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CLINICAL ARTICLE

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Introducing a novel approach to dental color reproduction using AI technology

Marat Wartanovic Awdaljan MDT[1] | **João Carlos Roque PhD**[2] | **James Choi CDT**[3] | **Luis Felipe Rondón DDS**[4]

[1]Labmatisse BV, Wijchen, The Netherlands
[2]Biomaterials Group (BIOMAT), Biomedical and Oral Sciences Research Unit (UICOB), Faculdade de Medicina Dentária, Universidade de Lisboa, Lisboa, Portugal
[3]Maven Dental Studio, Private Dental Laboratory, Oakbrook Terrace, Illinois, USA
[4]Department of Restorative Dentistry, Dental School, São Paulo State University – UNESP, São Paulo, Brazil

Correspondence
Marat Wartanovic Awdaljan, Avenida da República 43B (9), 1050-240 Lisboa, Portugal.
Email: marat@matisse.ai

Abstract

Objective: This article aims to describe a systematic method for tooth color reproduction with ceramics restorations employing artificial intelligence (AI) software named Matisse. It provides a comprehensive analysis of the entire process, beginning with shade-taking and extending to ceramic application in a complex clinical case in the anterior region—specifically, a single central restoration supported by an implant.

Clinical Considerations: The clinical case presented highlights the potential of Matisse software for generating ceramic (inSync-Jensen Dental, USA) and staining (Miyo-Jensen Dental, USA) recipes over a zirconia abutment (Katana-Noritake Dental, Japan). This approach achieves an optimal single central restoration utilizing CAD-CAM and layering techniques.

Conclusions: The systematic method employing the Matisse software achieved accurate color reproduction for a single central restoration supported by an implant. This result was achieved by the dental ceramist within the first attempt and without seeing the patient in the entire process.

Clinical Significance: The Matisse AI-assisted protocol offers a systematic and scientifically grounded method for color reproduction in dentistry for indirect restorations.

KEYWORDS
artificial intelligence, CAD/CAM, dental color, dental technology, digital dentistry, dental ceramics

1 | INTRODUCTION

Achieving precise color reproduction between indirect restorations and the natural teeth poses a formidable challenge, especially in the anterior dentition where aesthetics plays a major role.[1,2] This task is further compounded by the necessity to replicate natural tooth color in a laboratory setting rather than within the patient's mouth.[3] Addressing these complexities requires a nuanced comprehension of several factors. On the clinical side, this includes considerations such as the influence of the stump shade and available space for restoration.[4,5] On the laboratory side, factors such as the selection of framework material,[6] the choice of ceramic powders,[7] the effects of layering techniques,[8,9] and the post-sintering color and mechanical properties[10] are crucial.

Color reproduction with dental ceramics is often regarded more as an art than a science. Traditional methods have primarily depended on the artisanal skills and experiential knowledge of dental technicians. While these skills are indispensable, relying solely on them can lead to inconsistencies and frequent color mismatches, often resulting in time-consuming corrections or costly remakes.[11–13] Conventionally, the dental community has relied on subjective methods, which involve visual shade matching, selecting a shade from shade guides, and then communicating this information to the laboratory using a prescription.[14] However, dental shade guides offer a limited range of colors that do not fully encompass the color space of natural teeth, leading to considerable inaccuracies, particularly for less experienced dentists and dental technicians.[15–17] Additionally, the absence of reliable instructions from dental manufacturers on replicating shade guide colors with ceramics in diverse settings complicates the precise reproduction of the entire natural tooth color with this material.[13] Thus, significant errors arise in the initial step of color reproduction, continuing into subsequent stages due to the incorrect selection and placement of ceramic powders based on inadequate information.

The introduction of spectrophotometers and colorimeters, equipped with advanced color analysis software, represents a significant advancement in shade-taking and color measurement.[14,18] These tools, along with the CIELAB color space introduced by the Commission Internationale de l'Eclairage (CIE), wherein the L^* coordinate measures lightness, while the a^* and b^* coordinates represent red-green and yellow-blue, respectively,[19] enable the utilization of color difference formulas such as the CIE94 (ΔE_{94}).[20] This allows for the derivation of a specific value that can be correlated with human color perception and its thresholds of color differences,[21,22] thereby facilitating a quantitative assessment during the color reproduction workflow.[23,24] Additionally, digital cameras, coupled with software and specific neutral gray cards for more accurate color calibration, have been employed to improve color assessment and communication.[25–27] These implements also allow the capture of detailed information regarding the morphology, surface texture, and translucency of the tooth, thereby contributing to more comprehensive dental assessments.[28,29]

Despite those advancements in dental color measurement and shade-taking, a significant challenge persists in translating that information into the manufacturing process of color reproduction. In other words, the method of selecting the right combination of material shades and translucencies to accurately replicate not only the base color but also all the intrinsic color details (e.g., those observed in the incisal third of anterior teeth) has not been adequately addressed.[24] The Matisse software aims to fill this crucial gap.[30] Although inspired, Matisse takes a radically different approach than existing approaches of synthesizing color measurements into a restoration process.[11,12,23,26,31] Specifically,

1. the approach utilizes, in addition to a digital camera for a visual color check, also a dental colorimeter[32] for the bulk of the color measurements to ensure more consistent and accurate shade-taking,
2. the method provides recipes to match the stump shade and adjacent teeth offering a path to exactly replicate the patient's mouth situation,
3. the software provides ceramic recipes for each layer of the restoration by considering the effects of the background color and thickness of the layers,

FIGURE 1 Pre-operative x-ray displaying the initial condition of the case.

4. the method takes advantage of the full-color spectrum of ceramic and staining sets to get more versatile and robust recipes.

Finally, Matisse also offers a solution to directly stain full monolithic crowns and micro-layering crowns to the desired shade, hence bypassing the need for layering altogether. Overall, this hybrid methodology combines the strengths of traditional craftsmanship with cutting-edge technology, incorporating artificial intelligence (AI) algorithms.[33,34] As a result, it offers promising ceramic recipes tailored to match the natural tooth color.

This article aims to describe a systematic method for tooth color reproduction with ceramics restorations employing AI software named Matisse. It provides a comprehensive analysis of the entire process, beginning with shade-taking and extending to ceramic application in a complex clinical case in the anterior region—specifically, a single central restoration supported by an implant.

2 | CASE REPORT

A 40-year-old female patient sought treatment at a private clinic (Oakbrook Terrace, IL). Upon intraoral clinical examination, moderate

FIGURE 2 Temporary crown for the upper right central incisor following implant surgery.

TABLE 1 Features offered by the Matisse iOS App and the online Matisse software.

Matisse iOS App	Matisse software
• ColorModel • Framework advice • Micro-layering and Full Monolithic crowns	• ColorModel • Framework advice • The Dentin, Internal effects, and Enamel Recipes • Micro-layering and Full Monolithic crowns

to severe periodontal inflammation was observed on the palatal aspect of the right upper central incisor, which also exhibited an extensive restoration (Figure 1). The patient's dental history revealed a resorption, managed surgically on three previous occasions. Additionally, complementary studies showed internal resorption around the cavo-surface margin on the internal aspect of the tooth. Consequently, various treatment options were discussed, and following the patient's final acceptance, it was decided to proceed with extraction and immediate implant placement along with bone grafting. A dental colorimeter (Optishade, Styleitaliano-Smile Line, Saint-Imier, Switzerland) was used to register tooth images and color data. This clinical information was shared by cloud/IOS App to the dental laboratory (Lisle, IL), while the patient expected final restoration using a provisional restoration (Figure 2). The implant-supported single-central restoration was digitally designed (Exocad, Germany) and produced on zirconia (Kuraray Noritake Dental, Tokyo, Japan). The layering of restoration was achieved using the Matisse software recipes, providing a systematic solution to the challenge of color reproduction. The recipes can be generated utilizing an iOS application—Matisse iOS App (Labmatisse BV, Wijchen, The Netherlands) and the online Matisse software (https://www.matisse.ai/) (Labmatisse BV, Wijchen, The Netherlands) (Table 1), alongside a dental colorimeter and digital images. The following sections delineate the step-by-step integration of software and devices into the workflow, a graphical illustration is presented in Figure 3.

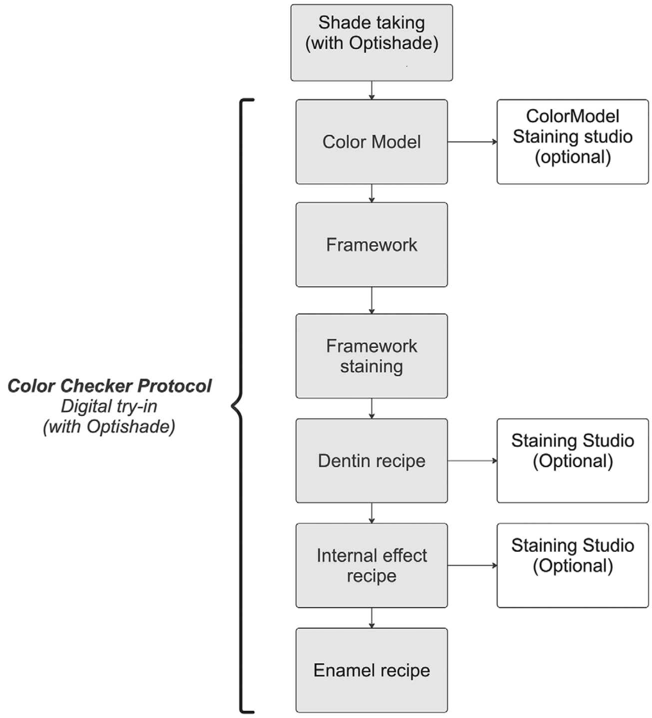

FIGURE 3 Flowchart illustrating the integration of software and devices into the workflow.

