



Introduction

Dental implants have become a widely utilized treatment in prosthodontics. For patients missing anterior teeth, they offer a conservative approach for tooth replacement but come with an esthetic challenge. The combination of several prosthetic materials with different optical properties is unavoidable with current anterior implant restoration options and can lead to undesirable esthetic outcomes when combined without intention. The clinician is faced with the selection of an abutment, restoration material, and typically a cement used to lute the two together. With multiple options to choose from, it can be difficult for clinicians to decide which combination will result in the most desired outcome. One of the initial steps towards providing a solution is to determine which variables, between abutment color, cement color, and ceramic material, influence the final shade of an implant restoration.

Research Aims

This study serves to evaluate color differences associated with the effect of anodization, cement opacity, and varying thicknesses of zirconia on the final shade of an implant restoration. There is no observed color difference from anodization, cement opacity, or zirconia thickness on the final shade of an implant restoration.

Materials/Methods

The experimental design is depicted in Figure 1. To determine the number of samples, an a priori analysis was performed utilizing data from a similarly published study to determine a recommended sample size of 4 with 0.98 power to achieve $\alpha = 0.05$ level of significance.⁵ The referenced study utilized a sample size of 7 which was replicated for this study.

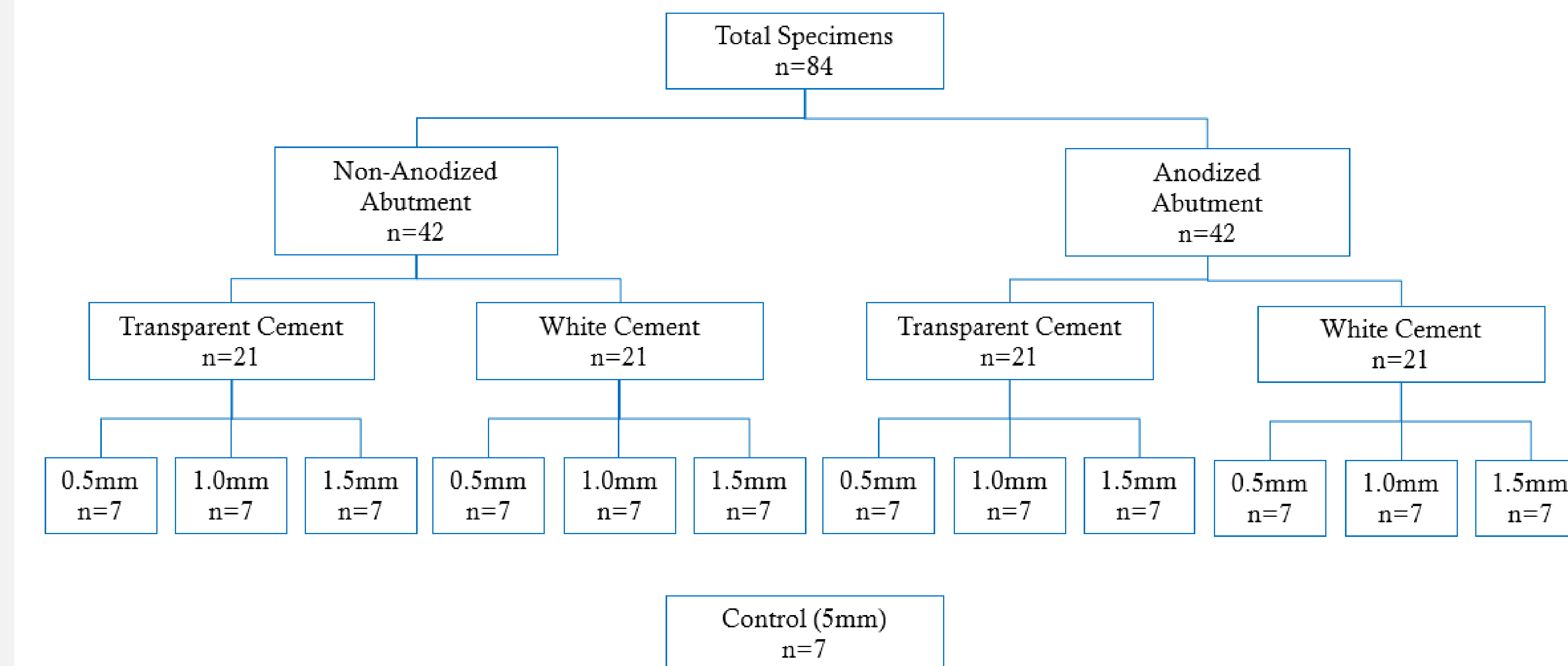
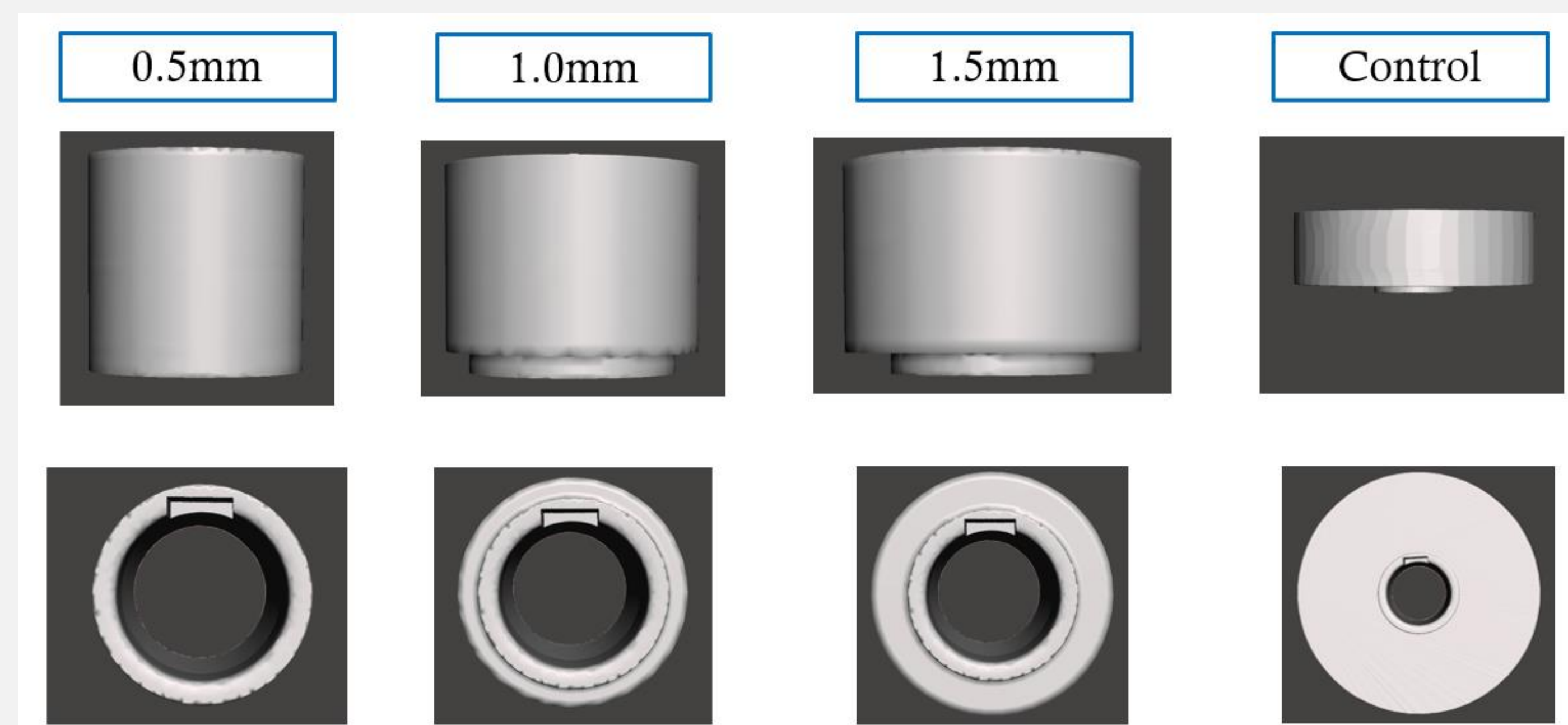


