Long-term evaluation of enamel colour change following orthodontic treatment: a randomised clinical trial

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Objective: To evaluate enamel colour change over a period of one year after the completion of fixed appliance treatment and to assess the influence of two different clean-up procedures and the resulting surface roughness.

Materials and methods: Seventeen orthodontic patients were debonded and the residual resin removed using tungsten carbide burs followed by enamel polishing with Stainbuster burs or Sof-Lex discs in a split mouth design. A spectrophotometric colour evaluation was performed after clean-up (T0), polishing (T1), and one year later (T2). Colour parameters were measured and enamel colour change (ΔE) was calculated. Surface roughness was determined at T1 and T2 using epoxy replicas. Data were analysed using paired and unpaired tests and Pearson's correlation.

Results: Significant differences in colour change and surface roughness caused by the polishing techniques at T1 were observed. However, this difference was not evident at T2 (p < 0.05). Surface roughness and colour change showed no significant correlation.

Conclusion: Enamel colour changed significantly when evaluated at T2 (one year post-orthodontic treatment). Stainbuster burs resulted in brighter and smoother teeth immediately after orthodontic treatment. The colour and surface roughness were not significantly different after one year and had no significant correlation.

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Introduction

An attractive smile is comprised of facial, gingival, micro and macro aesthetics. An integral component of micro-aesthetics is tooth colour. The natural colour of enamel varies from light yellow to grayish (bluish) white and is extrapolated through the Munsell system, which involves parameters of hue, value and chroma. However, colour is quantitatively better expressed through the Commission Internationale de l’Eclairage (CIE) colour parameters L*, a* and b*. L* measures the lightness while a* and b* represent the position on the red-green and blue-yellow axis, respectively.

Conventionally, orthodontic treatment focuses on various aspects of aesthetics, with colour often being overlooked. Orthodontic treatment involves bonding, debonding and clean-up procedures, the adverse effects of which may be manifested as structural defects of the enamel. These result in an alteration of the enamel surface, affecting the form and brightness of the teeth. This iatrogenic alteration of enamel colour has been studied both in vitro and in vivo.

Previous in-vitro studies have analysed enamel colour change before, during, and after orthodontic treatment and have reported significant enamel colour change following treatment. However, the results have to be interpreted with caution because extracted teeth in an in-vitro system do not always reflect the oral environment. The few in-vivo studies that have corroborated the in-vitro findings have limited their reports to the immediate post-debonding phase.
Following fixed appliance removal, the teeth are subjected to environmental variables, principally the buffering capacity of saliva, calcium homeostasis, remineralisation, residual composite and food colourant, all of which can further affect tooth colour. The in-vitro studies that have tried to simulate the long-term effects on colour, by a process called photoageing, have reported mixed results. After completion of orthodontic treatment, whether the altered enamel colour improves or deteriorates is of concern to the orthodontist as well as the patient, but to the best of current knowledge there are no in-vivo studies that provide definitive answers.

Surface roughness, which is an important factor that alters light refraction of enamel, depends on the finishing procedures applied by the clinician. Clean-up performed only with burs results in significant enamel scratches. Polishing with multistep Sof-Lex discs after resin removal by a tungsten carbide bur leaves a smoother enamel surface. Trakyali et al. reported reduced enamel colour change following the use of Stainbuster composite finishing burs. Hence Sof-Lex and Stainbuster burs were used as polishing interventions to assess surface roughness. The objectives of the present study were to evaluate enamel colour change one year after fixed appliance treatment, whether two different clean-up procedures would influence colour change and surface roughness, and also to assess if the colour change correlated with surface roughness.

Materials and methods

Ethical approval was obtained from the Institutional Ethics Committee. Based on the data of Karamouzos et al., the sample size was determined to be 15 patients with an alpha error probability of 0.05 and power of 80%. In anticipation of patient loss during the follow-up period, 17 patients were enrolled in the study.

