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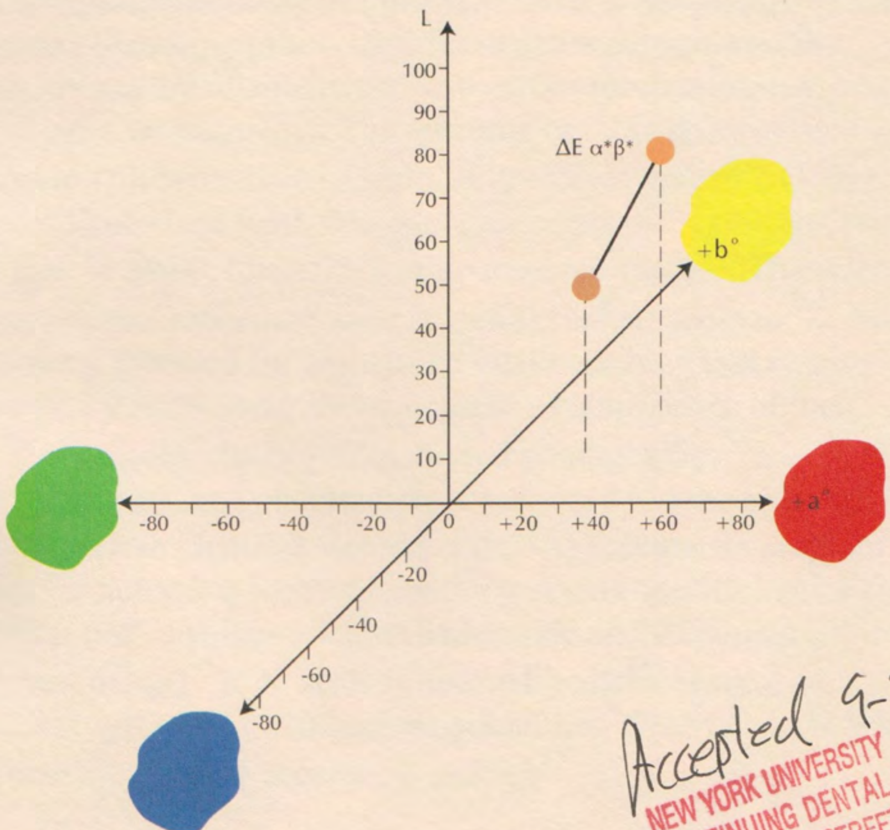

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Introduction. Vital tooth bleaching through the use of peroxide-based products has increased dramatically in recent years. However, few scientific research efforts had been made until 1989, when Haywood and Heymann published their paper that first introduced at-home tooth whitening, using carbamide peroxide [1]. The tray based vital tooth bleaching of sound yet discolored teeth substituted the porcelain laminate veneers, composites bonding or porcelain fused to metal crowns[2]. In dental market bleaching products differ in chemical composition, regiments, frequency of application and carrier mechanism (eg, trays, strips, and paint on formulas). The outcome of these products and procedures are the whitening of teeth[3]**.** Carbamide peroxide (10%) has been shown to produce tooth whitening and reports suggest that some changes may be stable for periods of up to seven years[4,5]. The safety and the efficacy of this procedure were of initial clinical concern [6,7]. Although, there are many products for nightguard vital bleaching that employ 10% CP approved by ADA there are no objective comparisons of their efficacy[8]. At present, shade guides, digital photography, spectrophotometers, and photometers are all used to measure tooth color [9-13]. The American Dental Association (ADA) acceptance program guidelines for home-use tooth-whitening products specifies color change standards for both a value-ordered shade guide and electronic color measurement using $L^* a^* b^*$ scale of four ΔE units[14]. Several color measurement systems fit within these guidelines. Evidence as to which, if any, of these systems are accurate is lacking[15]

MATERIAL and METHODS

Tooth Color Shade Guides.

In clinical dentistry, the shade guides are the gold standard for tooth color assessment, though it is accepted as a difficult task to capture preoperatively the translucencies, milky opacities and islands of color and to reproduce these features postoperatively using the shade guides.

However, perceptional evaluation of tooth shade using shade guides is not sufficiently precise and is highly subjective. Research has demonstrated that shade guides do not represent well the wide variety of tooth colors present in the population[16-19]. In addition, tab color varies noticeably from shade guide to shade guide from the same manufacturer[20]

The efficacy of bleaching has been examined using dental shade guides and gray scale. In investigating tooth whitening procedures more recent studies support value as the critical element of shade matching because it is consistent with the physiology of the human eye [18,21-24]

The current used shade guides in tooth bleaching research are:

The shade guides Trubyte® Bioform (Dentsply Int York PA, USA) and Vita Classical (Lumin® Vacuum Shade Guide, Vita Zahnfabrik, H. Rauter GmbH & Co. KG, Bad Sackingen, Germany) that can be arranged by brightness using information published by the manufacturer (Fig 1).