Figure 1. Flowchart of experimental design.



Materials/Methods

A total of 84 experimental specimens and 7 control specimens were designed in an open-source design software (Meshmixer, Autodesk). Specimens adapted to an abutment (Variobase C, RC, Straumann Group, 022.0044) with a cement thickness set to 80 microns and varying thicknesses of zirconia including 0.5mm, 1.0mm, and 1.5mm depending on the sample.



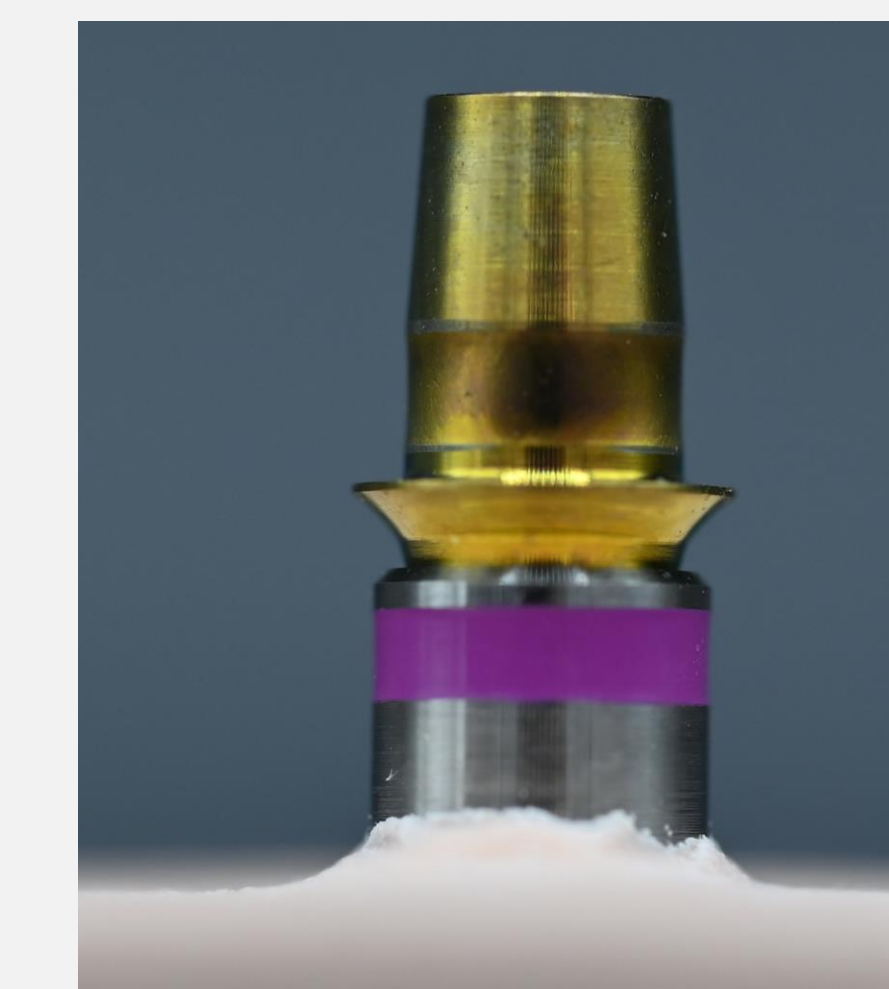
The samples were milled from monolithic zirconia (Haus HT Plus, Haus Milling Center; 3mol% yttriatetragonal Zr polycrystal [3Y-TZP], A2 Shade) by a 5-axis milling machine (Roland DWX-52D) and then fully sintered (Nabertherm LHT 01/17D) according to manufacturer instructions. Samples were then glazed (Glaze Paste Fluor, MiYO, Jensen Dental) and sintered again to manufacturer recommendations. A digital caliper was used to verify the thickness of each sample which was found to be true to the intended thickness $\pm 0.07\text{mm}$.

A total of 14 abutments were used for the study. Seven were designated for non-anodization and the other seven were anodized. The selected abutments were anodized at room temperature with a solution of 2g trisodium phosphate solution as an electrolyte in 500mL of distilled water. The titanium abutments and a stainless-steel plate were used as the anode and cathode respectively. A 63.4-V voltage was applied for 15 seconds to each abutment using a power supply to achieve a yellow-gold appearance. Abutments were then rinsed in distilled water in an ultrasonic cleaner for 10 minutes.

