Enamel Color Changes following Orthodontic Treatment

Abstract

Objective: To evaluate and compare the effect of various orthodontic bonding systems and clean up procedures on quantitative enamel colour change. Materials and Methods: A literature search was done to identify the studies that assessed the quantitative enamel colour change associated with the various bonding systems and cleanup procedures. Electronic database (PubMed, Cochrane and Google Scholar) were searched. First stage screening was performed and the abstracts were selected according to the initial selection criteria. Full text articles were retrieved and analyzed during second stage screening. The bibliographies were reviewed to identify additional relevant studies. Results: Sixteen full text articles were retrieved. Six were rejected because the methodology was different. There was significant enamel colour change following orthodontic bonding, debonding and clean up procedures. Conclusion: Self-etching primers produce less enamel colour change compared to conventional etching. Resin Modified GIC produces least colour change compared to other light cure and chemical cure systems. Polishing following the clean-up procedure reduces the colour change of the enamel.

Keywords: Color change, debonding, enamel color

Aesthetics is an integral part of orthodontics, and color is an important aspect of aesthetics. Hue, value, and chroma are the three objective variables used to describe color. The tooth color exhibits a large variation influenced by the structure of enamel and dentin. The other factors such as sunlight in the environment, light scattered from adjacent gingival and periloral tissues, and lip and gum color influence the appearance of the teeth. Tooth color is altered in the oral environment by intrinsic, extrinsic, and internalized discoloration.

Orthodontic treatment involves bonding, debonding, and clean-up procedures, resulting in structural defects. They are enamel loss by etching, surface alteration due to decalcification, and microcracks and scratches caused by the clean-up procedures. These result in changes in the enamel color. The enamel surface etching performed before bonding results in the formation of resin tags produced by the dissolution of the enamel and subsequent penetration and polymerization of adhesive. Several studies have reported the decrease in the resin tag length following the use of self-etching primer (SEP) in comparison to the conventional etching technique.

The discoloration of the adhesive resins may result from endogenous changes such as the formation of oxidation by-products and decomposition of initiators and exogenous changes by the formation of stains. Resins with reduced particle size and hardness, low water sorption, higher filler-resin ratio, and optimal filler matrix resin system increase the color stability of composites. Re-deposition of calcium fluoride that is formed during the reaction with enamel results in discoloration following bonding with resin-modified glass ionomer cement (RMGIC). The colored corrosion products and the crevice corrosion of the stainless steel result in enamel stains in the presence of voids and poor oral hygiene.

Clean-up procedures cannot completely remove the composite remnants without damage to the enamel surface. Various quantitative and qualitative studies show that clean-up with tungsten carbide burs produces less enamel damage. The clean-up done only with burs was aggressive and resulted in surface irregularities, even with low-speed handpieces. Polishing produces a smooth surface. Following debonding, a smooth enamel surface is desirable to minimize color change.

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How to cite this article: Pandian A, Ranganathan S, Padmanabhan S. Enamel color changes following orthodontic treatment. Indian J Dent Res 2017;28:330-6.

Access this article online
Website: www.ijdr.in
DOI: 10.4103/ijdr.IJDR_404_15

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There are two methods to determine tooth color: visual determination and instrumental measurement. Visual determination is highly subjective but remains the most frequently applied method for color determination. However, several factors such as external light conditions, fatigue of the human eye, experience, and age and the inherent limitations of the contemporary shade guides can influence visual color selection. The need for objective color matching and scientific advancements has led to the development of instrumental measurement devices. Various commercial systems, including tristimulus colorimeters, spectroradiometers, spectrophotometers, and digital color analyzers, are used currently and quantify color using the Munsell system.

There is an abundance of literature on enamel surface changes associated with orthodontic treatment and research on enamel color changes induced by bonding, debonding, and clean-up procedures has recently increased owing to the growing concern about aesthetics. While there are systematic reviews on the decalcification effects as a consequence of orthodontic treatment, there is no systematic review on the quantitative enamel color change following the use of the various bonding, debonding, and clean-up procedures.

