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Quantitative light-induced fluorescence assessment of white spots following semi-rapid maxillary expansion

Yasemin Nur Korkmaz[a,*], Ahmet Yagci[b], Suleyman Kutalmış Buyuk[c]

[a] Bolu Abant İzzet Baysal University, Faculty of Dentistry, Department of Orthodontics, Bolu, Turkey
[b] Erciyes University, Faculty of Dentistry, Department of Orthodontics, Kayseri, Turkey
[c] Ordu University, Faculty of Dentistry, Department of Orthodontics, Ordu, Turkey

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ABSTRACT

Background: This study aimed to investigate if the semi-rapid maxillary expansion (SRME) can cause white spot lesion (WSL) formation using quantitative light-induced fluorescence digital (QLF-D).
Methods: The SRME group comprised 15 patients (9 girls, 6 boys; 13.5 ± 1 years) who had transverse maxillary deficiency and underwent expansion with full-coverage expanders. The screw of the expanders in the SRME group was activated twice a day for the first week. After decementation at the end of the first week, the screw activation protocol was changed to 3 turns/ week. In the SRME group, the QLF-D images were captured before starting treatment and 3.18 ± 0.32 months later when the expansion treatment was completed. The control group consisted of 15 subjects (8 girls, 7 boys; mean age 14.2 ± 1.9 years) who never had orthodontic treatment. The images of the control group were obtained with 3 months interval. The images were analyzed in terms of demineralization using analysis software.
Results: The left central incisor was the only tooth that was affected by WSL formation in the SRME group after expansion. The left central incisor tooth's fluorescence levels were decreased and the lesion area increased significantly ($p < 0.05$). No significant mineralization changes occurred in the control group ($p > 0.05$).
Conclusions: SRME resulted in WSL formation in the left central incisor, while other teeth were not affected by demineralization. Although providing adequate oral hygiene is easier during SRME due to the removable appliance, the orthodontist should still be aware that it may cause demineralization.

1. Introduction

Semi-rapid maxillary expansion (SRME) was first described by Mew [1,2] with an activation period of 1 mm per week to obtain a physically more advantageous expansion than slow and rapid maxillary expansions (RME). Sandikçioğlu and Hazar [3] also used 1 mm/ week activation protocol for SRME in their study in 1997. In 2004, a new protocol was introduced to literature by İşeri and Özsoy [4]. Their schedule comprised 2 turns/ day for the first five to six days and then 3 turns/ week until reaching adequate expansion. This RME period followed by slow maxillary expansion has caused decreased tissue resistance and improved adaptation of the circummaxillary structures, resulting in more stable treatment outcomes.

Among numerous maxillary expanders, full-coverage bonded acrylic splint expander stands out with its characteristic of an increased anchorage and it provides control in the vertical dimension by hindering the tipping of the posterior teeth [5]. However, its complex structure facilitates plaque accumulation. Previously, RME using full-coverage bonded expander was shown to cause white spot lesion (WSL) formation through enhanced plaque accumulation, potential decementation, and microleakage [6]. WSL formation is an undesirable side effect of orthodontic treatment and the prevalence of visible lesions after treatment in university and private practice settings ranges from 25% to 28% [7,8]. In their 14-year follow-up study, Shungin et al. [9] showed that orthodontic treatment-related WSL areas did not return to before treatment levels and revealed the importance of preventing demineralization from occurring in the first place.

Increased oral hygiene is the first step to prevent WSLs. The midpalatal suture separates after the first five to six days in SRME and then the expander is debonded to be used as a removable appliance during the remaining expansion time. Owing to the removable appliance, the patients could clean the expander and their teeth easily. It is not known whether SRME treatment can prevent demineralization that was shown to occur during bonded RME treatment.

* Corresponding author at: Bolu Abant İzzet Baysal Üniversitesi Diş Hekimliği Fakültesi, Ortodonti A.D. Gölköy Kampüsü, Bolu, Turkey.
E-mail addresses: y.nur002@gmail.com (Y.N. Korkmaz), dtahmetyagci@hotmail.com (A. Yagci), skbuyuk@gmail.com (S.K. Buyuk).