Cement was mixed, restoration seated, and excess cement was removed by hand. Specimens were then light cured following manufacturer recommendation. A handheld spectrophotometer intended for dentistry (Vita Easyshade V, VITA Zahnfabrik) was used to measure each sample three times, once on each side not containing the retentive feature incorporated into the abutment. CIELab values – lightness (L^*), green-red chromaticity (a^*), and blue-yellow chromaticity (b^*) – were recorded for each measurement by one operator (J.C.) in the same room with no windows and constant lighting conditions. An average of each value between the three measurements was calculated and then compared to the average of values measured from the control sample using the CIEDE 2000 formula to determine color difference (ΔE_{00}).

To further interpret color differences, the perceptibility threshold (PT) and acceptability threshold (AT) were set at 0.8 and 1.8, respectively.⁹ For qualitative assessment, photographs were taken of each group with standardized lighting and camera settings. This was achieved using a light box with a designated distance from lens-to-sample and camera settings set to ISO 200, f/8, and 1/160 aperture.

A statistical software (IBM SPSS Statistics, version , IBM Corp) was used for data analysis. Shapiro-Wilk test of normality was used to determine a non-normal distribution of data for most groups ($p < 0.05$). Therefore, medians and interquartile ranges were reported and nonparametric analysis including Kruskal-Wallis was used to compare ΔE_{00} values among the groups. Mann-Whitney U-Test was used for pairwise comparison between thickness groups for post hoc analysis utilizing Bonferroni adjusted corrections for significance. Statistical significance was set to $\alpha = 0.05$ for all tests.



EFFECT OF ABUTMENT COLOR, CEMENT OPACITY, AND CERAMIC THICKNESS ON THE FINAL SHADE OF AN ANTERIOR IMPLANT RESTORATION

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Results

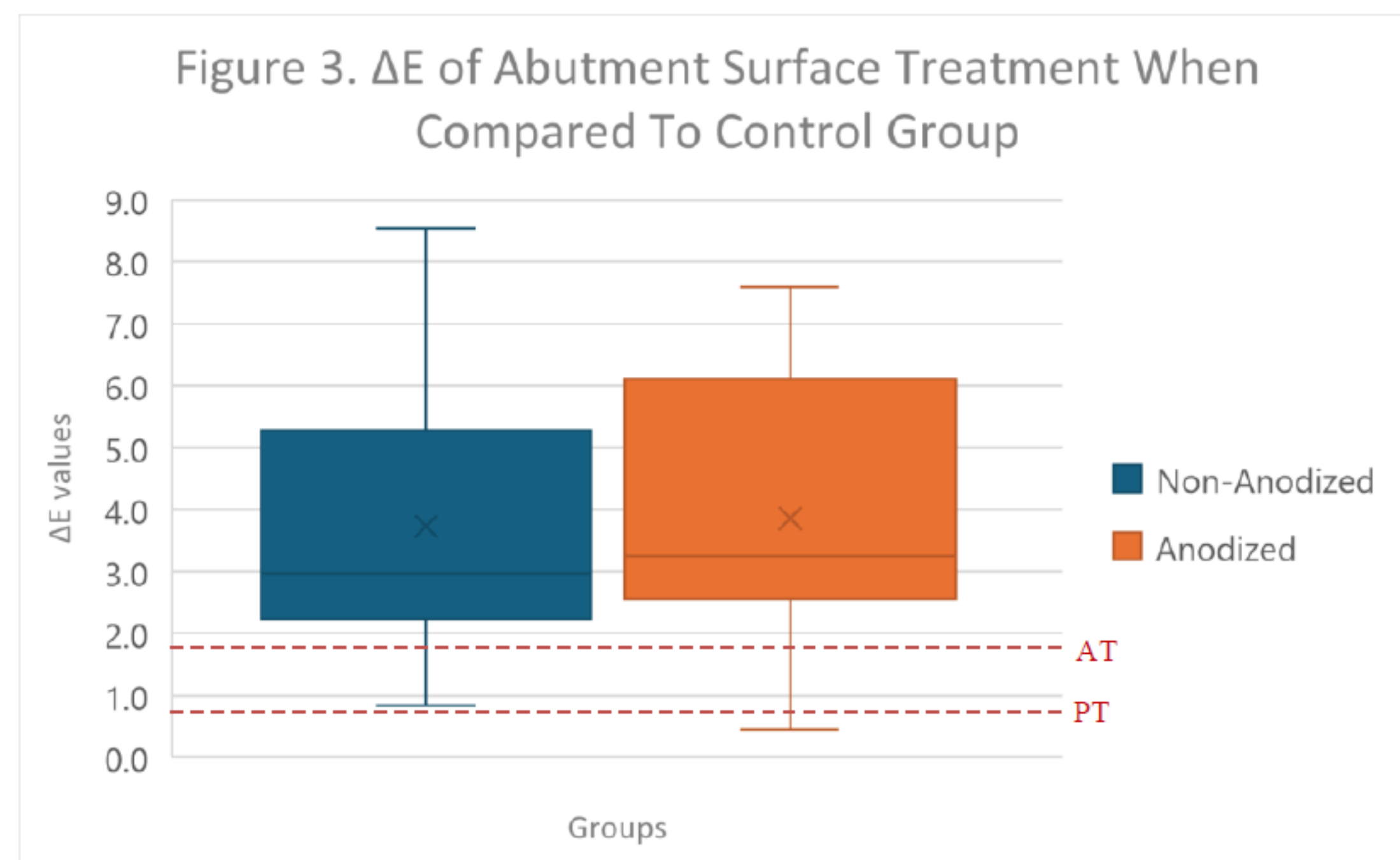


Figure 3. ΔE of non-anodized and anodized groups when compared to the control. AT = Acceptability Threshold. PT = Perceptibility Threshold.