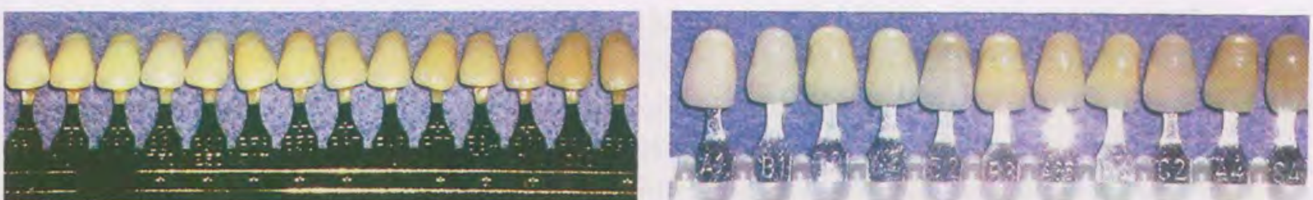

Fig 1. The Trubyte® Bioform and the Vita Classical arranged by brightness

Data published by researchers,[25] indicate that although the general trend is an increase in brightness from right to left, changes between adjacent pairs of tabs are irregular and some adjacent pairs exhibit reverse sequence of brightness. Another problem associated with brightness tab arrangements are the irregular intervals of ΔL^*. In these shade guides because tab arrangement are not uniform, comparing two subjects whose teeth changed the same number of tabs brightness is misleading for both of these two shade guides.

The most commonly used shade guide in clinical tooth-whitening research is the Vitapan Classical (Fig 1)(Vita Zahnfabrik, H. Rauter GmbH & Co. KG, Bad Sackingen, Germany) which consists of 16 shades and maybe arranged by value from the lightest (B1) to darkest (C4) as per manufacturer's instruction. However, this value-based ranking is no parallel to the L^* measurements, which represent the value in CIELAB color space, determined using the Minolta Chroma Meter CR-321. The measured shade difference in Vitapan Classical ΔE^*_{ab} can vary from 1.97 (C2 vs D4) to 4.88 (D2 vs A2); for two shade differences the variation of ΔE^*_{ab} ranges from 0.92 (B2 vs. A2) to 6.65 (A1 vs D2).Clearly, the numeric Vitapan Classical shade changes are not parallel to the measured ΔE^*_{ab} values[26,27].

It is of interest that, compared with the ranking by the L^* values personal color perception matches better with the value-based ranking of Vitapan Classical. The arrangement of the randomized 16 Vita shade tabs of 402 panelists on the basis of their perception of "whiteness" had 8 shades matching with the Vita value based ranking, including the "whitest" (B1) and the darkest (C4) extremes, the greatest deviation as in the four middle shades (C2, D4, A3, D3)(Table 3). So the value based ranking of 16 Vitapan Classical shades is known to be non linear in terms of "whiteness" of the tabs; it thus does not represent a true incremental increase in whiteness or darkness of the tooth color. Nevertheless, the results obtained from human panelists appear more clinically relevant because the major outcome of tooth-whitening treatment is the reduction of tooth shade (ie, the increasing whiteness) as perceived by the human eye. The inconsistencies in results between the shade guide, a visual instrument and the Minolta Chroma Meter, an electronic instrument is not unexpected. The complexity of the visual system precludes complete dependence on electronic shade matching in the near future. Until this equipment can produce a result that rivals the abilities of the eye and visual cortex to interpret light, learning to accurately shade match with eyes will remain an important task for discriminating dentists and patients[26,28]

The Vitapan® 3D Shade Guide (Vita Zahnfabrik) represents a different approach to shade guide fabrication [29]. The system consists of five groups of tabs of the same brightness though different chroma and hue.

Fig 2. The new by value arranged Vitapan® 3D Shade Guide

The change in brightness is consistent and uniform[30].

These features make the shade guide suitable for the use in bleaching procedures. One drawback of this shade guide is that the intervals between brightness group is ΔL^* 5.0.

One critical prerequisite for dental shade guides is to match the color range and distribution of human teeth. Efforts have been made to design computer models for dental shade guides and compare them with an existing shade guide (Vitapan Classical). The use of clustering and optimization enabled better representation of tooth color of the newly designed 24-tab shade guide as compared with the existing shade guide (Vitapan Classical). This new shade guide can provide a similar coverage of tooth color with fewer tabs, thus simplifying shade matching procedure[31].

The lack of a standard color order and a standard shade guide may render this method of shade determination inconsistent[8].

Digital photography.

Until recently no method was described that allowed dental photographs alone to replace shade selection by the dentist and/or the dental technician. Other methods had to be used to assess tooth color shade and brightness[32]. Nevertheless, a photographic image provides the dental technician with a lot of information, including tooth morphology, surface texture, color distribution, luster, and other properties (Fig 3)-This photographic image provides invaluable information regarding tooth color distribution)[33].

Fig 3. Digital image provides invaluable information regarding tooth color distribution.

Researchers have started to use digital cameras for the assessment of bleaching methods by generating a digital image and loading it into image editing software. This software provides numeric values of image color and brightness[34-40]. Older taken film processing images then can be digitized and analyzed with commercial software (eg, Adobe Photoshop Adobe Systems Incorporated, San Jose CA, USA)[41]. Digital cameras can be divided into three groups: amateur, semiprofessional, and professional cameras. Obviously, in dental photography only semiprofessional and professional cameras should be used[33]