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Quantitative light-induced fluorescence (QLF) is a technique that diagnoses non-cavitated caries lesions by evaluating changes in tooth mineralization through tooth autofluorescence which occurs during irradiation with visible blue light at 405 nm. The autofluorescence reduces in a demineralized lesion compared with healthy enamel in consequence of the replacement of minerals by water [10]. The different generations of QLF devices were shown to be effective tools of detection for enamel caries [11]. Studies indicated that the progression, regression or stability of a barely seen WSL could be analyzed by QLF [12]. QLF has proven beneficial in the monitoring of demineralized lesions both in patients undergoing fixed orthodontic treatment [13] and after the conclusion of orthodontic treatment [14]. Furthermore, QLF is a multifunctional device that was shown to have the possibility of realizing theragnosis in the field of tooth-bleaching [15]. In addition to incipient caries detection, QLF-digital (QLF-D), the upgraded generation of QLF, provides dental plaque assessment via red fluorescence. When irradiated with the blue light of QLF-D, endogenous porphyrins in bacteria generate red fluorescence [16]. Depending on the intensity of the red fluorescence, the cariogenicity of the dental plaque can be assessed [17].

In the literature, there are many studies related to dento-alveolar changes and post-expansion stability after SRME, as well as studies on its different effects [1,4,18,19]. However, no information analyzing the effect of SRME procedure on enamel demineralization exists. Knowing whether SRME causes demineralization is likely to be an important factor in the choice of expansion method by clinicians. Therefore, the aim of our study was to investigate the effect of SRME on WSL formation, which is one of the major side effects of orthodontic treatment and is as important as skeletal and dental effects for clinicians, using QLF-D. The hypothesis tested was that there will be no significant difference in the formation of WSLs between the SRME and untreated control groups.

2. Materials and methods

This prospective clinical study sample comprised 30 individuals who applied to Erciyes University, Faculty of Dentistry. The inclusion criteria were the presence of permanent maxillary ten anterior teeth without caries and fillings for both groups and additional maxillary deficiency with posterior crossbite for the experimental group. The examination of dental caries of the sample was performed by an experienced orthodontist by visual inspection with patients positioned in a dental chair, using reflector light, air/water spray and plane buccal mirror. Patients who had cavitation and distinctly visible opacity or discolorations of teeth were excluded. The presence of early enamel demineralization was recorded by QLF examination at T0 and was added to the analysis. Patients who had craniofacial anomalies, poor general and periodontal health and previous orthodontic treatment story were also excluded. The experimental group consisted of 15 patients, 9 girls and 6 boys, who had a transverse maxillary deficiency and the control group consisted of 15 patients, 8 girls, and 7 boys, who received no orthodontic treatment. The mean ages of the experimental and control groups were 13.5 ± 1 and 14.2 ± 1.9 years, respectively. The research was approved by the local research ethics committee of Erciyes University, Kayseri, Turkey. An informed consent form was signed by all parents. A power analysis was performed with G*Power software (version 3.1.9.2; Universitat Dusseldorf, Germany) using the ΔF parameter for maxillary right central incisor [6]. A sample size of 14 subjects in each group was calculated to give 80% power to identify significant differences with an effect size of 0.7433052 at a significance level of $\alpha = 0.05$.

A full coverage acrylic maxillary expander design which covered the palate and teeth was used for expansion in the experimental group as the initial stage of their treatment. Glass ionomer cement (Ketac Cem radiopaque; 3 M ESPE, Neuss, Germany) was used for the cementation of the expanders. Parents of the patients were instructed to open the screw twice a day at 12-hour intervals for the first week. At the end of the first week, the expanders were decemented and continued to be used as removable appliances for the rest of the treatment (Fig. 1). After decementation, the screw activation protocol was changed to 3 turns/week and the parents were told to continue the screw activation with the appliance in situ. The activation was stopped as the tips of the palatal cusps of the maxillary first molars contacted the tips of the buccal cusps of the mandibular first molars. The patients were asked to wear the expander all the time to prevent adaptation difficulty and relapse. The patient compliance regarding wearing the expander all the time during follow-up was evaluated by checking the adaptation of the expander to teeth during patient appointments which were scheduled biweekly. The mean expansion time was 3.18 ± 0.32 months.

