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Determining the colour of a tooth

It is a simple question to ask “How do I determining the colour of a tooth?” but it is not so simple to answer. First we must understand a few things about how the light around us affects our perception of colour before we can then describe the procedure to enable you to best guess a tooth’s colour.

Let us consider the following: If we are outside, in normal daylight, a person’s smile appears quite white. Yet when we examine the individual teeth more closely we can see variations in colour: mixtures and shades of reds, yellows, greys, and whites.

Inside a room however the same teeth can take on a different colour. This depends upon what types of light sources are influencing the subject’s smile (natural lighting and/or artificial lights).

Plus, when we get really close and observe the same teeth under a magnifying glass, the strength of colours that we saw before also seem to depend upon what tooth we look at - the front teeth or those further back in the mouth.

Why? What factors are affecting these colours? Why do they change?

Several physical factors play a role; let us take a look at them…
Light and Colour

What is colour?

First we really need to ask: *What is light?*

Image from www.cambridgeincolour.com

A very brief description would be:

It is electro-magnetic radiation comprised of photons. An electromagnetic field fluctuates around photons as they travel through space. These photons are invisible and can not be detected unless there is a material to exert a force against. The resultant exertion causes fluctuations which the human eye can detect and it is these changing rates of fluctuation that we interpret as colour.

The "Electro-Magnetic Spectrum" is measured in Hertz (From X-rays at 1,000,000 million mega-Hertz to Radio at 10 mega-Hertz). The visible portion of this spectrum, white light is but a small part.

Different wavelengths of light combine to form the millions of hues detectable by a person with normal colour vision.

Image from www.nsprinters.com
**Is white really white?**

The “white light” we see is actually equal measures of Red, Green and Blue (RGB) primary colours which the human brain interprets, using your eye cones, as white (We actually interpret white as colourless!!)

![Image from www.cambridgeincolour.com](image)

The fact is even small variations in the mix of RGB are still interpreted by us as “white”. Photographic instruments however are more sensitive and do not approximate. They record these minor differences, showing many whites with colour casts. That is why cameras and video-cams have “white balance” correction so you are able to make colour adjustments.

**Colour Temperature**

*How do I tell the difference between white and... white?*

In order to classify each type of white we use a colour temperature scale. The unit of measurement is “degrees Kelvin” or ºK. Funnily enough, higher colour temperatures are composed of a majority of cooler looking colours. Lower temperatures on the scale represent a majority of warmer looking colours. (Think of a welder’s torch the blue white flame is hottest!)

![Image from www.cambridgeincolour.com](image)

Note in the diagram above that white is a combination of colours where the balance is biased in certain areas of the spectrum.
Below are some examples of light sources and their approx. colour temperatures (taken from the Wikipedia article on colour temperature):

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Color Temperature (Kelvins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear blue sky</td>
<td>12,000 to 27,000</td>
</tr>
<tr>
<td>Overcast sky</td>
<td>7,000</td>
</tr>
<tr>
<td>Daylight fluorescent lamp</td>
<td>5,500</td>
</tr>
<tr>
<td>Blue flash lamp</td>
<td>6,000</td>
</tr>
<tr>
<td>White flame carbon arc</td>
<td>5,600</td>
</tr>
<tr>
<td>Sunlight</td>
<td>4,300 to 6,500</td>
</tr>
<tr>
<td>Clear flash lamp</td>
<td>3,600</td>
</tr>
<tr>
<td>Gas filled tungsten</td>
<td>3,200 to 2,885</td>
</tr>
<tr>
<td>Tungsten lamp</td>
<td>2,400 to 2,700</td>
</tr>
</tbody>
</table>

5500 K = Average daylight, and electronic flash = D55. A designation of D55 stands for "Daylight 5500K" and is the most common standard for professional light booths for photography, graphic arts, and other purposes. One thing to note: Daylight over the equator would be different to daylight over Northern Europe therefore sometimes you will see D65 as the average daylight temperature.

Fluorescent light bulbs now come in many variations e.g. Fluorescent warm White, cool white and “daylight. They require special consideration to identify their exact colour temperature and we use the CCT method to describe their qualities.

CCT – Correlated Colour Temperature (see glossary).

Something here for you to find out:

*What is the colour temperature of your surgery operating lamp?*
Who sets the standards on colour?
The CIE “Commission Internationale d’Eclairage” produced the original “Colour Standard Table” describing “Colour Space” in 1931.

Since then further standards have been developed. The one of particular interest to those in the dental profession is the standard for “Non-self-luminous objects such as textiles, paints and plastics” for the application of colour in industry created in 1976 (also known as CIE L*a*b).