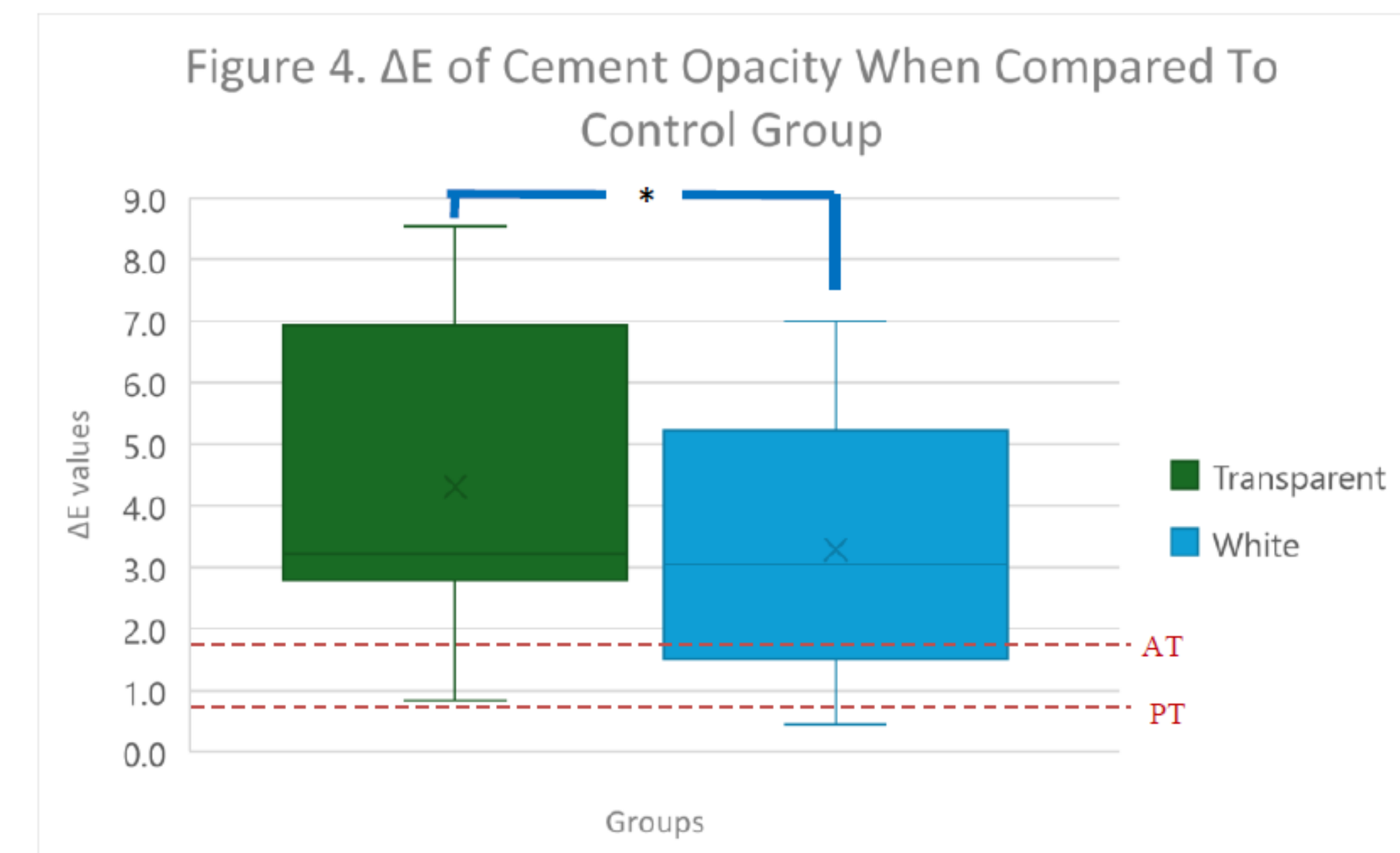


Figure 4. ΔE of transparent cement and opaque white cement groups when compared to the control. An asterisk (*) represents statistical significance between groups ($\alpha = 0.05$). AT = Acceptability Threshold. PT = Perceptibility Threshold.

