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Colour Effects on Extracted Teeth After a Tooth Whitening Regime: Assessment in an Artificial Oral Cavity

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Abstract - *The purpose of this study was to assess the reliabilty of a digital image analysis system and to assess its suitability for quantifying the colour (including whiteness) of extracted teeth in a purpose built artificial oral cavity after a whitening regime. Extracted teeth were treated with a scale and polish and a bleaching solution. The Image analysis system showed excellent intra operator repeatability. Significant tooth colour and whiteness changes occurred after the bleaching treatment. The digital image system has been shown to be a reliable and valid method for assessing colour and whiteness changes on extracted teeth after whitening treatments.*

KEY WORDS: Image analysis; Tooth colour; extracted teeth

INTRODUCTION

An understanding of tooth colour and its measurement is closely associated with the characteristic structure of teeth. The total colour effect of natural teeth is a result of light reflected and scattered from the enamel surface and underlying dentine[1], which in some cases can directly affect our perception of the appearance of tooth whiteness[2].

Quantitative and reproducible representation of tooth colour (including whiteness) is important both in clinical practice and when comparing commercial tooth whitening products. As attention to tooth whiteness becomes more prevalent there is a pressing need for a quantitative instrumental assessment for assessing changes in tooth whiteness. Currently, the most popular method of determining tooth colour, including whiteness, remains that of subjective shade matching using traditional colour guides, although objective (spectrophotometry, colorimetry and digital image analysis) methods are gaining popularity.

Visual shade matching has been used for assessing the efficacy of tooth whitening products[3], and although it is convenient and simple to use, its inherent subjectivity leads to poor intra- and inter-examiner reliabilty[4]. Spectrophotometry and colorimetry have been utilised in longitudinal tooth whitening studies[5,6], and although these instrumental approaches have been found to be accurate and reproducible, there are inherent problems with this application in dentistry. One major problem is the 'edge loss effect' when measuring curved and translucent samples, which leads to systematic errors in colour quantification[7]. As an alternative to spectrophotometry and colorimetry, the profile of the digital imaging approach has been raised in recent years, and has been applied to the measurement of tooth colour and whiteness[8,9]. However, currently there are few commercially available image analysis systems suitable for use in clinical practice, where tooth colour and whiteness measurement is required.

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In a previous study[10] a digital image analysis system was modified to assess tooth whiteness on individual extracted teeth, the results showed this system was able to assess the efficacy of tooth whitening products both accurately and sensitively. To bridge the gap between in vitro and in vivo assessments of tooth colour, a more realistic environment is required which would closely resemble the oral cavity.

It has been hypothesised that a digital image analysis system can detect changes in tooth colour, including whiteness more accurately after a tooth whitening regime in a purpose built artificial oral cavity to simulate that of the human mouth. Thus the aim of this study was to assess the reliabilty and suitability of a digital image analysis system, when quantifying the colour (including whiteness) of six upper and lower anterior extracted teeth.

MATERIALS AND METHODS

Preparation of extracted teeth

Thirty two extracted permanent non-carious anterior and posterior teeth were collected (Charles Clifford Dental Hospital, Sheffield, UK) with patient consent. The teeth were scrubbed with deionised water and a hard toothbrush to remove any tissue or debris. The teeth were then autoclaved at 121 °C for 30 min (to kill any bacteria and viruses, ensuring safe handling) and stored in phosphate buffered saline with 1 % thymol crystals to avoid any bacterial growth.

The artificial oral cavity

The artificial oral cavity consisted of a mandibular and maxillary arch constructed from pink acrylic resin and a low viscosity silicone to mimic the colour and contour of human gingival tissue. The thirty two extracted teeth were placed into their appropriate anatomical positions within each arch and secured using a water resistant adhesive. For all measurements, the arches were placed in an open ended box with all the interior faces painted black using an emulsion paint (fig. 1).