2.1 | Shade-taking

The first step involved shade-taking in the dental office, conducted using a dental colorimeter (Optishade, Styleitaliano-Smile Line, Saint-Imier, Switzerland) interfaced with an iOS application—Optishade App (Styleitaliano, Liguria, Italy). To minimize the risk of color discrepancies attributed to tooth dehydration, this procedure was performed within the initial minute of the dental appointment. The colorimeter was positioned directly in front of the tooth for measurement and stabilized on the adjacent teeth to maintain proper focus distance. Color determination was facilitated through the iOS application, which captured an image of the area recorded on the screen, delivering color measurements in terms of CIELAB or CIELCh color coordinates, showing the closest match with various shade guides and ΔE_{94} values (Figure 4). Preferably, there should be one image of the tooth preparation and another of the target tooth. In this case of a screw-retained implant crown, an image of the target tooth was sufficient. Once the files were shared with the Matisse iOS App, they automatically synchronize with the Matisse software.

2.2 | Setting initial parameters

To begin formulating the dental restoration recipe in the software, an *All-in-One* recipe was chosen. This provided a complete plan for addressing the specific case, selected from various available options. Initial parameters included ceramic brand, framework brand, framework staining (optional), total available space for ceramic layering,

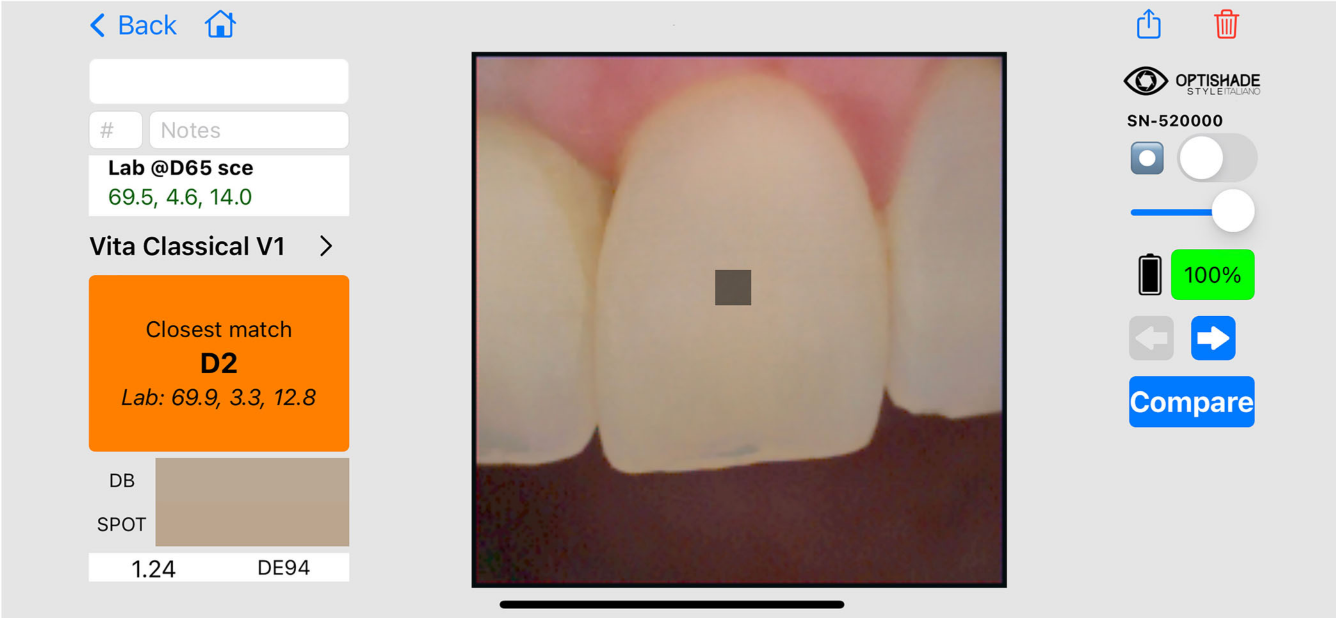

FIGURE 4 Image of the target tooth displayed in the Optishade App (Styleitaliano, Liguria, Italy), showing the CIELAB coordinates and the closest Vita Classic shade tab with the corresponding color difference (ΔE_{94}) value.

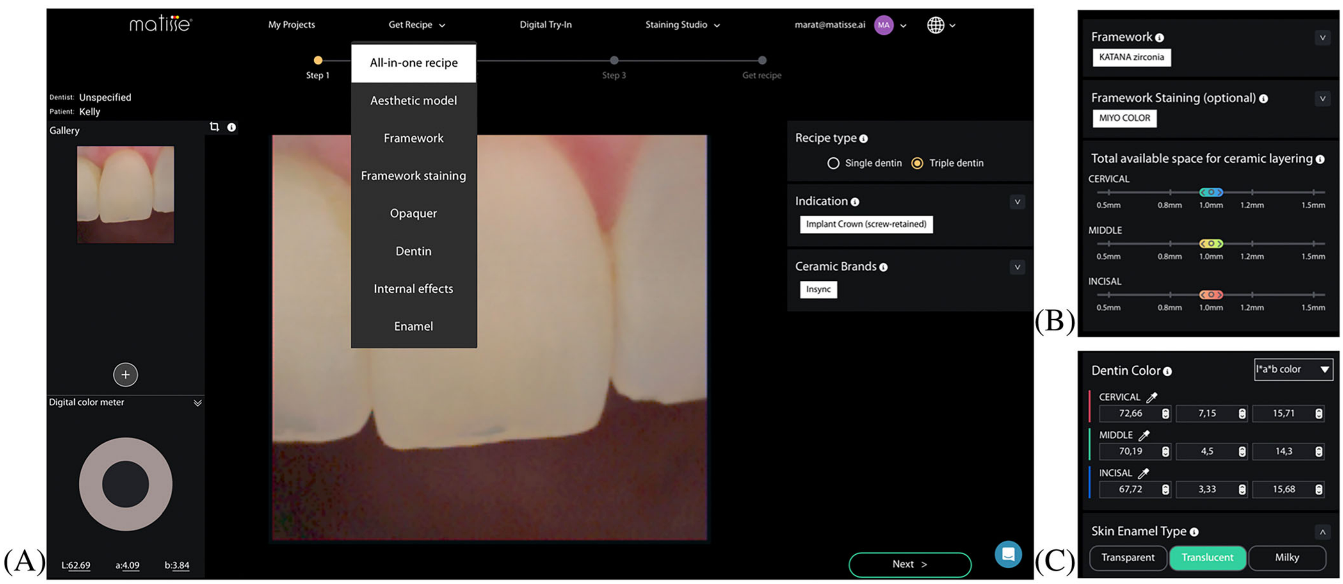

FIGURE 5 (A) Setting the initial parameters in Matisse software All-in-One Recipe, starting with the indication and ceramic brand. (B) The framework staining brand and total available space for ceramic layering. (C) The dentin color measurement in CIELAB coordinates and the skin enamel type.

CIELAB color coordinates of the natural tooth on three regions (cervical, middle, and incisal), and enamel type. Then, the Matisse recipes provided framework recommendations, including instructions for the framework staining, dentin recipes for the cervical, middle, and incisal thirds, as well as enamel advice. These steps constituted the initial phase, with the subsequent sections offering a more detailed and justified explanation of each step (Figure 5).

2.3 | ColorModel

To enable the dental technician to work in a color environment closely resembling the mouth, a resin recipe for a model was generated using the *Esthetic model* option. A model made of auto polymerizable polimetilmetacrilate (PMMA) resin mixed with cold curing liquid—Matisse Color Model resin (Labmatisse BV, Wijchen, The