Semiprofessional Cameras

Semiprofessional cameras include advanced viewfinder cameras and single lens reflex (SLR) cameras without interchangeable lenses.
There are some disadvantages when these cameras are used for dental photography as the distance between the flash and the front lens is too great. Some cameras offer a "macro" function that is not sufficient or that is only available in the wide-angle position of the zoom lens. The wide-angle position necessitates a short working distance, which results in distorted images. To use these cameras for dental photography, modifications of the lighting system were developed, often in combination with a macro lens.
In photography, color rendition and image brightness are influence mainly by the light, camera technology and various image output devises. In this context light and camera technology are of major interest
Photography means "writing/drawing with light". Daylight affects the color rendition of an image using a certain color cast. This is why color shade selection in the dental office should not be performed under daylight. Room illumination affects color rendition as well. Very often fluorescent tubes are used that are designed to imitate daylight. Normally, they have no continuous spectrum and are not perfectly neutral.
Light reflected from the clothing of the patient (as well as from that of the assistant and dentist), the walls, and the ceiling can cause a weak color cast. Therefore, neutral tones are recommended for use in the operating room.
The color temperature of the flash light itself is important. Powerful flash lights with a short flash duration time tend to be a little more bluish than weak flash systems. Inadequate color temperature depends on the mixture of gases in the tube. The type of flash is important as well as it determines the lighting angle. A ring flash with axial light direction causes another color rendition as a side (point or a twin) flash. The amount of light fired by a flash and the consequent image brightness depend also on the charge the flash condensator has. Often the condensator is not recharged completely, even though the flash ready LED indicates that the flash is set to fire again. It is wise to wait another three or four seconds before taking the photo. The influence of these factors cannot be avoided completely, but it can be minimized by the following measures:

- .Daylight should be blocked out.
- .Neutral colors should be used for the ceiling, walls, and clothing.
- .A powerful flash should be used.
- .The aperture should be closed at least to stop 16 or 22

The flash condensator should be given time to recharge completely[33].
Camera Alignment and Patient
Position. In this context, camera alignment has to be mentioned, although it is not a technical property of the camera but a question of its handling.

It is important to align the camera in a repeatable way. The optical axis of the camera should always be oriented according to the anatomic planes of the patient. It should be perpendicular to the patient's frontal plane and go over into the occlusal plane without an angle. Only in this way can one expect repeatable results concerning the inclination of the camera in relation to the front teeth. The use of a grid screen is strongly recommended to facilitate alignment. Some researchers recommend that a chin rest be used to stabilize the patient's position.
Exposure Mode. The principal problem with setting exposure modes is that the camera does not know what brightness an object has, whether it is very dark, very bright or has a medium brightness level. Therefore, the exposure system of the camera always tries to generate a picture with a medium brightness value, corresponding with a medium gray tone. Consequently, very bright objects (eg, a white cast) are reproduced darker, whereas dark objects are reproduced brighter. In these cases exposure compensation has to be used to adjust the exposure. In the case of a bright object, is dark, light has to be reduced. Therefore, an automatic exposure mode cannot be used to obtain reproducible results regarding tooth brightness. To make matters more complicated, the different light meter characteristics of a camera (ie, spot, center weighting and matrix metering) have an influence on image brightness too. In dental photography spot and center-weighted systems often result in images that are too dark since the white teeth are often in the image center. An exposure compensation (plus correction) has to be used in these cases. Matrix systems take different image segments into account individually for light metering. Normally, the center and lower segments are considered more than are the upper image parts. This works well for general photography, but can lead to wrong exposures in dental photography. To obtain reproducible results, manual exposure and flash modes (without TTL flash metering) must be used.
Camera Sensor. Brightness is recorded for each single pixel and then transformed into a electric signal.
Color rendition and image brightness depend very much on the type of sensor, the filters that are used for generating color information, the computer algorithms, the white balance settings and other influencing factors. To get reproducible results concerning color rendition and image brightness when using a digital camera, one would have to do the following:

- .Work in a consistent surrounding.
- .Use the same equipment (eg, a digital SLR camera with macro-lens and electronic flash).
- .Choose the same magnification ratio (eg, 1:1)

- .Select a manual exposure (ie, no automatic exposure mode; always preset the same aperture).
- .Select the manual flash mode (no TTL flash metering)
- .Select the same image resolution.
- .Select the same file type (TIFF or JPEG with same degree of image compression).
- .Set a low ISO value (eg, ISO 100 or 125)
- .Put a black background behind the teeth to avoid differences of the semitransparent tooth owing to the tongue position of the patient.
- .Use a standardized camera alignment.

Even if all these rules are obeyed, there will be differences causing a color cast and variability in image brightness. These are mostly due to a certain technical variability of the camera system (eg, aperture opening or flash function). Therefore, a method must be used that allows the fine tuning of color rendition and image brightness.

A certain variability of the images cannot be avoided completely, even if all efforts for standardization have been made. Therefore, one has to find a method to eliminate differences as much as possible. For this purpose, in professional photography a gray card is used.

A gray card is a piece of cardboard or plastic with a surface that has a reflectance value of 18%. This represents the middle tone used for exposure determination, half way between pure black and pure white. It is the same tone of gray for which a camera meter is calibrated; therefore a gray card is a neutral target, meaning the red, blue, an green values are equal. The idea behind the use of a gray card is to put something in the picture that has a known value in other words, that we know to be pure gray, and then let the software make sure that that object is interpreted as gray. Thereby, a color cast of the whole picture is eliminated. As normal gray cards available in the photographic stores are too bıg to include into a 1:1 shot, only a small piece of gray card is used; it can be punched out using an office hole punch and fixed to the surface of a tooth with a small amount of petrolatum.

