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Incidence of caries lesions among patients treated with comprehensive orthodontics

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Introduction: Dental caries, specifically decalcified white-spot lesions (WSL), is a well-known side-effect of orthodontic treatment. The incidence of labial incipient caries lesions and its relationship with various patient and treatment variables was investigated in patients treated with comprehensive orthodontics. **Methods:** Randomly selected orthodontic patient records (n = 350) were examined to determine incipient caries lesion development. Labial surfaces on pretreatment and posttreatment photographs were scored with a standardized scoring system. Independent variables were collected by chart abstraction. **Results:** The incidence of patients who developed at least 1 new WSL during treatment was 72.9%, and this incidence was 2.3% for cavitated lesions. Treatment duration was significantly associated with new WSL development ($P = 0.03$). Development of WSL and cavitated lesions increased (both, $P < 0.00$) despite increased attention to oral hygiene during treatment. Sex, age, extraction therapy, and various fluoridation sources were not associated with WSL development, but initial oral-hygiene score was moderately associated ($P < 0.06$). **Conclusions:** The incidence of WSL in patients treated with comprehensive orthodontics was significantly high, and the preventive therapy provided appeared to be ineffective. This widespread problem is alarming and warrants significant attention from both patients and providers that should result in greatly increased emphasis on effective caries prevention. (Am J Orthod Dentofacial Orthop 2011;139:657-64)

Orthodontic patients can find it difficult to maintain adequate oral hygiene around fixed appliances. The decline in oral hygiene that often accompanies orthodontic treatment might lead to an increased risk for development of caries lesions. The severity of the resultant dental caries can range from development of opaque white-spot lesions (WSL), or decalcification, to loss of surface integrity of enamel and cavitation.

A classic WSL study demonstrated that 49.6% of orthodontic patients exhibited enamel opacities on at least 1 tooth after orthodontic treatment.[1] Prevalence values of individual teeth with posttreatment white spots were 10.8% for bonded teeth and 12.0% for banded teeth. Significant increases in both prevalence and severity of enamel opacities following orthodontic treatment were reported.[1-4] The prevalence of posttreatment WSL in orthodontic patients was reported to be 84%, compared with 72.3% at pretreatment.[2] This increased prevalence of enamel lesions caused by orthodontic treatment lasted for 5 years or more after appliance removal.[3] More recently, 95.3% of a group of orthodontically treated patients experienced development of at least 1 new WSL or an increase in severity of an existing lesion.[4]

Orthodontic appliances physically alter the microbial environment.[5-10] Increased proliferation of the facultative bacterial population, including *Streptococcus mutans*, leads to a decrease in pH that tips the demineralization-remineralization balance toward mineral loss (demineralization), which in turn can lead to WSL development and eventually to cavitation and caries extending into the dentin.[11-14]

The need for a systematic method of caries recording in epidemiologic studies led to the development of a visually ranked caries scoring system that was reproducible and accurate: International Caries Detection and Assessment System II (ICDAS II).[15,16] Various stages of coronal caries are recorded in a reliable and reproducible way through clinical visual inspection.[17] Compared with later-stage caries detection by radiographs, the ICDAS

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II allows for ready detection of small differences in caries lesions.[18] The ability to detect early stages of enamel caries with high validity makes the ICDAS II the system of choice for clinical detection of WSL in orthodontic patients.[17] In the absence of clinical observation, however, color photographs can be used instead as a proper alternative. Color photography as a means of recording enamel opacity is a powerful method.[19] Assessment of enamel demineralization from color images appeared to be more reproducible than direct clinical observation with only the naked eye.[20]

Since intraoral photographs are routinely taken of orthodontic patients before and after treatment, we created a scoring system tailored for use with photographic images. Such a system can be a useful method for longitudinal assessment of caries status from photographic records. In this study, we used intraoral photographs and a specifically designed system to determine the incidence of new coronal caries development on labial surfaces of teeth before and after orthodontic treatment.