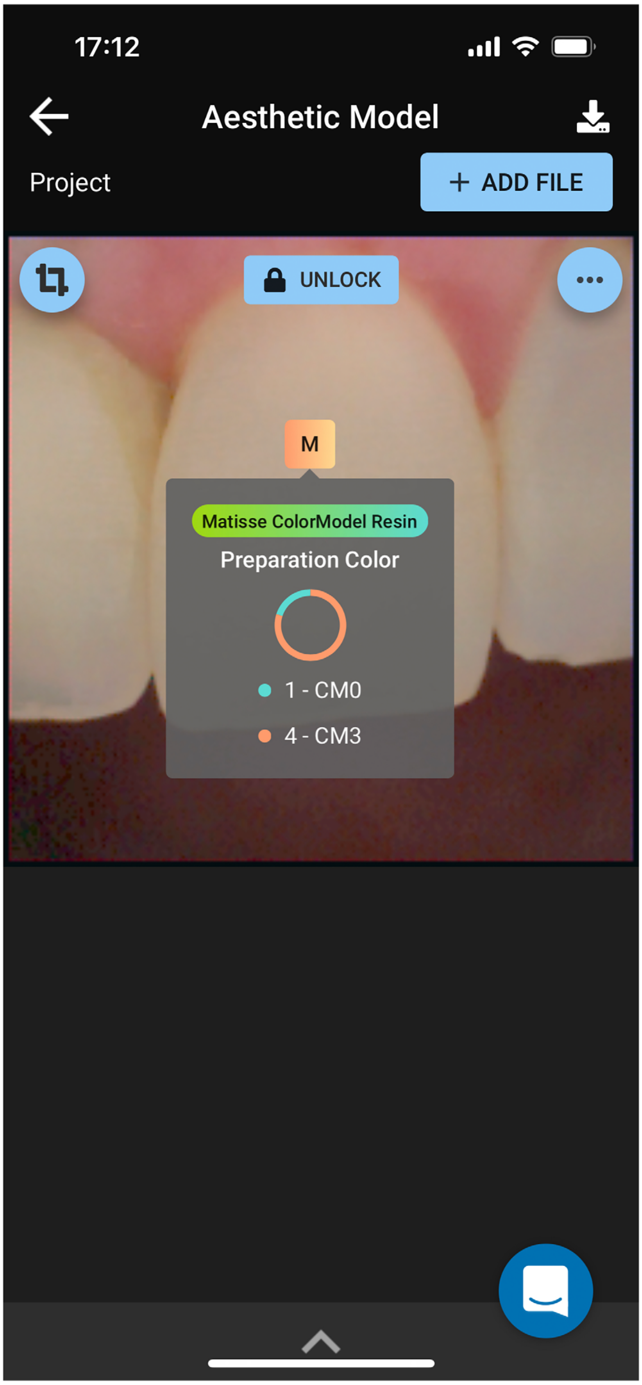

FIGURE 6 The suggested resin recipe of ColorModel by Matisse iOS App.

Netherlands), was obtained by pouring the resins into the impression. Following polymerization, the model was extracted, and a reduction of the gum tissue was performed to facilitate the application of pink wax—Metrowax No. 2 (Metrodent, Yorkshire, UK), to mimic the color of the gingiva. The reproduction of a stump shade was omitted (implant), with color replication solely based on the homonymous tooth (1-part CM0 and 4 parts CM 4) (Figures 6 and 7).

FIGURE 7 The ColorModel replicating the color environment of the mouth.

2.4 | Framework

The subsequent phase entailed selecting a substructure or framework material within the *Framework* option. The type of restoration to be manufactured was then chosen (Screw-retained implant crown), followed by the selection of the ceramic type (InSync ceramic, Jensen Dental, CT). The software provided guidance from the available options. Then, a brand of stains was chosen (MIYO Color, Jensen Dental, CT), and the available space for restoration on the cervical, middle, and incisal thirds was specified. In the present case, the software recommended a framework composed of Katana Zirconia HT 12 (Kuraray Noritake Dental, Tokyo, Japan) designed with a layering space of 1.0 mm (Figure 8).

2.4.1 | Framework staining

To ensure precision in the color of the framework consider the available space for ceramic and the desired final color. The software provided a staining recipe option used during the wash-bake process to reproduce the framework's color more closely to that of the natural tooth. This becomes especially beneficial if the dental technician opts for a framework different from the one proposed by the software. For this case, a MIYO (Jensen Dental, CT) color recipe was generated for the middle area. The wash-bake involved a recipe of 3-part Trans Smoke and 1-part Mamelon Coral, which was similarly applied to the cervical and incisal areas (Figure 9). Following the application of stains on the framework, the dental colorimeter was utilized to compare the CIELAB coordinates with those of the natural tooth before baking it in the ceramic furnace. After baking, the color accuracy of the wash-bake was ensured through the *Color checker* protocol (Figure 10).

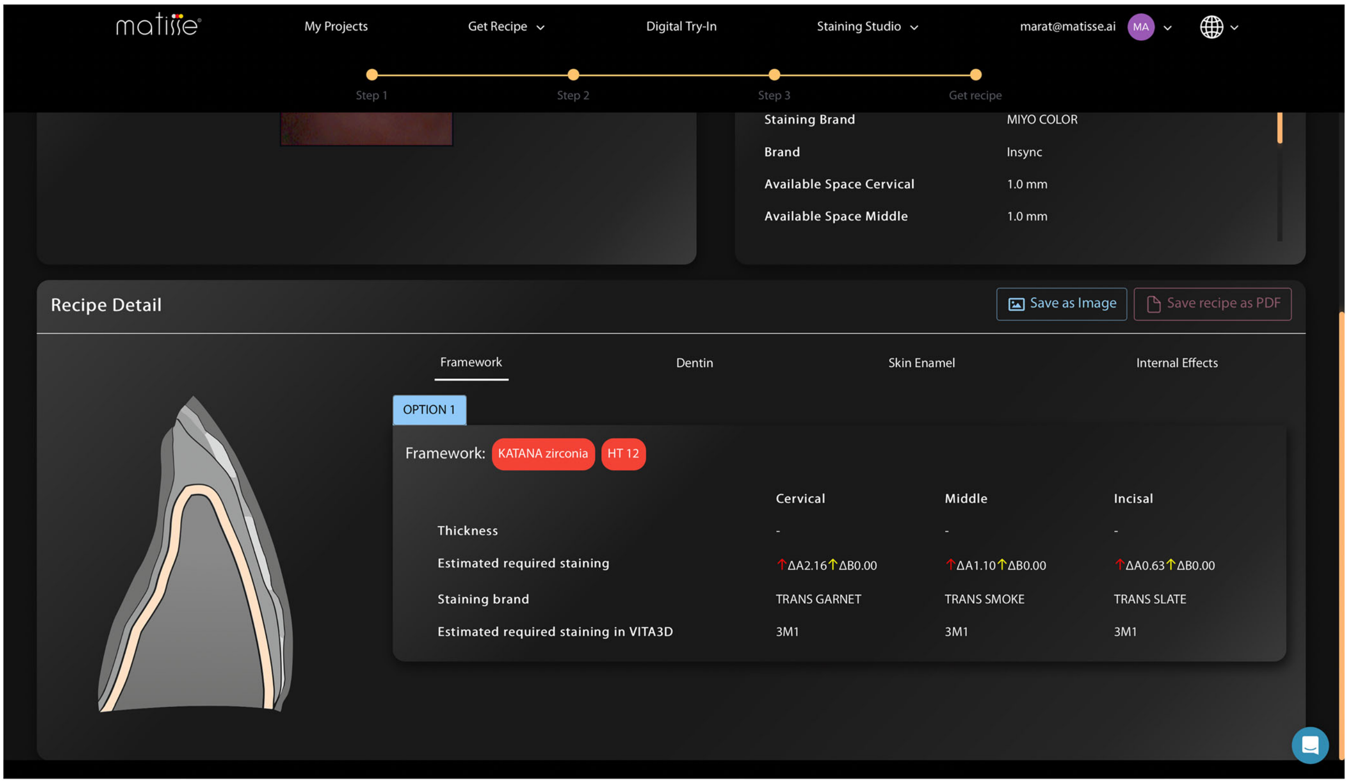

FIGURE 8 The generated framework advice by Matisse with a layering space of 1mm.

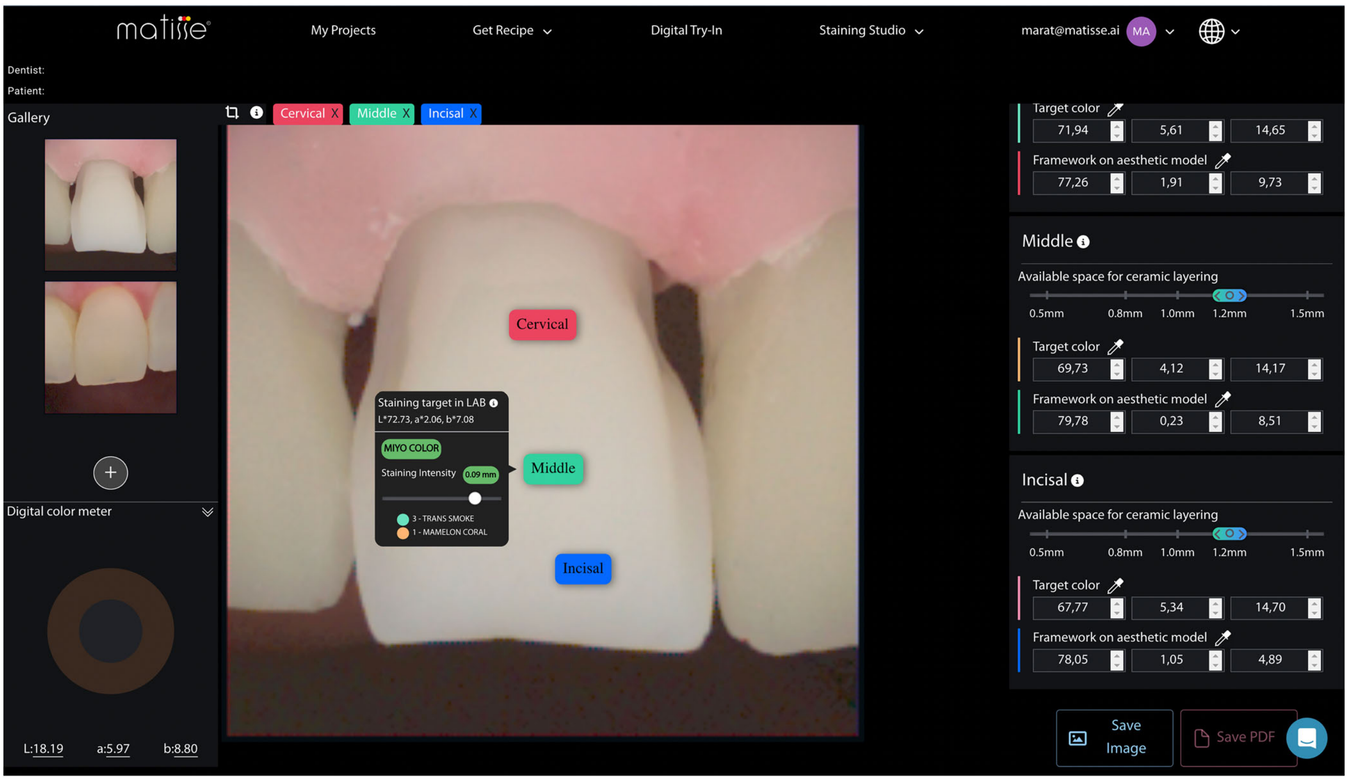

FIGURE 9 The Framework staining recipe generated by Matisse for the wash-bake preparation.

