WHITE PAPER

Carestream DENTAL

Shades of Intelligence

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Shades of Intelligence

We live in a world preoccupied with aesthetics. With the dawn of the selfie, the proliferation of social media and the multitude of outlets for self-promotion, the public is more concerned than ever before with the quality of their smile. The importance of the maxillary centrals, incisors and cuspids, or "Social 6," is at an all-time high, which dramatically impacts patient expectations for restorative outcomes when the need for dental work arises.

With so much emphasis on beauty, today's discerning dental professionals have their work cut out for them. Not only do they need to focus on restorative fit and function, but they must produce results that are also aesthetically pleasing, with tooth shapes and shades that match the adjoining teeth with minimal contrast. Finding the perfect shade match for a restoration is, therefore, more critical than ever before.

The selfie has created greater emphasis on the aesthetic quality of the smile

Finding the Perfect Match

As early as the 1930s, dentists have focused on the importance of finding the correct shade to provide more aesthetic restorations.[1] Even then, it was understood that radiant energy—or light reflecting off a surface—impacted color. However, with limited technology, the dentist was left to match the color visually.

With the invention of shade guides, dentists were provided with a series of tabs that could be placed on or near the tooth, allowing for visual selection of the shade. To this day, manual visual selection is the most frequently used method for shade matching.[2]

Manual, visual shade selection is the most commonly used method today

One of the biggest challenges of manual and visual color selection is that it is subjective, not only to the dental practitioner, but also to the patient. A slight aesthetic imperfection of the final restoration can lead to immense dissatisfaction for the patient and frustration for the dentist. If the patient requests a remake, the dentist typically absorbs the cost, which reduces or eliminates any profit margin associated with the restoration.

Additionally, several factors can impact manual visual shade matching, such as:[2-4]

- Artificial lighting, poor lighting, or lighting fluctuations
- Eye strain or retinal fatigue
- Color blindness, and/or the effects of both hereditary and acquired color vision loss
- Changes in color constancy, which renders a different color for the same object based on changing light sources and the angle of illumination
- Color limitations of shade guides, which lack the range of all values, hues and chroma present in the tooth
- Aged and discolored shade guides that have faded or darkened over time due to the chemicals used in the sterilization process
- Failure to capture the shade while the tooth is still hydrated
- Influence of surrounding or background colors

Because of limitations like these, approximately 50 percent of remakes for aesthetic restorations are the result of a failure to match shades accurately.[3]

Differences in Color Perception

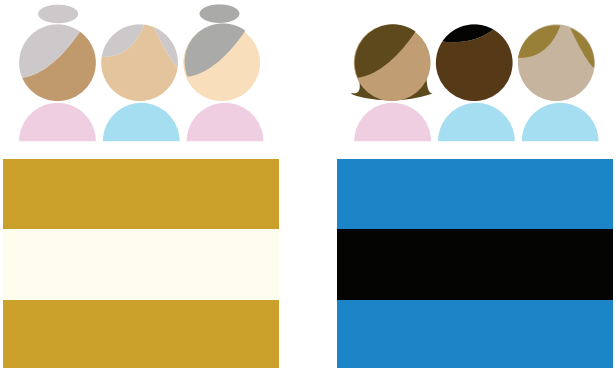
The perception of color is influenced by two things: illumination and the individual—and determining the role that either or both plays is a significant challenge.

In 2015, "The Dress" became a viral sensation after a Scottish woman, Caitlin McNeill, posted a photo of a dress to Facebook and realized that her friends could not agree on what color it was. Some of her friends believed it was blue and black while others argued that it was white and gold. Curious about what others thought, she later posted an image of the dress to her Tumblr account and asked those followers to confirm the color.[5-6] After going viral across multiple social media channels, and with much debate over the color, the dress manufacturer, Roman Originals, confirmed that the dress was blue and black.[7]

Left, dress photo shared on Facebook and Tumblr. Right, actual dress by Roman Originals.

Can we trust our eyes?

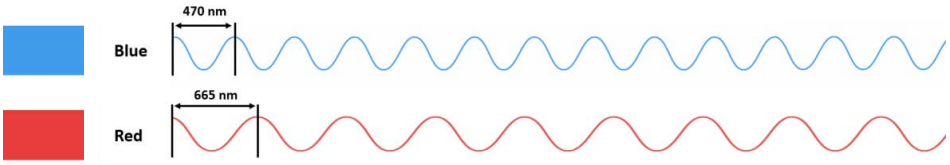
Neuroscientist Bevil Conway provided insight on the individual differences in color perception that were revealed by the viral post of the dress. After surveying 1401 people, 313 of whom had never seen the dress image before, the team found that people saw one of three color combinations: blue/black, white/gold and blue/brown.[8]



Conway concluded that color perception varies by the age and sex of the viewer. Women and older people were more likely to see the dress as white/gold, while younger people were more likely to see the dress as blue/black.