MATERIAL AND METHODS

Before patient record selection, this study received approval from the University of Michigan Institutional Review Board for Health Sciences (#HUM00015033, 8/10/2007, exempt). From 2296 patients treated in the graduate orthodontic clinic at the University of Michigan School of Dentistry between 1997 and 2004, 350 patient records were randomly selected by using a random number sequence generated at www.random.org[21] Inclusion criteria for record selection consisted of patients who (1) underwent comprehensive orthodontic treatment with full fixed appliances on labial tooth surfaces; (2) had both complete initial and final series of intraoral photographs; and (3) had complete treatment log information in their charts. Patients whose appliances were removed prematurely before completion of orthodontic treatment were excluded.

Data collection from deidentified patient charts included sex and age at initiation of orthodontic treatment, and treatment variables such as extraction therapy and comprehensive treatment time. Comprehensive treatment time was defined as the period between the start of full fixed appliance therapy and the removal of all active fixed appliances. A limited phase 1 treatment before comprehensive treatment was not included in treatment-time calculation. Initial oral-hygiene score, frequency of oral-hygiene discussions, oral-hygiene instructions, and fluoride application or rinse were recorded from progress notes in the chart. Fluoridation of the patient's primary water source was reported by the patient or guardian.

Intraoral pretreatment (initial) and posttreatment (final) photographs of each patient were taken as part of standard orthodontic record-keeping procedures. The posttreatment photographs were taken soon after debonding. All photographs, stored as 35-mm slides, were taken in the Clinical Photography Department at the University of Michigan School of Dentistry by 2 professional photographers using a standardized intraoral photography procedure. Mouth mirrors were rinsed with warm water, and the patient was asked to swallow before each photograph was taken. The position of the camera was in the occlusal plane and perpendicular to the maxillary incisors (frontal). The lateral photographs were taken by using a front-surface mirror. The shot was taken in the occlusal plane and perpendicular to the surface of the mirror, and an exposure compensation of 0.5 f-stop was used. The photographs were taken with a ring flash (virtually eliminating light reflections) at a fixed magnification of 1:1.2.

Initial and final photographs used for this study included a frontal view and right and left lateral views. Individual slides were scanned into digital format by using a Nikon Slide Feeder SF-200 (S) and Super Coolscan 4000 ED scanner (Nikon Corporation, Tokyo, Japan). Each 24-bit image with 4000 $\times$ 4000 dpi resolution was saved as a jpeg file. A total of 6 intraoral images per patient were scanned (3 pretreatment and 3 posttreatment slides).

Scanned images were imported into an individual PowerPoint (Microsoft, Redmond, Wash) presentation for each patient. Each presentation consisted of 3 slides with a solid black background. The images of each patient were paired, displaying both the pretreatment and the posttreatment image of each view together on 1 slide, and enlarged to 325% of their original size. A typical example of the side-by-side arranged images is shown in Figure 1. Investigators (A.E.R., A.O.A, and W.S.) could move back and forth in the image sequence while evaluating each patient.

The images were evaluated by trained investigators using a specifically adapted scoring system (Table I). Visible labial surfaces examined included maxillary and mandibular central and lateral incisors, canines, first and second premolars, and first molars. For the purpose of this study, the criteria for caries detection were based on 2-dimensional photographs. The chief investigator (A.E.R.) scored each visible labial tooth surface before and after orthodontic treatment. The scores were combined to determine the labial caries incidence for each patient.

The three investigators were calibrated in the use of the scoring system. They independently evaluated photographs of 35 randomly selected patients from the sample to determine interexaminer reliability. Fifteen days later,