Patients who had completed fixed orthodontic treatment and were in the age range of 14–21 years at the completion of treatment were included in the trial. The exclusion criteria were patients who had poor oral hygiene, dental caries, restorations, decalcifications in the teeth mesial to the first premolars, patients who smoked or had other deleterious habits. The study was divided into two parts.

Part 1: Assessment of enamel colour at three time points:

I. Immediately after debonding and clean up (T0)
II. After polishing (T1)
III. Follow-up after one year (T2)

Part 2: Surface roughness determination at two time points:

I. Immediately after polishing (T1)
II. Follow-up after one year (T2)

Part 1

All enrolled patients completed fixed orthodontic treatment using stainless steel brackets (Mini 2000, Ormco Corporation, CA, USA), which were bonded with similar etching and bonding protocols. On the completion of orthodontic treatment, the brackets were debonded using debonding pliers (Straight, Skodi Orthodent, Hyderabad, India) and cleaned by one clinician using 12-fluted tungsten-carbide burs (Prima Carbide burs, Thornleigh, Australia) attached to a low speed hand piece (NSK, Tochigi, Japan) until the visible composite was removed.

The VITA Easyslide advance spectrophotometer (Figure 1, VITA Zahnfabrik, Bad Säckingen, Germany) was used to objectively assess enamel colour of all natural teeth mesial to the first premolars (T0). The protocol followed by Karamouzos et al. for spectrophotometric colour evaluation was adopted. The CIE (Commission Internationale de l’Eclairage) colour parameters (L*, a* and b*) were measured for each tooth.

Figure 1. Measurement of CIE L*, a* and b* parameters using Vita Easyslide Compact Spectrophotometer.
Two different polishing procedures allocated between the two sides in a split mouth design were used. Upper and lower teeth mesial to first premolars on one side of the mouth were polished with Sof-Lex discs (SHOFU-Super Snap Mini Kit 48 disk, US Dental Depot, FL, USA). The discs were used at low rpm for 20 seconds on each tooth, until visibly smooth and polished surfaces were obtained (Group 1). Upper and lower teeth on the contralateral side were polished with Stainbuster burs (Stainbuster, Abrasive Technology, Inc. OH, USA) until visibly smooth and polished surfaces were obtained (Group 2). A second spectrophotometric colour evaluation was performed at this time point (T1). All patients were given oral hygiene instructions and recommended to use Colgate toothpaste (Colgate-Palmolive, NY, USA). The patients were recalled after a year and the teeth were cleaned to remove plaque. The spectrophotometric colour evaluation was performed under natural light and follow-up tooth colour (T2) was determined. To ensure blinding and to eliminate operator variability, all clean-up procedures were done by a single operator while colour measurements were performed by a different operator.

The resultant colour differences (\(\Delta E\)) between the groups were calculated according to the equation\(^{21}\)

\[
\Delta E^* = \sqrt{[(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]}\]

\(\Delta E_1\) indicates colour change between debonding (T0) and polishing (T1)

\(\Delta E_2\) indicates colour change between polishing (T1) and follow-up (T2)

\(\Delta E_3\) indicates colour change between debonding (T0) and follow-up (T2)

**Part 2**

A representative sample of eight patients from the total sample of 17 patients who were enrolled in part 1 of the study was randomly selected for surface roughness determination and the protocol described by Bonetti et al. was adopted.\(^{22}\) Epoxy replicas of the upper central incisors were impressed at T1. The replicas (Figure 2) were tested for surface roughness using a non-contact 3D optical profilometer (Bruker, Contour GT, MA, USA). The \(S_a\) values, which are the average roughness values, were measured and determined by the arithmetic mean of the height of peaks and depth of valleys from a mean line (Figure 3).\(^{23}\) After one year (T2), the surface roughness was re-determined.