"The big open question is what causes these differences in the population," Conway said. "One framework for understanding why you get these variations is to consider how light is contaminated by outside illumination, such as a blue sky or incandescent light. Your visual system has to decide whether it gets rid of shorter, bluer wavelengths of light or the longer, redder wavelengths, and that decision may change how you see 'The Dress.'"[9]

Ultimately, the differences in color perception were likely due to an assumption that people made when they viewed the photo. Viewers may have ignored the shorter, bluer wavelengths when they assumed the dress was illuminated by daylight, and likely ignored the longer, redder wavelengths when they assumed the dress was illuminated by artificial light. [8]



Short blue wavelength compared to longer red wavelength

One thing was clear as the result of this viral sensation—color perception does, indeed, vary by individual and is influenced significantly by illumination.

Automated shade-matching techniques

To counteract the known limitations and inconsistencies of manual visual color matching, various instruments have been introduced to automate shade selection, such as colorimeters, spectrophotometers and digital imaging devices. But a known issue of these devices is the limitation caused by the small capture window. This results in an edge loss effect, which is a loss of reflectance feedback caused by the scattering of light beyond the surface of exposure.

Colorimeters

A colorimeter is a device that determines color by measuring the absorbance of specific wavelengths of light. However, this device is not fool proof; in fact, this method of testing often results in an error in color coordinates when measuring reflectance of translucent materials in situations, as the light scatters beyond the surface area that was exposed to the colorimetric instrument.[2]

Spectrophotometers

Unlike colorimeters, spectrophotometers utilize the visible light spectrum to measure the amount of light energy reflected from an object and is one of the most accurate methods of dental shade matching.[10] A limitation of spectrophotometers is the need to maintain a constant geometry during capture, which requires regular alignment.

A disadvantage of colorimeters and spectrophotometers is the lack of integration with the patient's chart, where crucial shade details are stored.

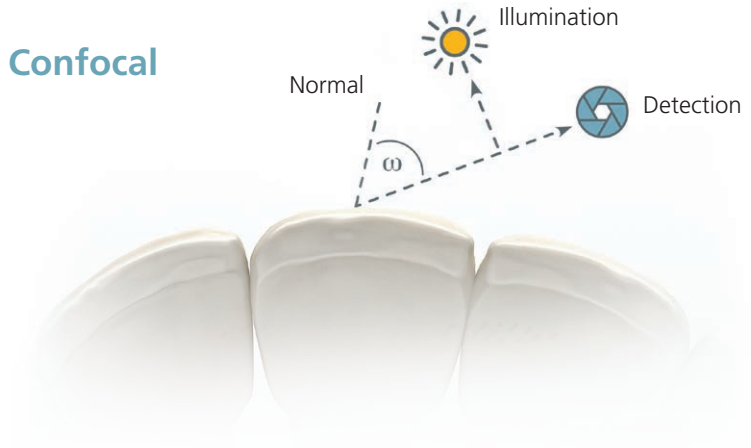
Digital cameras

For a more integrated approach, digital cameras have also been employed in the past decade to capture shade details; however, one disadvantage is that most capture images use the standard RGB, or red/green/blue color model, which has limitations. Additionally, the color of the image is significantly impacted by the light source, so there is still a subjective component when comparing the captured digital image to the patient's invitro situation.

Confocal intraoral scanners

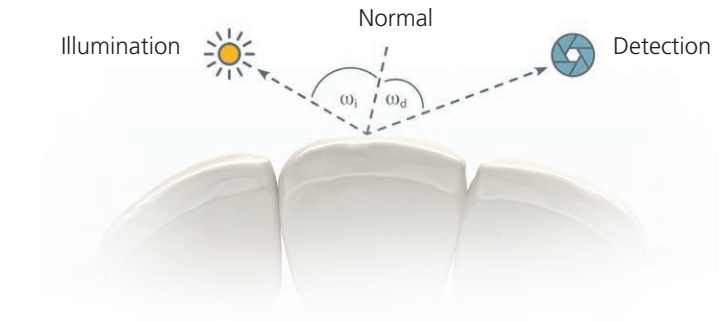
Similarly, some intraoral scanners also capture digital images of the teeth and rely on the same RGB values from the image capture to select an appropriate shade. Such devices can store the color value in the patient's chart and simplify the process of sending this information to the lab. Like the spectrophotometer, most intraoral scanners also select an image texture around a preferred geometry and texture, which renders most of the captured texture data ineligible for shade matching. Additionally, limiting the shade value to three colors provides limited information, which can also impact the accuracyof shade detection.