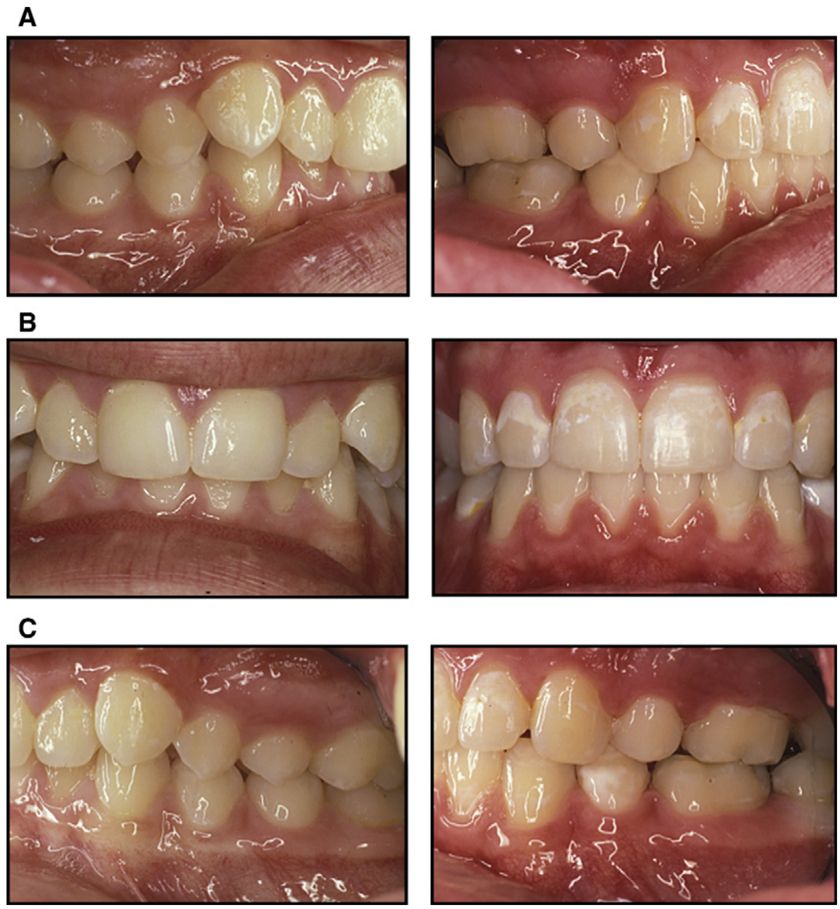

Fig 1. A typical example of the side-by-side arrangement of the clinical pretreatment and posttreatment images before scoring: **A,** right lateral view with new WSL visible on teeth 6, 28, and 30 (4 and 29 were extracted); **B,** frontal view with new WSL visible on teeth 7-10, 22, 23, and 26; **C**, left lateral view with new WSL visible on teeth 14, 19, and 21 (13 and 20 were extracted).

the same photographs were reexamined (A.E.R.) to determine intraexaminer reliability.

Statistical analysis

The overall incidence of labial caries development was determined from comparison of the pretreatment and posttreatment scores for each tooth. Lesion development was broken down into WSL and new cavitations. Means, standard deviations, and ranges were determined for surfaces affected by new lesions, and the incidence of new lesions was calculated. Incidence was defined as the number of new events: new cases of disease in the population, within a specified period of time.[22] Teeth that could not be evaluated (score 9), on either initial or final records, were not included in the calculations.

The dependent variables (WSL and cavitation or caries) were compared with the independent variables (sex, age at start of treatment, extraction vs nonextraction, treatment duration, initial oral hygiene, frequency of oral-hygiene discussions, fluoride rinses or topical application, and fluoridation of patients' water source and their interactions). The number of teeth developing new lesions was compared with the independent variables and analyzed with the Satterthwaite *t* test and analysis of variance (ANOVA). Multiple regression analysis was used to determine relationships between the dependent and independent variables mentioned above. Intraexaminer and interexaminer reliabilities were determined by using kappa statistics.[23,24] All analyses were performed with software (version 9.1, SAS Institute, Cary, NC).

RESULTS

Evaluation of examiner reliability demonstrated excellent agreement between initial assessments for

Table I. Surface assessment criteria for use with photographic images

Score	*Surface characteristic*
0	Sound enamel
1	WSL
2	Cavitation
M	Missing due to caries, orthodontic extraction, unerupted,* or congenitally missing
R	Restored†
9	Excluded because of inadequate photographic view

*Unerupted surface at the initial record received a score of 0; †R was ignored if a new lesion was present.

both intraexaminer (kappa = 0.95) and interexaminer (kappa = 0.77, 0.85, and 0.85) agreement for lesion assessment.

