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Evaluation of the value of re-wetting prior to resin infiltration of post-orthodontic caries lesions

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ABSTRACT

Objectives: Assessment of the influence of colour changes during the re-wetting process as a possible predictor for the final result after resin infiltration to mask post-orthodontic white spot lesions.

Materials and methods: Resin infiltration (ICON; DMG, Hamburg, Germany) was performed according to the manufacturer's recommendation with the exception of repeated, at maximum three etching procedures based on the subjective decision of the dentist during a so called re-wetting process using ethanol. The masking effect by ethanol as well as after resin infiltration was evaluated by digital images taken before, for nine seconds during re-wetting and one week after treatment using CIE L*a*b* colour space.

Results: Twenty-nine patients (16 female) with a total of 221 lesions (ICDAS 2) were included (mean age 16 years). Mean time after debonding the orthodontic appliances was ten weeks. Colour changes during re-wetting, evaluated in the first ten patients (71 lesions) showed a significant correlation between the minimum ΔE observed during re-wetting and the final ΔE after resin infiltration ($r = 0.65$, $p < 0.001$; Spearman correlation). The main drop in ΔE becomes visible after three seconds when performing the re-wetting process.

Regarding the 221 lesions, resin infiltration significantly reduced the colour difference between sound and lesion areas from a baseline ΔE ($25^{th}/75^{th}$ percentiles) of 10.9 (8.2/13.2) to a ΔE of 4 (2.1/5.8) after one week ($p < 0.001$). The number of etching procedures correlated significantly with baseline ΔE ($p < 0.05$).

Conclusions: The minimum ΔE observed during the re-wetting process seems to be a useful predictor for the final result of resin infiltration of post-orthodontic caries lesions. More prominent lesions with higher ΔE at baseline seem to require more erosion of the surface layer. In general, a significant and considerable clinical reduction of ΔE could be observed.

Clinical significance: We corroborate that resin infiltration technique is a very useful method to mask caries lesions having developed during treatment with fixed orthodontic appliances. Colour changes while re-wetting the lesions with ethanol seem to be a valuable indicator for the number of required etching procedures.

1. Introduction

During treatment with fixed orthodontic appliances there is an increased risk for patients to develop caries lesions on vestibular surfaces [1]. Caries risk is increased due to impaired oral hygiene being more difficult around brackets where plaque accumulates more easily [2]. Due to their whitish appearance these are often termed as white spot lesions. White spot lesions develop quickly [3] and are often an aesthetic burden to the patients even years after removal of orthodontic appliances [4]. Their characteristic whitish, opaque appearance can be physically explained by a higher degree of light refraction within the lesion body compared with the surrounding sound enamel due to differences between the transmission media like entrapped air and saliva within the lesion body [5]. Despite several applied preventive measures, prevalences for white spot lesions after treatment with fixed orthodontic appliances of 23 % [6], 50 % [1] or even 97 % [2] have been reported.

After removal of the orthodontic appliances white spot lesions may remineralize in case of improved oral hygiene, which might be supported by the application of fluorides [7] or casein phosphopeptide amorphous calcium phosphate containing pastes [8], but they are also prone to abrasion [9]. However the aesthetic appearance most often remains impaired [10,11]. Other treatment options include microabrasion, which is in general more suitable for superficial lesions,

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because the carious enamel has to be removed almost completely, which may result in concave surfaces when deeper lesions are treated [12–14]. Satisfying and predictable results to improve the aesthetic appearance may be also achieved by direct or even indirect restorations [15]. However these rather highly invasive procedures should be considered mostly for cavitated lesions and in adjunction to the aforementioned therapies.

Resin infiltration technique, being primarily developed to arrest approximal caries lesions is more efficacious to arrest proximal caries lesions compared with non-invasive measures alone [16], but is also able to mask white spot lesions in front teeth [17]. This effect is due to a relatively high refractive index (RI) of the resin infiltrant (1.51) being higher than the substituted water (1.36) or air (1), but still lower than the RI of sound enamel (1.63). Following etching with HCl gel in order to modify the less porous pseudointact surface layer of the caries lesion, the lesion body is infiltrated with the low-viscosity resin. With increasing degree of infiltration light scattering is reduced within the porous lesion body [18]. The masking effect of white spots by resin infiltration has been evaluated in vitro [18,19] as well as in vivo [20–23]. However, most studies included only few patients, and not all evaluated ΔE values as an objective outcome. Moreover, most studies were performed according to the manufacturer's recommendations to etch only once before infiltration. It has been argued that with increasing numbers of etching procedures or increasing etching duration, the aesthetic outcome might be improved due to better penetrability of the resin [24].

Difficulties encountered during clinical application are the reliable prediction of the degree of masking of the white spot lesions. One reason for insufficient masking effects, as result of hindered penetration of the resin, could be large variabilities in the thickness of the surface layer being presumably thicker and less permeable for inactive lesions, which might be reflected by less roughness and higher reflection compared with active ones [25]. Pores of active lesions were reported to be larger and the surface layer less mineralized [26], so that the resin could penetrate deeper into the lesion body. Nonetheless, there are no proven procedures or measures after etching that help to estimate the ability of the resin infiltrant to penetrate through the (remaining) surface layer prior to its application. This is desirable, since once the infiltrant has been applied and the result is not satisfactory no non-invasive method seems capable to remove the infiltrant to allow for deeper infiltration afterwards.