Many intraoral scanners utilize confocal systems to capture the shade measurement; however, they are limited to capturing the tooth color properties from only one angle. This is because the illumination and detection of the tooth surface occur at the same angle and along the same path. Confocal intraoral scanners, therefore, are unable to account for changes in the illumination.



Triangulation intraoral scanners

Because the texture and appearance of dentition changes with both the illumination direction and the detection direction, it is important to take both into account for correct shade matching. To build a more accurate representation of the tooth, collection of shade detail from multiple angles is essential to providing more accurate shade descriptions of the tooth material. Triangulation systems can measure the tooth color properties of both varying illumination and detection angles along different paths.



What is Triangulation?

To appreciate the benefits of triangulation, we must first understand what range imaging is and how it is used to build a 3D model. Range imaging systems build a 3D model by collecting coordinate data from a variety of different surfaces. Triangulation is a type of range imaging method that allows for the calculation of the 3D object of interest based on knowing the positions and angles of images from two different points of view.

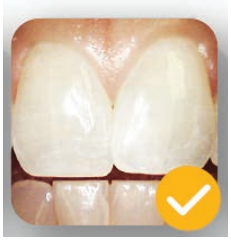
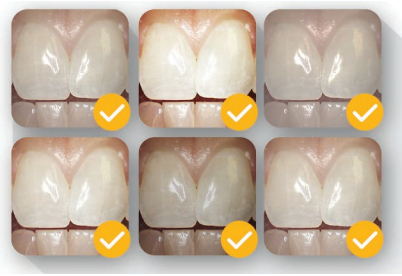
The human brain constantly makes use of triangulation via binocular vision, as our two eyes are located on the same plane. To better understand how triangulation system works using the power of your vision, look at the image of the airplane below and complete the exercise below:

1. Place one finger between you and the airplane image below
2. Focus on the airplane, and you should see two fingers
3. Now focus on your finger, and you should see two airplane images

Active Triangulation combined with Bidirectional Reflectance Distribution Function (BRDF)

Some intraoral scanners, like the CS 3700 by Carestream Dental, build a more detailed 2D angular distribution of the color, which includes a more accurate and complete characterization of the tooth color properties and leads to more accurate and reliable shade-matching results. Using an active triangulation method, the CS 3700 utilizes a pattern of structured light (lines or bars) to project onto the tooth surface as the illumination. The object distorts the pattern of light due to its surface shape, and the CS 3700 image processing and triangulation algorithms work in concert to utilize the altered light pattern to determine the shape and structure of the 3D object.

In addition to active triangulation, the CS 3700 also utilizes BRDF, or bidirectional reflectance distribution function, to collect shade values from 3D surfaces factoring variations in lighting conditions.[11] Unlike systems that capture the RGB value from a stored mesh, the CS 3700 measures the true material properties of the tooth without the influence of the scanner, resulting in more accurate color measurement. Thanks to triangulation, there is no strict orientation requirement, and the scanner can capture the tooth shade as the scanner orientation changes. An additional benefit of triangulation and BRDF is greater color dimension.[12]

Texture-Based Shade Matching Selects a single preferred geometry obtained from the scanned dataset	**BRDF[12]** Processes all data directly from the tooth surface, factoring in all angles and changes in lighting intensity and direction
	

Summary

Gone are the days where fit and function were the principal focus of any restoration. Today, the cosmetic aspects of restorative results are front and center in the minds of patients—and the quality of the color match is central to their overall satisfaction. Practitioners are challenged with creating restorations that must measure up on all these fronts, and the costs for remakes are high when patient expectations are not met.

Fortunately, technology has evolved to ease the process of matching the color of new restorations to adjoining teeth. Practitioners no longer must rely on their best guess or limited technology for the selection of the appropriate color. Instead, they can take advantage of new technology, like triangulation in combination with BRDF, to deliver more ideal shade-matching results, which in turn leads to higher patient satisfaction.

To learn more about the CS 3700, or any of Carestream Dental's innovative solutions, visit **carestreamdental.com**.

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