**Aim**

Hence, the aim of this systematic review was to evaluate and compare the effect of various orthodontic bonding systems and clean-up procedures on quantitative enamel color change.

**Materials and Methods**

**Inclusion and exclusion criteria**

The inclusion criteria were as follows:
- Randomized controlled trials, prospective clinical trials, controlled clinical trials, and *in vitro* studies
- Intervention of bonding, debonding, and clean-up of the tooth
- Comparison of different adhesive systems
- Studies with the color change in the enamel surfaces as the outcome
- Quantitative evaluation of the color change using a spectrophotometer or colorimeter.

The exclusion criteria were as follows:
- Case report and case series, cross-sectional studies, and descriptive studies
- Visual color determination
- Color change following bleaching, decalcification, and white spot lesions.

**Information sources**

The search protocol chosen utilized three electronic databases – PubMed, Cochrane database, and Google Scholar with no time restriction until September 2014.

**Search**

PubMed search results with keywords are depicted in Table 1.

**Risk of bias**

Quality assessment of the *in vivo* studies was performed according to the Effective Public Health Practice Project Scale for quality assessment of quantitative studies. The risk of bias was assessed using “Cochrane Collaboration’s tool for assessing risk of bias.”

Currently, there are no validated guidelines or tools to assess the quality and risk of bias of *in vitro* studies. Although the structure of *in vitro* studies closely resembles that of a clinical trial, they lack external validity. The quality and transparency are promoted by reporting the following criteria:
- Sample size calculation
- Meaningful difference between groups
- Sample preparation and handling
- Allocation sequence, randomization, and blinding
- Statistical analysis.

**Results**

**Study selection**

The process of selection of the included studies from the initial yield is shown in Figure 1.

| Keywords                  | Items found |
|---------------------------|-------------|
| Tooth color               | 88          |
| Orthodontic adhesive      | 134         |
| Orthodontic debonding     | 18          |
| Adhesive removal          | 120         |

Figure 1: Search strategy
Study characteristics

The study characteristics are summarized in Tables 2 and 3.

Risk of bias within studies

Assessment of validity showed that research quality and methodological soundness were high in one study and moderate in the other two in vivo studies. No studies were excluded on the basis of risk of bias. The sample was justified in two studies, and control sample data were reported in four of the investigations. Meaningful difference was established between the groups, sample preparation, and handling followed a definite protocol. Randomization and statistical analysis were performed in all the studies. Intraclass correlation coefficient (ICC) was used to compare the three values (L, a, b) used for measuring color component. This was done to determine the reliability of collected data. The ICC showed high reliability in the studies by Zaher et al.

Results of individual studies

The color change following the use of different adhesives is measured with ΔE values, and the results of individual studies are summarized in Table 4.

Discussion

An important aspect in the visual assessment of a finished orthodontic case is tooth color aesthetics. Color change of

| Authors         | Sample size (human premolars) | Bonding technique                                      | Aging and staining process                          | Method of color evaluation | Results                                                                                       |
|-----------------|--------------------------------|--------------------------------------------------------|-----------------------------------------------------|----------------------------|---------------------------------------------------------------------------------------------|
| Joo et al. [24] | 135                            | CE and SEP with different adhesives                    | Staining 37°C, 0.5% methylene blue solution for 1 h  | Reflection spectrophotometer | Staining color change was not different in CE and SEP following finishing-polishing         |
| Trakyali et al. [25] | 75                            | CE with different adhesives                            | Photo-ageing                                        | Colorimeter                | Color changes were not clinically observed                                                  |
| Zaher et al. [26] | 55                            | Conventional and SEP with Transbond XT adhesive       | -                                                   | Reflectance spectrophotometer | SEP produce less resin tag depth compared to the CE group                                    |
| Boncuk et al. [27] | 175                           | Conventional and SEP with Transbond XT adhesive and RMGIC | Photo-ageing                                        | Spectrophotometer          | Highest color change observed in etch and rinse group and least in RMGIC                    |
| Ye et al. [28]  | 120                            | Light cure, chemical cure, and RMGIC                  | Staining with coffee solution for 1 week            | Spectrophotometer          | Chemical cure showed highest color change, and RMGIC showed least color change             |
| Jahanbin et al. [29] | 100                           | Chemical cure with and without primer, light cure with and without primer and no mix | Tea-coffee solution immersion at 37°C for 1 week    | Colorimeter                | No significant difference between groups                                                    |
| Eliades et al. [30] | 26                            | CE with Transbond XT adhesive and RMGIC               | Photoaging                                           | Colorimeter                | No significant difference between groups                                                    |

