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Tooth color and whitening – digital technologies

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ABSTRACT

Objectives: To review the key concepts of color in the dental domain with specific reference to the use of digital technology to measure color and color appearance.
Materials and methods: The literature on color assessment in dentistry is considered and methods for assessing whiteness, yellowness and color appearance are collated and described.
Results and conclusion: A variety of methods for assessing color have been shown to exist and be viable including digital imaging. Equations to predict whiteness are identified; there is evidence that they are effective but further evaluation may be needed.

1. Introduction

Tooth color is important to both dental professionals and consumers [1]. Professionals may wish to select the correct shade for a dental restoration or to measure the efficacy of tooth-whitening systems whereas consumers seek improved tooth color to enhance their confidence and self-esteem. Although visual assessment of tooth color is widely used, digital technologies are increasingly being preferred. This paper reviews the key concepts of color (including whiteness and yellowness) in the dental domain and then describes the use of digital technology to measure color and appearance.

2. Color, whiteness and yellowness in dentistry

It is important to understand what is meant by the term *color*. Fig. 1 shows two teeth that are presented on two differently colored backgrounds. Physically the two teeth are identical but most observers would see them as being different in color. It is helpful to distinguish between physical color and perceptual color. According to this distinction, the two teeth have the same physical color but different perceptual color. However, it is the perceptual color that is almost always of interest to consumers.

The physical signal that is the source of color perception is the spectral distribution of light that reaches the eye when a tooth is illuminated. This spectral distribution is a product of the tooth's spectral reflectance factors and the spectral power distribution of the light source. However, the third component that needs to be considered is the observer. The perceptual dimensions of color are lightness, chroma and hue [2,3]. Fig. 2 demonstrates these three perceptual attributes using digitally manipulated teeth as examples.

Lightness is the attribute of teeth whereby they appear to reflect more or less light relative to a similarly illuminated white sample. Chroma is the attribute by which teeth appear to be more colorful relative to the brightness of similarly illuminated white sample. Hue is the attribute by which teeth look redder, yellower or bluer, for example. Perceptual color is influenced by a number of factors including the background against which the samples are viewed and a number of background effects such as contrast [4], assimilation [5] and crispening [6] have been documented.

The terms whiteness and yellowness have specific meanings and changes in whiteness and yellowness are usually associated with changes in more than one of the perceptual color attributes (lightness, chroma and hue) at the same time. In dentistry an increase in whiteness is traditionally attributed to teeth that increase in lightness and decrease in chroma. A decrease in whiteness naturally occurs due to changes in absorption and scattering of the dentine and enamel of the tooth (intrinsic staining) or when materials attach to the tooth surface (extrinsic staining) [7]. Extrinsic staining can be removed by brushing and use of toothpaste [8,9] whereas intrinsic staining can be reduced by bleaching. Yellowness is another perceptual term that is sometimes used in dentistry. In general yellowness will increase with staining (or aging) and will be associated with an increase in chroma and a decrease in lightness; it is also likely to be reduced by bleaching. It is possible that yellowness and whiteness are antonyms in practice; however, research is needed to explore this more fully. Note that the terms whiteness and yellowness are perceptual terms and quite distinct from the terms whitening and yellowing which refer to physical processes (such as bleaching and ageing). Note that a change in a single color

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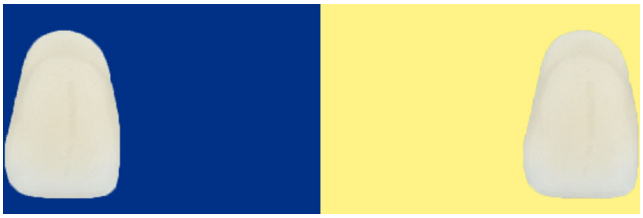

Fig. 1. The two teeth are physically identical but the one on the left looks lighter and yellower than the one on the right because of the contrast effect with the background.

attribute (as shown in each of the rows of Fig. 2) with no change in the other attributes is very unlikely to happen as the result of a real physical process such bleaching, staining or ageing. Fig. 3 shows the sorts of perceptual changes that typically results from actual physical processes such as bleaching or the deposition of a blue colorant on the surface of a tooth.

In dentistry there are several reasons why it is useful to assess tooth color [1]. Tooth color is assessed in order to enable a prosthetic (crown) to be produced that will be aesthetically pleasing to the patient [10]. Tooth color (particularly whiteness) is also assessed in order to quantify the efficacy of tooth-whitening systems [9]. Measurement of tooth color is used to assess clinical outcomes in a range of dental procedures including avulsion and replantation [11]. A number of tooth shade guides are available and are routinely used to visually assess tooth color. Although visual assessment using shade guides is very useful there are some limitations [12–14]. Firstly, the visual assessment made by one operative may differ from that made by a different operative (the subjective problem). Secondly, the visual assessment may be influenced (see Fig. 1) by the lighting or by the surround against which the tooth is viewed (the environment problem). Thirdly, the shade guide itself may not be optimal for the task in that the samples may not be uniformly spaced (the reference problem). For these reasons, methods to instrumentally assess tooth color are increasingly being used [15] and these are described in the next section.