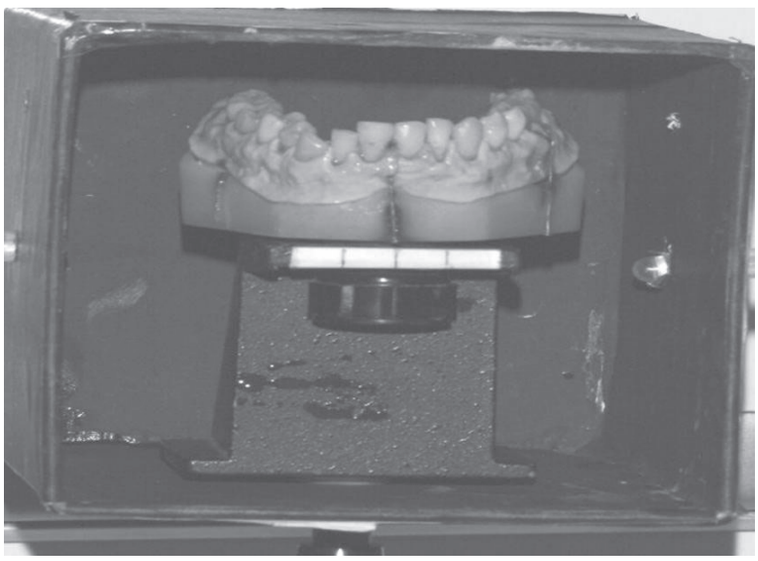

Figure 1. *The artificial oral cavity showing the lower arch with the extracted teeth in their correct positions.*

Artificial saliva soaking

The arches containing the extracted teeth were soaked in a sterilised and filtered artificial saliva for 24 hours before and during the study period except for treatment and measurement periods. The artificial saliva contained 2 mmol/L $CaCl_2$, 4.2 mmol/L $MgCl_2$, 4 mmol/L NaCl, 1.3 mmol/L NaSCN, 15 μmol/L NaF, 8 nmol/L KI, 5 mmol/L $KHCO_3$, 6 mmol/L KH_2PO_4, 10 mmol/L KCl, 3.2 mmol/L urea, 0.55 mmol/L glucose, 5.4 mg/L lactoferrin, 0.264 g/L lysozyme, 0.38 g/L α-amylase, 2 mg/L lactoperoxidase, 2.2 g/L serum albumin (all from Sigma-Aldrich) made up to 1 litre with deionised water. The artificial saliva was warmed to 37 °C using a water bath one hour before each treatment step to simulate the temperature of the human oral cavity. The artificial saliva was replaced daily to avoid bacterial growth.

Standard toothpaste brushing

Each extracted tooth was brushed with Boots Essentials toothpaste to provide a baseline colour and whiteness value. A pea sized amount of the paste was squeezed onto the head of an Oral B plaque remover toothbrush. Each tooth was brushed for 1 min. After the brushing treatment any excess paste was rinsed off using 5 ml of deionised water administered with a 5 ml pipette.

Scale and polishing

Each extracted tooth was subjected to a two minute scale and polish using a Cavitron SPS portable polishing machine and an Oral B medium abrasive toothpaste.

Bleaching step

After the scale and polish step, the teeth were soaked for 1 hr in 37.5 % Urea hydrogen peroxide equivalent to 15 % hydrogen peroxide. After this step each tooth was rinsed with 5 ml deionised water.

Measurement methods

The extracted teeth assessed in this study were the central incisors (11, 21, 31, 41) lateral incisors (12, 22, 32, 42) and the canines (13, 23, 33, 43) (N=12). The colour and whiteness of each extracted tooth was measured before any treatment (baseline) and after each treatment step using digital image analysis. Visual shade matching was also carried out to verify the image analysis results.

The image analysis system

The system consisted of a Kodak DCS 410 digital camera (aperture F11, shutter speed 1/10 sec), mounted on a purpose built frame (Fig. 2) rotated around cephalometric head positioning apparatus. The lighting array was developed to closely match daylight conditions and comprised four 50 W Solux halogen lamps and eight 4 W UV fluorescent tubes. The Solux lamps were arranged in a ring structure, with the UV lamps at 30 ° to each Solux lamp.

Image acquisition

Before each set of measurements, a system calibration was carried out using a standard white tile. An image was taken of each extracted tooth and transferred from the camera using a twain driver and displayed using Adobe Photoshop (version 5). Images were saved as tagged image format files (TIFFs).

