A New Method for Quantifying Labial White Spot Lesions

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Abstract

Aims: This study aimed to evaluate the prevalence as well as incidence of White Spot Lesions (WSL) before and after labial multibracket appliance (MB) therapy. The goal was also to determine the intensity of WSL based on the Enamel Decalcification Index (EDI) by Banks & Richmond (1994). Moreover, this study investigated the scope of WSL by using a newly-developed evaluation tool.

Materials & methods: Digital photographs of 121 patients (63 □, 58 □) with labial metal brackets were analyzed retrospectively before and after MB therapy. The patients were 12.5±2.1 years old. The treatment took 3.1±1.4 years. Adult patients as well as patients with structural or restaurative modifications were excluded from the study. All patients received standardized prophylactic instructions. The labial surfaces of anterior teeth, canine teeth, and premolars in the upper (UJ) and lower jaws (LJ) were evaluated by using the Enamel Decalcification Index (EDI) by Banks & Richmond (1994, levels 0-3) and a specially developed scaled graticule with concentric circles to quantify the extent of WSL (in %). The statistical data analysis was based on crosstabulations and logistic regression.

Results: Before MB, 69.4% of the patients had WSL. After MB therapy, 97.5% of the patients presented at least one WSL. The incidence amounted to 28.1%. Before MB, 18.4% of the tooth surfaces (TS) showed an EDI level of 1-3. After MB, 51.8% of the TS featured WSL. Before and after MB, the prevalence for WSL was higher on UJ and LJ canine teeth and premolars than on incisors. 18.2% of the TS showed a WSL to the extent of ≥ 20-100% before MB and 52.3% after MB. The majority (40.8%) of the newly-developed WSL concerned ≥ 40% of TS. The incidence in the UJ was highest for the first and second premolars (71-79%), followed by the lateral incisors (61-63%). In the LJ, the incidence was highest for the second and first premolars (64-76%) and lowest for incisors (22-35%). The logistic regression showed a statistically increased risk to develop WSL after MB for lateral incisors, UJ canine teeth, and for UJ and LJ premolars in male patients. The probability for developing a new distal WSL is higher than developing gingival, mesial, and occlusal WSL.

Conclusion: Labial MB therapy is found to drastically increase the risk of developing WSL. Particularly, premolars and canine teeth showed an increased prevalence. In using the specially developed evaluation index, we were able to verify through simple handling and intra-rater reliability a concise quantification of the extent of labial WSL.

Introduction

The Fourth German Oral Health Study (*Deutsche Mundgesundheitsstudie* DMS IV) [1], conducted in 2005, showed that for 45% of children (age 12) and for 58% of teenagers (age 15), orthodontic treatment had already been initiated or planned. It can be assumed that around 80% of these patients receive permanent orthodontic appliance. The use of multibracket appliances (MB) increases plaque retention that, in the course of treatment by way of demineralization, may cause decay [2-5]. Several studies showed that the occurrence of plaque is considerably higher for patients with labial MB compared to coeval patients without MB [6, 7]. Despite intense efforts to enlighten, instruct, and motivate patients regarding effective oral hygiene procedures, demineralizations, so-called white spot lesions (WSL, incipient lesion, active initial lesion), are a common clinical problem with great significance. Literature specifies the development of WSL associated with MB treatment with a prevalence of 2% to 96% [2, 8, 10, 16-19]. This large variation found in the research results at hand is due to differences with respect to the number of examined tooth types, analytical methods, age at the beginning of treatment and at its end, duration of treatments, materials used, ethnic origins, and patient selection [20] (Table 1: Literature overview of the corresponding parameters for analyzing the prevalence and the incidence of WSL after MB treatment)

A WSL typically develops in locations where plaque is able to remain on the tooth surface for a certain amount of time [8]. Favored locations for plaque retention during MB treatment are predominantly observed in the area of orthodontic brackets, archwires, loops and ligatures, which aggravate oral hygiene [2, 3, 9-11], and, above all, in the gingival part of the tooth [2], as it is less accessible for cleaning. Moreover, the physiological self-cleaning process based on unobstructed movements of the orofacial muscular system and the salivary flow rate becomes restricted [12]. In this case, the use of topical fluorides can significantly reduce the risk of demineralization [13]. These can be applied locally in the form of fluoride toothpastes, mouth rinses, gels and varnishes, as well as fastening materials that release fluorides. The main effect of these measures is the reduction of demineralization processes and the stimulation of remineralization [14, 15].

