1M1S, 2M3S, 3M2S, 4M3S, 5M3S, CoCr, Au, ZrO_2)*, resulting in *45* combinations for each zirconia and a total of *270* measurements.

The integrating sphere of the device is capable of receiving both diffuse and specular lights. The device – PerkinElmer® Lambda 1050 UV/Vis/NIR – measures the reflection spectrum by which the L^*a^*b (L: lightness, a: colour components green–red, b: colour components blue–yellow) values can be calculated. Based on that, any colour can be defined in a three-dimensional coordinate system (Figure 3).

ΔE values *(the colour difference between two colours in the coordinate system)* were calculated from the L^*a^*b values using the CIEDE2000 formula of the latest international standard: [9]

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

Figure 2. PerkinElmer® Lambda 1050 UV/Vis/NIR spectrophotometer.

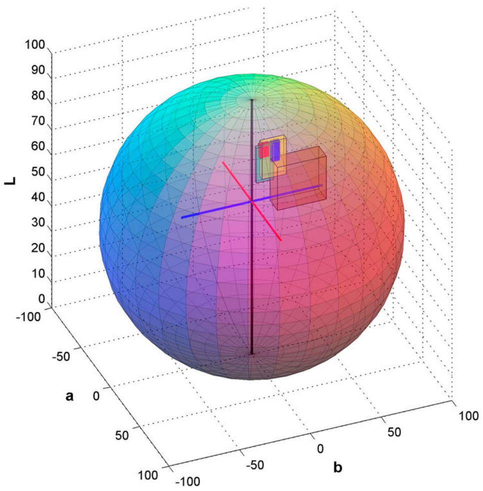

Figure 3. Colour space figure by G. Gajdatsy.

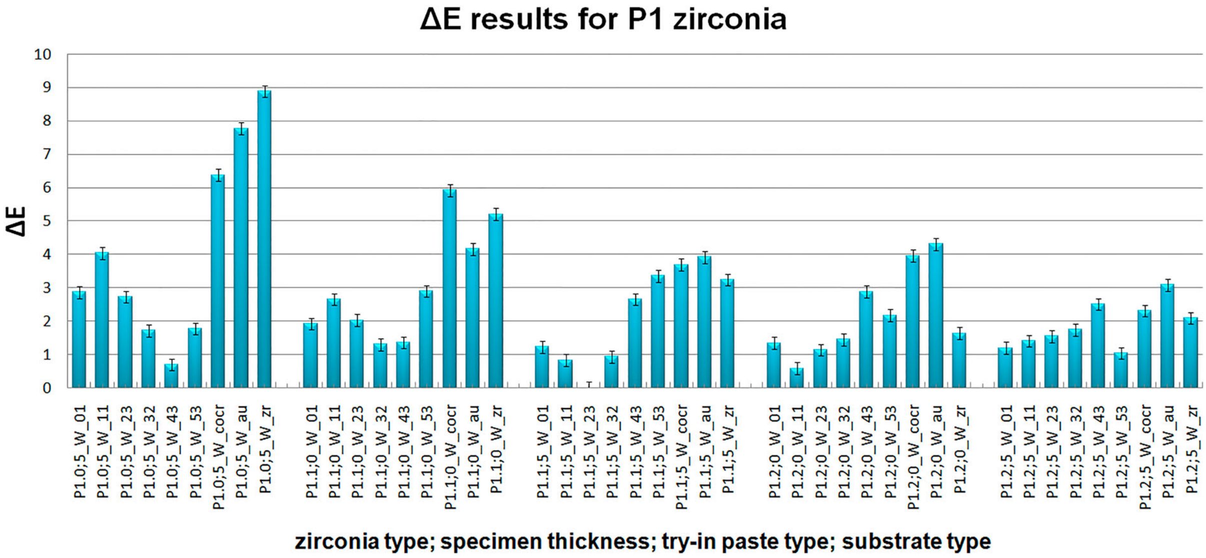

Figure 4. Different zirconia (P1) layer thickness combined with different substrate materials.

Reference specimens were selected and the above-mentioned combinations were compared to them. References were P1: 1.5 mm P1, 2M3S (also referred to as '23') specimen, warm try-in paste, and W: 1.5 mm W, 2M3S (23) specimen, N try-in paste.

A research has recently been carried out at Semmelweis University regarding perception of colour difference. Subject could not perceive colour difference below ΔE0.8, considered colour difference visible yet acceptable between ΔE0.8 and 1.8. Therefore, colour difference above ΔE1.8 is above the acceptability threshold [10].

Linear regression modelling was used to estimate differences in ΔE between W and P1 samples. The sample indicator variable was used in full interaction with the categorical variables of crown thickness and substrate type.

Results

The results were explained according to the measured parameters of L^*, a^*, b^*, and ΔE in four sections.