CE=Conventional etching, SEP=Self-etching primer, RMGIC=Resin modified glass ionomer cement

| Authors         | Sample | Bonding technique | Treatment duration | Method of color evaluation | Type of study | Results                                                                                       |
|-----------------|--------|-------------------|--------------------|---------------------------|---------------|---------------------------------------------------------------------------------------------|
| Corekci et al. [31] | 22 Treatment: 22 | Grengloo Light bond Kurasper Transbond Chemical and light cure | Treatment: 6.8±1.2 months Control: 8.5±1.1 months | Spectrophotometer | Controlled clinical trial | Composites have similar effects of enamel discoloration                                        |
|                 | Control: 22 |                   |                     |                           |               |                                                                                             |
| Karamouzos et al. [32] | 26 patients |                   | 18-26 months        | Reflectance spectrometer  | Prospective clinical trial | Chemically cured resin showed greater color change                                            |
| Al Maaitah et al. [33] | 34 patients | Different etching techniques without primer and no mix | 12-15 months         | Reflectance spectrometer  | Prospective clinical trial | Etching techniques had no statistically significant change                                      |
Table 4: ΔE values of reviewed studies using different adhesives with tungsten carbide burs

| Authors           | Control | Light cure | Chemical cure | RMGIC |
|-------------------|---------|------------|---------------|-------|
|                   | Transbond XT | Transbond | Blugloo | Eagle bond | Light bond | Amelogen | Grengloo | Kurasper F | Prime dent | Unite | System plus | Concise |
| Joo et al.        | 6.6±1.6 | 7.6±1.3 | 9±1.9 | 8.8±2.2 | 7.2±1.4 | 0.56±0.25 | 0.56±0.38 | 0.51±1.14 | 0.58±0.37 | 0.51±0.32 |
| Trakyali et al.   | 1.60±0.29 | 6.26±1.4 | 5.67±1.45 | 7.1±2.7 | 5.5±1.26 | -         | -         | -         | -         | -         |
| Zaher et al.      | 1.60±0.29 | 6.26±1.4 | 5.67±1.45 | 7.1±2.7 | 5.5±1.26 | -         | -         | -         | -         | -         |
| Boncuk et al.     | 1.60±0.29 | 6.26±1.4 | 5.67±1.45 | 7.1±2.7 | 5.5±1.26 | -         | -         | -         | -         | -         |
| Ye et al.         | 5.2     | -         | -         | -         | -         | -         | -         | -         | -         | -         |
| Jahanbin et al.   | -       | -         | -         | -         | -         | -         | -         | -         | -         | -         |
| Eliades et al.    | -       | -         | -         | -         | -         | -         | -         | -         | -         | -         |
| Corecki et al.    | 0.29±0.17 | 2.13±0.97 | -         | -         | 2.37±1.22 | 2.29±1.44 | 2.11±0.79 | -         | -         | -         |
| Karamouzos et al. | 2.60±0.76 | -         | -         | -         | -         | -         | -         | -         | -         | 3.00±0.82 |
| Maaitah et al.    | -       | -         | -         | -         | -         | -         | -         | -         | -         | 2.85±0.3  |

CE=Conventional etching, SEP=Self-etching primer
Pandian, et al.: Enamel color changes following orthodontic treatment

The enamel surface affects the clinical performance and patient satisfaction. Last decade has seen an increase in the number of studies on the enamel color alteration after orthodontic treatment pertaining to orthodontic bonding systems and clean-up procedures. Our review included ten articles, of which seven[24-30] were in vitro studies and three[31-33] were in vivo studies.