A world-standard software is the Adobe Photoshop program, which is used to edit the images. Following the step-by-step procedure outlined here will allow you to get comparable photographic results:

1. After starting the Photoshop program, open the Windows (Microsoft) Information menu; this will give you the color information of each single pixel.
2. Use Ctrl+O to open the image to be analyzed.
3. To eliminate an overall color cast open the levels dialogue by pressing CTRL+L (or Image, then Adjust, then Levels). A histogram and three eye-dropper tools will appear. The middle one is the gray one. Select it and move it over the piece of gray card in the picture. Click

again to eliminate the global color cast of the image. This can be controlled by checking the Information panel: The R, G, and B values, which would have been slightly different before will now, have the same value. The L*a*b* values will have changed as well: a*and b* will be set to 0; the L* value will not have changed.

4. Change the color space from RGB to L*a*b* . This has to be done for L*a*b* values to be recorded using the histogram of Photoshop. Also, it provides the advantage that L*a*b* values can be compared with the results of electronic devices that use these same values. If these data are only used for patient information and a comparison with other data is not planned, this step is not necessary: click Image then Mode then Lab.

5. To obtain images with a comparable brightness, image brightness is compared with a medium value. The brightness of an image is expressed by the L* value. By clicking Image, then Adjust, then Brightness/Contrast the overall image brightness can be changed. The brightness level is adjusted to an L* value of 54. This sets the brightness of the whole image to a fixed value, which then be compared with the brightness of other images.

6. The tooth to be measured is selected by using the magnetic lasso. The selected tooth will be surrounded by a broken line on the monitor. This line indicates that all measurements refer only to the image content within the line.

7. Reflections on the tooth surface must be excluded. This can be done easily by use of the "magic wand"+ALT

8. L*, a*, and b* values of the selected area are metered by clicking Image, then Histogram. The Photoshop histogram gives information about the mean L*, a* and b* values, their median, the standard deviation, and the number of pixels that were taken into account.

To transform the Photoshop L*a*b* values into the Commission Internationale de I'Eclairage (CIE) L*a*b* values, one has to consider that the range of these values is different in both systems. In Photoshop The range of the mean L*value (L[PM] is 0 to 255. The CIE L* value ranges from 0 to 100. A transformation can be done by using the following formula: L*=L[PM]x100/255.

The a* and b* values are transformed in the same manner. The Photoshop values range from 0 to 255, and the CIE L* a* b* values from +120 to + 120. The transformation formulas are as follows;

a*={a[PM]-128}x240/255

.b*={b[PM]-128}x240/255,

where a[PM] and b [PM] are the Photoshop mean values of a* and b*, respectively[33].

Computer Shade Matching

The shade guide tab is positioned next to the tooth to be matched. Digital images produced via digital camera may be viewed on a computer. Visual color comparison is performed by the observer. Matching of the shade tabs in the same position within the monitor screen should minimize any effects of variability in the display screen[42]

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Colorimetry

Digital Colorimetry is a new era in tooth color measurement that suggest precision and accuracy in defining tooth color. Digital devices are RGB cameras, colorimeters and spectrophotometers.
Spectrophotometers are suggested as a precise and accurate method for vital tooth bleaching[43] .

Colorimeters.

Much of the dental research on the color of natural teeth and porcelains, in vivo and in vitro, has been conducted using colorimeters[44-48]. These instruments are engineered to directly measure color as perceived by the human eye. A colorimeter filters light in three of four areas of the visible spectrum to determine the color of an object. Colorimeters are difficult to design and, if made improperly, will result in reduced accuracy compared with a spectrophotometer. However, well-designed colorimeters such a X-Rite's ShadeVision system can provide greater data efficiency because they only store the three data points of hue, value, and chroma instead of the 16 of more data points of reflectance recorded by a spectrophotometer[49]
Although several specialized colorimeters such as ShadeEye (Shofu Dental Co) (Fig 4), ShadeScan (Cynovad Inc) (Fig 5), and ShadeVision (X-Rite Inc) (Fig 6) have become available during recent years, are designed mainly for dental practitioners and thus have rarely been used for research purposes.

Fig 4. The ShadeEye (Shofu Dental Co) colorimeter.

Fig 5. The ShadeScan (Cynovad Inc) RGB colorimeter.

Fig 6. ShadeVision (X-Rite Inc) colorimeter.

The measured color is expressed in $L^* a^* b^*$ data exclusively in tooth-whitening research, probably owing to their popularity in virtually all fields of color measurement. The L^* values ranges from 0 to 100 and

increases with the lightness of color. The $+a^*$ to $-a^*$ indicate the red and green directions respectively, and $+b^*$ to $-b^*$ point to the direction of yellow and blue colors respectively. With the coordinates, the $L^* a^* b^*$ system allows the numeric definition of a color as well as difference between two colors. The color difference is calculated using the following formula $\Delta E^*=[(\Delta a^*)^2+(\Delta b^*)^2+(\Delta L^*)^2]^{1/2}$.
A colorimeter that was commonly used initially for objective measurement of tooth color and evaluation of whitening efficacy in clinical studies is the Minolta Chroma meter (Models CR-221 or C-321, Minolta Corporation USA, Ramsey NJ, USA) (Fig 7).


Fig 7. The Minolta Chroma meter (Model CR-221) colorimeter.