A histogram of the incidence of new WSL between the initial and final records is shown in Figure 2. The overall incidence of patients who developed at least 1 WSL during orthodontic treatment was 72.9% (n = 255). The incidence of newly developed cavitated lesions that were unrestored on the final record was 2.3%. Of the 8 patients who developed cavitated lesions during orthodontic treatment, 4 (1.1%) developed 1 new cavitated lesion, 3 (0.9%) developed 2 new cavitated lesions, and 1 (0.3%) developed 4 new cavitated lesions. The overall number of patients exhibiting at least 1 new labial restoration (filling or full coverage) at the final records was 16 (4.6%). Of these 16 patients, 13 (3.7%) had 1 new restoration, and 3 (0.9%) had 2 new restorations.

The various changes in tooth status per patient (mean percentages and standard deviations) are summarized in Table II. Of the maximum of 24 surfaces investigated per patient, on average, 4.2 surfaces showed new WSL. There were only a few new cavitations (0.04) and restorations (0.05). Even though it happens infrequently, some early WSL regressed to sound enamel (reversals, 0.07).

Table III presents the relationship between the development of WSL and cavitations and the independent variables. Demographic variables of sex and age at the start of treatment were not significantly related to the development of new decalcified or cavitated lesions. There was a significant relationship between increased treatment length and the number of newly developed decalcified lesions ($P = 0.03$). The mean number of labial surfaces per patient who developed new WSL was 3.01 for those with a treatment length of less than 22 months. This increased to 5.28 teeth for patients with therapy longer than 33 months. The number of new cavitated lesions, however, showed only a nonsignificant trend ($P = 0.08$) with increased treatment time. In addition, the number of newly developed lesions (both WSL and cavitations) showed no significant association with extraction or nonextraction treatment protocol.

Although no relationship was demonstrated between pretreatment oral-hygiene scores and lesion development, the recorded number of oral-hygiene discussions between provider and patient was significantly associated with development of both WSL ($P < 0.0001$) and cavitated ($P = 0.0006$) lesions. The mean number of new decalcified lesions for patients with whom no oral-hygiene discussions had been noted in the chart was 3.08, whereas the mean number of decalcified lesions for patients who were given oral-hygiene instructions on 3 or more occasions increased to 7.78. A similar increase was shown for the mean number of cavitated lesions for patients having 3 or more oral-hygiene discussions (mean, 0.20) vs those with whom oral hygiene was not discussed after the initial instructions (mean, 0.01).

There was no significant association between the number of new lesions and fluoride supplements such as fluoridated water source, fluoride rinse recommendations, or topical fluoride treatments given by the provider.

Table IV shows the results of the multivariable regression analysis of the independent variables and WSL development. Age group ($P = 0.03$), treatment length ($P = 0.01$), and number of oral-hygiene discussions ($P < 0.0001$) were associated with the development of WSL. There was a decrease in WSL associated with increasing age group (regression coefficient, −0.59). An increase in WSL was associated with both increased treatment time (regression coefficient, 0.07) and more oral-hygiene discussions (regression coefficient, 1.88).

Placement of new restorations, both fillings and full coverage, between the initial and final records was not significantly associated with any independent variable.

DISCUSSION

Despite vast improvements in preventive dental care, the development of dental caries and, more specifically, decalcified WSL, have continued to be well-recognized and troubling negative side-effects of orthodontic fixed appliance therapy. In this study, we used pretreatment and posttreatment intraoral photographs to determine the incidence of labial caries lesions in patients who underwent comprehensive orthodontic treatment with full fixed appliances. Since caries has a multi-factorial nature, several additional variables were evaluated (Table III).