![Sample epoxy replica of the studied teeth.](image)

![Surface roughness measurement using profilometer.](image)
**Statistical analysis**

The collected data were analysed using SPSS statistics software, version 23.0 (IBM, CHI, USA). To find significant differences between the bivariate samples in the paired groups, the paired sample *t*-test was used, and for independent groups the unpaired sample *t*-test was used. To assess the relationship between the variables, Pearson’s correlation was applied. In all the above statistical tools, the probability value of <0.05 was considered as significant.

**Results**

At baseline, information regarding age, gender, and oral hygiene status was collected and were found to be similar in both groups (Table I). There was a progressive increase in ΔE values from T0 to T2 (Table II). The teeth became progressively lighter (*L* value) from T0 to T2 and these changes were statistically significant. Changes in *a* values were minimal and were also not statistically significant. *b* values demonstrated that the teeth shifted towards the blue region of the blue-yellow axis at T1 but shifted towards the yellow region at T2. These changes were statistically significant.

There were no statistical differences between the two interventions, namely Sof-Lex and Stainbuster burs at all time points except in *L* value at T1 (Table III). *L*, *a* and *b* values were cumulatively assessed to calculate ΔE. Intervening time periods (ΔE1 and ΔE2) demonstrated statistical significance. Nonetheless, the overall colour changes (ΔE3) were similar between the two groups in the long term (*p > 0.05*). Therefore, it may be surmised that there is no difference between the two polishing techniques over the evaluated period of one year (Table IV).

Sof-Lex discs produced a significantly rougher surface at T1 (*p < 0.05*). This was negated over a period of one year. At T2 both interventions resulted in similar surfaces when compared with T1 (Table V). There was no significant correlation between surface roughness and enamel colour change (Table VI).

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**Table I.** Baseline characteristics of patients.

<table>
<thead>
<tr>
<th>Demographic details</th>
<th>Clinical characteristics</th>
<th>Cooperation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>OHI (S)</td>
<td>Good 20%</td>
</tr>
<tr>
<td>16.5 y</td>
<td>Fair 80%</td>
<td>Average 40%</td>
</tr>
<tr>
<td>Gender</td>
<td>Male 7</td>
<td>Female 10</td>
</tr>
</tbody>
</table>

**Table II.** Mean CIE values at T0, T1, and T2 and ΔE (ΔE1, ΔE2 & ΔE3) for all studied teeth (*N = 178*) (*p < 0.05*).

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T0-T1</th>
<th>P value</th>
<th>T1-T2</th>
<th>P value</th>
<th>T0-T2</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>81.16±4.49</td>
<td>83.38±3.80</td>
<td>86.65±3.98</td>
<td>2.22</td>
<td>0.000</td>
<td>3.27</td>
<td>0.000</td>
<td>5.49</td>
<td>0.000</td>
</tr>
<tr>
<td>A</td>
<td>-0.88±1.26</td>
<td>-0.85±1.18</td>
<td>-0.93±1.50</td>
<td>-0.02</td>
<td>1.000</td>
<td>0.08</td>
<td>0.523</td>
<td>0.06</td>
<td>1.000</td>
</tr>
<tr>
<td>B</td>
<td>19.94±6.22</td>
<td>19.22±5.89</td>
<td>22.35±5.49</td>
<td>0.72</td>
<td>0.000</td>
<td>-3.13</td>
<td>0.000</td>
<td>2.42</td>
<td>0.000</td>
</tr>
<tr>
<td>ΔE</td>
<td>3.20±2.14</td>
<td>5.59±2.31</td>
<td>7.70±5.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table III.** Intergroup comparison of *L*, *a* and *b* values at T0, T1 and T2 between Groups 1 and 2 (*p < 0.05*).