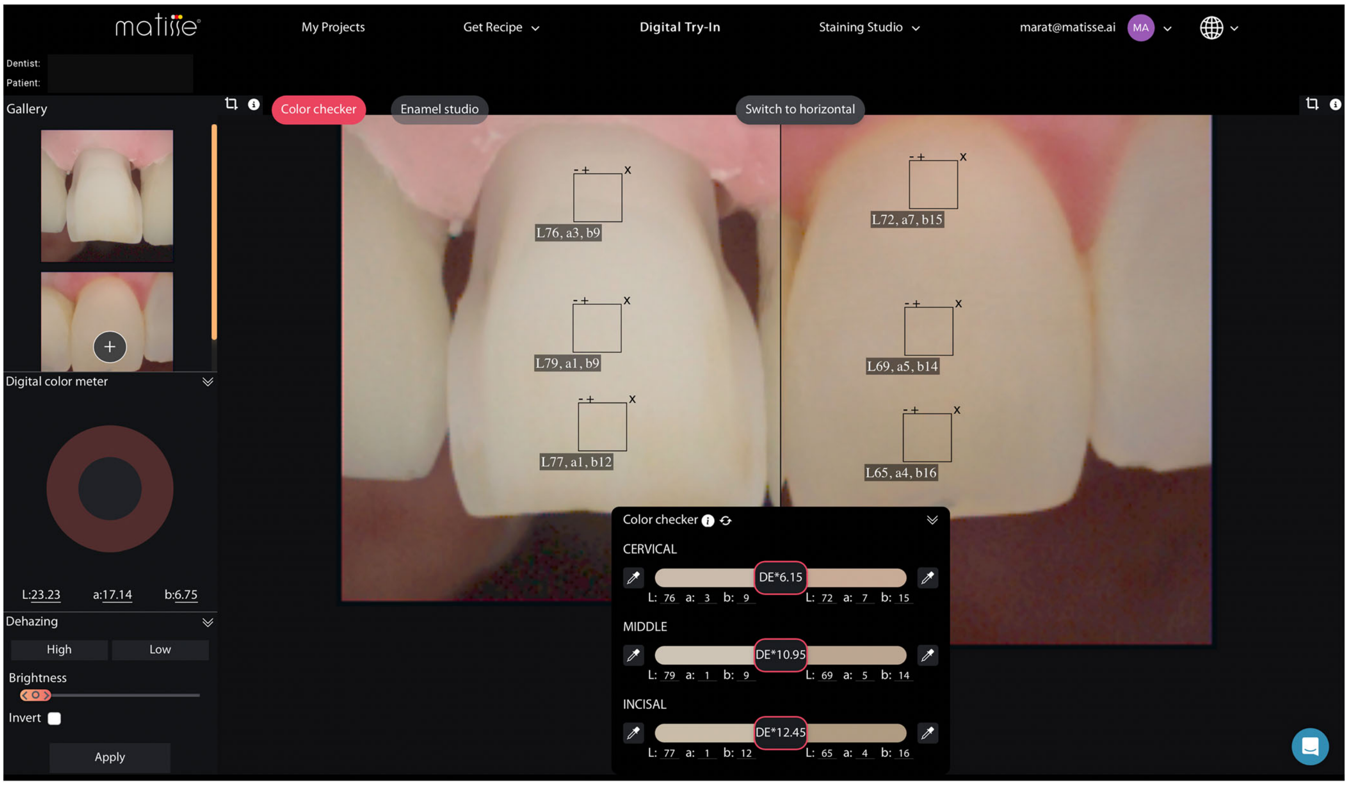

FIGURE 10 The Color checker depicting color difference (ΔE_{94}) values for the cervical, middle, and incisal parts of the stained framework and the target tooth.

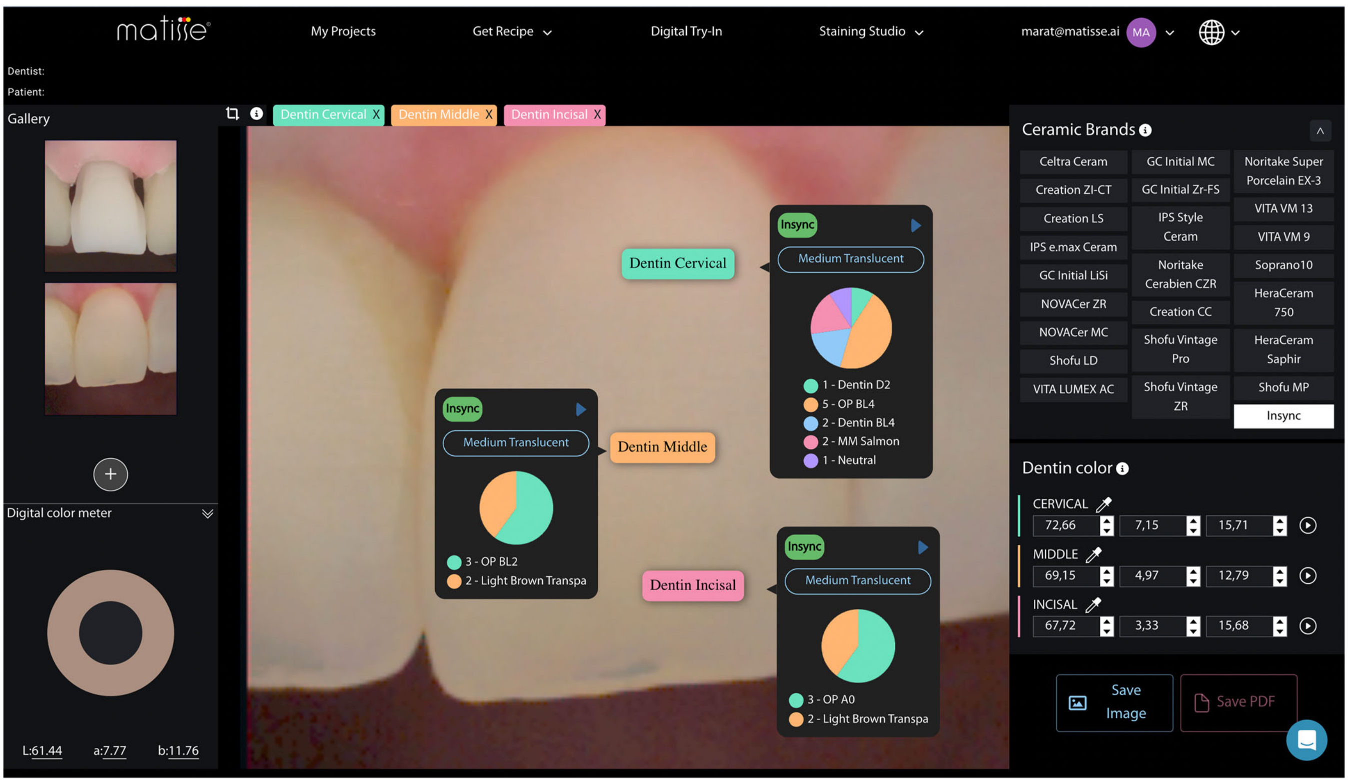

FIGURE 11 The Matisse ceramic powder dentin recipes for the cervical, middle and incisal areas.