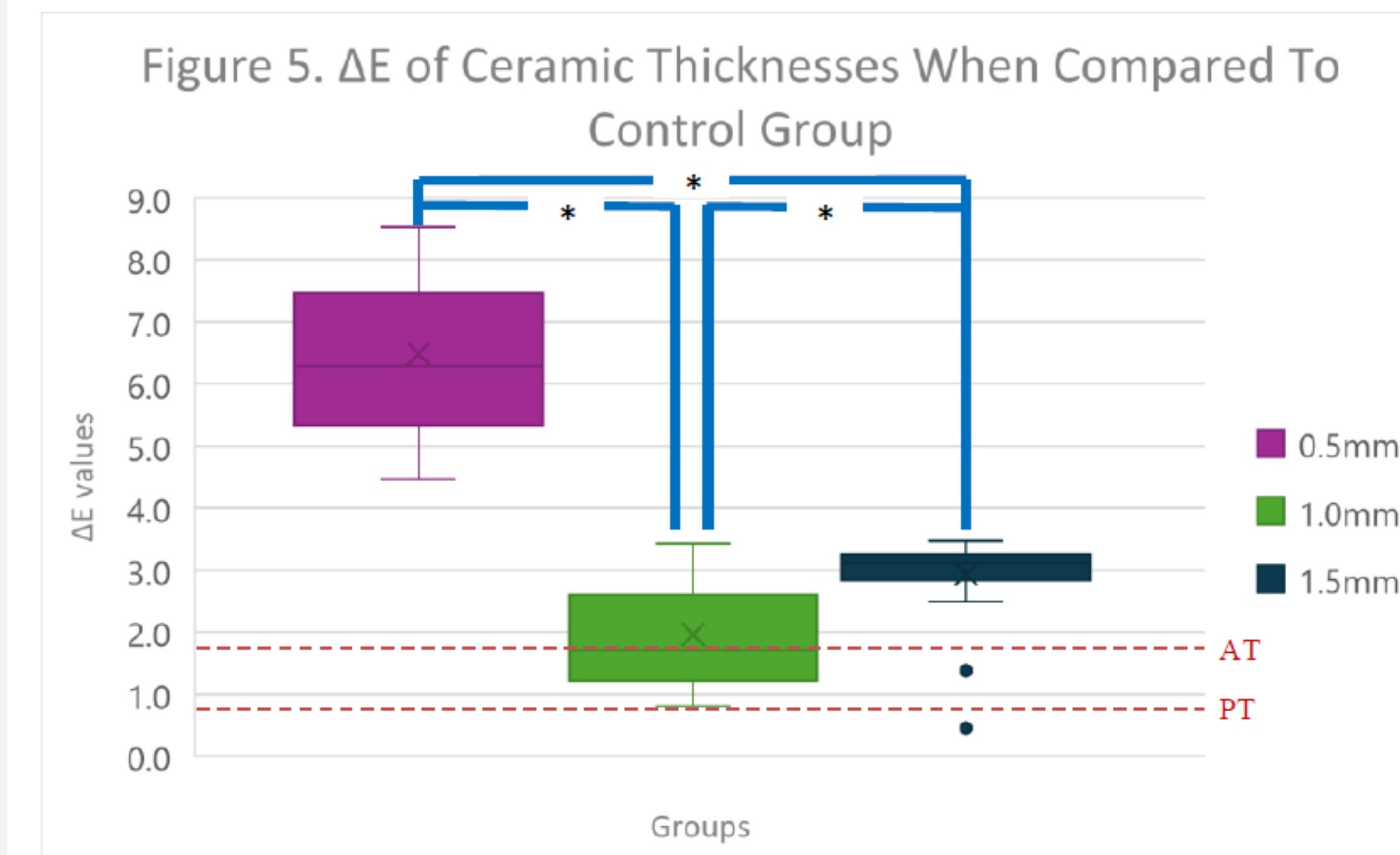


Figure 5. ΔE of 0.5mm, 1.0mm, and 1.5mm ceramic thickness groups when compared to the control. Groups connected with an asterisk (*) show a statistically significant difference ($\alpha = 0.05$). AT = Acceptability Threshold. PT = Perceptibility Threshold.

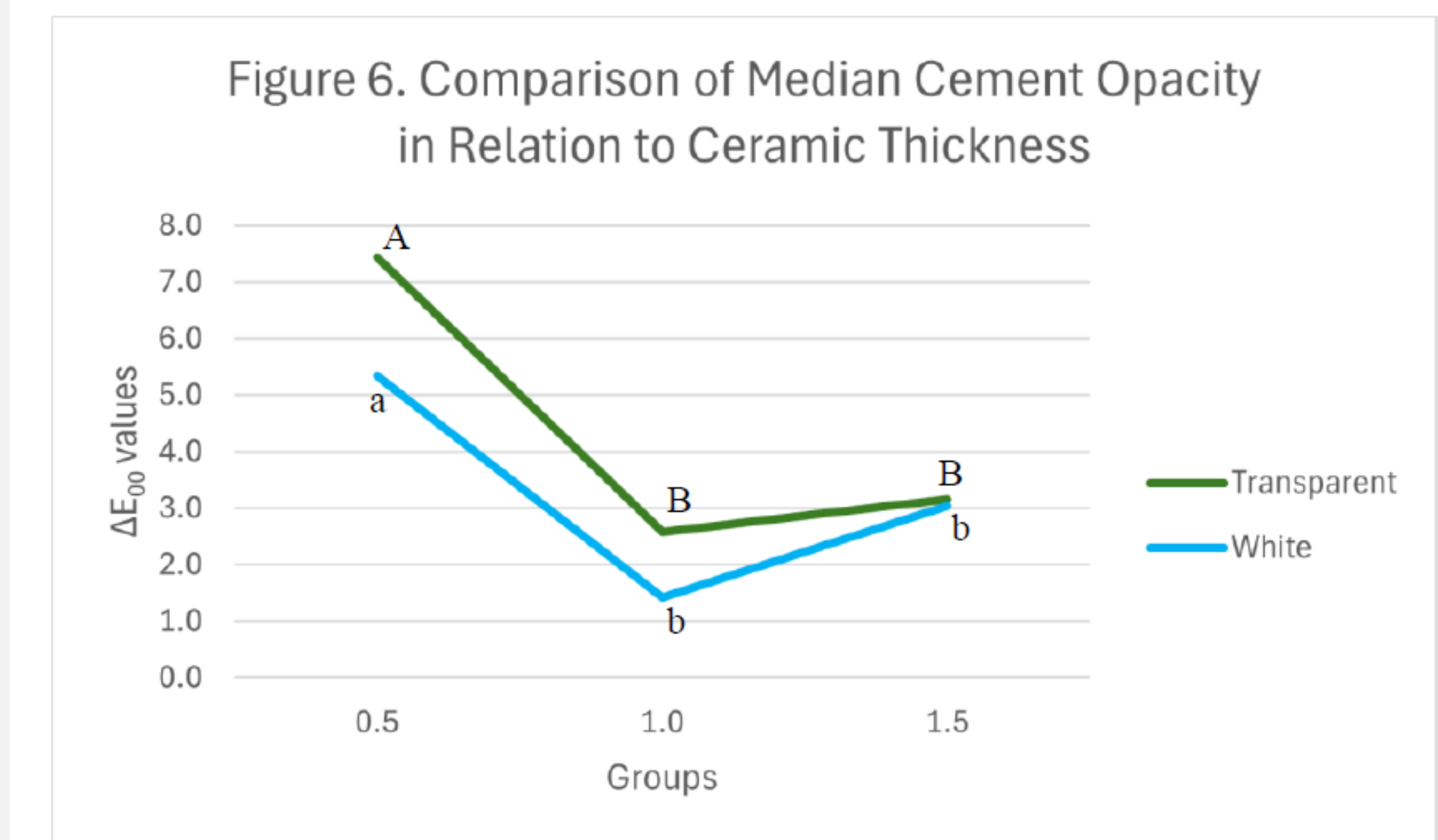


Figure 6. Median ΔE of transparent cement and opaque white cement groups at each ceramic thickness of 0.5mm, 1.0mm, and 1.5mm. Bonferroni corrected post hoc comparisons where plotted points with different uppercase or lowercase letters are significantly different ($\alpha = 0.05$).