VITA-Zahnfabrik based their VITA shade guide system on CIE L*a*b or more precisely a cylindrical representation of this standard called CIE L*c*h.
CIE L*a*b standard defines three axes of colour based on the mathematical 3D “Cartesian coordinate system” of x, y and z axes. It is likened to a sign post at a cross roads. The three axes represent the following:

\( a = \) Red (+) to Green (-)
\( b = \) Yellow (+) to Blue (-)
\( L = \) black=0%, grey=50%, and white=100%

The CIE L*c*h representation uses cylindrical coordinates to define the following:

\( h = \) Hue (Colour)
\( c = \) Chroma (Saturation)
\( L = \) Value (Lightness-Darkness)

VITA states that all natural tooth colouring lies within the light area of the red to yellow quadrant (indicated by the banana).
**Light transmission**

When light strikes a material it can behave in several different ways; let us examine a few:

**Direct transmission:**
This is where light passes through a transparent material. It has to strike perpendicular to the surface otherwise refraction occurs and the light is bent off at an angle.
What is worth bearing in mind here is that light can be passed through one material and be absorbed by another directly behind it and you will see this background colour even if it is slightly refracted by the foreground material.

**Reflection**
Where light strikes a material and bounces back or off at an angle. One of the easier concepts to grasp as we use mirrors every day! There are different types of reflection:

**Direct reflection:** a bright light source can cause glare on the surface of the material. Changing the angle of reflection (or the direction of the light source) helps counteract this effect.

**Diffuse reflection:** where the amount of light reflection is the same in all directions. Think of overcast daylight. The Sun's rays are dispersed through clouds giving a bright but soft ambient light. We can put this type of reflection to good use as it produces images with soft shadows and even illumination providing the light source is large and some distance from the surface of the material.

**Absorption**
Where light strikes a material and is never seen again. Most materials absorb light (or should I say part of it because the rest is reflected back) defining the colour as we see it.

**Diffusion**
Where light strikes a material and scatters in a random pattern. Translucent materials or opalescent materials produce this type of frosted, cloudy, or sparkly effect. [*Also see diffuse reflection.*]
**How do materials in the mouth affect light or colour?**

**Natural teeth**

In brief; if we were to look at a cross section of a tooth we will see the different layers of material that affect on the colour of the tooth.

*So what do we see?*

We see a thin enamel layer covering the dentine.

*How do these affect the colour?*

![Diagram of tooth showing enamel and dentine layers with arrows indicating absorption, reflection, and transmission.]

The enamel layer can be likened to glass. It is made of tiny granules which, like glass, can be transparent and/or translucent (even opalescent). It allows light to pass through it but maybe not all in a straight line!

The dentine is made of tiny tubules similar in construction to a honeycomb. Each absorbs, reflects, and/or refracts the light that strikes them giving the dentine its own distinct colour.
Restorations

All forms of restorations, from simple fillings to complex crown and bridge work, will influence tooth colour in the mouth. Materials such as porcelain, composite, and metal alloys all absorb and reflect light in different ways which must be taken into account if you are trying to match a colour of an adjacent tooth.

Why?

Remember light can pass through enamel surfaces and reflect off dentine too. This same light can then be reflected back from other teeth or other surfaces influencing your colour perception.
How do manufacturers of dental materials help us choose the correct materials to match the colours we have picked?

All manufacturers have their own coloured shade guides (sometimes called tabs). Each guide is marked with a shade code. Using this code, a cross reference can be made using manufacturers’ material charts (or chromatic charts) in-order to obtain the corresponding coloured ceramic or composite material.

Probably the most well known shade guides are produced by VITA-zahnfabrik. They created the first system back in 1929. Their “Classic V” system has been the defacto standard for many years.
**The traditional shade taking procedure**

**What is Shade Taking?**

The traditional technique utilizes industry standard ceramic samples, or "shade guides", to record the colour of the patient's natural teeth - The value, chroma, hue, and translucency. This colour communication record (photograph and/or printed form) along with other details such as shape, can then be analysed by the lab technician during the restorative process so that the final restoration will be, as near to as possible, a faithful mimic of adjoining teeth in patient's mouth.

**What do I need?**

- A patient!
- Somewhere to sit that is well lit with daylight (natural or artificial).
- A full set of a manufacturers shade guides. These are the small mounted coloured samples which are marked with identifiable colour codes. They are available from any manufacturer although **VITA** shade guides are widely used and recognized throughout the dental profession.
- A colour communication form or laboratory form to record your results.
- A light source. It is recommended that shade taking be performed using daylight rated lamps with a high **CRI** value. Several manufacturers make specialist “daylight” emitting appliances including: Solux, Osram Lumilux, Waldmann and Optident.
- Magnified inspection glass to aid examination and to prevent your eyes from tiring (may be illuminated like the Waldmann Hand Held or Optident Trueshade).
- A camera (optional). Photographic images help convey the colour, shade, and shape information in a way that words alone can not provide. For this reason it is highly recommended that camera should be part of your shade taking kit.
So which camera should I buy?