The data for prevalence and incidence vary with respect to the age of the study subjects. Some studies concluded that the risk of developing new and more severe lesions is significantly higher for male than for female patients [10, 21, 22]. By contrast, Gorelick et al. [8] detected a higher incidence in females. Geiger et al. [16], however, could not verify a significant distinction.

Upon inspecting the different tooth types with respect to the development of labial WSL, the prevalence is significantly higher for the lateral incisor of the upper jaw as well as for the premolars of the lower jaw [2, 8, 17, 22-24]. Furthermore, several studies have shown that WSL develops primarily in the area of the gingival tooth surface [2, 24]. Plaque retention particularly develops at the lateral incisor due to the small space between bracket and marginal gingival, which also increseas the risk of demineralization [2, 8, 17, 19]. On the upper incisor, labial WSL could already be detected four weeks after beginning MB therapy [22, 25].

The large range of variation upon measuring WSL is due to the applied analytical methods [26].

Gorelick et al. (1982) developed a clinical-visual research method for evaluating WSL for the first time. It features four levels: level 1=no WSL, level 2=no lesion, mild demineralization, level 3=no lesion, grave demineralization, level 4= cavitation, presence of cavity. This WSL index by Gorelick et al. [8] is suitable for depicting prevalence and incidence of demineralizations [11]. The boundary between level 2 and level 3 is not clearly defined with respect to extent and intensity. This can result in inaccuracies upon evaluating the progression before and after MB treatment, particularly if different observers evaluate identical patients based on the WSL index (interexaminer reliability). Therefore, a research calibration as well as a standardized evaluation procedure is necessary for using this index.

Årtun & Brobakken (1986) modified this index to draw more precise conclusions regarding the extension of WSL [2]. They divided each vestibular tooth surface around the bracket into four areas: gingival, mesial, distal, and occlusal or rather incisal. They also modified the scale division: level 0=no WSL, level 1=WSL implies < 1/3 of the surface uncovered by the bracket, level 2= WSL implies > 1/3 of the surface uncovered by the bracket, level 3= WSL implies > 2/3 of the surface uncovered by the bracket. The results of their research showed a high inter-rater reliability. Upon classifying the rate of demineralization, the tooth surfaces were inspected separately, which enabled a precise monitoring of the process. Årtun & Brobakken's index was further modified by Banks & Richmond (1994) to include the evaluation of tooth surfaces affected by carious lesions, which is also known as Enamel Decalcification Index (EDI) [24]. Level 0 corresponds to an intact enamel surface, level 1 describes demineralizations of less than 50% of the tooth surface, level 2 represents demineralizations of more than 50% of the surface, and level 3 corresponds to demineralizations that affect 100% of the inspected area or a carious lesion. Overall, they sum up the results of the evaluated surfaces of each tooth and each patient to conclude on the degree of demineralizations.

Quantitative light-induced fluorescence (QLF) determined the highest WSl prevalence. Contrary to direct visualization, QLF is considered an objective diagnostic tool, albeit a considerably more labor-intensive and cost-consuming one [26]. The disadvantage of this method is that, apart from demineralizations, calculus, plaque, and discolorations also fluoresce differently from healthy tooth enamel [27].

These indices described in current literature, however, only consider the intensity of WSL but not its extent.

The present study was conducted to evaluate the prevalence and incidence of labial WSL within a certain patient population. andalso to determine its intensity and especially the extent of WSL by using the Enamel Decalcification Index (EDI) by Banks & Richmond (1994) and a newly developed evaluation instrument, a measuring crosshair

Materials And Methods

We examined the medical records of all patients who were treated with MB appliances in the upper jaw (UJ) and lower jaw (LJ) and completed their treatment between 2000 and 2010. The following inclusion criteria had to be fulfilled: 1) no previous treatment with a multibracket appliance, 2) no crowns/veneers, restauratives, or structural changes in the enamel on the buccal surfaces of the teeth to be examined, neither before nor after MB treatment, 3) a conventional metal bracket Discovery® with 0.22 Slot (Dentaurum, Ispringen, Germany) was pasted on all anterior teeth, canine teeth, and premolars in upper and lower jaws, 4) MB treatment time has to be at least one year, 5) availability of the complete documentation records (intraoral photographs) of the time prior to and after MB therapy.