Traditionally shade guides have been used to assess tooth color. The Vitapan Classical shade guide, consisting of 16 shade guide tabs, is routinely used to assess tooth color. When arranged from lightest to darkest, this shade guide can be used for visual evaluation of tooth whitening [16]. The Vita Toothguide 3D-Master consists of 29 tabs that are ordered around the parameters of lightness, chroma and hue and has a broader color range than the Vitapan Classical shade guide [17]; however, it is less widely used for assessing tooth whitening because of the three-dimensional non-linear arrangement of the tabs [16]. The Vita Bleachedguide 3D-Master, which has 15 tabs (that consist of the odd numbers, 1, 3, 5, etc., in a 29-point scale) ordered in terms of whiteness, has been shown to be effective for the visual evaluation of changes in tooth whiteness [16].

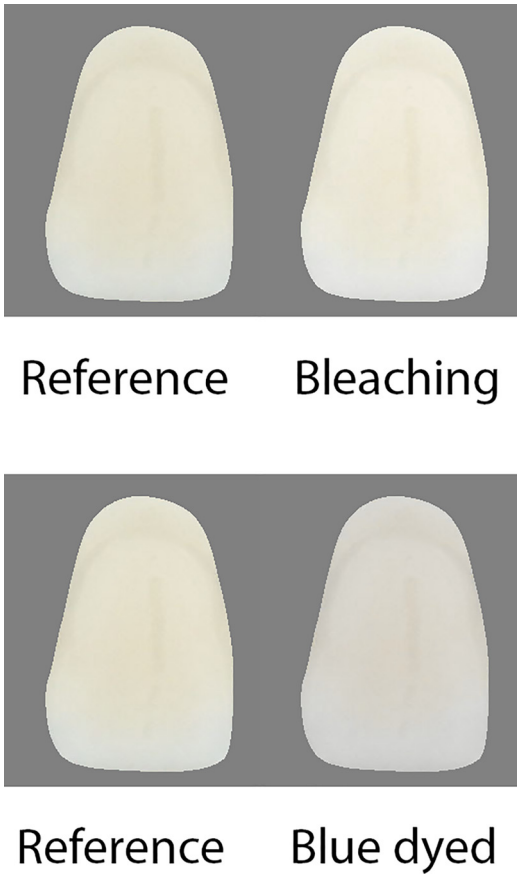

Fig. 3. The top row shows the typical effect of bleaching where L^* is increased and a^* and b^* are decreased. The bottom row shows the typical effect of the deposition of a blue colorant where L^* is decreased and b^* is decreased. Both processes result in a reduction in perceptual yellowness and an increase in perceptual whiteness. In order to address the question of which of the right-most teeth is whiter it is necessary to develop whiteness.

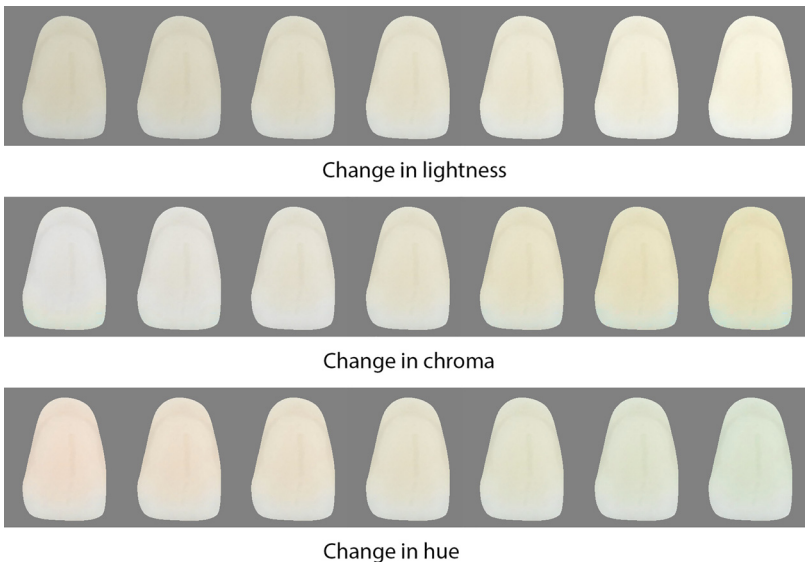

Fig. 2. Variations in lightness (top row), chroma (middle row) and hue (bottom row). The middle tooth is all three rows is the same and teeth to the right and left show increasing and decreasing amounts of the attributes respectively. Note that a change in a single color attribute (as shown in each of the rows) with no change in the other attributes is very unlikely to happen as the result of a real physical process such bleaching, staining or ageing.