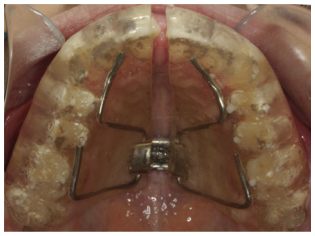

Fig. 1. Removable full-coverage acrylic splint expander.

The patients were warned to avoid hard food to prevent fracture of the appliance. The patients at both groups were requested to brush their teeth after meals throughout the treatment. The SRME patients brushed their teeth and the appliance with the appliance in place while it was cemented. After decementation, they were asked to remove the appliance only during brushing. Both groups were given the same instructions for oral hygiene and the same brushing training. They were told to only use toothbrush and toothpaste. Additional fluoride supplements except these were not requested.

QLF-D Biluminator 2-camera system (Inspektor Research Systems, Amsterdam, The Netherlands) was used to take QLF-D records of the patients. Two different experienced examiners did the investigation with QLF-D. Same camera position and angulation was provided while capturing the QLF-D images of the teeth in a dark room by a trained examiner who was blinded to the groups. The camera position and angulation was standardized for T0 and T1 assessments by adjusting the camera with a tripod at a fixed point while the patient was in the natural head position. The image capturing software (C3 v1.26, Inspektor Research Systems) was used to keep the QLF-D images (Fig. 2). T0 records of the SRME group were obtained before cementation of the expander. T1 records were captured 3.18 ± 0.32 months later when the expansion was completed. The T0 and T1 records of the control group were obtained with 3 months interval.

A second investigator who was blinded to groups carried out QLF-D image analysis via image analysis software (QA2 v1.26; Inspektor Research Systems) (Fig. 3). The buccal surfaces of upper incisors, canines, and premolars were analyzed in terms of four parameters (Fig. 4). 1 month after the first analysis, the calculations were repeated by the same examiner. All of the measurements had intra-class correlation coefficients above 0.940, which confirmed the reliability.

2.1. Statistical analysis

With the use of the Shapiro-Wilk test, the data was found not to be normally distributed and thus non-parametric tests were used. The Wilcoxon signed rank test was used for the intragroup analysis, while the Mann-Whitney U test was used for the intergroup comparisons. The level of statistical significance was set at $p < 0.05$ (version 15.0; SPSS 20, Chicago, Ill).

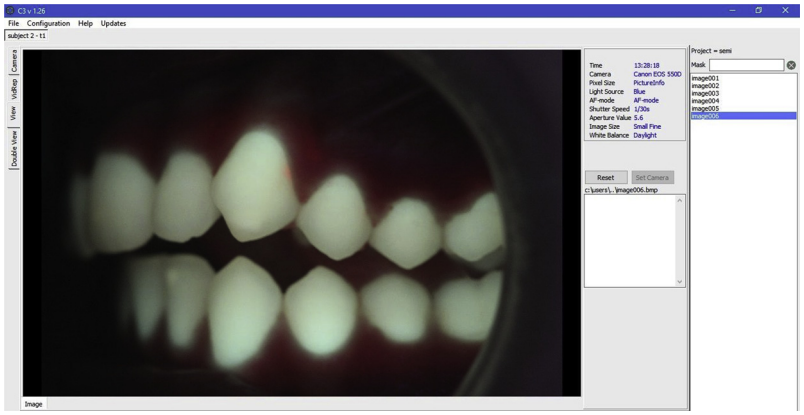

Fig. 2. Left lateral intraoral QLF-D image in the image capturing software (C3 v1.26, Inspektor Research Systems).

3. Results

The mean ages of the groups at the start of the treatment were not significantly different ($p > 0.05$).

None of the teeth except for the left central incisor showed significant changes between the parameters at T0 and T1 in the SRME group. Fluorescence level of the left central incisor enamel decreased after expansion, showing demineralization ($p < 0.05$). The mean scores and p values of 150 enamel surfaces in the SRME group were shown in Table 1.

Table 2 displays the mean scores and p values for four parameters in

Parameter	Description
ΔF (%)	The percentages of fluorescence loss with respect to the fluorescence of sound tooth tissue
$A_{\Delta F}$ (px^2)	Lesion area with ΔF equal to or less than a -5% threshold
ΔQ (%px^2)	The percentage of fluorescence loss with respect to the fluorescence of sound tissue times the area that indicated lesion volume
ΔR (%)	Percentage of increase of the ratio of the red and the green component with respect to that ratio of sound tissue that is related to the presence of porphyrins and indirectly related to bacterial activity

Fig. 4. Descriptions of measured QLF-D parameters.