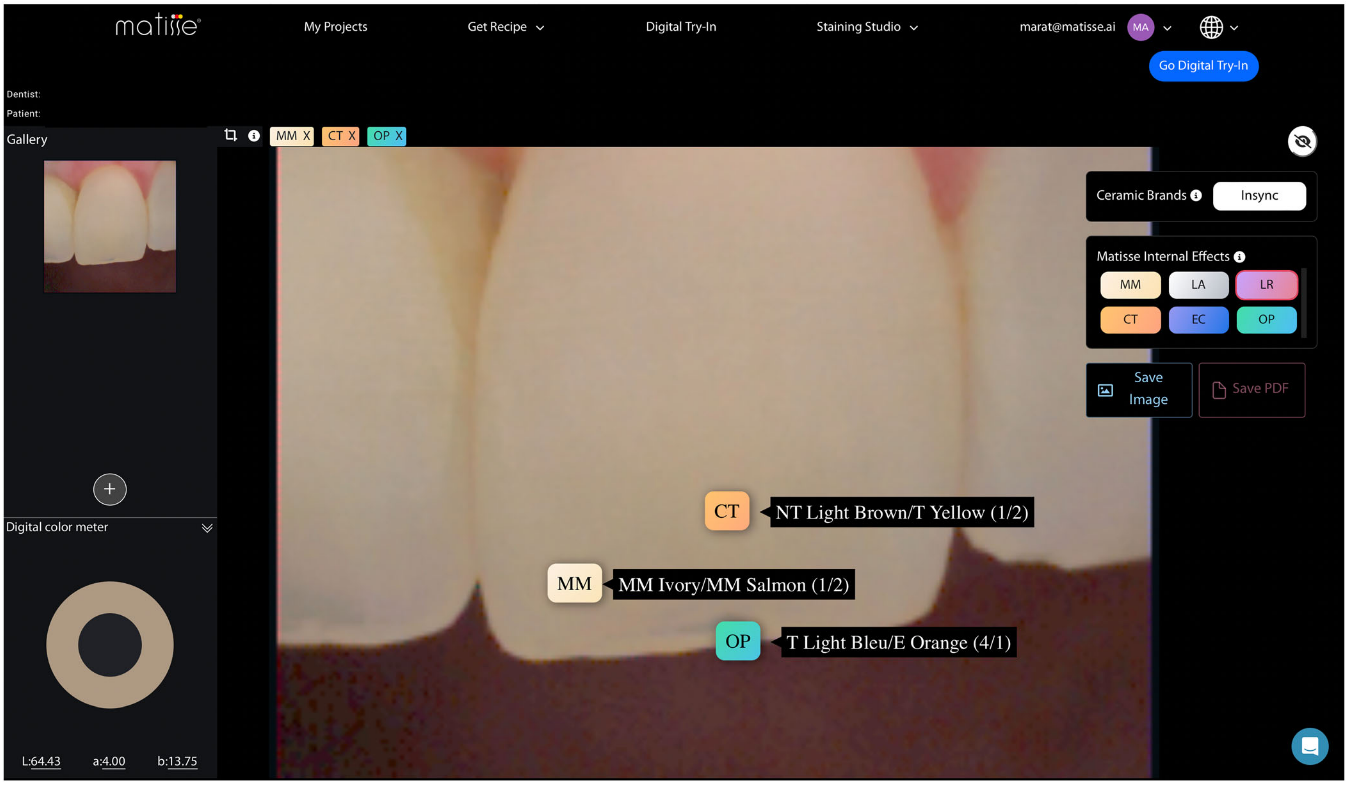

FIGURE 12 The Matisse ceramic powder internal effects recipes.

2.5 | Color checker

The *Color checker* protocol was fundamental to ensure the color accuracy of the restoration at each stage. It started by utilizing the dental colorimeter to measure the color of the framework material. Subsequently, within the software *Digital Try-in* option, a colorimetric analysis of various regions of the restoration was conducted, comparing values to the target tooth and quantifying color differences using the ΔE_{94} formula.

2.6 | The dentin and the internal effects recipes

To guide the layering technique the Matisse software generated a recipe containing ceramic powders for cervical, middle, and incisal areas. It provided multiple options for each of these areas, but for the sake of simplicity the recipe with the fewest powders was selected for the middle and incisal zone. Depending on the characteristics of the tooth, it could have been determined which zones would require a ceramic recipe instead of relying solely on the initially proposed three areas. The recipes and the mixing ratios were for the cervical area a 5 powders recipe (1× Dentin D2, 5× Opacious Body Bl4, 2× Dentin Bl4, 2× Mamelon Salmon, and 1× Neutral), for the middle area a recipe of 2 powders (3× Opacious Body Bl2 and 2× Light Brown Transpa) and for the incisal area (3× Opacious Body A0 and 2× Light Brown Transpa) (Figure 11). Furthermore, the software enabled the generation of recipes for internal characterizations, providing to specific features such as mamelons, cervical translucency, enamel canvas, opalescence, light reflection, and light absorption zones, as selected by the dental technician from the images. In this case, the recipe and the mixing ratios were: (Mamelon:MM Ivory/Salmon 1:2 ratio, Cervical translucency: NT Light Bown/T Yellow 1:2 ratio and Opalescence: T Light Blue/E Orange 4:1) (Figure 12). The mixtures were prepared based on a portioner of the same size (Figure 13).

2.6.1 | Staining studio

The software also provided ceramic paste or staining powder recipes to correct any color discrepancies that arise after the initial baking process, due to incorrect interpretation/ application by the dental technician. This involved utilizing the internal staining technique, and the recipe was adjusted based on the color of the restoration after baking. For this process, the coefficient of thermal expansion of the materials needed to be in the same tolerance range. In this particular case, after the first baking, the chroma in the middle and incisal parts was lower (Figure 14). Consequently, the *Staining studio* was employed to obtain a MIYO (Jensen Dental, CT) color correction recipe (Figures 15 and 16), which was applied internally before layering the enamel. The *Color checker* protocol was employed after baking, resulting in a closer match to the target tooth while considering the influence of the future enamel layer (Figure 17).

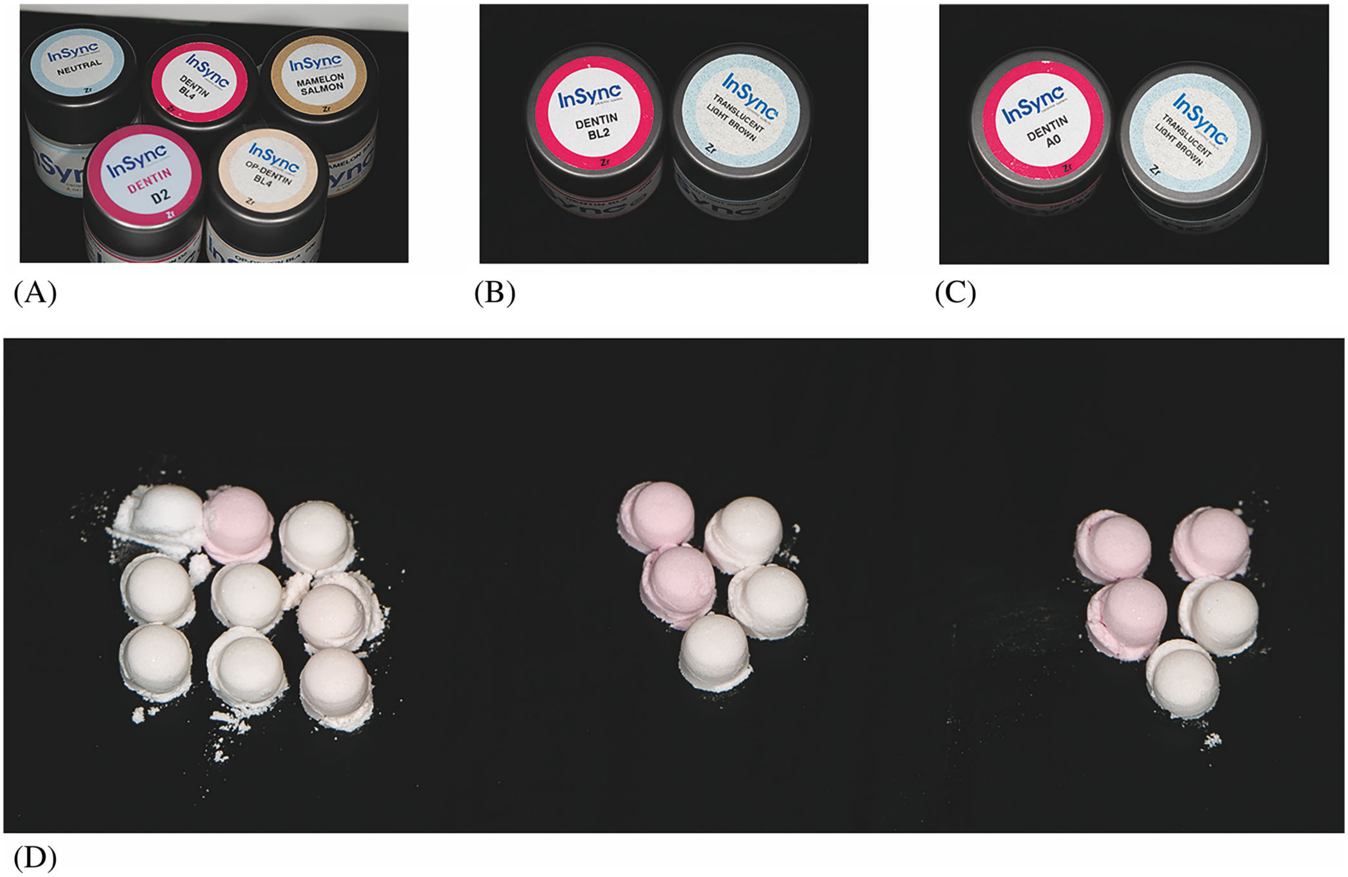

FIGURE 13 The different ceramic powder recipes for the three regions (A) cervical, (B) middle, (C) incisal, and (D) The dentin recipe mixing rations containing solely ceramic powders.