This Minolta Chroma Meter CR-321 consists of a measuring head and an instrument panel. It is designed to measure small areas of glossy surfaces. The aperture provides a measuring area of 3mm in diameter, with 45^0 circumferential illumination by 30 optical fibers and 0^0 viewing geometry. The major limitations of using this device for tooth whitening measurements are firstly the small aperture area $7.02mm^2$ which is <10% of the labial surface area of a typical maxillary central incisor and secondly the lack of an established standard method to correlate the $L^* a^* b^*$ values to tooth color perceived change leading to inconsistencies in ranking between device measurements and shade guides. The Minolta Chroma Meter CR321 alone does not appear to be adequate for determining tooth color change in whitening studies, although the quantitative measurements may be useful as supplement or supportive data. Research is needed to develop and improve the instrument and technique for quantitative measurement of tooth color and interpretation of the data for evaluating tooth color change[26]
In addition, a colorimeter can deliver color information accuracy similar to spectrophotometers while reducing the data load time by avoiding the unnecessary color mapping associated with spectrophotometers. The ShadeVision system provides simple, consistently reliable shade measurement information for precise, quantifiable communications between the dental office and laboratory, significantly improving the

assurance of an accurate shade match when compared with traditional techniques[50].

Spectrophotometers

A spectrophotometer measures and records the amount of visible radiant energy reflected or transmitted by an object one wavelength at a time for each value, chroma, and hue present in the entire visible spectrum[49, 51-55]. The extensive data obtained from spectrophotometers must be manipulated, and a data-reduction strategy employed, to translate the data into a useful format, eg, a spectral curve[56]. Widespread use of spectrophotometers in dental research and clinical setting has been hindered by the fact that the equipment is expensive and complex, and that, until recently, it was difficult to measure the color of teeth in vivo with these machines. The best research spectrophotometer uses what is called spherical optics, in which the object is placed inside the spectrophotometer and exposed to light from many different angles and directions. This gives the most accurate and precise spectral analysis of the reflectance properties of the object. However, spectrophotometers for dental use cannot achieve this same 360-degree light exposure since the tooth cannot be placed inside the device. Instead, light is directed at the surface of the tooth.

There are two basic optical light settings used in reflectance spectrophotometer instruments: illumination at 0 degrees and observation at 45 degrees (0/45) or illumination a 45 degrees and observation at 0 degrees (45/0). Because of the limited access afforded by the oral cavity, only the 45/0 option is suitable for clinical use.

An example of a spectrophotometer developed for clinical use is the SpectroShade from MHT (Fig). The SpectroShade system uses dual digital cameras linked through optic fibers to the spectrophotometer to measure the color of the tooth. There is a multimodal dual-light mechanism that illuminates the tooth and allows readings of its translucency and reflectivity[57].

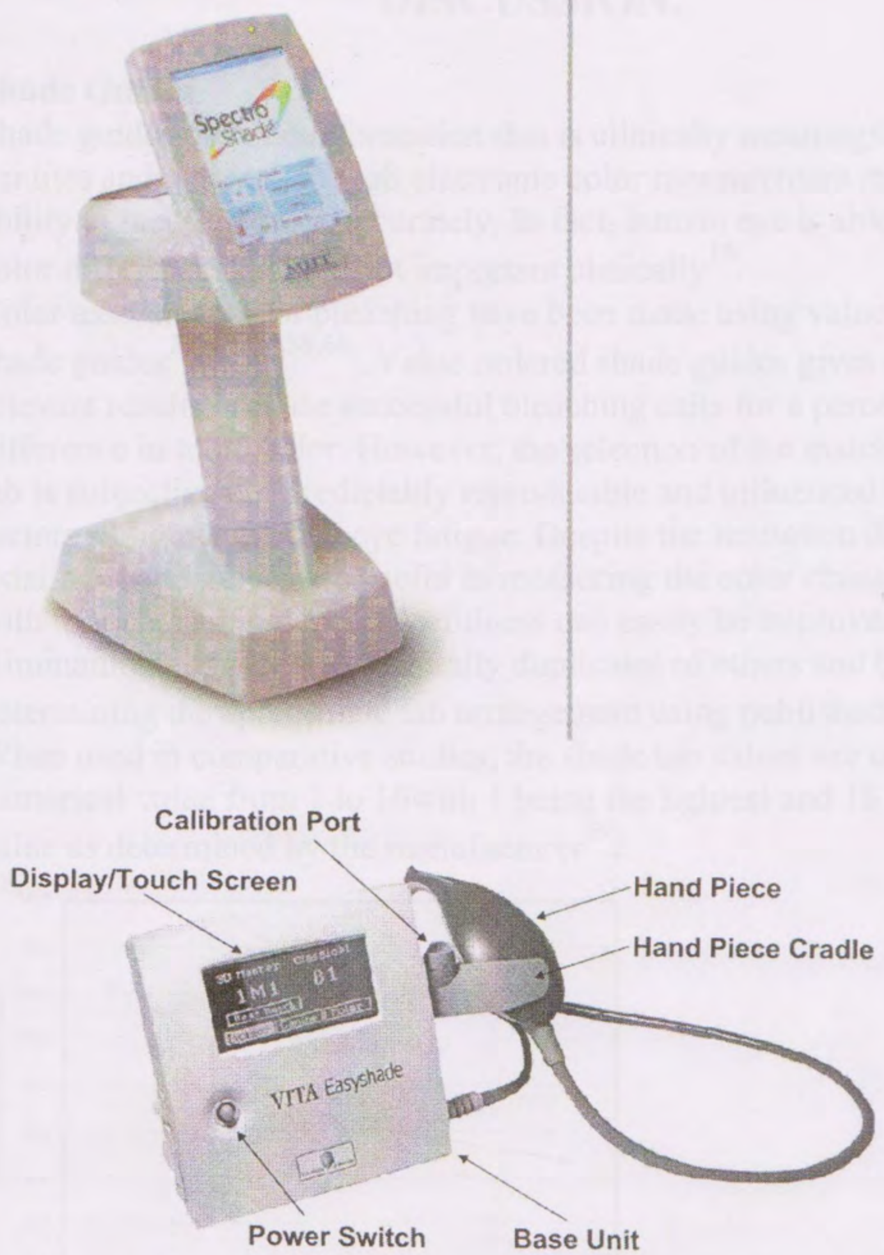

Fig 8. The SpectroShade from MHT and EasyShade by Vita spectrophotometers

The SpectroShade has the capability to display shade results in advanced color graphics[50].