Figure 4 shows the effect of different ceramic layer thickness combined with different substrate materials. It is clearly visible that in case of P1 samples coverage of the substrate linearly increases with layer thickness. There were 19 specimens below the acceptability threshold of 1.8 ΔE. A significant correlation was identified between layer thickness and the substrate material at the lower thickness range (0.5–1.0 mm) of specimens; nonetheless at the mid- and high-range (1.5–2.5 mm) substrate colour was less influential. ΔE value for the reference sample was zero; thus, measurement precision is confirmed. Other spectrophotometers commonly used in dental practice are unable to produce such results.

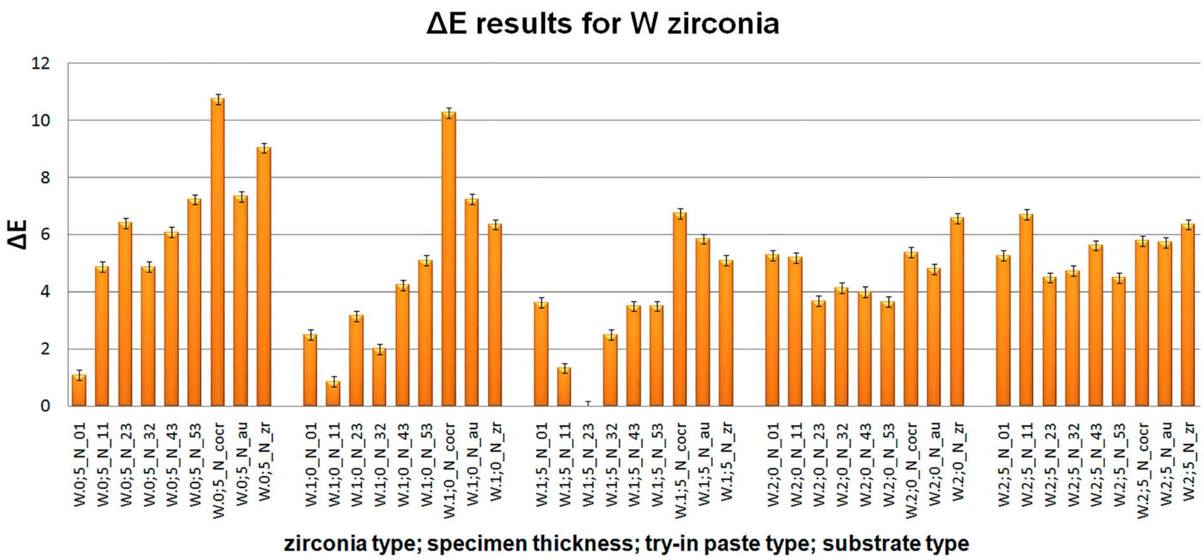

Figure 5. Different zirconia (W) layer thickness combined with different substrate materials.