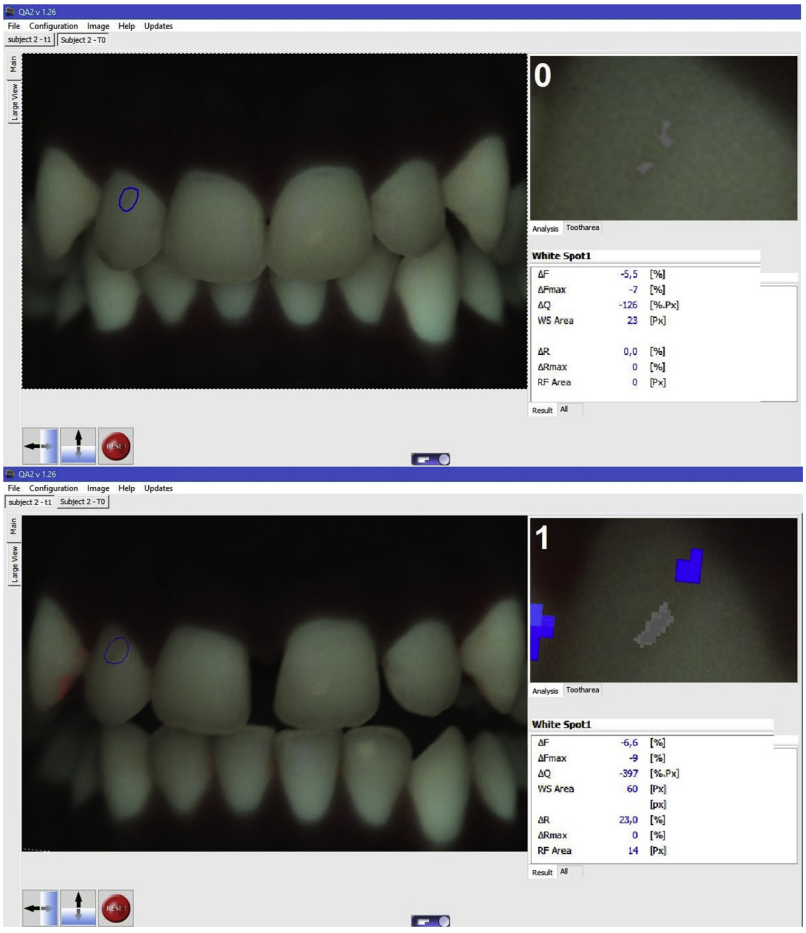

Fig. 3. Progression of demineralization of an existing white spot lesion in the right lateral incisor after SRME identified with the image analysis software (QA2 v1.26; Inspektor Research Systems).

Table 1
Mean (Standard deviation) and *p* values of four tested parameters in the SRME group.