Purpose. This paper analyzes the efficacy of the bleaching procedure through the measurement of the color change of vital teeth regarding their color parameters of value, chroma and hue, by visual, colorimetric and spectrophotometric means.

DISCUSSION.

Shade Guides.

Shade guides provide information that is clinically meaningful to both dentists and patients, though electronic color measurement may have the ability to measure more accurately. In fact, human eye is able to detect color differences that are not important clinically[15].

Color assessments for bleaching have been made using value-ordered shade guides[22, 24, 58,59,60,]. Value ordered shade guides gives clinically relevant results because successful bleaching calls for a perceivable difference in tooth color. However, the selection of the matching shade tab is subjective not predictably reproducible and influenced by such factors as lightening and eye fatigue. Despite the limitation discussed, existing shade guides are useful in measuring the color change that occurs with tooth bleaching. Their usefulness can easily be improved by eliminating tabs that are essentially duplicates of others and by determining the appropriate tab arrangement using published L^* data[15]. When used in comparative studies, the shade tab values are converted to a numerical value from 1 to 16with 1 being the lightest and 16 the darkest value as determined by the manufacturer[59].

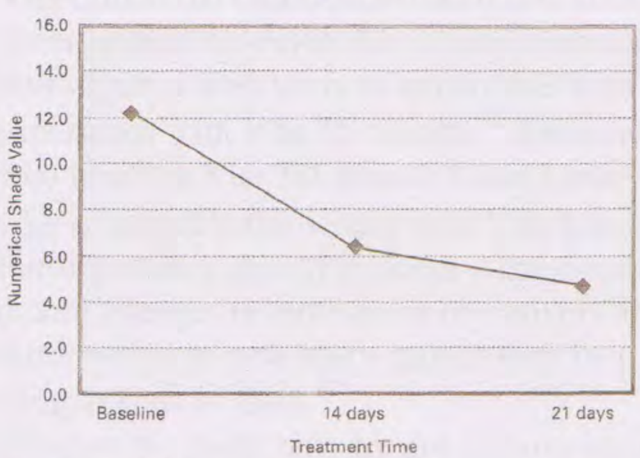

Fig 9. Number of shade tab change from the baseline to the end of the bleaching procedure (Oliver al 1999)

Although the value scale is not perfectly linear, the changes are measured as if the scale represented a continuous and approximately linear ranking, for the purpose of analysis[61]. This model has been adopted in most tooth bleaching studies and has been acknowledged to yield "clinically relevant" data[7] .Some important information regarding clinical color assessment is given by the following studies:

Using the Vita Lumin shade guide 10 observers matched only 43% of the shades correctly[42], which is a slightly lower figure than previous studies in which 64% correct matches were scored by 70 observers using the similar Vita shade guide, but shade matching was carried out on the laboratory bench and the shade selected for matching had a wide range of color (A1, A2, B1, B2, C1, C2, D2 and D4)[62]. In a study it was matched 50% correct in day 1 and 65% correct in day 14 using only six shades of the Vita shade guide to match 20 extracted natural teeth. The limited number of shade tabs used in that study makes it relatively easier to select a shade and increases the probability of getting the right shade[63]. Another study, which may explain differences between studies reported in the literature, showed that it is more difficult to match shades intraorally than in the laboratory with 43% and 55% correct matches respectively[64]. Clinical assessment of the restored teeth shades by equally inexperienced students on both Vita 3D-Master shade and Vita Classical guides showed significantly differences between the shade guides with a systematic design and that based on empirical values. All restorations whose shades had been determined with the 3D-Master could be placed without any further shade corrections. In contrast, almost 17% of restorations determined with the conventional system (Vita Classical) required subsequent shade modifications[65]

Other researchers found a lower failure rate in visual shade taking with Vita Lumin the traditionally designed shade guide system. In this investigation, however, the shades were determined in vitro and by investigators with years of experience with Vita Lumin but little experience with Vita 3D-Master[66]. On conversely, general practitioners who used the Vita 3D-Master found better values versus prosthodontists who achieved better values with Vita Lumin[67]

Further studies should consider a combination of experiments designed to record changes in tooth color objectively and subjectively. The introduction of new shade guides may help to standardize clinical comparisons of teeth [68] .

Because the shade tabs are not linearly arranged (evenly spaced) (Fig 10)

TABLE 2. VITA CLASSICAL SHADE GUIDE: MANUFACTURER'S SUGGESTED ARRANGEMENT BY VALUE.

L^*	78.9	79.6	76.7	75.3	76.0	74.2	71.0	71.9	75.4	72.6	74.1	72.3	71.8	68.8	68.6	64.8
Tab	B1	A1	B2	D2	A2	C1	C2	D4	A3	D3	B3	A3.5	B4	C3	A4	C4
No.	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
ΔL^*	–0.7	2.9	1.4	–0.7	1.8	3.2	–0.9	–3.5	2.8	–1.5	1.8	0.5	3.0	0.2	3.8	—

ΔL^* = change in brightness.