2.7 | Enamel recipe

Finally, the enamel recipe was formulated based on the perceived translucency of the natural enamel, allowing selection from three options: Milky, Translucent, or Transparent. In this case, Translucent was selected as the main enamel type and the obtained recipe was InSync Enamel 59 (Jensen Dental, CT) (Figure 18). The enamel layer was only used for the finishing touch and to ensure the correct shape. The thickness of the dentin and internal effects layer must shape the tooth for 95%–98% and the enamel layer only 2%–5%. The final outcome of the case and subsequent follow-ups are depicted in Figures 19–24.

3 | DISCUSSION

Historically, the dental industry has grappled with the challenge of accurately replicating the natural color of teeth in indirect restorations, often relying on shade guides and the subjective judgment of dentists and dental technicians.[14] However, this conventional approach frequently led to inconsistencies and mismatches, necessitating costly, and time-consuming corrections.[11–13] Advancements in restorative techniques within the dental field, particularly in color reproduction, represent a critical intersection between technology and traditional dental craftsmanship.[1,2] The Matisse software,[30] as outlined in this article, integrates AI algorithms alongside a calibrated color-measuring process to deliver precise ceramic recipes tailored to various clinical scenarios.[33,34] A discussion of the rationale and science behind these generation of the recipes is beyond the scope of this article. Nonetheless, the Matisse software supports an expanding range of dental ceramics and stains available on the market. Currently, it incorporates 24 ceramic and staining systems that are regularly updated and upgraded.

The systematic approach described minimizes reliance on subjective judgment by enabling color control at every step through the *Color checker* protocol. This process computes color coordinates within the CIELAB color space[19] of both the restoration and the teeth to be replicated and calculates a color difference (ΔE_{94})[20] that can be associated with the perceptual sensitivity of the human visual system. With a threshold for detecting color differences set at 0.67 units,[21] this assessment enables the dental technician to identify and resolve any color discrepancies during the manufacturing process, thereby reducing the margin for error. Also, the *Framework staining* and *Staining studio* steps provide recipes to ensure color precision or assist in correcting any color discrepancies as needed. In the presented case, to achieve a more accurate color on the framework, a MIYO recipe

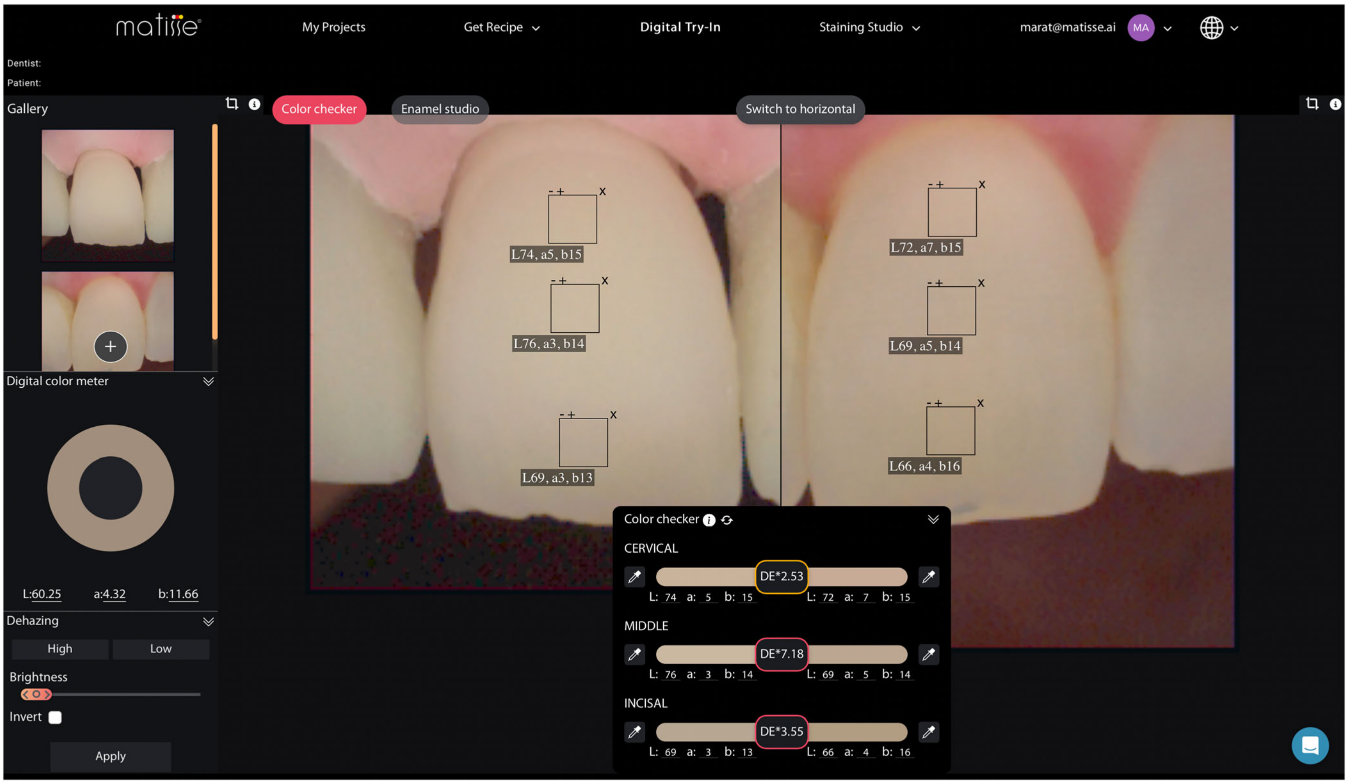

FIGURE 14 Comparing the restoration after the first bake to the target tooth using the Color checker protocol.

was generated. Additionally, for the dentin, a lower chroma was observed in the middle part, prompting the generation of a recipe using the same ceramic to compensate for it. The projected staining recipe considered the influence of the future enamel layer, resulting in a higher lightness compared with that of the natural tooth. Following the enamel bake and glazing of the tooth, the *Color checker* was conducted to assess the ΔE_{94} difference.

When working with ceramic materials, dental technicians must account for the material's relative translucency. Therefore, the Matisse software utilizes the full system of ceramic powders in a ceramic brand. This enables control over translucency, which is influenced by its thickness.[7–9] Also, it offers customized guidance on the ideal thickness of the material in various areas, whether for infrastructures for layering or monolithic restorations intended for staining. It is extremely important to give the correct information of thickness and available space in each area of the restoration. This aspect is of utmost significance, as material thickness can significantly differ between tooth and implant-supported restorations, thereby guaranteeing a natural esthetic and optimal fit of the final restoration. In cases where more than one tooth is being replicated, an individual recipe can be made for each tooth based on specific tooth thickness available space and stump shade.

Also, it is important to highlight that dental technicians retain the flexibility to choose their preferred framework material, even if it is not listed among the software's available options. This customization can be achieved through color adjustments of lightness and chroma during the initial stages of baking, utilizing the *Framework staining* feature as demonstrated in the presented case. This allows the use of bleach shades as the framework base to enhance lightness and provides greater control over the color reproduction process.

Although the method was originally devised for analog laboratory workflows, it seamlessly integrates into modern digital laboratory practices. Dental technicians can enhance the efficiency of the restoration design process through CAD/CAM technology by implementing the recommended material thickness guidelines of the software. Furthermore, during the *ColorModel* stage, the software suggests the production of a 3D model, featuring a color range from ivory to A3, along with a recipe for either Matisse flowable composite stains (Labmatisse BV, Wijchen, The Netherlands) or Optiglaze (GC, Tokyo, Japan) available through the *Staining Studio* option. This procedure facilitates the simulation of working within the patient's precise color environment, thus promoting comprehensive digital workflow integration. It signifies a notable departure from conventional methods reliant on visual estimation or arbitrary material selection.[1,2,11,14] Another noteworthy aspect was that the entire workflow was conducted remotely, with information exchanged through a cloud-based platform. This eliminated the need for a technician to directly observe the patient, and the restoration was delivered without requiring a ceramic try-in appointment.

Despite its innovative approach, the implementation of the software is not without challenges. One of them is the shift in mindset required from dental technicians, transitioning away from traditional techniques and shade guides that have dominated the industry for decades,[14] toward a scientific approach based on color coordinates.[23,24]