At the beginning of MB treatment, all patients received the same oral hygiene instructions. They were instructed to use their tooth brushes and interdental brushes 2-3 times daily after meals and to apply fluoride toothpaste and mouth rinse. In addition, they were advised to use a fluoride gel once a week after brushing their teeth at night (Elmex Gel, GABA International, Therwil, Switzerland).

We analyzed intraoral digital photographs of 313 patients, treated with a labial MB appliance in upper and lower jaws. Patients older than 18 years were excluded from the study, which is why 76 (24.3%) patients were excluded. With 47 (15%) other patients, there were no photographs taken directly before the adhesive fastening of the bracket. After debonding the brackets, pictures of 54 patients (17.3%) were unavailable. Due to the poor quality of photographic images, five patients (1.6%) could not be analyzed adequately. Three cases (0.96%) were not evaluated as these patients were also treated with a Herbst appliance.

Eventually, 121 patients (63 male, 58 female) were included in the study (n=9680 tooth surfaces). At the beginning of the multibracket treatment, their average age was 12.5±2.2 years. The average treatment time was 3.1 ±1.4 years.

All of the analyzed intraoral photographs were taken with a digital reflex camera with a RGB-CCD-sensor (Nikon D80, Nikon Corporation, Chiyoda, Tokio, Japan). The maximum resolution was 10.2 megapixels (corresponding to 3872 × 2592 pixels). In addition, we used a macro lens (105mm, Sigma F2.8 DG Macro, Kawasaki, Japan) with an appropriate ring flash (Sigma electronic Flash Macro EM-140 DG, Sigma Corporation, Kawasaki, Japan).

Three standardized digital photographs (frontal, right lateral and left lateral photographs) from the time before and after MB treatment were evaluated. The four anterior teeth, canine teeth, and the first and second premolars in UJ and LJ were evaluated. Molars were excluded because bands were applied during MB treatment.

The EDI by Banks & Richmond [24] was applied to evaluate the intensity of WSL on the labial tooth surfaces before and after MB therapy. In the process, the labial tooth surface is divided into four areas around the bracket: g=gingival, m=mesial, d=distal and o=occlusal. The scaling of level 0-3 is classified according to the extent of White Spot Lesions. (Figure1: Description of the des Enamel Decalcification Index (EDI) by Banks & Richmond in order to measure the intensity of White Spot Lesions.)

Overall, the results of the analyzed surfaces were totaled for each individual tooth. Since the EDI only considers the intensity of demineralizations, we innovated the method in order to be able to additionally evaluate the extent of the lesions. We prepared an evaluation tool. The graticule reflects the division of the EDI according to Banks, which divides the tooth surface into four areas. The concentric circles represent a percentaged division of the surfaces and each corresponds to 20%. This evaluation tool with graticute and concentric circles was printed on a transparent polyester film of the size A4 (LabelOcean GmbH, Bad Zwischenahn, Germany) for laser printers and was adapted to each tooth that was subject to evaluation (fig. 2). In the process, the film was aligned centrally and fixed on to the screen.

Figure 2: Evaluation tool with graticule and concentric circles printed on film and evaluation with the polyester film adapted and fitted to the tooth.

The photographs were interpreted according to a standardized procedure in a completely darkened room by a calibrated examiner on a computer (ACER Aspire 6920G, Acer Inc, Taipeh, Taiwan) with a PnP monitor and NVIDIA GeForce 9500M GS with 1366x768 pixels (color depth 32 bit). The digital photographs were opened with the program "Windows Photo Gallery" (Microsoft Corporation, Redmond, USA), and each tooth subject to evaluation was digitally adapted to the size of the evaluation tool. First, we evaluated pictures that were taken before brackets had been fastened. The examination was conducted in the order of the following sequence: tooth 11 and 12 frontally, tooth 13 to 15 laterally, and subsequently, we proceeded with the second, third, and fourth quadrants. The first data collected always corresponded to the extent (in %), whereas the second data collected corresponded to the intensity (in line with the EDI).

Statistical Evaluation:

The statistical evaluation of the data was conducted in collaboration with the Institute for Medical Biometry, Epidemiology, and Informatics Mainz (IMBEI) by using SPSS (V.17.0.1 for Windows, IBM Corporation, Armonk, USA).