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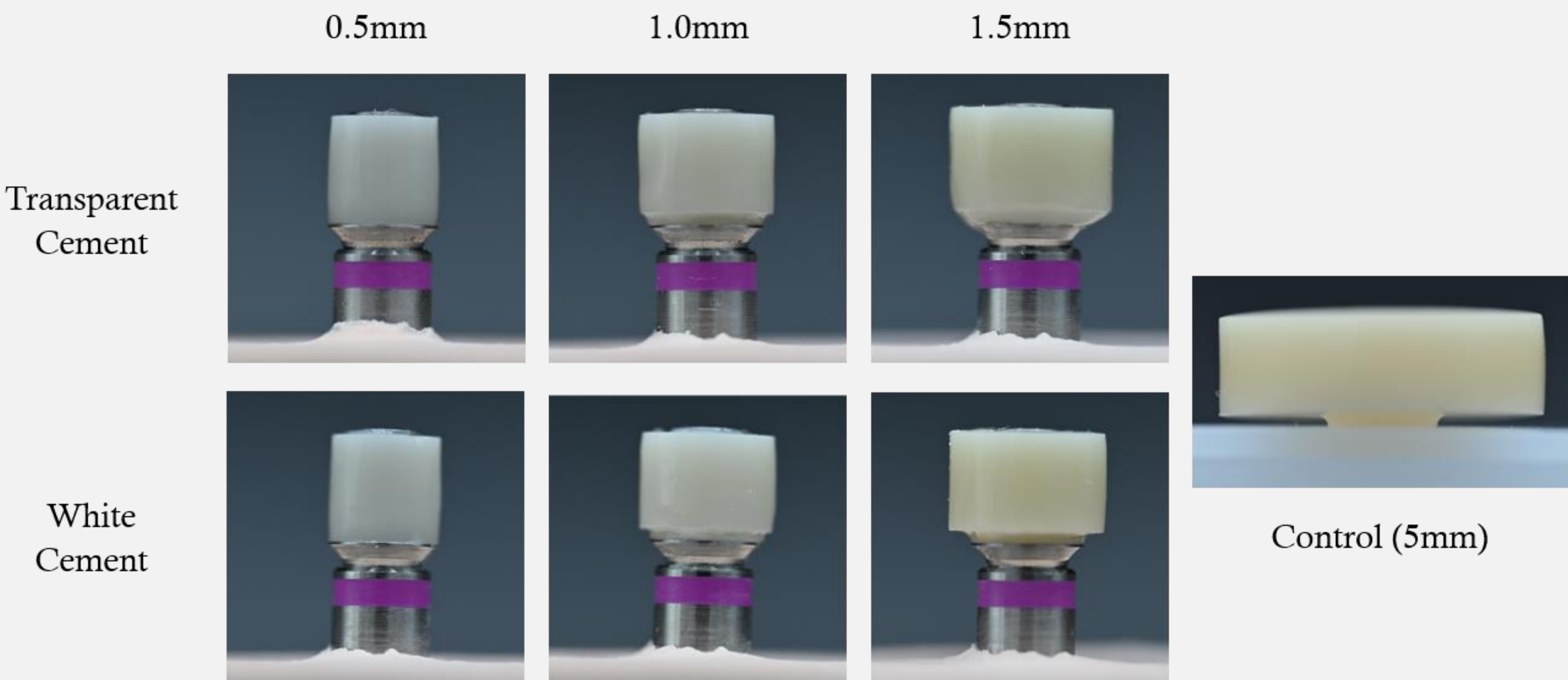
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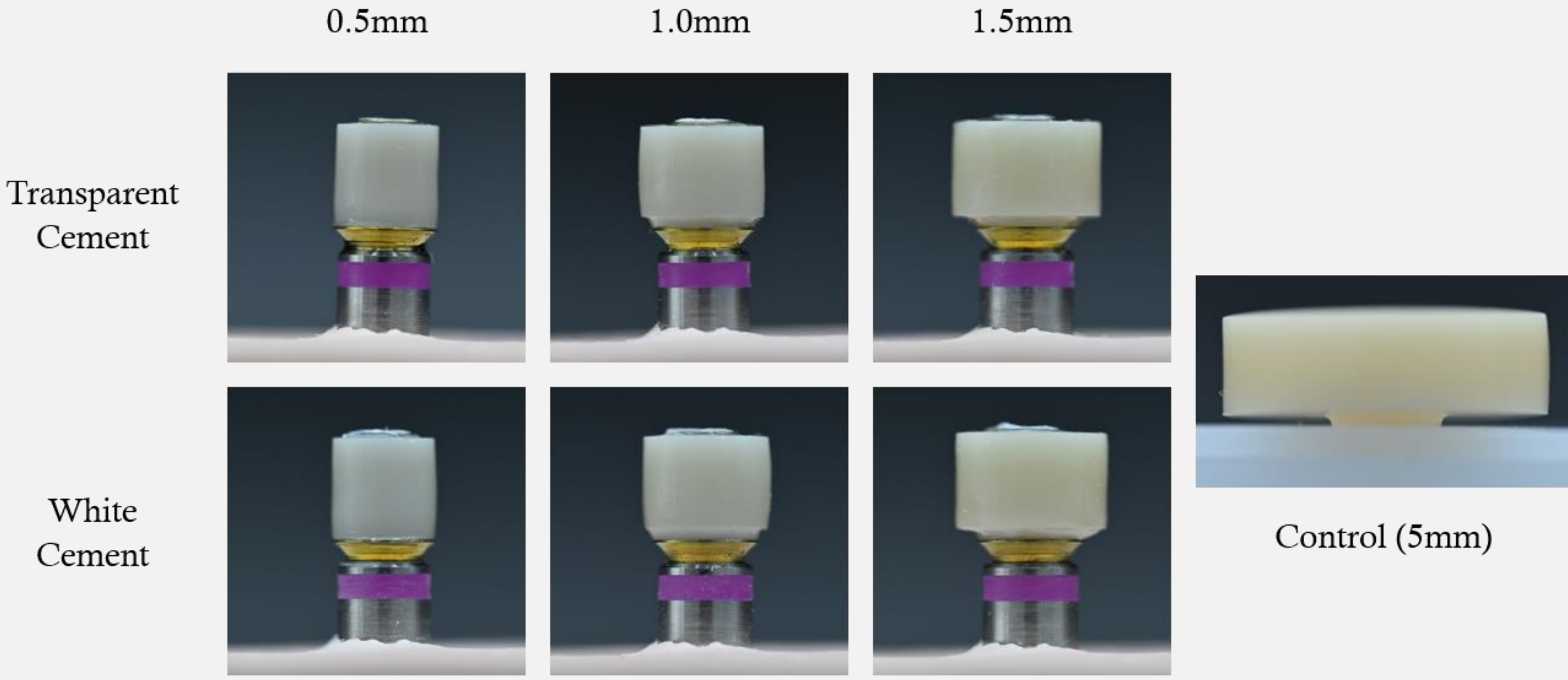