The use of intraoral photographs for caries determination in orthodontic patients is a well-accepted method, and standardized photographs taken before and after appliance placement are readily available. Photographic records provide an efficient means to capture the appearance of enamel and are a permanent record at

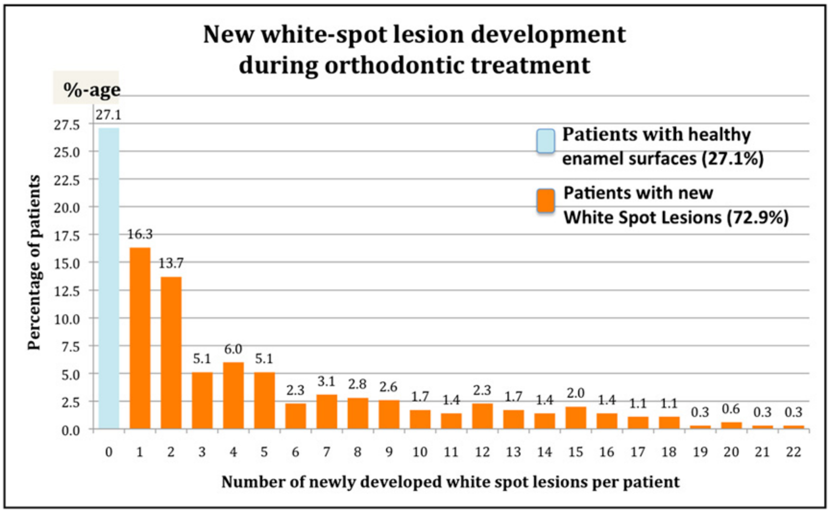

Fig 2. Histogram of the incidence of new WSL between the initial and final records (number of new WSL per patient developed during orthodontic treatment).

Table II. Change in labial surfaces per patient (maximum of 24 surfaces)

	Labial enamel surfaces		
Changes per patient	*%*	*Mean*	*SD*
No change	70.3	16.87	5.62
New WSL	17.3	4.15	5.11
New cavitated lesions	0.2	0.04	0.30
New restorations	0.2	0.05	0.26
Reversals	0.3	0.07	0.41
Extracted teeth	7.1	1.71	1.86
Congenitally missing	0.8	0.18	0.63
Excluded (could not be judged)	3.8		

a given time, allowing an examiner to blindly and randomly assess a patient's caries experience. Although the photographic method has been found to be relatively robust for assessing the prevalence of demineralized enamel lesions, some have argued that it is relatively poor for assessing individual lesions longitudinally.[19] This is due to varying photographic conditions and artifacts between time points: lighting, angulation, and magnification. Controlling these factors will make the photographic records sound for longitudinal study. Fortunately, all photographs evaluated in this study were taken by 2 professional photographers with a reliable standard procedure. Angulation, magnification, and lighting conditions were maintained, eliminating a major source of photographic variability. Due to the limitations associated with photographs (eg, partial view because of deep overbite), about 4% of the tooth surfaces were excluded (Tables I and II). This would result in underestimation of reporting the WSL in our study.

Pretreatment and posttreatment lesions were assessed by examining each patient's initial and final photographs in a side-by-side arrangement. This allowed for exclusion of preexisting enamel variations (eg, anatomic anomalies, hypoplasia) and caries lesions, and increased examiner consistency and reliablility.

The simplified caries scoring system developed for this study accounted for the 2-dimensional image. Although neglecting clinical adjuncts such as light reflection and surface air drying, it allowed for photographic caries assessment. Several studies on enamel opacities in orthodontic patients used intraoral photographs for caries determinations.[1,3,4] These reports, however, showed large variations in the incidence of WSL. These variations might have been due to the different methods of assessing and scoring decalcifications.[25] We study used a simple standardized system designed for photographic assessment of caries.

Gorelick et al[1] compared orthodontically treated patients with untreated controls. Although their study had the benefit of comparisons with a control group, it was cross-sectional in design. What was reported to be the "incidence" of white-spot development was actually the "prevalence" of lesions in the 2 groups, treated and untreated. Our study was designed to report the true incidence of labial lesions by comparing the same 350 patients longitudinally at 2 time points.

A recent study that calculated the incidence rate through longitudinal photographic assessment found a higher incidence, with 95.3% of orthodontic patients developing at least 1 WSL.[4] Compared with our study, however, a relatively small sample size was used (n = 53).