Theoretically, the application of a fluid after the etching procedure allows to evaluate whether the surface layer is sufficiently modified to allow access to the lesion body. This is based on the refractive index (RI) of fluids, which is closer to enamel than the RI of air. Once the surface layer is sufficiently "opened" and the fluid enters the lesion body, light scattering will be reduced [27].

The aim of the present study was to evaluate whether the final result after resin infiltration might be predicted by color changes during re-wetting as reflected by ΔE measurements. We primarily hypothesized that the ΔE one week after resin infiltration correlates with the minimum ΔE observed during re-wetting. Secondly we hypothesized that the number of etching procedures performed correlates significantly with the baseline ΔE.

2. Materials and methods

2.1. Study design & participants

The study design was a single centre, open observational prospective study. Approval was given by the ethical committee of the RWTH Aachen (EK 110/13). All patients respectively their guardians gave their informed written consent before participating in this study. The study has been registered (DRKS00005067).

Participants having developed white spot lesions during treatment with fixed orthodontic appliances were recruited in the Department of Orthodontics, RWTH Aachen University, Germany. Exclusion criteria were allergies to any of the used materials, cavitated caries lesions or debonding longer than 12 months ago. Buccal caries lesions of the first premolars, canines and the front teeth of the upper and lower jaw showing active non-cavitated caries lesions (ICDAS Code 2; International Caries Detection and Assessment System (ICDAS-II)) were included.

2.2. Infiltration treatment

After cleaning the teeth with fluoride-free polishing paste (Cleanic; Kerr, Bioggio, Switzerland), teeth were isolated with liquid rubberdam (OpalDam; Ultradent, South Jordan, USA) to protect the gingiva and keep the work field dry. Lesions were etched with 15 % HCl gel (Icon etch; DMG, Hamburg, Germany) for 120 s, the etching gel was rinsed for 30 s and the teeth were dried with oil free air. The dried teeth were then re-wetted with alcohol (Icon dry; DMG, Hamburg, Germany). During this re-wetting process the dentist decided whether the masking result was subjectively satisfying (i.e. the lesion almost disappeared) with an observer distance of approximately 50 cm. If not, etching (again 120 s) and re-wetting was repeated (maximum number of procedures = three). After the final etching and re-wetting procedure the resin (Icon infiltrant; DMG, Hamburg, Germany) was applied for 180 s. Before light curing (60 s), excessive resin was removed using a cotton roll. A second resin application was performed for 60 s. Thus, the only difference to the manufacturer's recommendation were repeated etchings for the teeth with no satisfying masking effect during re-wetting after once or twice etching. Finally, the lesions were polished with discs (Sof-Lex; 3 M, Saint Paul, USA) and a polishing brush (Occlubrush; Kerr, Orange, USA). One operator (C.K.) performed all treatments.

2.3. Photo documentation

To assess the masking effect digital images were taken prior to treatment (baseline) and compared with the pictures one week after

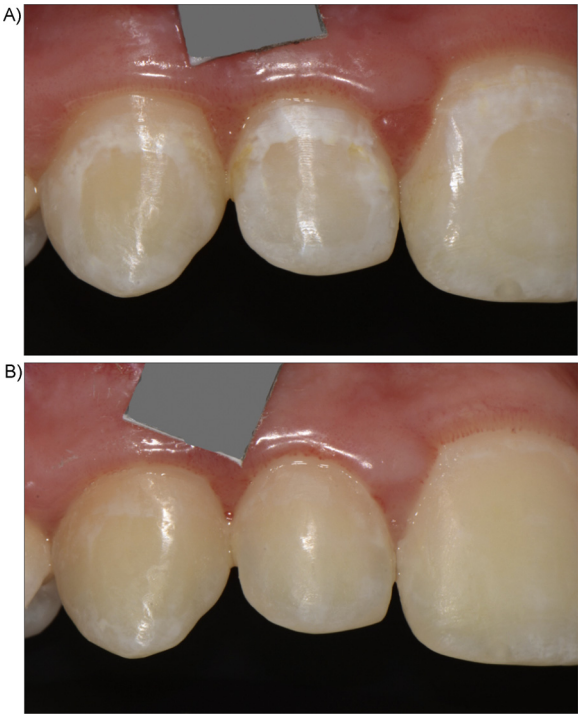

Fig. 1. A: Teeth 13, 12, 11 showing distinct white spot lesions at baseline. Grey card for colour standardisation in situ **B**: Teeth 13, 12 and 11 one week after treatment.