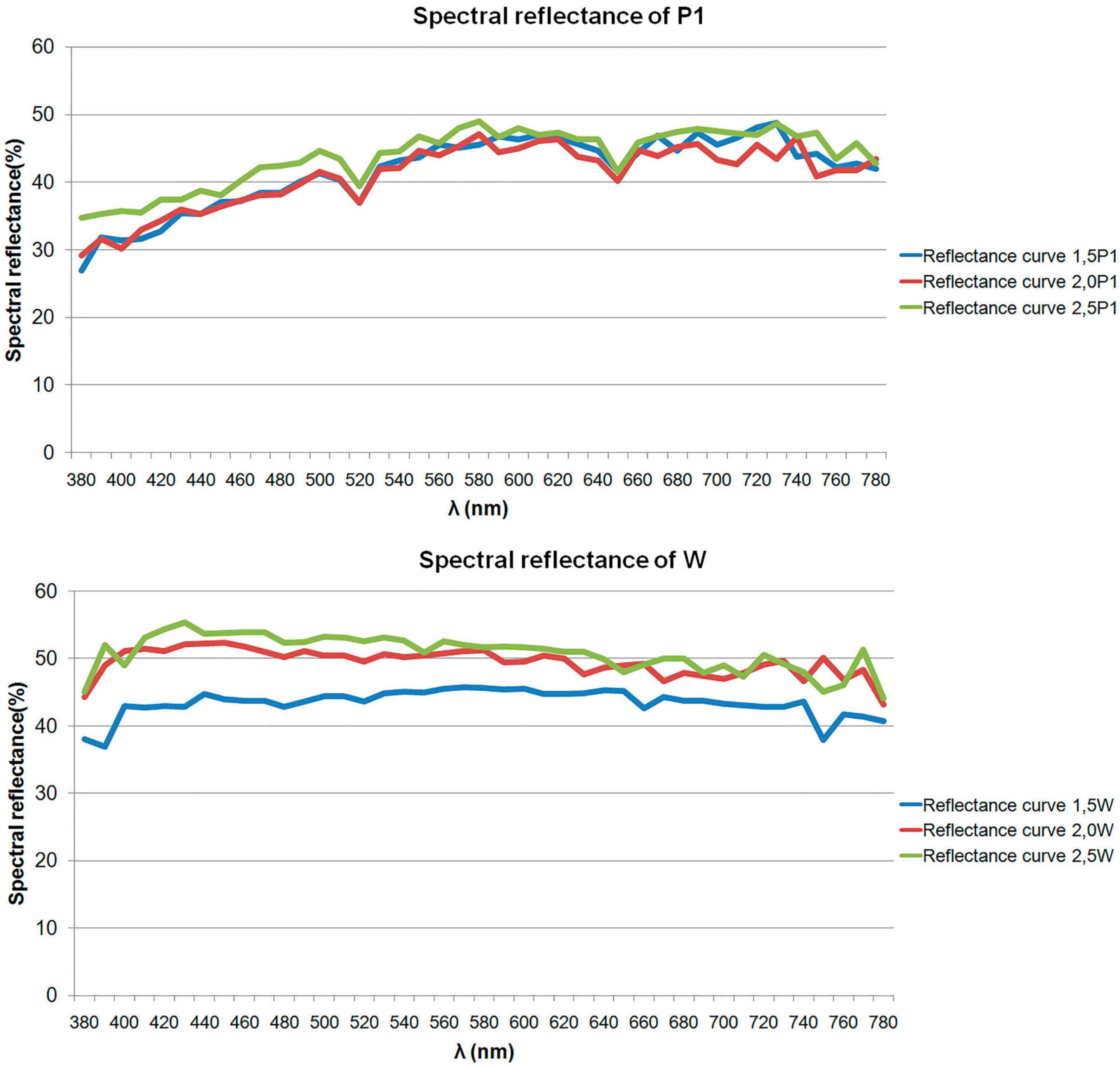

Figure 6. Reflectance curves P1 and W zirconia specimens.

The diagram (Figure 5) shows the effect of different ceramic layer thickness (of W specimens) combined with different substrate materials. Even in case of an uncoloured material such as WHITE, a clear trend is visible of layer thickness affecting translucency, although for the lower thickness range (0.5–1.5 mm)

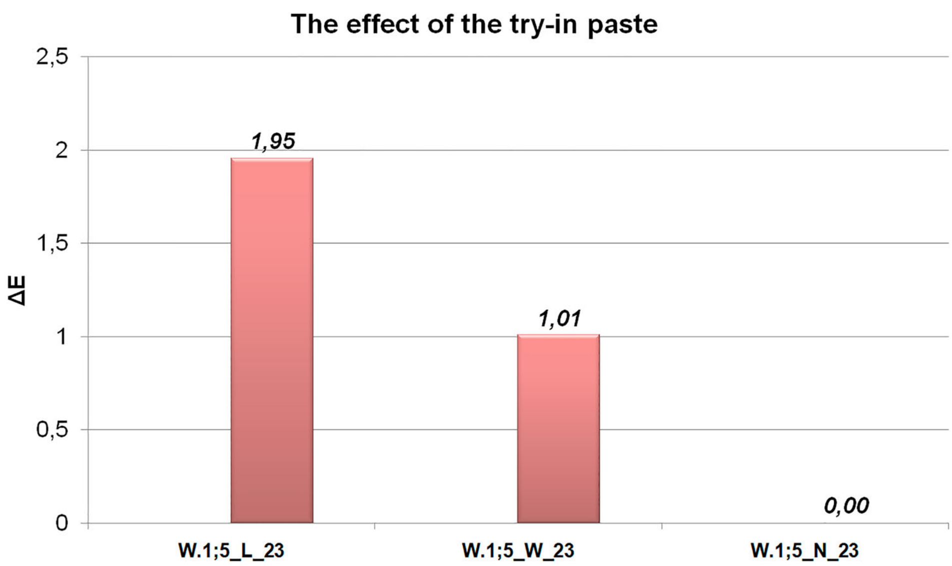

Figure 7. The try-in paste effect – L: light+, W: warm, N: neutral.