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>P value</th>
<th>T1</th>
<th>P value</th>
<th>T2</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>81.66±4.11</td>
<td>0.189</td>
<td>82.91±3.74</td>
<td>0.018</td>
<td>86.94±3.49</td>
<td>0.333</td>
</tr>
<tr>
<td>Group 1</td>
<td>80.85±4.68</td>
<td></td>
<td>84.16±3.76</td>
<td></td>
<td>86.36±4.42</td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td>-0.81±1.24</td>
<td>0.393</td>
<td>-0.81±1.13</td>
<td>0.435</td>
<td>-0.90±1.46</td>
<td>0.757</td>
</tr>
<tr>
<td>Group 1</td>
<td>-0.96±1.22</td>
<td></td>
<td>-0.93±1.19</td>
<td></td>
<td>-0.97±1.53</td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td>19.4±6.40</td>
<td>0.181</td>
<td>19.70±6.17</td>
<td>0.737</td>
<td>22.74±6.35</td>
<td>0.345</td>
</tr>
<tr>
<td>Group 1</td>
<td>20.52±5.45</td>
<td></td>
<td>19.38±5.28</td>
<td></td>
<td>21.96±4.47</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

Previous studies that have been limited to colour assessment at the immediate post-debonding phase have confirmed that there was significant enamel colour change following orthodontic treatment.\textsuperscript{8-10} In the oral environment, discolouration may occur via many means: extrinsic discolouration arising from superficial absorption of food colourants, coloured mouth rinses and plaque, and internalised discolouration arising from the chemical structure of the adhesive materials and corrosion products of stainless steel brackets.\textsuperscript{6,24} Hence, the magnitude of the change of tooth colour in the oral environment that takes place over a period of time remains an unanswered question.

The few in-vivo studies, which have assessed the immediate colour change, have only evaluated the influence of etching, adhesive systems and the composition of the adhesives.\textsuperscript{8-10,11} It has been concluded that the type of adhesive system influenced enamel colour. The importance of leaving a pristine tooth surface after orthodontic debonding is paramount and previous in-vitro studies have shown that the clean-up procedures have a significant effect.\textsuperscript{11,14,15} The spectrophotometric evaluation was performed in the middle third of the teeth because it best represents tooth colour.\textsuperscript{29}

Surface roughness measurements were performed using a 3D non-contact surface profilometer which is best able to evaluate surface roughness.\textsuperscript{23} Since natural teeth in in-vivo conditions cannot be subjected to such assessment, replicas were examined. The replicas were fabricated using Aquasil polyvinyl siloxane impression compound and epoxy resin, as suggested by Bonetti et al.\textsuperscript{22} The maxillary central incisors were chosen to assess the surface roughness because they play a significant role in aesthetic judgement performed by lay people.\textsuperscript{30}

Table IV. Inter group comparison of $\Delta E$ values at T0, T1 and T2 between Groups 1 and 2 (N = 89) ($p < 0.05$).

<table>
<thead>
<tr>
<th>Group 1</th>
<th>$\Delta E_1$</th>
<th>$P$ value</th>
<th>$\Delta E_2$</th>
<th>$P$ value</th>
<th>$\Delta E_3$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.19 ± 1.08</td>
<td>6.18 ± 1.57</td>
<td>0.000</td>
<td>7.90 ± 6.63</td>
<td>6.33</td>
<td>0.622</td>
<td></td>
</tr>
<tr>
<td>4.28 ± 2.30</td>
<td>5.00 ± 2.75</td>
<td>0.000</td>
<td>7.51 ± 3.49</td>
<td>3.49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table V. Inter group comparison between the mean surface roughness measurements at T1 and T2 for Groups 1 and 2 (N = 16) ($p < 0.05$).

<table>
<thead>
<tr>
<th>Group 1</th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_1-T_2$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.03 ± 0.36</td>
<td>0.70 ± 0.21</td>
<td>0.53 ± 0.10</td>
<td>0.35 ± 0.20</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Table VI. Correlation between colour change and difference in surface roughness between T1 and T2 (N = 16) ($p < 0.05$).