(Fig. 1). Care was taken to avoid colour changes due to teeth dehydration [28]. Digital images for colour measurement were taken using a digital SLR camera (Nikon D7000; Nikon, Chiyoda, Japan) with a ring flash (Sigma EM-140 DG; Sigma, Kawasaki, Japan) and a macro lens (AF S Micro Nikkor 105 mm 1:2.8; Nikon, Chiyosa, Japan). For having standardized conditions all pictures were taken by one operator (C.K.) and the camera was used by manual settings of shutter speed 1/250, aperture F29, iso-sensitivity 100 and a fixed white balance of 6250 K. The flash intensity of left and right tubes was set at ¼. Lip retractors were used to get a direct view to the treated tooth and to avoid shadow formation. The distance between tooth and lens was 20 cm. As reference for colour standardization, a piece of a neutral grey card (18 % grey; Mennon, Lake Forest, USA) was attached to the gingiva, close to the tooth of interest.

In order to assess whether the course of colour differences during the re-wetting process may serve as a possible predictor for the final result after resin infiltration, the chronology of colour changes during this process was evaluated in the first 10 patients of this study. A picture was taken just before the re-wetting process, followed by serial pictures (1 picture per second) during re-wetting for the next 9 s.

2.4. Colour analysis

Colour matching and colour analysis was performed using Photoshop (Photoshop Adobe CS6; Adobe, San Jose, USA). For colour determination the CIE L*a*b* colour space was used, in which every colour is defined by values of L* (lightness), a* (green-red chromacity) and b* (blue-yellow chromacity). The colour difference (Delta E, ΔE) was calculated with the formula $\Delta E_{(c\text{-}h)} = ((L_c - L_h)^2 + (a_c - a_h)^2 + (b_c - b_h)^2)^{1/2}$, where c is defined as carious (white spot lesion) and h as healthy enamel. Possible colour deviations were eliminated by referencing every image to the grey card [29].

The L*a*b* values of healthy enamel and white spot lesions are reported as means of four different measuring points with a size of 11 × 11 pixels (Fig. 2). The measuring points were chosen in the area of the most obvious opaque and white lesion and in the adjacent healthy enamel. The same measuring points were used in the pre- and post-treatment analysis for resin infiltration and for evaluation of the colour changes during the re-wetting process.

2.5. Statistics

Statistical analysis was performed using SPSS (SPSS Statistics 24; IBM, Armonk, USA). Lesions (one lesion/buccal surface) were defined as statistical unit. The pilot phase was planned with ten patients. Based on the pilot results of the first 71 lesions (10 patients) sample size calculation was performed. A correlation of 0.65, $\alpha = 0.01$ and $1\text{-}\beta = 0.9$ indicated that 28 lesions were necessary to evaluate whether the final result after resin infiltration may be predicted during re-wetting. This number had been reached within the first 10 patients. In the following 19 patients only the ΔE values before and after resin-infiltration as well as the number of etching procedures were evaluated to get a sufficient number of lesions for evaluating the final outcome and to allow a follow up of two years (calculations will be presented there).

Normal distribution of the data was tested using the Shapiro-Wilk-test. Correlations were analysed by the Spearman correlation coefficient. Differences of ΔE values at baseline and one week after treatment were analysed with the Wilcoxon signed rank test. The baseline ΔE values in the different groups (lesions etched once (E1), etched twice (E2) and etched three times (E3)) were compared with the Kruskall-Wallis test with Bonferroni adjustment.

To compare the differences between ΔE values of the different re-wetting courses, we used a Wilcoxon signed rank test for the group with two re-wetting procedures and the Friedman test with pairwise comparisons (adjusted by the Bonferroni correction) for the group with three re-wetting courses. Delta E values, unless otherwise specified, were noted as median (25th/75th percentiles). The level for significance was set at 5 %.

3. Results

Between November 2013 to December 2014, 31 patients were included in this study of which two patients missed presentation for follow-up after one week and were excluded from analysis. Therefore 29 patients (16 female and 13 male) with an average age of 16 years with a total of 221 lesions (ICDAS 2) were included in this study. Of these 221 lesions, 110 were located at front teeth, 57 at canines and 54 at first premolars. Mean time after debonding was ten weeks (SD: 13 weeks).

3.1. Re-wetting

In the first ten patients of this study having 71 lesions, colour changes during the re-wetting process were evaluated by serial pictures. The final ΔE after resin infiltration correlated significantly with the minimum ΔE observed during re-wetting ($r = 0.65$, $p < 0.001$; Spearman correlation). In general, colour changes during re-wetting showed an intense decrease of ΔE within the first three seconds (from t0 [start of re-wetting] to t3 [3rd second after the start]) followed by only small changes during the remaining observation period (from t4 to t9) (Fig. 3). At t3, a reduction of 84 % of ΔE was observed in group E1. In group E2 a reduction of 82 % of ΔE during the first re-wetting and of 84 % during the second re-wetting was observed at t3. In the group E3 with three re-wetting procedures we observed a reduction of ΔE of 70 % during the first, a reduction of ΔE of 79 % during the second, and a reduction of 75 % during the third re-wetting at t3.

Statistical analysis revealed for group E2 that the second re-wetting was associated with significantly ($p < 0.001$ to $p < 0.05$) lower ΔE values at every measured time point, except t0 ($p > 0.05$), as compared to the first re-wetting (Fig. 3). In group E3 we observed significant differences of ΔE between the first and third re-wetting at every measured time point ($p < 0.001$ to $p < 0.05$) except t9 ($p > 0.05$) and between the first and second re-wetting at some time points (t1, t3, t4, t5, t6) ($p < 0.05$). However, there were no significant differences of ΔE at any measured time point between the second and third re-wetting ($p > 0.05$).