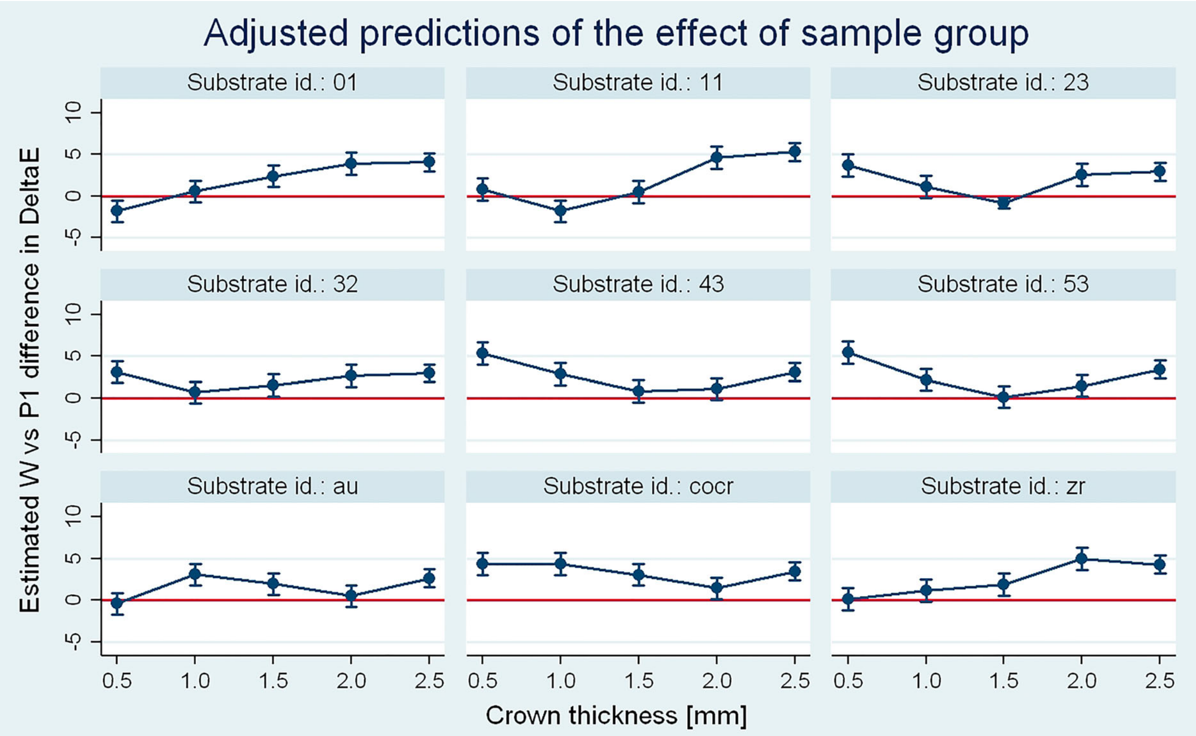

Figure 8. Linear regression estimates of the P1 vs. W difference in ΔE.

the substrate material also has a significant influence. For 2.0–2.5 mm samples, it is only the zirconia with an effect of colour perception.

The diagrams above (Figure 6) clearly show what effect is seen in the reflection range with different thickness of zirconia if there is a lower level of colouring liquid applied (sample W). The reflection rate drops, since there is not enough scattering seed in the material, and backscattering is also on a low level.

P1 samples (with a high level of added colouring liquid) presented more significant ΔE values the thinner the material was. The reason for this phenomenon is that added colours shall only prevail in the reflected diffuse spectrum if light penetrates the samples in the optical depth necessary and thus the related spectral components can be absorbed along a longer optical path. Nonetheless in case of WHITE, such phenomenon is almost unperceivable, if there is low level or absolutely no colouring additives in the ceramic structure.

For this reason, further analysis was carried out regarding the try-in paste effect (Figure 7). As the diagram above clearly shows (for 1.5 mm samples) all ΔE results are below the perceptibility threshold. For thicker samples, such effect is even less considerable, almost impossible to be measured mathematically.

Figure 8 shows linear regression estimates of ΔE differences between W and P1 as a function of substrate type (*indicated in the panel labels*) and thickness, where the 95% confidence intervals around the point estimates (blue dots) exclude the red line, ΔE of W is significantly different from that of P1.

Conclusion

The sample thickness-dependent ΔE values are significantly different in case of material W, compared to the other, coloured ceramic samples. Our explanation is that the volume scattering property of W's material structure enables high diffuse reflectance with a homogeneous spectrum above a certain thickness value, similarly to the analyzed material in reference. In contrast, the other samples like 'P1' contain different amounts of colouring additives that absorb certain components of the reflected spectrum. This result lowers total reflected intensity and more colour-specific measured L^*a^*b value as the sample thickness is increased.

The applied try-in pastes make no perceivable difference.

Applying coloured zirconia is highly eligible for preparing aesthetic crowns as their substrate-covering effect makes it possible to reproduce the desired colour. Uncoloured zirconia nonetheless has a narrower range of usability: W specimens are affected by substrate material in the lower thickness range, and although the masking is good in the higher thickness range, the indication area is more limited due to the white colour.

In order to achieve a fully standardised methodology, our research team will carry on with the study in the future, analysing other materials and combinations to gain insight of the behaviour of crown combinations.

Disclosure statement

No potential conflict of interest was reported by the authors.

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