Table III. Bivariate analysis of development of new lesions

Independent variable	*n*	White-spot lesions *Mean*†	*SD*	P *value*	Cavitated lesions *Mean*†	*SD*	P *value*
Sex				0.10		0	0.30
Female	207	3.78	4.77		0.02	0.18	
Male	143	4.70	5.53		0.06	0.41	
Age group (y)				0.07			0.56
9–12	59	5.15	5.62		0.02	0.13	
12–13	79	4.53	5.31		0.13	0.11	
13–16	147	4.14	4.91		0.05	0.38	
>16	65	2.82	4.61		0.08	0.37	
Treatment length (mo)				0.03*			0.08
<22	86	3.01	4.48		0	0	
22–27	84	3.94	4.77		0.04	0.41	
27–33	96	4.45	5.23		0.01	0.11	
>33	82	5.28	5.76		0.11	0.42	
Extraction vs nonextraction				0.19			0.14
Extraction	170	4.52	5.29		0.06	0.39	
Nonextraction	180	3.80	4.92		0.02	0.17	
Initial oral-hygiene score				0.06			0.31
Poor-fair (1-2)	178	4.64	5.38		0.05	0.37	
Good-excellent (3-4)	152	3.57	4.72		0.02	0.14	
Hygiene discussions (n)				<0.00*			<0.00*
0	212	3.08	4.15		0.01	0.12	
1–2	93	4.84	5.63		0.02	0.21	
≥3	45	7.78	6.16		0.20	0.73	
Primary water source				0.55			0.15
Nonfluoridated	120	4.23	4.93		0.02	0.13	
Fluoridated	138	4.61	5.47		0.07	0.43	
Fluoride rinse recommended				0.10			0.86
No	308	3.95	4.93		0.04	0.30	
Yes	42	5.60	6.12		0.05	0.31	
Topical fluoride treatment				0.11			0.88
No	307	3.96	4.94		0.04	0.30	
Yes	43	5.53	6.06		0.05	0.31	

**P* value significant at ≤0.05; †Mean number of lesions in labial surfaces per patient.

In addition to varying methods, these studies, including ours, were designed to determine the incidence of enamel demineralization in a specific population. Variables such as geographic and socioeconomic status and private practice vs university settings also might have contributed to the differences in the reported incidences of WSL in the literature.[12]

The field of orthodontics has seen many advances in recent years. An intricate issue facing clinical orthodontics, however, still remains unresolved: the high incidence of posttreatment WSL. Orthodontic practices and training programs should focus greater efforts on this preventable condition that affects most orthodontic patients. Despite the high incidence of WSL associated with orthodontic treatment, fortunately relatively few of these lesions progress so fast that, upon removal of the orthodontic appliances, a restoration is indicated. Continual posttreatment exposure to healthy saliva results in a physiologic rebalance by natural remineralizaton processes. Demineralization can be arrested and sometimes even reversed if the lesion affects only the outer layers of enamel.

Although age was not a significant factor in lesion development ($P = 0.07$), the multi-variable regression model demonstrated that, as age increased, WSL development tended to decrease by 0.59 lesions per age group ($P = 0.03$). This information is an important and relevant factor for orthodontists who decide at what age to initiate treatment.

A significant association was found between the number of newly developed white spots and treatment length ($P = 0.03$). A trend was detected, indicating that as treatment duration increased, development of WSL also increased. Multiple regression analysis showed that, for each month of treatment with full fixed appliances, the number of WSL increased by an estimated factor of 0.08 lesions per month. This suggests that, from the time appliances are placed to their removal,

Table IV. Multivariable regression model of WSL development

Variable	Parameter estimate	SE	P value
Sex	−0.73	0.55	0.19
Age group	−0.59	0.28	0.03 *
Treatment length	0.07	0.03	0.01 *
Initial oral-hygiene score	−0.08	0.56	0.89
Oral-hygiene discussions (n)	1.88	0.39	<0.00 *

*P value significant at ≤0.05.

the development of WSL continues at a steady rate. After 22 months of treatment, an average of 3.01 surfaces developed WSL; after 33 months, the risk increased to an average of 5.28 new WSL. This might have been because the longer the fixed appliances were in place, the longer the teeth were exposed to cariogenic challenges of increased plaque accumulation. Longer treatment, however, was not significantly related to an increased experience of cavitated lesions ($P = 0.08$). Future studies that include the nature of the individual and local microbial environment seem warranted to understand this phenomenon in greater detail.