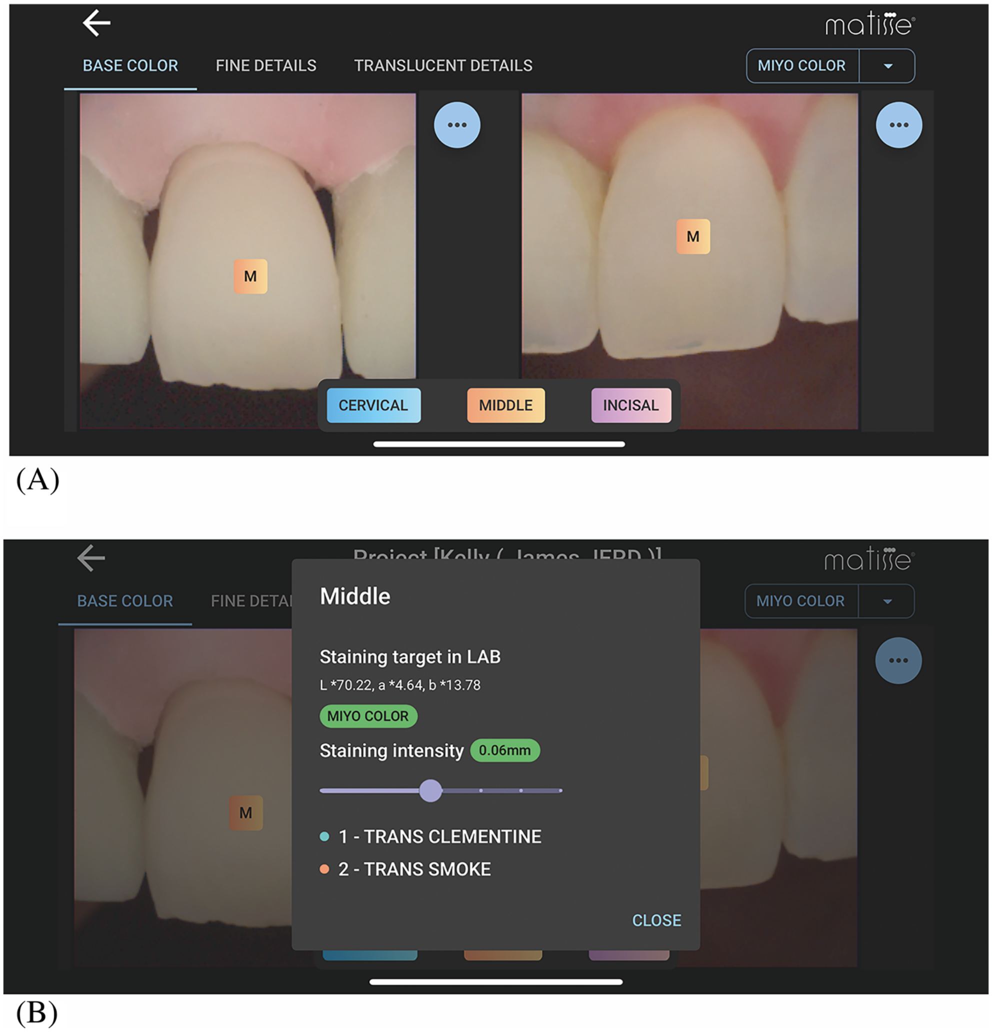

FIGURE 15 (A) Matisse iOS App Staining studio. (B) The staining recipe for middle and incisal areas.

FIGURE 16 A silicone portioner (Smile Line, Saint-Imier, Switzerland) is used to prepare the given ceramic paste recipes by Matisse iOS App.

While precision is one of its main features, this approach also introduces the potential for operator errors to significantly impact the outcome. Accurate utilization of the dental colorimeter and strict adherence to the specified workflow are crucial for achieving the desired outcomes.[30,32] Any deviation or incorrect application may result in suboptimal results, highlighting the necessity for comprehensive training and mastery of the technique. During shade-taking, it is imperative to position the colorimeter with the adjacent teeth supporting the overextended sides of the cone, ensuring the correct confocal distance of the sensor to the tooth. Patients should be instructed to position their tongue against the palate, to prevent red colors from appearing behind the tooth, and to breathe through their nose as much as possible, to minimize air moisture settling on the device sensor. If the lateral teeth are misaligned with the tooth being measured, a support should be used to stabilize the device and adjust the cone distance for proper positioning.

Concerning the application of digital instruments for tooth color assessment, the image acquisition protocol emerges as a critical consideration.[14,18] Variations in device type, light angulation-intensity, and settings can yield distinct recorded values, a concern described when employing digital photography techniques.[23–28] In the presented case report, a dental colorimeter was utilized for color measurement. This device, specifically designed for dentistry, exhibits a repeatability <0.3 ΔE_{94} units,[32] value below the human color perception threshold for detecting color differences on abrupt edges within

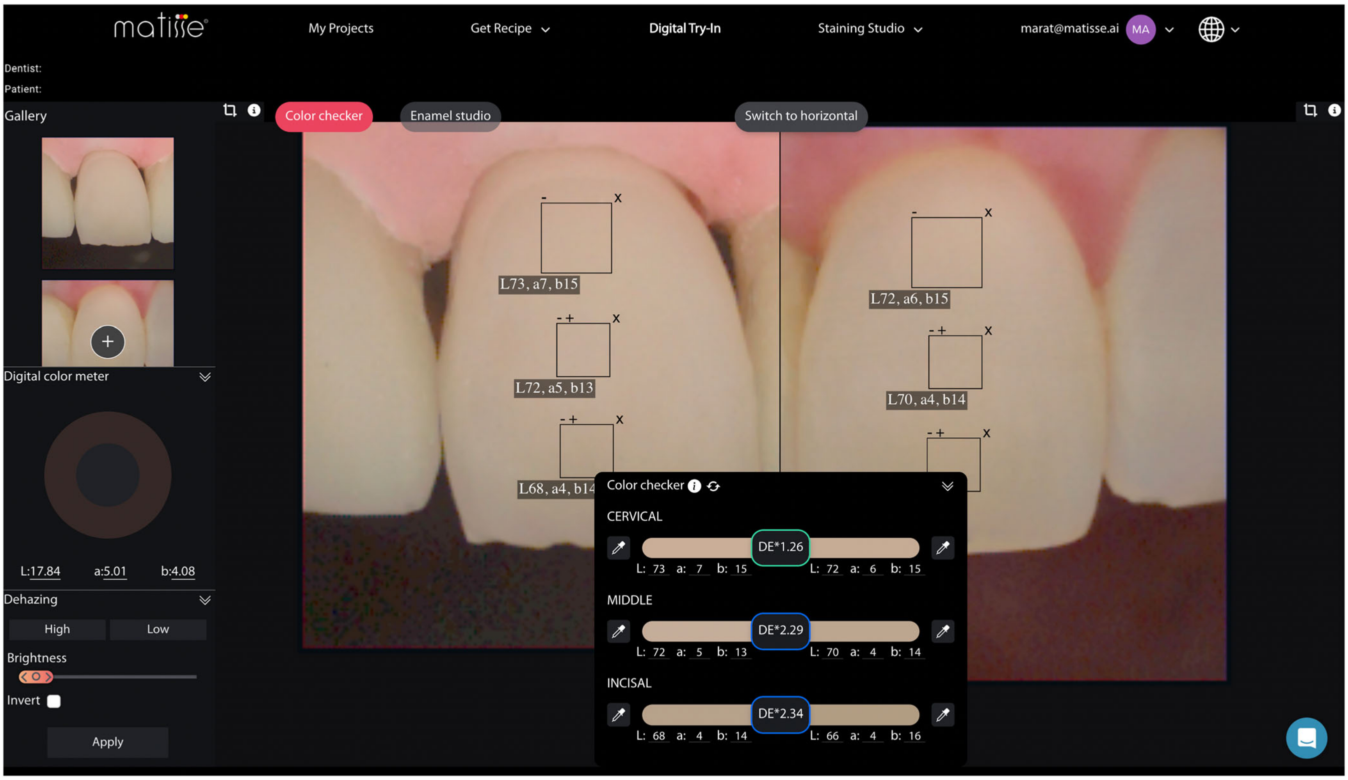

FIGURE 17 The Color checker protocol after baking, showing the color difference (ΔE_{94}) values between the restoration and the target tooth in the cervical, middle, and incisal parts.

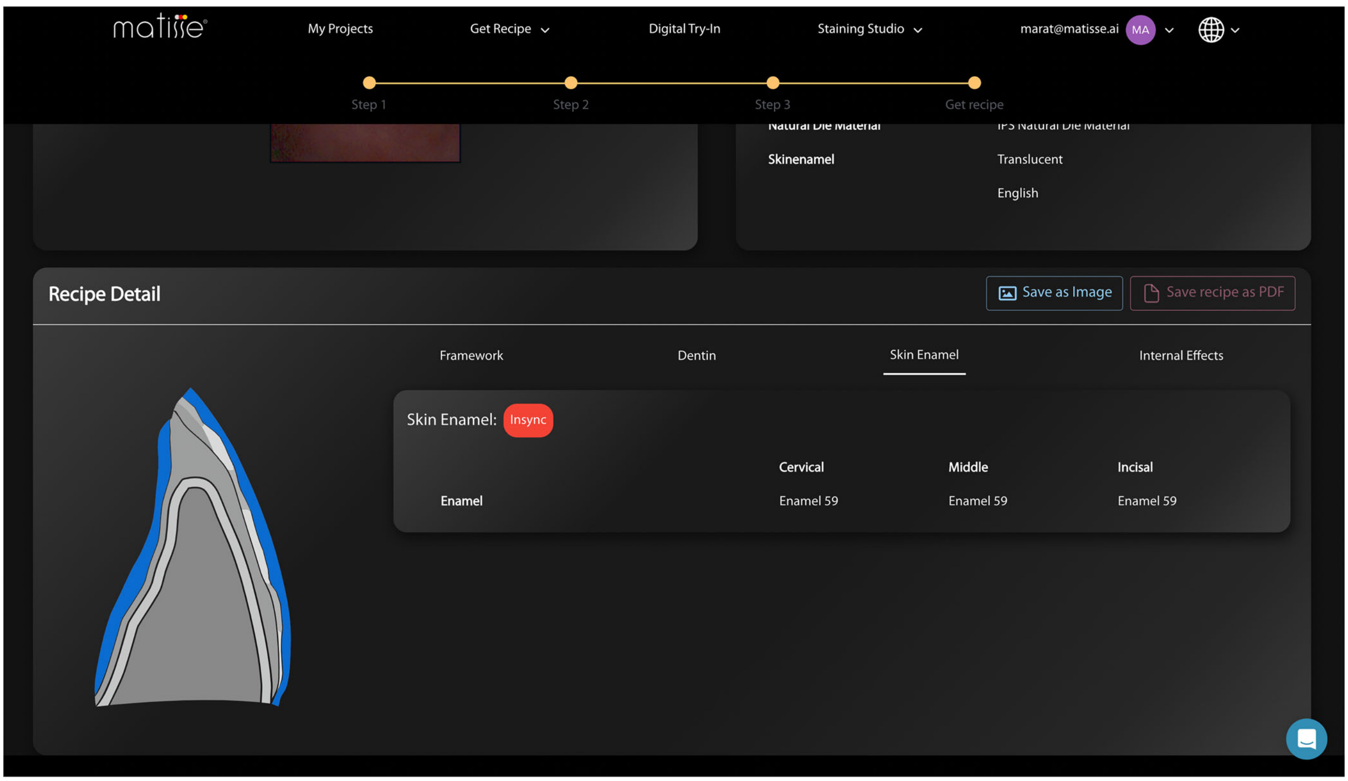

FIGURE 18 The suggested enamel recipe by Matisse to finalize the restoration.