The final ΔE after resin infiltration improved (lower value) significantly from the lowest ΔE observed during re-wetting ($p \leq 0.001$). There was a difference of ΔE 1.52 (0.15/2.68) compared with the minimum ΔE during re-wetting. However, the rapidness of ΔE reduction during re-wetting did not correlate significantly with the result one week after resin infiltration ($r = -0.07$, $p = 0.54$; Spearman correlation).

3.2. Effect of resin infiltration

The number of etching procedures performed during treatment differed: in 22 lesions the etching procedure was performed once (E1), in 76 lesions the etching procedure was performed twice (E2) and in 123 lesions the etching procedure was performed three times (E3) (Fig. 4). Statistical analysis revealed a significant higher baseline ΔE in group E3 compared with group E1 ($p < 0.05$). Overall, a significant but weak correlation of the number of etching procedures performed with the baseline ΔE was observed ($r = 0.163$; $p < 0.05$; Spearman correlation).

At baseline, we observed a colour difference expressed as ΔE (median (25th/75th percentiles)) of 10.9 (8.2/13.2) between carious and sound enamel regarding all 221 lesions. Overall, infiltration treatment significantly reduced the colour difference to ΔE 4.0 (2.1/5.8) ($p < 0.001$; Wilcoxon test).

In all groups resin infiltration significantly reduced ΔE (Fig. 5): in group E1 ($n = 22$) ΔE was reduced from 8.8 (6.8/12.2) to 2.5 (1.5/3.8) ($p < 0.001$), in group E2 ($n = 76$) from 11.1 (8.2/13.0) to 2.6 (1.7/