<table>
<thead>
<tr>
<th>$\Delta E_2$</th>
<th>$Sa_1-Sa_2$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 -0.09</td>
<td>0.840</td>
<td></td>
</tr>
<tr>
<td>Group 2 0.57</td>
<td>0.143</td>
<td></td>
</tr>
</tbody>
</table>

two parameters. Therefore, the influence of surface roughness on colour change was assessed.

While enamel colour may be influenced by many parameters, the effect of age changes on colour was minimised by the selection of adolescents for study. The etching technique, adhesive used, debonding protocol, protocol for colour assessment and the spectrophotometric method of colour evaluation were also standardised.\textsuperscript{7,12,17} A split mouth technique nullified factors such as age, diet, and oral care.\textsuperscript{28} The clean-up only with tungsten carbide burs is not recommended and it is mandatory that a polishing technique follows.\textsuperscript{14,19} Although various options have been suggested, the present study chose to use either Sof-Lex discs or Stainbuster burs based on previous findings.\textsuperscript{12,15} The spectrophotometric evaluation was performed in the middle third of the teeth because it best represents tooth colour.\textsuperscript{29}
Colour changes derived from $L^*$, $a^*$ and $b^*$ parameters generate a $\Delta E$ value which was previously classified by Johnston and Kao. A $\Delta E < 1$ cannot be detected by human observers. $\Delta E$ values $> 2$ may indicate a colour change. It was proposed that a critical value of 3.7 $\Delta E$ units was required for the clinical detection of a colour change. The colour change after polishing in both the groups was in accordance with previous studies. The contribution to this change was due to an increase in lightness and a decrease in the yellowness of enamel. Since colour is measured using reflected light that is influenced by surface characteristics, the increase in lightness can be attributed to an alteration in enamel surface roughness due to polishing. The reduction in the yellowness can be attributed to the removal of adhesive remnants by the polishing procedure. The tooth colour improved after one year when compared to the immediate post-debonding colour readings. Not only were the later improvement values statistically significant, they were also clinically significant since the corresponding $\Delta E$ value was greater than 3.7 units as the proposed clinical threshold. Of the three parameters, changes in $L$ can be readily detected by the human eye. The increase in lightness over one year could be attributed to better light reflection from the enamel surface by the abrasive action of foods and tooth brushing. The increase in yellowness can be attributed to the discolouration of the resin tags due to adsorption of food stains or the corrosion of orthodontic appliances. A scan of the available literature revealed an absence of post-debonding, long-term, in-vivo evaluation of colour change and hence the present results could not be compared.

The polishing technique therefore only plays a significant role in the immediate post-polishing colour change period and not in the long term. Long-term colour changes could be attributed to enamel loss, food, and brushing habits that smooth the enamel surface and reduce the difference between the two polishing techniques. Nonetheless, the importance of ensuring a smooth enamel surface following appliance removal cannot be overstated to reduce the accumulation and retention of dental plaque leading to an increased risk of decalcification. Enamel had a significantly smoother surface following the use of Stainbuster burs when compared with Sof-Lex discs immediately after polishing (T1). The initial surface roughness of both groups was similar after one year as no significant difference between the two methods was apparent. In addition, there was no correlation between surface roughness and colour change. Therefore, factors other than surface roughness caused by clean-up procedures influenced enamel colour over the long term.

Further studies that evaluate tooth colour prior to the placement of orthodontic appliances, followed by a similar long-term follow-up, are required to decisively determine the influence of orthodontic treatment on enamel colour.

Conclusion

Enamel colour improved one year after the debonding of fixed appliances. Polishing with Stainbuster burs resulted in brighter teeth at debond when compared with Sof-Lex discs. However, the enamel colour change was not significantly different between both the interventions after one year. Polishing with Stainbuster burs resulted in smoother tooth surfaces at debond. However, the surface roughness was not significantly different between both groups after one year. There was no significant correlation between surface roughness and tooth colour change.

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