Results

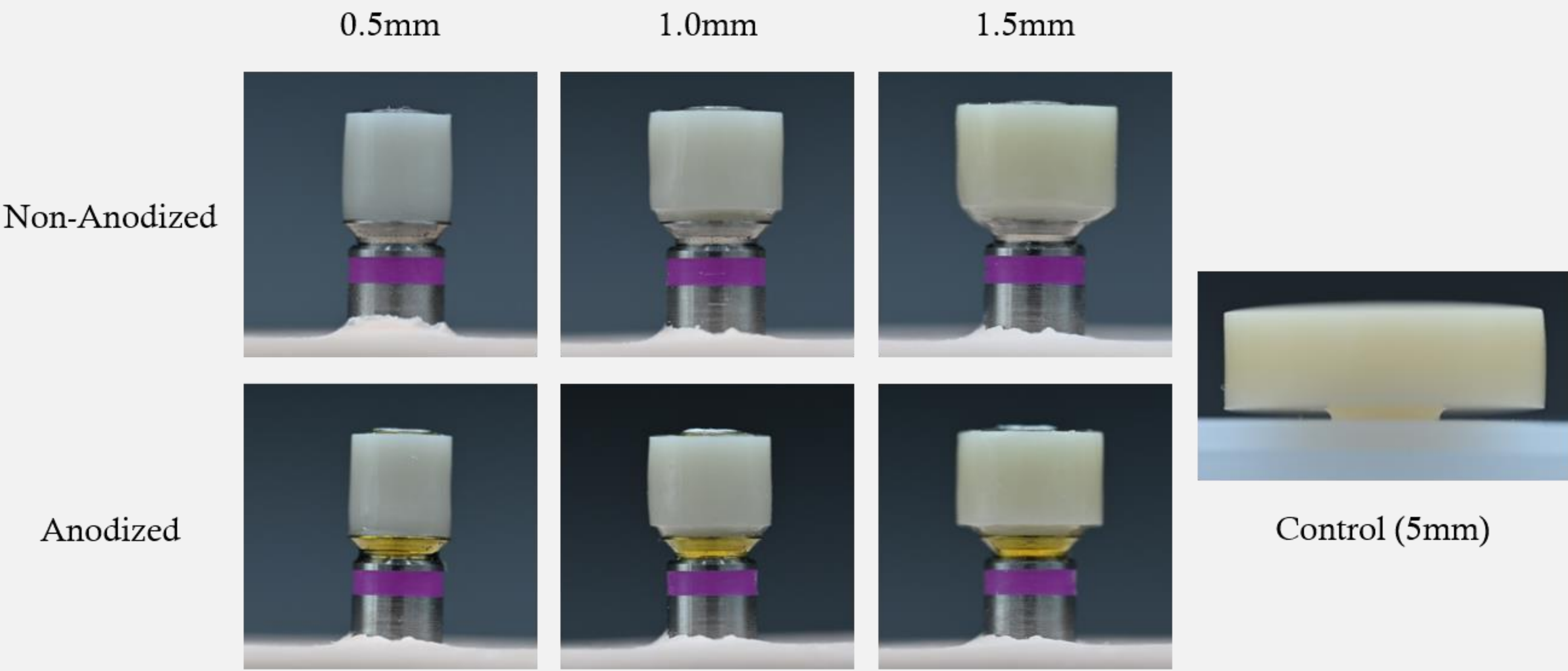
NON-ANODIZED ABUTMENT



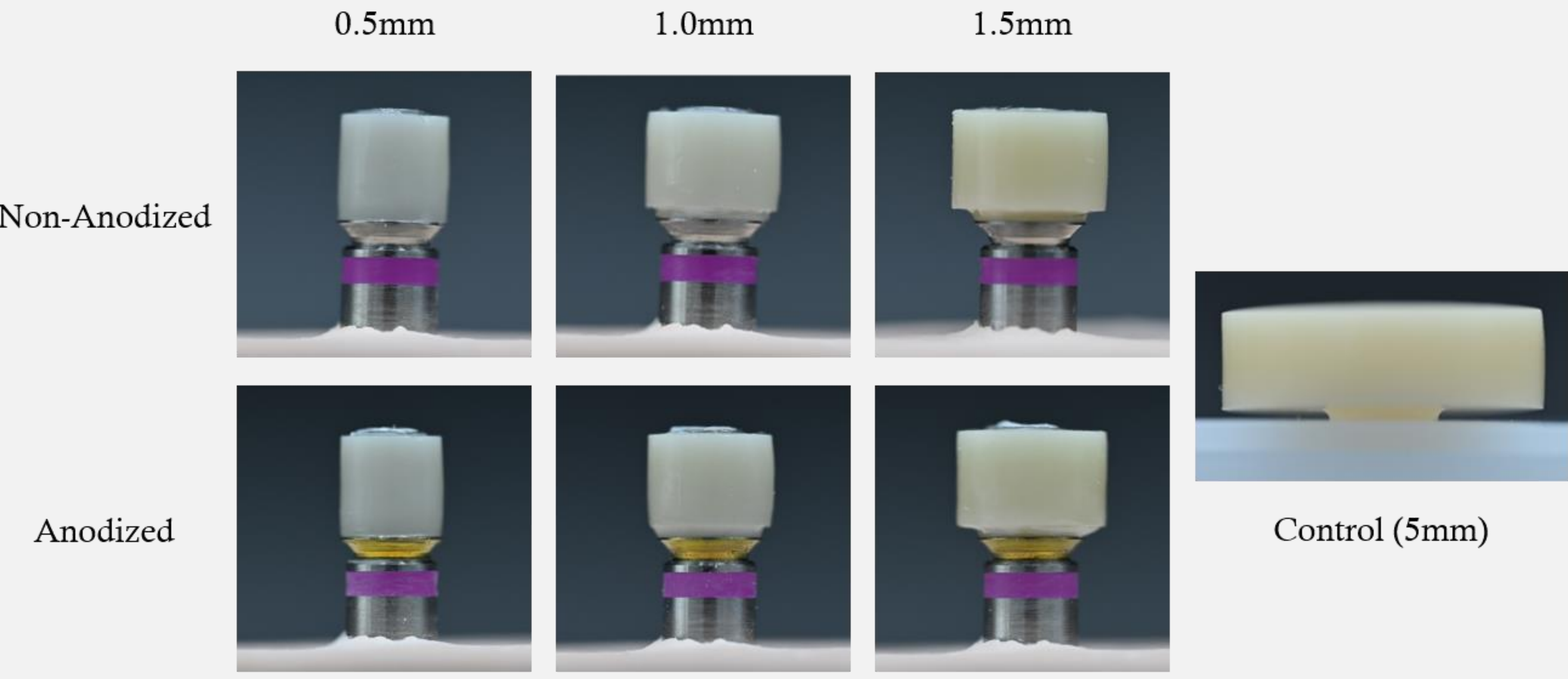
ANODIZED ABUTMENT



TRANSPARENT CEMENT



WHITE CEMENT



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Discussion

The results in this in vitro study showed that there is a significant color difference observed between surface treatment, cement opacity, and zirconia thickness on the esthetic outcome of the final restoration. Therefore, the null hypothesis was rejected.

In the present study, anodization was tested as a variable to determine effect on final restoration shade. Previous studies have shown that anodization has a significant effect on the color difference of a restoration.^{3,5} However, most of these studies tested lithium disilicate to which this study focused on monolithic zirconia, which is tested to be less transparent than lithium disilicate. Sirawuttipong and Palanuwech tested multiple surface treatments but found a significant color difference between non-anodized and anodized abutments, but only when a clear cement was used. This study found no significant difference with the inclusion of anodization.

Cement opacity was also evaluated as a possible contribution towards color difference. Sirawuttipong and Palanuwech similarly tested an opaque and clear cement and concluded that the type of cement significantly affected the color difference (ΔE_{ab}) of untreated and anodized abutments at all corresponding ceramic thicknesses (1.0mm, 1.5mm, 2.0mm, and 2.5mm). The findings from this study are consistent with these results as there was a significant difference noted with cement depending on the ceramic thickness. There was likely no significant color difference at the 1.5mm thickness between transparent and opaque white cement due to the thickness of zirconia masking the underlying color, despite the difference noted in the previous study at an increased thickness.⁵

This study resulted in a significant difference observed with thickness of the ceramic material. This is consistent with other studies as the results commonly show a decrease in color difference with an increase in ceramic thickness. This is seen for both lithium disilicate and zirconia ceramics alike.^{3,5}