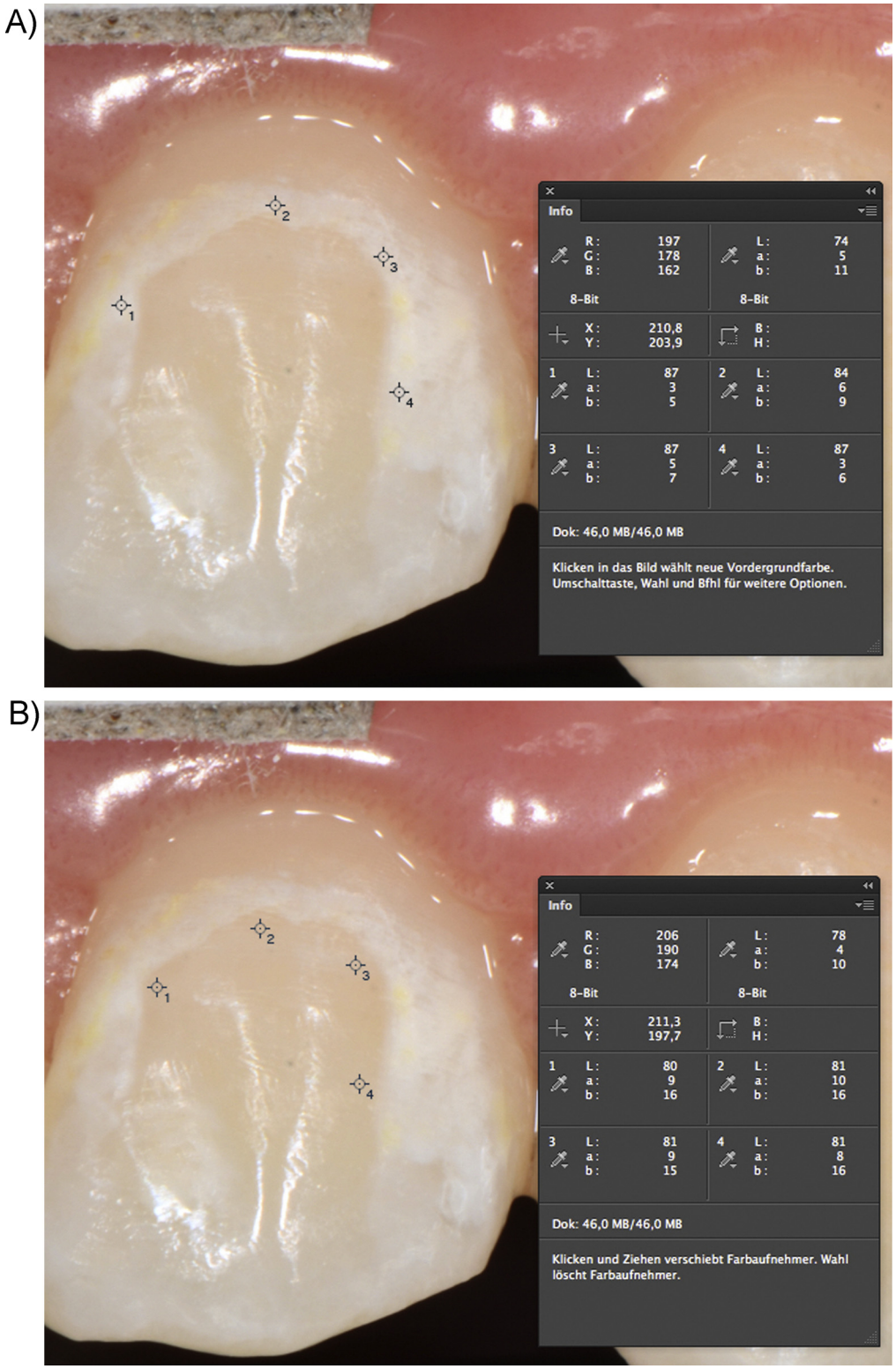

Fig. 2. A: digital photograph of tooth 22 before treatment with four colour samplers on the lesion showing the L, a and b values. **B:** same picture with 4 colour samplers on the sound enamel and corresponding L, a and b values.

4.9) ($p < 0.001$), and in group E3 (n = 123) from 11.4 (8.5/14.0) to 5.0 (3.0/6.6) ($p < 0.001$).

4. Discussion

To our best knowledge, our study is the first to investigate the course of ΔE changes during the re-wetting-procedure and correlate these changes to the final result following resin infiltration. The primary hypothesis that the ΔE one week after resin infiltration correlates with the minimum ΔE observed during re-wetting could be confirmed. During re-wetting, we observed a steep ΔE reduction within the first three seconds followed by a plateau for the next six seconds. The

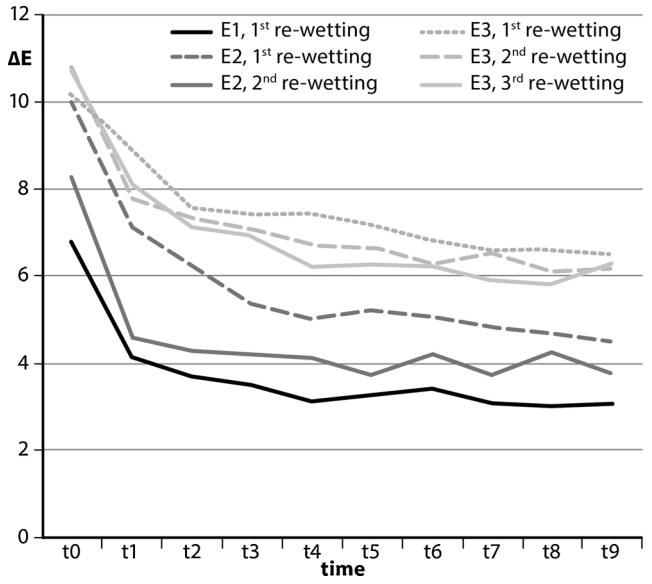

Fig. 3. Course of ΔE reduction after etching (t0) and during re-wetting (t1-t9). Black line: teeth with one etching/re-wetting procedure (E1). Grey lines: teeth with two etching/re-wetting procedures (E2; dashed line representing the first non-satisfying re-wetting procedure). Light grey lines: teeth with three etching/re-wetting procedures (E3; dotted and dashed lines representing the first and second non-satisfying re-wetting procedures). For reasons of clarity, the 25th/75th percentiles are not shown.

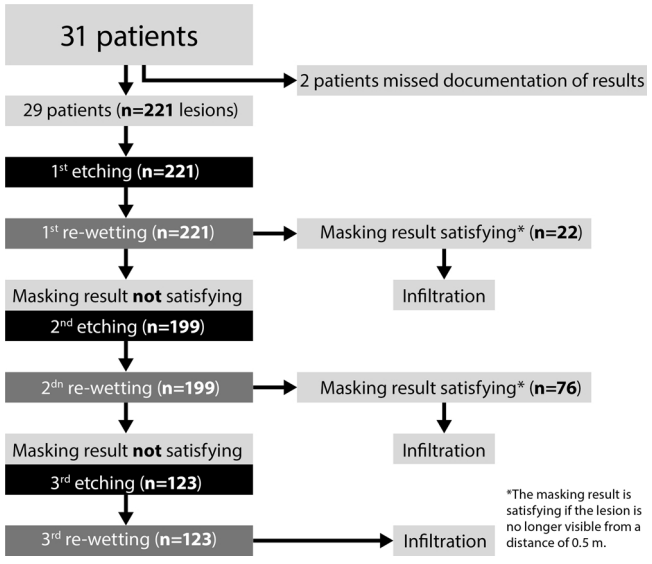

Fig. 4. Protocol of etching and re-wetting procedures.

minimum ΔE during re-wetting correlates significantly with the ΔE one week after treatment, even if the final result after resin infiltration showed a further reduction of ΔE 1.52 (0.15/2.68) as compared to the minimal ΔE during the re-wetting procedure, which might be explained by the the higher refractive index (RI) of the resin infiltrant of 1.51 being closer to sound enamel (1.63) compared with the alcohol used during re-wetting (1.36) [30]. These findings support our impression that the re-wetting procedure helps to estimate the final result and thereby supports the dentist's decision for possibly required further etching procedures before resin infiltration is performed. For re-wetting we used the Icon-Dry solution, because its use is already integrated in the course of treatment as compared to other possible fluids (e.g. water). Although the primary purpose of the Icon-dry solution is to enhance the drying effect by air, its application in the first seconds