Image analysis

Each TIFF file image was examined using Adobe Photoshop software. The extracted tooth crowns were highlighted using the freestyle drawing tool within the drawing toolbar of Adobe Photoshop. The mean R, G and B values of each tooth crown were obtained and then converted to CIE whiteness index (CIE WI) values[10] using a system specific algorithm. CIE L*, a*, b* values for each test tooth were also obtained, where the L* value is a measure of

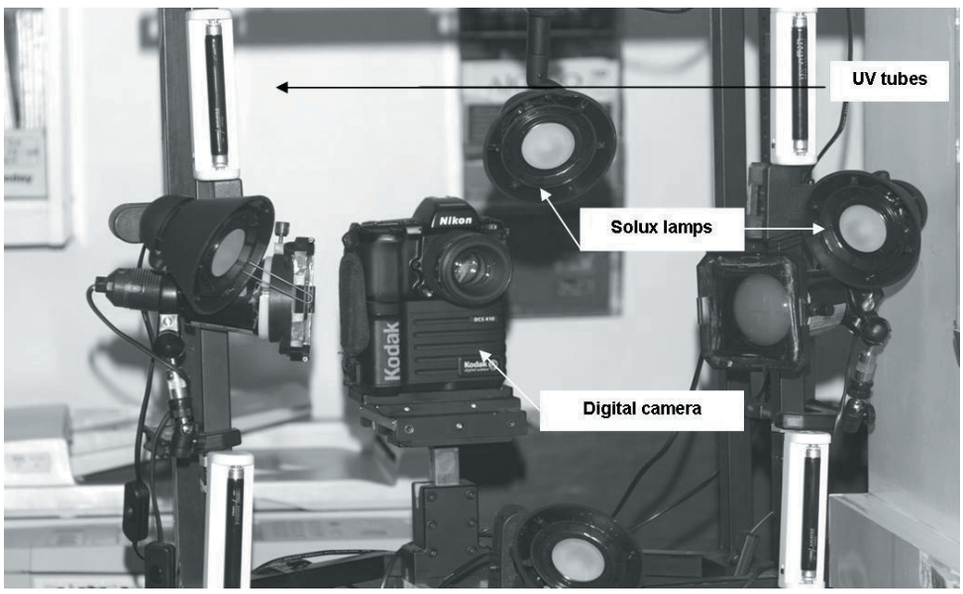

Figure 2. *The custom made frame showing digital camera and modified lighting.*

lightness, the a* value is a measure of redness (positive a*) or greeness (negative a*) and the b* value is a measure of yellowness (positive b*) or blueness (negative b*). The a* and b* values approach zero for white samples.

System validation

The reliabilty and reproducibilty of the image system was tested by taking images of the 12 untreated extracted test teeth once a day over 5 days (N=60) and obtaining CIE WI values.

Whiteness assessment by visual shade matching

A Vitapan 3D Master colour guide containing 26 fired porcelain tooth shaped shade tabs was used for all visual whiteness assessments. The shade tabs represent the colour range of normal human teeth and incorporated all three categories (hue, value, and chroma) of colour perception. Each tab colour is identified by its Lightness (1-5), Hue [L (yellow), M (medium), R (red)], and Chroma (degree of saturation: 1, 1.5, 2, 2.5, and 3). Three further bleaching tabs were obtained (Vita Zahnfabrik, H.Rauter Gmb H & co.Kg, Germany), OM1, OM2, OM3. For shade matching each set of tabs could be removed from the main base.

All the visual shade matching was carried out under the same standardised conditions as the image analysis method above. A single trained assessor used the Vitapan 3D Master Colour guide to match the shade of the extracted tooth crown to the nearest matching tab. Each assessment was carried out whilst the teeth were still moist. The trained assessor had many years experience in clinical tooth shade matching and had attended dental courses in tooth shade and colour theory, as well as supervising undergraduate and postgraduate dental students on tooth colour projects. To allow for direct comparisons between the image analysis system and visual shade matching techniques, a previously obtained perceived whiteness ranking of the Vita 3D shade guide was used[11], where the least white tab was ranked 1, and the whitest tab ranked 29.

Analysis of data

Fleiss' coefficient of reliability[12] was used to calculate the CIE WI differences between the 60 repeat measurements of the untreated extracted teeth to assess intra-operator repeatability of the image system, reliabilty was confirmed by obtaining 95 % limits of agreement[13] for the first and second repeat measurements of the 12 test teeth.