The color changes were evaluated using spectrophotometers and colorimeters. Seven of the ten articles assessed the color change using a spectrophotometer.[24,26-28,31-33] Spectrophotometry is the most reliable form of color measurement. A standardized protocol for spectrophotometric color evaluation was performed. The measuring error was minimized by taking three or five consecutive readings in most of the studies.[26-28,31-33] The threshold levels of 1–3.7 ΔE units were visually perceptible or clinically acceptable. The proposed acceptable limit was set at 3.7 ΔE units. Any deviation in the quantity of illumination output from the internal light source was compensated by the calibration process.[26,27,31-33]

In in vitro studies, photoaging was performed to simulate internal discoloration. In studies by Trakyali et al., Boncu et al., and Eliades et al., photoaging was performed to simulate internal coloring.[25,27,30] The efficacy of photoaging was confirmed in the study by Boncu et al. by the color change observed in the control group. The results showed that photoaging produced statistically significant color change.[27] Eliades et al. suggested that photoaging induced color changes of the debonded surfaces above the threshold.[30] In contrast, findings by Trakyali et al. indicate that photoaging performed following debonding did not cause any color change.[25]

Staining was performed to simulate external coloring in the studies by Joo et al., Jahanbin et al., and Ye et al.[24,28,29] In the studies by Ye et al. and Jahanbin et al., staining with 1-week immersion time was done because it was reported that the maximum discoloration occurred during the 1st week.[28,29] Hence, the long-term staining potential can be analyzed reliably.

Among the articles reviewed, the three studies which compared experimental groups with controls showed statistically significant colour change following orthodontic treatment. The color change between the experimental groups lacked statistical significance.

While comparing the color change following different etching systems using Transbond XT adhesive, two of the four studies showed decreased color change using self-etching technique.[26,27] In the study by Zaher et al., self-etching systems produced less color change compared to the conventional system. They attributed this to the decreased resin tag-depths in SEP since all the experimental groups showed significant color change between baseline and finishing. When all the experimental groups were pooled, a significant positive correlation of moderate strength was found between color change and resin tag depth.[29] Boncu et al. showed increased color change in the conventional etch group when compared to the self-etch group. The self-etch primers superficially demineralize and penetrate dentin and the monomers are polymerized reducing the resin tag-depths.[27] The study by Joo et al. stated that SEPs showed increased color change owing to the greater stain susceptibility. The study also revealed that conventional etching technique left more adhesive on the tooth surface.[24] The results of the study by Al Maaitah et al. showed that the two etching techniques had no statistical significance on tooth color difference. They explain that the long-term discoloration is not evaluated, and hence, the depth of resin tag does not influence short-term superficial discoloration.[31]

Comparing various light cure systems, the three studies showed that there was no significant color difference between them.[24,29,31] Joo et al. attributed this to the complete removal of adhesive resin layer following polishing.[24] In the study by Jahanbin et al., most of the color change was attributed to the uptake of stain by the components of the enamel, not the resin tags. They stated that the type of light cure adhesive and the methods of application had no effect on changes in enamel color.[29] Corekci et al. showed that the different light cure systems showed similar color alterations although they are acceptable and statistically significant.[31]

While comparing the effect of the two adhesive systems, light cure and chemically cure, two of the studies showed that chemical cure resins produced increased color change in comparison to light cure which was statistically significant.[28,32] This finding was contradictory to the findings in two other studies.[25,29] The results by Trakyali et al. showed that the color change in the chemically cured group was statistically not significant. The highest statistically significant ΔE value was clinically not visible to human eye.[25] Similarly, the results of the study by Jahanbin et al. were also statistically not significant.[29] According to Ye et al., the greater color change in the chemical cure resin is due to the amine accelerator oxidation and inhibitors modifying the color.[20]