Tooth[a]	ΔF(%) T0	ΔF(%) T1	ΔF(%) *p*	ΔQ(%px²) T0	ΔQ(%px²) T1	ΔQ(%px²) *p*	A(px²) T0	A(px²) T1	A(px²) *p*	ΔR(%) T0	ΔR(%) T1	ΔR(%) *p*
11	−0.73(1.92)	−0.82(2.18)	1.000	−1.07(3.03)	−1.53(4.39)	0.414	0.20(0.56)	0.27(0.80)	0.564	1.65(6.40)	3.39(8.97)	0.655
12	−1.34(2.89)	−1.99(4.36)	0.500	−8.53(24.37)	−147.33(389.17)	0.345	1.47(4.22)	12.27(32.29)	0.345	2.01(7.80)	8.19(15.10)	0.068
13	−1.21(3.25)	−1.91(4.13)	0.109	−74.07(262.23)	−66.93(191.77)	1.000	7.27(25.02)	7.07(20.01)	1.000	3.17(12.26)	2.74(7.23)	0.655
14	−0.47(1.83)	−1.34(2.77)	0.285	−0.47(1.81)	−21.33(52.73)	0.109	0.07(0.26)	3.20(7.93)	0.109	3.75(10.18)	6.43(17.68)	0.180
15	−1.35(2.87)	−1.65(2.85)	0.753	−16.73(50.04)	−16.60(37.68)	0.528	2.13(5.96)	2.53(5.69)	0.596	1.85(7.18)	3.89(10.60)	0.655
21	−0.77(2.03)	−3.04(3.53)	0.028	−1.53(4.05)	−29.73(60.66)	0.051	0.27(0.70)	4.33(7.52)	0.018	1.81(7.02)	2.95(7.84)	0.655
22	−1.77(3.06)	−3.01(3.91)	0.236	−58.60(117.69)	−105.73(290.80)	0.866	8.73(17.35)	12.00(32.34)	0.866	3.32(8.82)	1.83(7.07)	0.180
23	0.00(0.00)	−1.51(3.27)	0.109	0.00(0.00)	−44.53(147.08)	0.109	0.00(0.00)	4.60(14.34)	0.109	0.00(0.00)	0.00(0.00)	1.000
24	−0.79(2.08)	−0.94(2.51)	0.461	−4.73(15.33)	−28.00(77.75)	0.465	0.80(2.60)	3.87(10.38)	0.465	0.00(0.00)	3.31(8.75)	0.180
25	−0.81(2.13)	−1.11(2.31)	1.000	−13.73(39.72)	−12.47(32.38)	0.715	2.27(6.54)	2.20(5.66)	1.000	0.00(0.00)	2.26(8.75)	0.317

[a] According to the FDI system of notation.

the control group. None of the parameters showed statistically significant changes between T0 and T1 ($p > 0.05$). The control group showed no WSL formation.

The differences between the parameters at T0 and T1 were compared between the SRME and control groups. The values for intergroup comparisons were given in Table 3. The groups were reasonably similar to each other in terms of mineral loss except for the left central incisor.

4. Discussion

Early detection of demineralization is of great importance to avoid the irreversible point where restorations are inevitable, so that remineralization of the lesions can be possible. To date, many devices have been developed for this purpose. In this study, QLF-D was chosen as an assessment tool for demineralization owing to its advantages such as faster image acquisition, ease of use and continuous lesion management by monitoring dynamic mineralization changes in the lesions.

Knowledge of the cariogenicity of the dental plaque may raise awareness regarding the risk of demineralization and provide an advantage to prevent WSL formation. Even in the intraoral areas which are clinically hard to see, the mature plaque is observed as red fluorescence with the QLF-D images. This property of the system simplifies detection of demineralization risk through identification of the cariogenic level of the dental plaque. The reason for demineralization is considered to be the mature plaque, rather than the young plaque and the red fluorescent emitting plaque is assumed matured [20,21]. High levels of red fluorescence were not observed before and after SRME in the present study, indicating the adequate oral hygiene levels of the patients. This could be attributed to strict oral hygiene instructions given to patients prior to treatment. Additionally, the removal of dental plaque is much easier for patients using removable appliances compared to fixed appliances and this may have increased the effectiveness of brushing.

The use of QLF-D for assessing enamel demineralization after SRME appears to be advantageous since it provides a quick and precise evaluation that is both simple for the patient and the clinician. However, its clinical use may be limited since it is a relatively expensive device.

Although the effects of fixed orthodontic appliances on demineralization are well documented in the literature [22,23], the effects of removable orthodontic appliances had not been investigated. SRME is a method that includes both fixed and removable appliance phases and to our knowledge, this is the first study to investigate its effects on WSL formation. It was previously indicated that bonded rapid maxillary expanders caused demineralization of the teeth under the appliance [6]. The present study showed that in contrast to the control group, demineralization was detected in the SRME group, albeit in a single tooth. Thus, the hypothesis of this study was rejected. Demineralization under the removable full-coverage expander may be the result of food accumulation between the acrylic surface of the expander and the teeth.

The skeletal effects of SRME treatment had been investigated in different studies. Although greater skeletal expansion than dental expansion occurs immediately after RME, Proffit [24] indicated that the dental and skeletal effect rates of rapid and slow expansion are similar 10 weeks after expansion. Ramoglu and Sari [18] showed that RME and SRME procedures had similar dentofacial effects in the transverse, sagittal and vertical planes. İşeri and Özsoy [4] stated that SMRE stimulated adaptation of circummaxillary sutures and caused less tissue resistance and thus, the dentoskeletal changes after SRME remained stable after three years of retention in older adolescents and adults. However, the long treatment duration and demineralization risk should be considered before choosing this treatment modality.