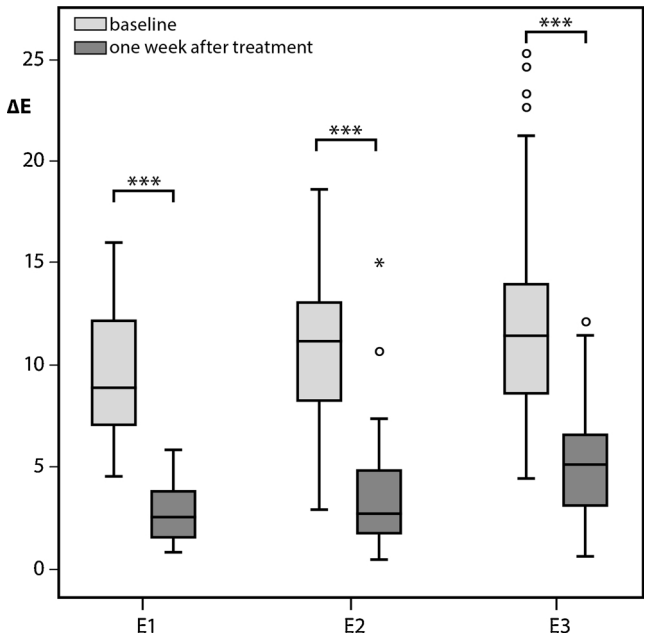

Fig. 5. Box-and whisker-plots of ΔE values at baseline and one week after treatment, differentiated by different number of etching procedures. E1 lesions with one etching procedure (n = 22), E2 lesions etched twice (n = 76) and E3 lesions with three etching procedures (n = 123) (box = upper and lower quartile, horizontal line = median, whiskers = minimum/maximum, asterisk = extreme, circles = outliners). Statistically significant differences are marked by asterisks (*** $p < 0.001$).

resembles a re-wetting procedure, because during our observation period within the first nine seconds, we observed no drying or evaporation of the Icon-Dry solution.

The second study hypothesis, that the number of etching procedures performed correlates significantly with the baseline ΔE could also be confirmed. Our data show that there is a positive but weak correlation of number of etching procedures performed and the baseline visual severity of the white spot lesion as described by initial ΔE. Thus, teeth with more obvious lesions received more likely two or three etching procedures.

To achieve a satisfying result, a preferably complete infiltration of the resin into the lesion body is necessary [31]. For this, the superficial layer of the lesion has to be modified during the etching procedure to open the pores and to allow the resin or the ethanol to penetrate into the lesion body. However, the thickness of this layer shows a high variability [32] and thereby makes the success of this procedure highly dependent on the dentists experience. This might explain that the duration and repetition of the etching procedures differed throughout the following studies. Kim et al. only performed one etching procedure of 120 s for all patients [20], whereas Knösel et al. described a more individualized protocol of three or four etching procedures with a total etching-time of 6, 7 or 8 min depending on the observation of ΔE reduction during the re-wetting process [22]. A similar protocol was used in our study, in which we determined the number of etching procedures for every lesion depending on the aesthetic results during the re-wetting procedure. Also in case of an unsatisfying result during the third re-wetting, we limited the etching procedures to a maximum of three to maintain the micro-invasive character of the infiltration technique. Since each etching procedure removes approximately 35–45 µm of the surface layer [32], three etching procedures would result in a maximal reduction of 105–135 µm and thus most presumably a complete removal of the surface layer in most active and inactive lesions. More frequent unnecessary repeated etching procedures would result in an unreasonable removal of enamel without an improvement of the result because the limiting factor appears now to be the depth and /or the

degree of mineralization of the lesion body itself rather than the remaining superficial layer of less porous enamel. This assumption is supported by our results showing in group E2 that the second etching procedure resulted in a significant reduction of ΔE during re-wetting as compared to the re-wetting following the first etching procedure. However, in group E3 the third etching procedure only had minor impact as compared to the second etching procedure (Fig. 3).