You do not have to have a professional rated camera to take good quality images. And there is no one perfect camera for this job. But you should consider the following if you are thinking of purchasing a camera for the purpose of shade taking:

- It should have a lens (typically around 100mm) with a macro focus setting which will allow you to stand close or a short distance away from your subject.
- If you wish to send images via email they need to be digital. The images do not necessarily need to be larger than 640x480 pixels in size therefore a 3Mbit Camera would be perfectly suitable.
- It should have a metering system able to cope with the special lighting conditions that are required (or you should be able to manually adjust the white balance).
- You should be able to turn off in-line flash units to protect the patient’s eye sight and reduce direct glare from the reflective elements in the mouth.
- You do require good illumination therefore you will require either a dedicated directional light source or an off-set flash unit (i.e. not in-line with the camera's lens). Options for SLR camera types include: Ring mounts, adjustable flash guns, flash brackets or remote mountings (tripods). Some compacts have similar options but these may be limited.
- A grey card (colour reference card) to set the white balance of your camera.

One last thing to think about is storage – How will you store your photographs digital or film. Using a digital format requires that you save images to disk or other digital media (like memory cards) and send emails therefore some additional hardware (a computer, CD disks, memory cards, image backup etc.) will be required.
Above is an example of an image taken under fluorescent light. Notice the blue cast inherited from that light prior to changing the cameras white balance.

See OSRAM leaflet on fluorescent light “Light can be white, white, white or white”.
What do I do?
The patient’s teeth should be clean before determining the shade. The teeth should be still moist for shade determination. The patients clothing should be covered with a grey or blue bib. The patient should not be wearing any lip stick.

- Describe the shade taking process to the patient to put them at ease.
- Identify the chroma (saturation) of the dentine in both upper canines.
- Determine the amount of enamel that is covering the dentine of these canines (i.e. significant, modest, or insignificant). Using this determine the value (lightness or darkness) of the canines.
- Now look for the hue (colour) to obtain the selection of the shade group (or family).
- Depending upon the tooth being restored, look for the overall colour harmony of the complete dentition (e.g. anterior teeth generally have less chroma).
- Now take a photographic record of the patient’s dentition with your shade reference tab(s) along side. Write your shade taking results on the laboratory works order sheet along with any special requirements (i.e. Inner structures of the tooth (mamelons), texture and shine of the tooth surface (texture: smooth, shiny: matt)

Send these details to the laboratory via post, email, or hand and include the job reference and patient’s name, any photographic images, and all shade tab references.

Then follow up with any verbal instructions by telephone.
What can affect my results?

As a dentist
- A direct light source. Strong sources of light can cause direct reflection and glare which will cause your camera’s meter to over compensate and ruin your photograph.
- Variations in light sources: A coloured light source (see colour temperature) can influence how you perceive colours. This can be exacerbated by having multiple light sources of different types e.g. Fluorescent, halogen and daylight.
- Eye correction (glasses) and tired eyes. Remember to have your eyes checked regularly and wear glasses if required.
- Life style (Late nights, drinking etc.).
- Bright clothing (reflecting colour).
- Incorrect camera settings will convey poor information. Attention is particularly required for Colour balance (white balance), focus, subject placement, exposure settings, and ISO settings.
- Poor quality camera and/or optics (lenses). Note: this does not mean cheap, just poor quality. Do your research, and read reviews carefully.
- Poor quality reproduction of image data (e.g. printing, image compression, PC monitor calibration etc.).

As a patient
- Smoking.
- Tooth bleaching.
- Saliva (lack of moisture in the mouth).
- Tooth staining (e.g. wine or tea).
- Dying tooth tissue.
- Lip-stick (colour reflection).
- Bright clothing (colour reflection).

Are there other ways to identify the shade of a tooth?

Innovations in shade determination are taking the form of micro-processor controlled digital imaging systems such as the DCM-ikam, Vita’s Easyshade, and X-Rite. As technology improves many more are coming on the market.

Image from www.vita.com
References

Internet
CIE www.cie.co.at
ICC www.color.org
WIKI www.en.wikipedia.org/wiki/Color_space
VITA www.vita-zahnfabrik.com

SOLUX www.solux.net
OSRAM www.osram.com (*Extensive information under section: Tools and Services > Downloads > General Lighting)
THE COLOUR MUSEUM www.colorsystem.com

Books
Light Science & Magic by Fil Hunter and Paul Fuqua.
Real World Color Management by Bruce Fraser ISBN: 978-0321267221
Analysis by Gérald Ubassy: www.ubassy.com

Glossary
Correlated Colour Temperature (CCT) - Refers to the apparent colour of the light source:
  o 2800K-3200K considered "warm"
  o 4100K-4900K considered "white"
  o 5000+ "cool.
Comes from heating a blackbody (think of a piece of coal) up to a certain temperature, as the coal gets hotter and hotter it changes from orange (i.e. 2300K) to yellow (3000K) to white (4700K) to blue (5000K)

Colour Rendering Index (CRI or Ra) - Measure of how well a light source replicates a given lighting condition. 100 being perfect, 90 fair, 80 poor.

Interpolated - The mixture of two or more shades of porcelain to achieve an intermediate shade. For example, 3M2 can be mixed with 3M3 to achieve the shade 3M2.5