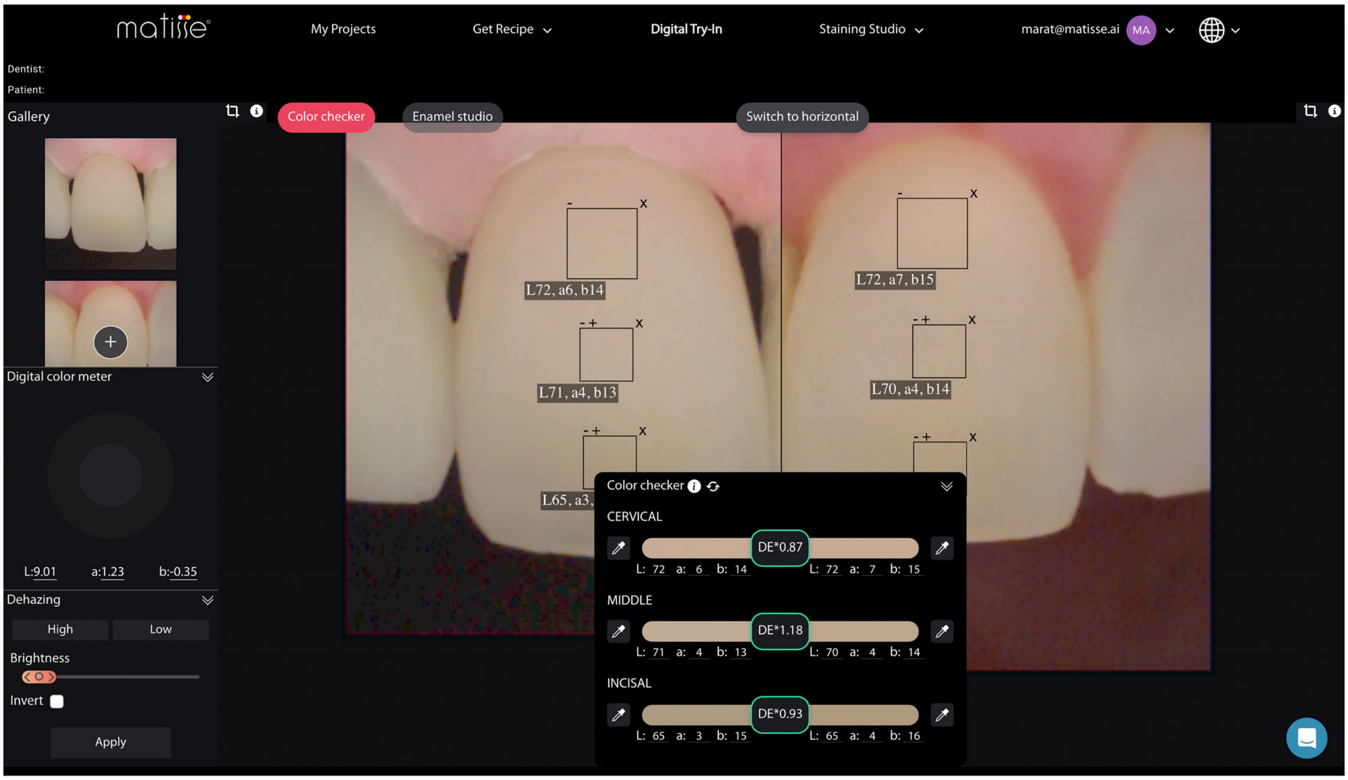

FIGURE 19 The final color check protocol, showing color difference (ΔE_{94}) values (cervical 0.87, middle 1.18, and incisal 0.93).

FIGURE 20 Final outcome of implant restoration on the Matisse ColorModel.

FIGURE 21 Final outcome of implant restoration on the gypsum model.

the dental color space.[21] This underscores the reliability of the color measurement provided by the equipment. Additionally, for a more comprehensive evaluation of the restoration, the technique can be complemented in the final stages with color-calibrated digital images.[25–27] This allows for verification of accurate characterization, texture, translucency, and scrutiny of the crown's morphology and finishing.[28,29]

The ultimate challenge in esthetic dentistry is achieving a restoration that closely matches the color of the target tooth, particularly for upper central incisors, recognized as one of the most challenging clinical scenarios.[23,24] In the case described, ΔE_{94} units of 0.87, 1.18, and 0.93 were recorded using the *Color checker* protocol for the cervical, middle, and incisal thirds, respectively. These values closely approach the threshold for detecting color differences of the ΔE_{94} color difference formula, set at 0.67 units.[21] It is noteworthy that this formula defines only one threshold for detecting color differences, unlike other color formulas that establish thresholds for perceptibility and

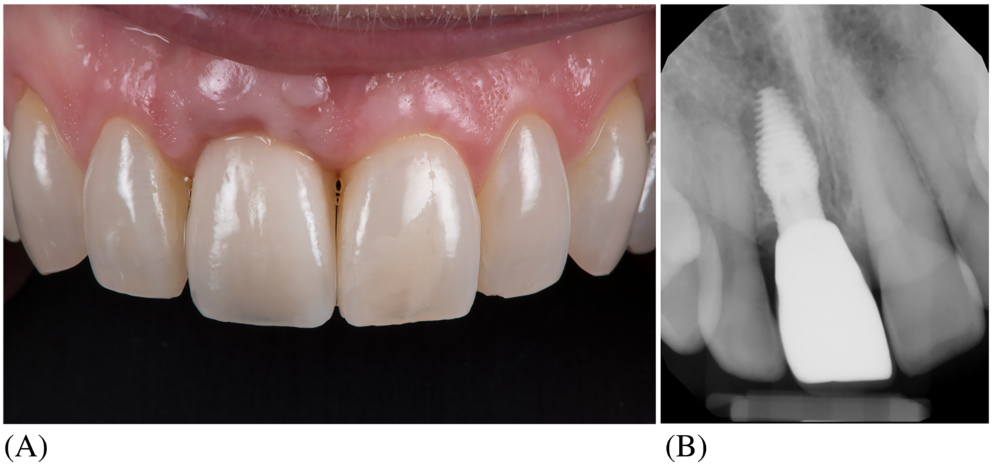

FIGURE 22 (A) Immediate outcome following implant restoration placement. (B) X-ray displaying the final condition of the case.

FIGURE 23 One-year follow-up after placement of implant restoration.

FIGURE 24 One-year follow-up after placement of implant restoration with the patient's smile.

acceptability,[22] allowing for a more comprehensive interpretation in terms of human vision.

The Matisse software marks a substantial advancement in esthetic dentistry.[30] By harnessing the precision of modern colorimetric tools and digital technologies, it provides a systematic and scientifically grounded approach to color reproduction. Additionally, it holds promise for significantly reducing the need for corrections and remakes, thereby enhancing the quality of dental restorations, and ultimately improving patient satisfaction. As the dental market is changing and is focusing on more minimal layering and staining techniques, the software on its option of *Staining studio* can adapt to the new reality of laboratory workflow. Nonetheless, its widespread adoption and success will likely depend on overcoming challenges related to training, adaptation, and the incorporation of additional visual verification steps. Continuous enhancements in user-friendliness, training protocols, and integration with existing dental laboratory workflows will be pivotal in realizing the full potential of this innovative approach.

4 | CONCLUSION

Within the limitations of this current case report, it was concluded that the systematic method employing the Matisse software achieved accurate color reproduction for a single central restoration supported by an implant. This result was achieved by the dental ceramist within the first attempt and without seeing the patient in the entire process.

ACKNOWLEDGMENTS

I want to express my gratitude to Dr. Brian Vence for his exceptional clinical work, and to James Choi for his exceptional lab work. I am also profoundly grateful to Dr. Nithin Govindarajan, for his vigilant supervision. Their dedication and thoughtful contributions have been absolutely pivotal to the success of this case report.

CONFLICT OF INTEREST STATEMENT

M.W. Awdaljan, as the founder and director of Labmatisse BV in The Netherlands, has financial interest in select products showcased in this case report.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Marat Wartanovic Awdaljan https://orcid.org/0009-0002-8718-4502
João Carlos Roque https://orcid.org/0000-0002-9012-073X
Luis Felipe Rondón https://orcid.org/0000-0001-7427-1565

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