Lastly, perceptibility and acceptability thresholds were evaluated in the present study for the effect of abutment surface treatment, cement opacity, and zirconia thickness on the final esthetic outcome. The results from this study show that median values from each of the experimental groups were above the perceptibility threshold and acceptability threshold. Ceramic thickness of 1.0mm showed the least detectable color difference.

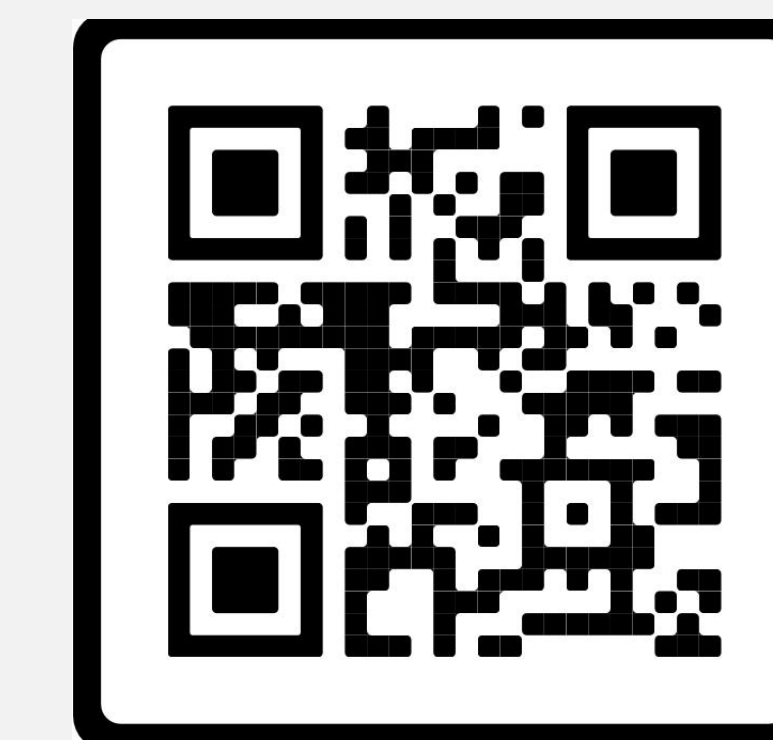
Limitations in the present study included that only one restorative material was tested as opposed to comparing other common ceramic materials including lithium disilicate or veneered porcelain to zirconia. Only a white and transparent shade of cement at only one thickness was tested, which could be improved in future studies by expanding the variability of these factors. Only gold anodization was tested, but pink anodization is also common for effects on gingival esthetics.

Conclusions

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Anodization alone did not significantly affect the color difference of a zirconia implant restoration ($p > 0.05$).
2. Cement opacity significantly affected the color difference of a zirconia implant restoration ($p < 0.05$).
3. Ceramic thickness significantly affected color difference of a zirconia implant restoration ($p < 0.05$). Cement opacity significantly affected color at 0.5mm and 1.0mm ceramic thicknesses, but not at 1.5mm ceramic thickness.
4. All experimental groups showed median color differences above the perceptibility threshold ($\Delta E_{00} > 0.8$). Only ceramic thickness of 1.0mm was within acceptability threshold ($\Delta E_{00} > 1.8$), but this is likely due to error in the data.
5. Zirconia thickness should be of utmost priority to control the esthetic outcome of an implant restoration. As a monolithic zirconia restoration decreases in thickness, the underlying cement can increase color differences.

References



Acknowledgements

Thank you to the Texas A&M Department of Graduate Studies for research funding. Thank you to the Department of Comprehensive Dentistry and co-authors for academic support and