Fig 10. The shade tabs of Vita Classical are not linearly arranged (evenly spaced).

they are not included in a study, and spectrophotometer was used instead. Because of the unevenly spaced of two shade tabs there is a major problem comparing different articles and claim for the same degree of efficacy (eg four shade tabs of L^* change)[8]. Recently, there is a reasonably good correlation between earlier obtained data by visual assessment and the present data by two instrumental methods of digital imaging and the use of a spectrophotometer [69].

Digital photography.

Digital images. With regard to tooth-bleaching procedures, the important values for assessment are L*, the whiteness of a tooth, b*, the yellowness, and a* the redness. After tooth bleaching major changes of the L* and b* values can be found, whereas the a* values show only minor differences. The Δb* score (the difference in yellowness before and after bleaching) has the most perceptual relevance. From a clinical point of view, the ΔE* score (composite color change) seems to be of minor interest as it is not indicative of an overall color change of the tooth.

Compared with electronic devices such as spectrophotometers and colorimeters, digital photography when used for the assessment of tooth color and the outcome of bleaching procedures has an additional advantage in that there are numeric data that can be evaluated as well as an image. This is critical to achieving an accurate clinical impression. Nevertheless, all photographic methods seem to have their limitations because a lot of variables play important roles.

In principal, methods using film that is later digitized cannot be more precise than methods using direct digital photography as conventional methods add more variables to the process.

In digital photography the influence of factors such as light, camera technology, and clinical procedure on the resulting pictures can be reduced to a minimum but not completely eliminated. The used of a digital technique does not guarantee a reasonable outcome. Although technical details provided in some publications sound impressive and sophisticated, they may have no impact on accuracy.

We took digital images but we did not use these images to compare the performance of the test and control products. We imported some of the images into commercially available photographic analysis software, which could highlight tooth yellowness by switching from standard RGB mode to $L^* a^* b^*$ mode and then displaying the images using the b^*channel only. By counting numbers of yellow pixels, researchers could develop this technique further and test it as a potential method of measuring tooth color quantitatively as high-definition digital cameras became available [7].

There are, of course, differences in the accuracy of various methods but there is no photographic method that is free of disadvantages and inaccuracies. Even when standardizing the procedure as much as possible, there are a certain variations of a technical nature that cannot be avoided[33]. We took digital images but we did not use these images to compare the performance of the test and control products. We imported some of the images into commercially available photographic analysis software, which could highlight tooth yellowness by switching from standard RGB mode to $L^* a^* b^*$ mode and then displaying the images using the b^*channel only. By counting numbers of yellow pixels, researchers could develop this technique further and test it as a potential method of measuring tooth color quantitatively as high-definition digital cameras became available [7] The digital images are obtained using a ring flash, which has a spectral energy curve that is not the same as D65 used in spectrophotometers. In the future, by including color standards in the same image, adjustment for these aspects of digital color matching could be made using various algorithms to calibrate the values. The reproducibility of the digital images as measured by the coefficient of variation of L^* values varied between 0.08% and 1,39% compared to the coefficient of variation 0.05 to 0.49% of the mean for the same shade tabs measured using the reflectance spectrophotometry. The digital camera can be used for color measurements in the dental clinic [42].
After selection of suitable lighting conditions and the establishment of a robust mathematical transformation, it is demonstrated that digital camera imaging systems and the subsequent image analysis are reliable in tooth color quantification. With further advancement in software design to automate the calibration procedure, imaging could play an important role in clinically assessing tooth color [69]

Photographs. Color assessments for bleaching have been made using digitized photographs [23]

Computer Shade Matching.
Computer matching was found statistically different from the conventional visual matching method with 61% correct matched shade tabs of Vita Lumin compared with 43% for the conventional method. The 10 observers in general made comments that they found the computer matching method easier than the conventional and 7 out of 10 preferred the computer method despite the fact that they had had relatively longer experience using the conventional method. Computer matching may improve dentist-laboratory communication [42]
Colorimeters.

The most commonly used colorimeters in bleaching outcome measurement research are the (CR-221 Chroma Meter, Minolta, Ramsey, New Jersey) [68,70], or (CR-321 Chroma Meter, Minolta, Ramsey, New Jersey)[26] and the Shade Vision System (SVS, X-rite, 3100 44th St SW, Grandvill, MO, USA) mainly designed for clinical use[70].
The use of the colorimeter also has its advantages and drawbacks; it gives more objective results than shade guide tabs, but is affected by tooth translucency, tooth contour, tooth texture and difficulties in repeatable tooth repositioning. The L^* (lightness) and b^* (Yellow/blue) pretreatment colorimeter results were shown to be affected consistently by bleaching procedures, but no significant differences were found in the a^* (red//green) measurement[71, 72].
To simplify the quantification of color change the difference in the three L^* a^* b^* colorimeter parameters have been integrated into a single ΔE^* parameter[21, 72]. Also, an integrated C parameter that describes the level of dental colorization from absolute white was proposed and a novel algorithm of color determination for the color analyzer[73]. The B parameter represents brightness or the amount of light backscattered from the tooth and C represents the relative spectral deviation from the absolute white. The electronic color analyzer assesses dental colors by calculating numerical values of B and C from measured spectral reflectance. A more positive B parameter and more negative C parameter represent improved color change with baseline measurement[74].
Interpretation of statistical differences detected in L^* a^* b^* measurements to clinical significance of whitening efficacy is a challenge, particularly when the perceived shade data are not available. Owing to the nature of the data the quantitative L^* a^* b^* measurements tend to provide a greater statistical power to detect the significance at relatively smaller difference. However, the clinical relevance of these statistically significant differences is unclear. The certainty of the statistical significance is further discounted by the clinical discrepancies in the color ranking as well as the color spacing within and between Vitapan Classical and Minolta Chroma Meter. Clearly, the interpretation of statistics of Chroma Meter results without shade data needs to be done extremely cautiously, especially when the clinical efficacy of two tooth-whitening systems is compared. It of interest that there appear to be marked differences in the L^* a^* b^* values of tooth measurements obtained from the Minolta Chroma Meter CR-321 compared with other systems, such as other colorimeters (eg, ShadeEye and ShadeVision), spectrophotometers (eg, EasyShade and SpectroShade), and digital imaging system (Procter & Gamble), that are also capable of generating the same parameters. In general, the L^* a^* b^* values of tooth measurement obtained from the Minolta Chroma Meter