A patient's oral hygiene around fixed appliances can alter the susceptibility to caries during orthodontic treatment. Initial oral-hygiene scores were abstracted from patient charts and dichotomized into poor-to-fair and good-to-excellent categories. The initial oral-hygiene information available in the charts was limited and subjective, and could potentially be why we found no correlation between initial oral hygiene and development of new WSL or cavitations. It is advisable to use objective assessment methods for recording oral-hygiene status (eg, periodontal screening and recording or plaque index) so that this relationship can be further investigated.

The number of times that orthodontic care providers offered oral-hygiene instructions was significantly associated with development of new WSL ($P < 0.0001$) and cavitated lesions ($P = 0.0006$). The number of oral-hygiene conversations increased concurrently with the development of both WSL and cavitated lesions (parameter estimate, 1.88). The frequency of oral-hygiene discussions was most likely the result of poor oral hygiene and the presence of WSL. Although orthodontists attempt to reinforce oral hygiene to patients, their attempts are often unsuccessful.

Previous research has shown that use of fluoride products during orthodontic treatment might inhibit demineralization and prevent or slow down caries development.[26-29] Surprisingly, no fluoride variable examined in this study was found to be associated with development of new WSL or cavitated lesions. It might be a clear limitation of this study that fluoride chart information was seemingly deficient, resulting in a questionable quality of abstracted fluoride data. In addition to inaccurate self-reporting of water source fluoridation and incomplete record keeping by providers, patient compliance with recommended fluoride rinse protocols might have been poor, as previously reported.[29]

This study accounted for only independent variables that were readily available in the patients' charts. It was by nature limited to a retrospective design. By using a multi-variable regression model with several independent variables, the model could explain a small, but significant, portion of WSL. The adjusted R^2 of 0.11 showed that only a small proportion of the variability seen in this data set could be accounted for by the model. Because dental caries is multi-factorial, this result was expected. Clinically, therefore, when evaluating the risk of WSL, orthodontists should remember that these variables account for only a small portion of lesion development.

The size of the lesion was not accounted for in this study. When examining the photographs, however, the evaluators noted not only more WSL, but also for many patients an increase in lesion size. Future, more detailed caries assessments should include lesion size.

The high prevalence and incidence of preventable WSL during and after orthodontic treatment with fixed appliances warrants a more detailed investigation of this phenomenon in a prospective randomized controlled clinical trial by using a direct method of assessing early caries lesions with well-documented charting.

CONCLUSIONS

Based on before-and-after orthodontic treatment photo records, this study showed a high incidence of new WSL (72.9%) in patients treated with comprehensive orthodontics, and the incidence of new cavitated lesions in this population was 2.3%. Sex, age, and oral hygiene at the start of treatment were not associated with lesion development, but a significant association was evidenced with treatment duration. Patients in treatment for less than 22 months developed on average 3 WSL, and those in treatment for 33 months or longer developed on average more than 5 lesions. Linear regression analysis suggested that, as the duration of fixed appliances increased by 1 month, 0.08 new WSL developed.

The lack of association between supplemental fluorides and lesion development might have been due to the limited chart data available. However, the preventive therapy provided during treatment was not effective. This widespread problem of WSL development is an alarming challenge and warrants significant attention from both patients and providers that should result in greatly increased emphasis on effective caries prevention. Orthodontists should be aware of the high risk of WSL and decide at the patient level whether it is appropriate to start or continue treatment in patients who are already experiencing enamel demineralization. The risk of developing incipient caries lesions during orthodontic treatment should not be underestimated by orthodontists.

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