In general, resin infiltration achieved a significant reduction of ΔE from 10.9 (8.2/13.2) to a final value of 4.0 (2.1/5.8), which is just slightly above the threshold for perception, described as a ΔE of 3.7 [33]. Subgroup analysis revealed that lesions being etched once (group E1) showed a reduction of ΔE below 3.7 in 73 % of the cases, whereas lesions etched twice or three times showed this reduction in only 62 % and 32 % of lesions, respectively. The final result was less satisfying in those teeth that required more etching procedures, most presumably due to higher baseline ΔE that was more difficult to be reduced by the resin. These findings are in line with previous studies [20–22] also showing a good masking effect of resin infiltration for post-orthodontic white spot lesions. However, comparison of the extent of the effect is difficult due to different measuring methods and outcomes used in the former studies. For example, a lower reduction of ΔE (from mean ΔE 7.88 to ΔE 5.65) as compared to our patient population has been reported and might be a result of differences in ΔE measurement [22]. We calculated ΔE at the most prominent sites within the lesion, whereas in the other study colour intensity of the whole white spot lesion was measured using a spectrophotometer. It appears that included lesions in our patient population showed more obvious white spot lesions as compared to the patients in the former study (initial mean ΔE of 11.2 at severe sites vs. an average ΔE of 7.88) [22]. Another study reported the results by categorization in “completely masked”, “partially masked”, and “only little changes” [20]. Although this categorization was based on ΔE measurements, the exact changes in ΔE are not retraceable and therefore not directly comparable to our results. Nonetheless, Kim et al. reported satisfying results in most lesions in this small case series with 18 post-orthodontic lesions. A third study used grey scale values on digital pictures before and after treatment and showed a significant change of the grey scale values after resin infiltration for lesions without surface disruption (from 126.091 to 221.268) as well as in the group with roughened surfaces (from 95.585 to 155.612) [21].

In general, clinical digital pictures are prone to be influenced by a lot of variables like camera adjustment or ambience of light. Therefore, we took our digital pictures under standardized conditions and performed colour assessments with an image software, which is reported to be reproducible [34]. To eliminate any further interferences we adjusted every image to a piece of neutral grey card [29] and compared colour differences within one and not between different digital images.

5. Conclusion

Based on the data of our study we conclude that the observation of colour changes during the re-wetting process, may serve as a good predictor for the (even better) final aesthetic result after resin infiltration. The main drop in ΔE during re-wetting becomes visible after three seconds and the visual appearance at that time point is best to predict the final result and to decide whether a further etching procedure is advisable. The number of etching procedures performed significantly correlates with the baseline ΔE, thus more obvious lesions received more likely two or three etching procedures. Overall, we can confirm that resin infiltration achieved a significant reduction of ΔE to values just slightly above the threshold for perception.

The Charité - Universitätsmedizin Berlin (Germany) holds US and European patent for an infiltration technique for dental caries lesions in which one of the authors (HML) is appointed as inventor. HML receives royalties as well as research funding from DMG (Hamburg, Germany), the manufacturer of Icon.

Declaration of Competing Interest

The Charité - Universitätsmedizin Berlin (Germany) holds US and European patent for an infiltration technique for dental caries lesions in which one of the authors (HML) is appointed as inventor. HML receives royalties as well as research funding from DMG (Hamburg, Germany), the manufacturer of Icon.

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References

[1] L. Gorelick, A.M. Geiger, A.J. Gwinnett, Incidence of white spot formation after bonding and banding, Am. J. Orthod. 81 (2) (1982) 93–98.
[2] J.G. Boersma, M.H. van der Veen, M.D. Lagerweij, B. Bokhout, B. Prahl-Andersen, Caries prevalence measured with QLF after treatment with fixed orthodontic appliances: influencing factors, Caries Res. 39 (1) (2005) 41–47.
[3] B. Ogaard, G. Rolla, J. Arends, Orthodontic appliances and enamel demineralization. Part 1. Lesion development, Am. J. Orthod. Dentofacial Orthop. 94 (1) (1988) 68–73.
[4] B. Ogaard, Prevalence of white spot lesions in 19-year-olds: a study on untreated and orthodontically treated persons 5 years after treatment, Am. J. Orthod. Dentofacial Orthop. 96 (5) (1989) 423–427.
[5] E.A. Kidd, O. Fejerskov, What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms, J. Dent. Res. 83 Spec No C (2004) C35–8.
[6] K.C. Julien, P.H. Buschang, P.M. Campbell, Prevalence of white spot lesion formation during orthodontic treatment, Angle Orthod. 83 (4) (2013) 641–647.
[7] D. Sardana, J. Zhang, M. Ekambaram, Y. Yang, C.P. McGrath, C.K.Y. Yiu, Effectiveness of professional fluorides against enamel white spot lesions during fixed orthodontic treatment: a systematic review and meta-analysis, J. Dent. 82 (2019) 1–10.
[8] E.C. Reynolds, F. Cai, N.J. Cochrane, P. Shen, G.D. Walker, M.V. Morgan, C. Reynolds, Fluoride and casein phosphopeptide-amorphous calcium phosphate, J. Dent. Res. 87 (4) (2008) 344–348.
[9] A.M. Kielbassa, L. Gillmann, C. Zantner, H. Meyer-Lueckel, E. Hellwig, J. Schulte-Monting, Profilometric and microradiographic studies on the effects of toothpaste and acidic gel abrasivity on sound and demineralized bovine dental enamel, Caries Res. 39 (5) (2005) 380–386.
[10] D.R. Willmot, White lesions after orthodontic treatment: does low fluoride make a difference? J. Orthod. 31 (3) (2004) 235–242.
[11] D.L. Bailey, G.G. Adams, C.E. Tsao, A. Hyslop, K. Escobar, D.J. Manton, E.C. Reynolds, M.V. Morgan, Regression of post-orthodontic lesions by a remineralizing cream, J. Dent. Res. 88 (12) (2009) 1148–1153.
[12] D.P. Dalzell, R.I. Howes, P.M. Hubler, Microabrasion: effect of time, number of applications, and pressure on enamel loss, Pediatr. Dent. 17 (3) (1995) 207–211.
[13] F.S. Wong, G.B. Winter, Effectiveness of microabrasion technique for improvement of dental aesthetics, Br. Dent. J. 193 (3) (2002) 155–158.
[14] L.S. Tong, M.K. Pang, N.Y. Mok, N.M. King, S.H. Wei, The effects of etching, microabrasion, and bleaching on surface enamel, J. Dent. Res. 72 (1) (1993) 67–71.
[15] S.J. Sadowsky, An overview of treatment considerations for esthetic restorations: a review of the literature, J. Prosthet. Dent. 96 (6) (2006) 433–442.
[16] S. Chatzimarkou, D. Koletsi, K. Kavvadia, The effect of resin infiltration on proximal caries lesions in primary and permanent teeth. A systematic review and meta-analysis of clinical trials, J. Dent. 77 (2018) 8–17.
[17] S. Paris, H. Meyer-Lueckel, Masking of labial enamel white spot lesions by resin infiltration - a clinical report, Quintessence Int. 40 (2009) 713–718.
[18] S. Paris, F. Schwendicke, J. Keltsch, C. Dorfer, H. Meyer-Lueckel, Masking of white spot lesions by resin infiltration in vitro, J. Dent. 41 (Suppl. 5) (2013) e28–34.
[19] C. Rocha Gomes Torres, A.B. Borges, L.M. Torres, I.S. Gomes, R.S. de Oliveira, Effect of caries infiltration technique and fluoride therapy on the colour masking of white spot lesions, J. Dent. 39 (3) (2011) 202–207.
[20] S. Kim, E.Y. Kim, T.S. Jeong, J.W. Kim, The evaluation of resin infiltration for masking labial enamel white spot lesions, Int. J. Paediatr. Dent. 21 (4) (2011) 241–248.
[21] S.M. Hammad, M. El Banna, I. El Zayat, M.A. Mohsen, Effect of resin infiltration on white spot lesions after debonding orthodontic brackets, Am. J. Dent. 25 (1) (2012) 3–8.
[22] M. Knosel, A. Eckstein, H.J. Helms, Durability of esthetic improvement following Icon resin infiltration of multibracket-induced white spot lesions compared with no therapy over 6 months: a single-center, split-mouth, randomized clinical trial, Am. J. Orthod. Dentofacial Orthop. 144 (1) (2013) 86–96.
[23] M. Knosel, A. Eckstein, H.J. Helms, Long-term follow-up of camouflage effects following resin infiltration of post orthodontic white-spot lesions in vivo, Angle Orthod. (2018).