For the whiteness treatments the changes in CIE L*,a*,b* and CIE WI from baseline using the mean values of the 12 test teeth were calculated. Two tailed paired t-tests (95 % confidence level) were carried out on the above colour changes.

RESULTS

Fleiss' coefficient of reliability for the 60 repeat measurements of the untreated extracted teeth using the image system and spectrophotometry was 0.982, which was in the excellent range according to the benchmarks for Fleiss'[14].

The 95 % limits of agreement (Fig. 3) were +/- 3.65, with the mean difference and standard deviation being 0.77 and 1.87 respectively.

The mean changes from baseline of the CIE L*, a*, b* colour coordinates and whiteness index of the 12 extracted teeth after the two whiteness treatments are shown in Table 1 and Figures 4&5. The visual change in whiteness is also shown in Figure 5.

There were significant changes in CIE L*, CIE b* Colour coordinates ($p<0.05$) after the bleaching treatment, but no significant changes occurred after the scale and polish treatment. CIE WI changes and visual whiteness changes were also significant ($p<0.05$) after the bleaching step.

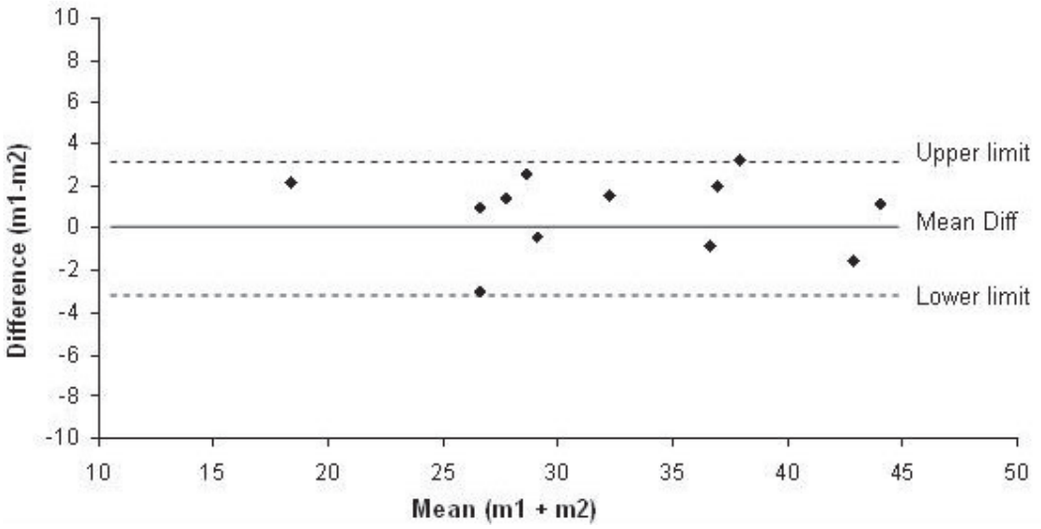

Figure 3. *The 95% Levels of agreement for the first and second repeat measurements of the 12 extracted teeth. Values are in terms of CIE WI obtained from image analysis.*