The patients were told to remove the device from their mouths after the meal so that they could effectively brush their teeth and the device. They were also warned to wear the appliance back immediately after brushing. They were asked to brush using only toothpaste and toothbrush and not to apply any other dental cleaning instruments. Effects of fluoride supplements on WSL prevention in patients undergoing treatment with brackets are well known [25,26]. Studies regarding their

Table 2
Mean (Standard deviation) and *p* values of four tested parameters in the control group.

Tooth[a]	ΔF(%) T0	ΔF(%) T1	ΔF(%) *p*	ΔQ(%px²) T0	ΔQ(%px²) T1	ΔQ(%px²) *p*	A(px²) T0	A(px²) T1	A(px²) *p*	ΔR(%) T0	ΔR(%) T1	ΔR(%) *p*
11	−0.93(2.47)	−1.19(2.48)	0.593	−3.87(11.86)	−36.07(109.60)	0.285	0.53(1.60)	5.47(15.86)	0.285	1.47(5.68)	2.13(5.64)	0.655
12	0.00(0.00)	−1.13(2.35)	0.109	0.00(0.00)	−2.60(5.50)	0.109	0.00(0.00)	0.47(0.99)	0.102	0.00(0.00)	0.73(2.84)	0.317
13	−0.43(1.65)	−0.76(2.01)	0.655	−0.40(1.55)	−12.60(36.93)	0.180	0.07(0.26)	2.20(6.46)	0.180	2.90(11.23)	3.08(9.15)	1.000
14	−1.05(2.94)	−0.87(2.30)	0.655	−25.47(88.91)	−7.67(26.55)	0.180	2.67(8.58)	1.13(3.87)	0.180	2.33(9.04)	3.15(12.19)	0.317
15	−0.47(1.83)	−0.95(2.56)	0.180	−2.33(9.04)	−42.13(155.34)	0.180	0.33(1.29)	5.13(18.54)	0.180	1.58(6.12)	4.27(11.32)	0.180
21	−0.93(2.47)	−1.29(2.69)	0.655	−6.40(16.93)	−23.67(62.54)	0.109	0.93(2.49)	3.40(8.75)	0.109	0.00(0.00)	0.00(0.00)	1.000
22	−1.21(4.70)	−1.75(3.09)	0.715	−81.40(315.26)	−13.60(35.84)	0.715	4.47(17.30)	1.80(4.33)	0.715	0.80(3.10)	4.00(15.49)	0.317
23	−0.33(1.29)	−0.37(1.45)	0.317	−0.67(2.58)	−1.47(5.68)	0.317	0.13(0.52)	0.27(1.03)	0.317	1.13(4.39)	0.93(3.61)	0.317
24	0.00(0.00)	0.00(0.00)	1.000	0.00(0.00)	0.00(0.00)	1.000	0.00(0.00)	0.00(0.00)	1.000	0.00(0.00)	1.73(6.71)	0.317
25	−0.82(2.17)	−1.87(2.75)	0.138	−2.40(6.34)	−13.07(27.96)	0.053	0.40(1.06)	2.20(4.64)	0.052	0.73(2.84)	1.80(6.97)	0.317

[a] According to the FDI system of notation.

Table 3
Mean(Standard deviation) and *p* values in four tested parameters, the intergroup comparison.