In two of the studies, RMGIC showed less color change compared to light cure and chemical cure resins and the difference was statistically significant.[27,28] This is because no enamel conditioning was performed, while the main surface color changes are those of polished enamel. In contrast to the previous findings, a study by Eliades et al. showed increased change with RMGIC, but it was statistically insignificant.[30]

Clean-up procedures influence the color changes in the enamel significantly.[24-27,29,30] In the study by Trakyali et al., the increase in ΔE value between baseline-debonding and baseline-polishing in Transbond, Eagle Bond, and Reliance groups are due to surface roughness as a result of tungsten
carbide bur. Trakyali et al. also concluded that clean-up performed only with tungsten carbide burs may lead to increased enamel surface roughness.\[25\] Eliades et al. found no significant difference in color change between teeth subjected to etching and no etching. This was attributed to the surface roughness and altered morphological picture induced by debonding and finishing, which might outweigh the effect caused by the presence of remaining resin tags.\[10\] The magnitude of color change was greater during orthodontic treatment than after treatment in the study by Boncuk et al.\[27\] According to Zaher et al., the adhesive removal and finishing procedures were more invasive in comparison to the resin tags.\[26\] In the study by Joo et al., the finished polished surface showed lower surface irregularity and complete removal of undetectable thin residual layer and the finished surface.\[24\] Jahanbin et al. showed that following polishing, the difference between the buccal and palatal (control) surfaces was not statistically significant.\[29\]

In the study by Joo et al., the finished condition showed higher stain susceptibility than finished-polished condition.\[24\] This was due to the thin adhesive layer, which is removed by polishing. Following finishing and polishing, there was no significant difference between the control and experimental groups, suggesting the need for polishing. Comparing the ΔE value between baseline-debonding and baseline-polishing in studies by Trakyali et al. and Jahanbin et al., there is a significant decrease in the baseline-polishing value.\[25,29\] This clearly emphasizes the need for polishing following debonding.

Despite aesthetics being a prime concern in orthodontics, the studies on this topic are sparse. Among the ten articles reviewed, seven were in vitro studies. More number of in vitro studies done in the future would contribute more to the knowledge in this area. Furthermore, the few in vivo studies performed till date have analyzed only the short-term (immediate postorthodontic treatment) enamel color change. There is a need for long-term studies, which would throw more light not merely on color changes but influencing factors such as enamel surface roughness, corrosion products, stain susceptibility of the residual resin tags among others.

Limitations

The lack of saliva, food coloring, and inability to simulate the mechanical abrasion caused by brushing are the limitations of the in vitro studies. Trakyali et al. could not assess the long-term discoloration caused by absorption of food colorants as in the in vivo conditions.\[25\] Joo et al. failed to assess the refractive index, which is affected by the clean-up procedures.\[24\] The limitation of Zaher et al. was the small number of teeth included in each group that causes lack of significant correlation between color change and resin tag length.\[26\] The color of the enamel is affected by several factors, which limits the determination of the sole effect of resin tag length. Systematic and random errors are the major limitations of the three clinical trials.\[31‑33\] Systematic errors resulting from calibration techniques, fluorescence, metamerism, and variations in instrument geometry are difficult to manage. Taking multiple measurements and averaging minimized the random errors in all the studies. To minimize the systematic error, calibration was performed in most of the studies, but the other factors were difficult to control. Other parameters such as curing times and treatment duration, which have an effect on the color, have not been analyzed in the included in vivo studies.

Summary and Conclusion

This review included ten articles that assessed the enamel color change following orthodontic bonding, debonding, and clean-up procedures. On the basis of the results obtained from this review, the following conclusions can be drawn.

• There is a significant enamel color change following orthodontic treatment
• SEPs produce less enamel color change compared to conventional etching. There is a need for long-term clinical trials to confirm this finding
• RMGIC produces least color change compared to other light cure and chemically cure systems
• Polishing is required, following the clean-up procedures to reduce the color change of the enamel
• Further well-designed in vivo studies are recommended to validate the findings and to compare the results across trials.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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