[24] S. Paris, H. Meyer-Lueckel, Resin infiltration after enamel etching. in: J. Perdigao (Ed.), Tooth Whitening – an Evidence-Based Perspective, Springer, Berlin, 2016, pp. 211–223.
[25] M. Ando, M. Fontana, G.J. Eckert, R.A. Arthur, H. Zhang, D.T. Zero, Objective and quantitative assessment of caries lesion activity, J. Dent. 78 (2018) 76–82.
[26] N.J. Cochrane, P. Anderson, G.R. Davis, G.G. Adams, M.A. Stacey, E.C. Reynolds, An X-ray microtomographic study of natural white-spot enamel lesions, J. Dent. Res. 91 (2) (2012) 185–191.
[27] E.A.M. Kidd, O. Fejerskov, What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms, J. Dent. Res. 83 (Spec. No) (2004) C35–38.
[28] M.D. Russell, M. Gulfraz, B.W. Moss, In vivo measurement of colour changes in natural teeth, J. Oral Rehabil. 27 (9) (2000) 786–792.
[29] W.M. Bengel, Digital photography and the assessment of therapeutic results after bleaching procedures, J. Esthet. Restor. Dent. 15 (Suppl. 1) (2003) S21–32.
[30] Z. Meng, X.S. Yao, H. Yao, Y. Liang, T. Liu, Y. Li, G. Wang, S. Lan, Measurement of the refractive index of human teeth by optical coherence tomography, J. Biomed. Opt. 14 (3) (2009) 034010.
[31] H. Meyer-Lueckel, S. Paris, C. Infiltration, H. Meyer-Lueckel, S. Paris, K.R. Ekstrand (Eds.), Caries Management – Science and Clinical Practice, Thieme, Stuttgart, New York, 2013, pp. 245–258.
[32] H. Meyer-Lueckel, S. Paris, A.M. Kielbassa, Surface layer erosion of natural caries lesions with phosphoric and hydrochloric acid gels in preparation for resin infiltration, Caries Res. 41 (3) (2007) 223–230.
[33] W.M. Johnston, E.C. Kao, Assessment of appearance match by visual observation and clinical colorimetry, J. Dent. Res. 68 (5) (1989) 819–822.
[34] A. Sluzker, M. Knosel, A.E. Athanasiou, Sensitivity of digital dental photo CIE L*a*b* analysis compared to spectrophotometer clinical assessments over 6 months, Am. J. Dent. 24 (5) (2011) 300–304.