CR321tend to be lower than those obtained with other systems. Theoretically, the measurement should be the same for the same color as they are based on the three-dimensional coordinates of the CIELAB color space. One of the plausible factors that may contribute to this difference is the small (3mm in diameter) measurement aperture of the Minolta Chroma Meter CR321. A study using a spectrophotometer and a spectroradiometer found that the L^* a^* b^* values obtained from extracted human teeth decreased with the smaller-size measuring windows[75]. The L^* measurements were 54.32, 49.41, 47.61 for window diameters of 5, 4 and 3mm, respectively. The trend for a^* and b^* a measurement was similar, indicating that tooth color measurements using a small window tend to shift toward green and blue coordinates in the CIELAB color space. The authors suggested that these shifts are caused by the wavelength-depended edge loss. Although the applicability of these spectrophotometric data to the Minolta Chroma Meter is unclear it appears that a larger measuring aperture is desirable not only because of the possible influence of wavelength-dependent edge loss on the shift of measurement in color coordinates but also because, clinically, the whole labial surface of the tooth is perceived for its color [26]

The use of a properly calibrated colorimeter allows for objective color measurement [76]. However, recorded statistical differences may not be clinically evident, because a subjective, problematic mismatch exists between shade guides and the color of natural teeth [77,20].

For all measurement methods the correlation coefficient was significant on at least one recording day, with the greatest sensitivity shown with Shade Guide and least with the chromameter. Nevertheless, the agreement between dichotomized Shade Guide and Shade Vision System was extremely high with substantial agreement between these systems and L^* a^* b^*. In the present study, the mean change in color (ΔE^*) by chromameter was used which is mainly dependent on the change in lightness/darkness (ΔL^*). Observationally, changes in a^* and b^* were as expected, representing reduction in redness and yellowness an effect reported by others[78]

Spectrophotometers

A very high and statistically significant correlation was found to exist between the spectrophotometer and digital camera for all L^*a^* b*color coordinates. The reproducibility of the digital images as measured by the coefficient of variation of L^* values varied between 0.08% and 1,39% compared to the coefficient of variation 0.05 to 0.49% of the mean for the same shade tabs measured using the reflectance spectrophotometry. The high correlation found between the methods opens the way for a large number of clinical studies in bleaching and shade evaluation [42]

Based on the CIE whiteness index, the whitening effect assessed by image analysis is more marked than by spectrophotometry. Spectrophotometers underestimate CIE whiteness index values for translucent dental materials. Spectrophotometry (Colorimetry) gives inaccurate absolute values for tooth color, but gives the same ranking order as the quantitatively correct image analysis approach [69].

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L^* a^* b Parameters.

The bleaching outcome is mostly assessed in the L^* b* parameters. Minimal change is exhibited in the a^* or red/green direction ($\Delta a^*<1.0$) [68]. This is consistent with the findings of another study that reported that variance in a^* values had a minor influence on total tooth color change[79]. When teeth are bleached, the relative lightness (value) of the teeth is increased, making them appear whiter. Therefore, bleaching does not necessarily involve making the teeth more opaque and refractive; rather, intrinsic colored pigments are removed allowing a tooth to become whiter yet remain highly translucent [50]

Tooth whiteness can be assessed quantitatively by several "whiteness indices" (Y). The most popular whiteness index is that certified by CIE and is a visually related CIE tristimulus value in the X, Y, Z system. [69].

CONCLUSIONS.

1. **In the studies of vital tooth bleaching, the whitening outcome is both qualitatively and quantitatively documented.**
2. **Quantitative assessment of the efficacy of whitening systems requires not only accuracy and precision of the color measurement but also standardized methods to correlate the quantitative data to tooth color changes that are linear, evenly spaced and perceivable by human eyes. The ultimate challenge is to determine not the color change but a method indicating shade reduction mainly in the direction from darkness to whiteness after a whitening treatment.**
3. **Shade guides provide information that is clinically meaningful to both dentists and patients, though electronic color measurement may have the ability to measure more accurately. In fact, they may be able to detect color differences that are not important clinically.**

4. **The digital camera image analysis systems and the subsequent image analysis are reliable in tooth color bleaching quantification.**
5. **The use of a custom positioning jig is introduced in a number of clinical bleaching studies with colorimeters.**
6. **With the use of reflectance spectrophotometers , the subjectivity of color assessment can be minimized and shade differentiation can be more objectively compared.**
7. **The high correlation found between the methods opens the way for a large number of clinical studies in bleaching and shade evaluation**

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