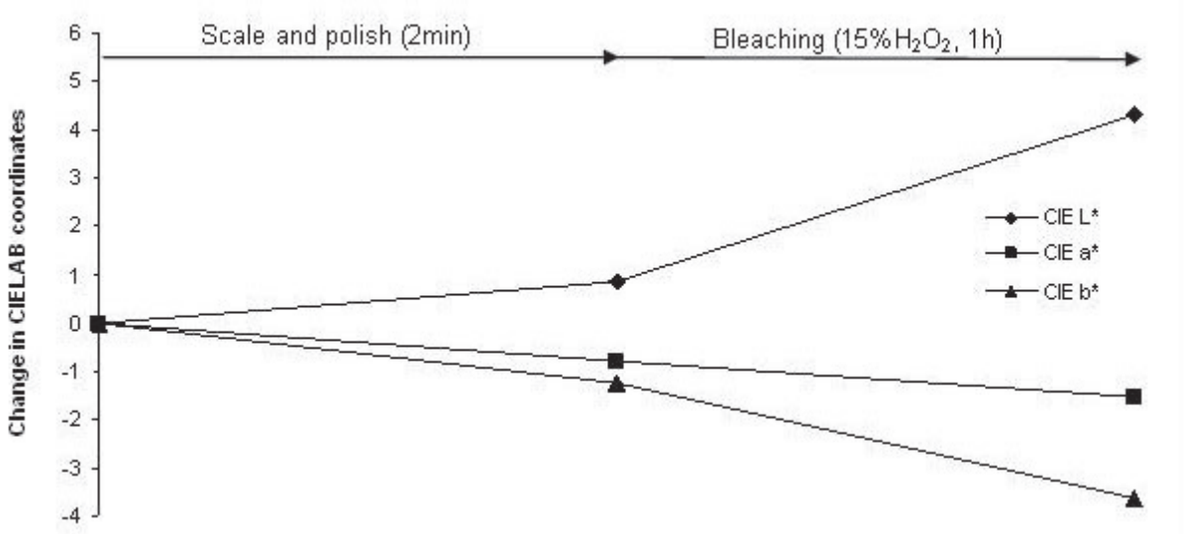

Figure 4. *Mean changes in the CIE colour L*,a*,b* coordinates for the 12 extracted teeth obtained by image analysis.*

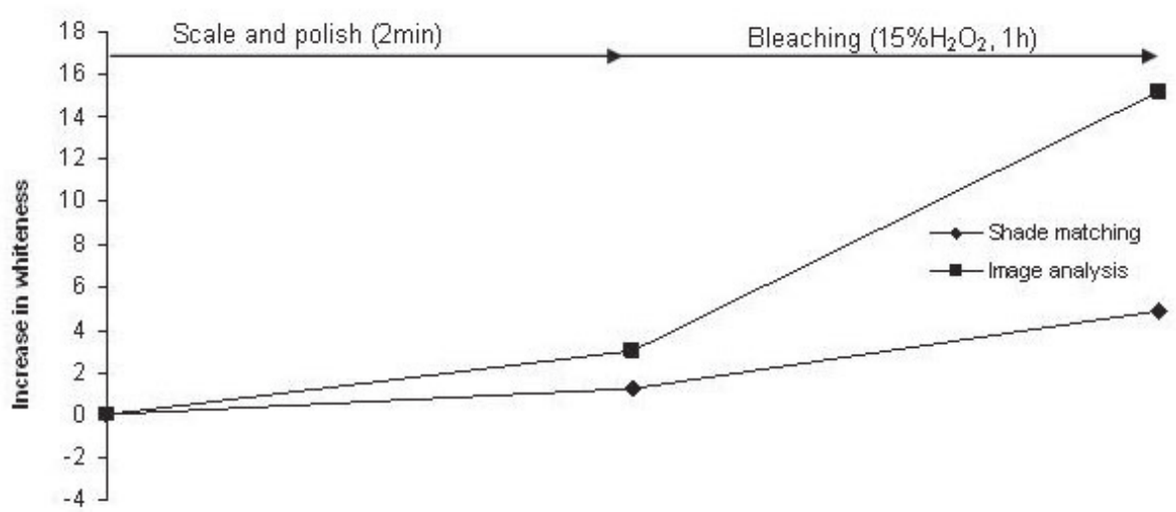

Figure 5. *Mean changes in the CIE WI for the 12 extracted teeth obtained by image analysis and the visual change in whiteness by visual shade matching.*

Table 1. *Mean changes in CIE colour coordinates and whiteness index from baseline for the 12 extracted teeth after each of the two whitening treatments.*

Colour indices	*After scale and polish*	*After bleaching*
CIE L*	0.84	4.29
CIE a*	-0.78	-1.53
CIE b*	-1.23	-3.64
CIE WI	1.21	4.91

DISCUSSION

For assessing tooth colour and whiteness after whitening treatments an ideal method for colour measurement should be reliable, show a high level of precision and be quick and easy to use with minimal training required. The custom made frame for the digital camera was designed to allow accurate and reproducible colour measurements of extracted teeth, and the lighting incorporated into the image analysis system was developed to closely reflect standard daylight conditions. The artificial oral cavity was designed to assess extracted teeth in positions and angles of those found in the human mouth, bridging the gap between in vitro and in vivo measurements. Tooth colour is directly related to light reflection so the curvature and angles at which teeth are viewed play a large part in the total perceived colour. As the extracted teeth came from numerous people of varying ages and gender the curvature of the arches were not symmetrical. In this study only the anterior teeth were assessd as these are the teeth which are of prime importance for the assessment of whitening products. The extracted teeth were autoclaved to destroy any bacteria or viruses on or within the tooth structure, thus ensuring the teeth were safe to handle and removing any cross contamination issues. Although autoclaving may have altered the internal and surface structure of the tooth, we believe this would not have affected our colour assessments of the extracted teeth for the purpose of method development.