Tooth[a]	Semi-rapid ΔF(%)	Control ΔF(%)	ΔF(%) *p*	Semi-rapid ΔQ(%px²)	Control ΔQ(%px²)	ΔQ(%px²) *p*	Semi-rapid A(px²)	Control A(px²)	A(px²) *p*	Semi-rapid ΔR(%)	Control ΔR(%)	ΔR(%) *p*
11	−0.09(2.32)	−0.25(1.55)	0.458	−0.47(2.61)	−32.20(107.56)	0.929	0.07(0.46)	4.93(15.51)	0.929	1.74(6.88)	0.67(4.17)	0.944
12	−0.65(4.82)	−1.13(2.35)	0.613	−138.80(372.24)	−2.60(5.50)	0.651	10.80(29.39)	0.47(0.99)	0.613	6.17(13.91)	0.73(2.84)	0.612
13	−0.69(1.71)	−0.33(1.50)	0.164	7.13(286.99)	−12.20(35.49)	0.587	−0.20(28.71)	2.13(6.22)	0.725	−0.43(8.99)	0.18(15.13)	0.725
14	−0.87(2.39)	0.17(0.98)	0.587	−20.87(52.01)	17.80(62.36)	0.151	3.13(7.83)	−1.53(4.73)	0.028	2.69(7.52)	0.81(3.15)	0.498
15	−0.30(3.87)	−0.48(1.54)	0.873	0.13(63.05)	−39.80(146.31)	1.000	0.40(8.17)	4.80(17.26)	1.000	2.04(9.53)	2.69(7.84)	0.362
21	−2.27(2.96)	−0.35(1.42)	0.587	−28.20(59.19)	−17.27(46.92)	0.032	4.07(7.35)	2.47(6.47)	0.429	1.14(5.27)	0.00(0.00)	0.152
22	−1.23(3.82)	−0.53(3.61)	0.317	−47.13(238.69)	67.80(282.57)	1.000	3.27(27.08)	−2.67(13.84)	0.943	−1.49(5.73)	3.20(12.39)	0.943
23	−1.51(3.27)	−0.37(1.45)	0.277	−44.53(147.08)	−0.80(3.10)	0.277	4.60(14.34)	0.13(0.52)	0.277	0.00(0.00)	−0.20(0.77)	0.317
24	−0.15(3.49)	0.00(0.00)	1.000	−23.27(81.02)	0.00(0.00)	1.000	3.07(11.00)	0.00(0.00)	1.000	3.31(8.75)	1.73(6.71)	0.577
25	−0.31(2.61)	−1.05(2.24)	0.344	1.27(22.14)	−12.67(22.66)	0.096	−0.07(3.67)	2.20(3.76)	0.096	2.26(8.75)	1.07(4.13)	0.962

[a] According to the FDI system of notation.

effect in patients undergoing SRME should be designed in the future to diminish demineralization.

The importance of wearing the appliance full time except brushing was cautiously explained to patients. They were told that the adaptation of the appliance to teeth will be lost if they fail to wear it all the time. All patients in this study used the appliance as told and no adaptation problems occurred. However, the weakness of the removable appliances is that it completely depends on patient cooperation. Treatment duration will increase in non-cooperated patients.

Compared with the bonded RME, the removable appliance has some deficits that complicate the treatment process. After decementation, the patients were told to continue to eat with the expander in place during meals to avoid adaptation difficulty and relapse. They were told to avoid hard and hot food to not cause damage to the expander. Despite the full coverage design of the appliance that increases the retention, the patients had difficulties while eating. A bonded expander would have been more comfortable than a removable one during eating. No additional impairments were observed related to mouth opening or limitation of jaw movement during treatment. Nevertheless, new studies regarding the patient's pain level, discomfort and quality of life during SRME are required.

Another weakness of SRME is the elongated treatment time compared with RME. The slower expansion protocol results in the increment of the duration of treatment and this will reduce the patient cooperation.

The inability to control the nutritional regime of the subjects was a limitation of this study. Although the patients were told not to consume certain foods and drinks, the possible differences in their eating habits that may have an effect on demineralization could not be controlled. Another limitation was that the control group comprised patients who did not receive orthodontic treatment. Although SRME patients had a brushing regime similar to untreated controls rather than the RME patients, there was not a matching procedure between the controls and the experimental subjects. Further studies with the RME controls should be designed in this regard.

Our results showed that the left central incisor was the only tooth that showed demineralization after expansion in the SRME group. The mineral loss in the left central incisor may be attributed to the position of this tooth that was near the midline of the appliance, which may have caused increased plaque accumulation. Additionally, the reason of the difference between both central incisors may be associated with the initial localization of the crowding in this area, the tooth brushing hand, the eating habits of the patient or the difference in the initial mineralization level of both teeth.

5. Conclusion

While providing sufficient oral hygiene is easier with removable SRME, the orthodontist should be aware that it could still result in demineralization. SRME patients, especially those with increased demineralization risk, should be monitored for the formation of WSLs.

Declarations of interest

None.

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