A bleaching concentration of 15 % hydrogen peroxide was choosen for this study as this level of peroxide is commonly used in professional in-house whitening treatments in the United States[15]. A level of 0.1% peroxide, which is currently the UK legal limit[16], would not have produced a measurable change in tooth whiteness.

Adobe Photoshop was used for colour analysis, as this package enabled colour values to be obtained quickly and simply, and has been used in previous studies for tooth shade evaluation[17,18].

In this study the reliabilty result of the image analysis system was found to be within the excellent range for Fleiss' coefficient of reliability, and this result is in agreement with previous studies using the image system on extracted teeth[10,19].

The changes in CIE Lab coordinates for the 12 extracted teeth after the two tooth whitening treatments showed the teeth became lighter and less chromatic i.e. more towards a whiter shade, this was also true for the CIE whitening index results. There was a greater colour change and increase in whiteness after the bleaching treatment than for the polishing treatment. This was probably as a result of the bleaching step removing the intrinsic staining within the enamel and dentine layer which caused the majority of the tooth colourations, and removing these whitened and lightened the teeth.

Visual shade matching was included in this study to back up the whitening results obtained by image analysis. Although the image system can detect small increases in whiteness, a visual increase in whiteness is important when assessing the efficacy of whitening products as people using these products would want to be able to see a change in whiteness of their treated teeth.

The digital image analysis system is able to provide highly accurate repeat measurements of tooth colour and whiteness measurements, as precise repositioning of a tooth surface is simple to achieve and the whole surface of a tooth can be assessed to give total tooth colour. This technique does not require tooth surface contact, avoiding any cross-infection issues and removing the need for sterilisation between subjects. A permanent database of high resolution images can be obtained using image analysis, allowing re-evaluation of the data at a later date. In addition to the assessment tooth colour, the image system is able to make spatial measurements such as area and perimeter of tooth discolorations such as stains, demineralised areas and areas of a tooth surface affected by anomalies.

Although the image analysis approach is of an objective nature, there is an element of subjectivity relating to the drawing by hand of an area of interest around the tooth crown. Therefore this procedure may introduce a small element of random error.

Conclusion

It was concluded that the digital image analysis system can detect changes in tooth colour, including whiteness after a tooth whitening regime in an artificial oral cavity. The image system has been shown to be a reliable and suitable instrumental method for assessing tooth colour including whiteness and could be utilised for assessing the efficacy of tooth whitening products or dental anomalies.

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MANUFACTURERS DETAILS

All Chemicals for artificial saliva, Sigma-Aldrich, Poole, UK

Dulux black waterproof emulsion, ICI paints, Slough, UK

Phosphate buffered saline and thymol crystals, Sigma-Aldrich Company Ltd, Poole, UK

Essentials Toothpaste, Boots PLC, Nottingham, UK

Oral B plaque removing toothbrush, Gillettec, Galashields, UK

Cavitron SPS portable polishing machine, Dentsply Ltd, Weybridge, Surrey, UK

Oral B toothpaste, Oral B Consumer Services, Boston, Mass, USA

Urea hydrogen peroxide, Sigma-Aldrich, Poole, UK

Solux lamp, Outside-in Ltd, Cambridge, UK

Fluorescent tubes, Lighting Technology, Manchester, UK

Standard white tile, Avian technologies, Ohio, USA

Adobe PhotoShop, Adobe Systems, Uxbridge, UK

Vita 3D Master colour guide, Vita Zahnfabrik, H.Rauter GmbH & co.Kg, Germany

Trevalon Pink veined resin, Ivoclar Vivadent Ltd, Leicester, UK

GI-Mask silicone, Coltene Whaledent Ltd, West Sussex, UK

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