For calculating the intra-rater reliability, we calculated the Intraclass Correlation Coefficient (ICC).

The examined surfaces for each tooth were summarized after the plausibility check.

In the process, the indices of intensity (Enamel Decalcification Index, EDI) were binary-recoded, so that 0 stands for no WSL and 1 for the existence of a WSL. For each tooth, we then created crosstabulations. On the basis of the following formulas, the prevalence was calculated per tooth prior to and after MB treatment:

Prior prevalence = prior WSL / total number of patients

Subsequent prevalence = subsequent WSL / total number of patients

In addition to evaluating the prevalence before and after MB treatment, the distribution of the examined indices (EDI and evaluation index respectively) was illustrated with respect to the frequency of emergence per tooth and tooth surface.

The data collected for the intensity of demineralizations (EDI index), allowed us to draw meaningful conclusion on the presence of WSL.

For illustrating the incidence of WSL after MB treatment, the evaluation was conducted by using crosstabulations and the following formula:

Incidence = (number without prior WSL & number with subsequent WSL) / number without prior WSL

For interpreting the incidence, the calculation of the upper and lower boundaries of the confidence interval was made on the basis of this formula:

$$p_{1,2} = \frac{2m + u^2 \pm u\sqrt{u^2 + 4m(1-p)}}{2(n + u^2)}$$

The incidence lies within the calculated range with a probability of p=0.95. Additionally, the examined indices (EDI and evaluation index respectively) were illustrated with respect to the frequency of re-emerging after MB treatment.

The binary logistic regression analysis was conducted in order to statistically evaluate significant influence factors. Gender, duration of treatment, tooth type, and tooth surface were defined as variables to be examined. We considered data p<005 as statistically significant. In total, we devised three analytical models: 1. WSL prior to MB treatment, 2. WSL after MB treatment, and 3. incidence of WSL.

Results

The intra-rater reliability of evaluating the digital photographs resulted in an ICC of 0.99 for the EDI index and of 0.96 for the evaluation index.

A patient was considered sick if one surface of one tooth showed a WSL. We examined 121 patients with 20 teeth each and 4 tooth surfaces (in total n=9680 tooth surfaces).

In total, 69.4% of patients (65% male and 74% female) had a WSL prior to MB therapy. After MB therapy, 97.5% of patients (98.4% male and 97% female) presented at least one WSL. The incidence of patients affected by WSL amounted to 28.1%.

In the upper jaw, posterior teeth right and left were more often affected by WSL before MB therapy than canine and anterior teeth right and left. The second premolar on the right (63.6%) and the first premolar on the left (63.6%) were most often affected by WSL prior to treatment. After orthodontic treatment, both premolars and canine teeth left and right were most often affected by WSL (75.2-83.5%) (fig. 3a).

Similar to the upper jaw, the lower posterior teeth right and left were more often affected by WSL before treatment than canine and anterior teeth right and left.

Both second premolars were most often affected by at least one WSL (56.2-57%). After completing MB treatment, most of the WSL appeared, just like in the upper jaw, on premolars and also canine teeth right and left (fig. 3b).

Figures 3a and b: Bar diagrams describing the prevalence of WSL of upper teeth a) and lower teeth b). The x-axis divides the examined teeth according to the time of their examination (WSL prior to MB; WSL after MB). The y-axis displays the percentage that corresponds to the occurrence of WSL; only the positive results (WSL=1) were included.

Prior to MB therapy, 81.6% of all tooth surfaces did not show a WSL, and 18.4% showed mild to grave WSL. After MB therapy, we detected WSL with an EDI level 1-3 on more than half of the tooth surfaces (51.8%). The prevalence of WSL intensity decreased along with an increasing EDI level prior to and after MB therapy (fig. 4).

Figure 4: Bar diagram describing the WSL prevalence distributed by percentage of intensity (with Enamel Decalicification Index, EDI). The x-axis shows EDI levels 0-3 and their percentage of the WSL evaluation prior to and after MB. The y-axis specifies the prevalence in %.

Prior to MB therapy 18.2% of the tooth surfaces presented a WSL with an extent of ≥ 20-100%, which increased to 52.3% after MB treatment. The majority (40.8%) of newly developed WSL concerned 40% of the tooth surfaces. After MB treatment, an increase of the extent could be found in all areas in a range between 20 and 100% with a peak at 40% (fig. 5).

Figure 5: Percentaged distribution of the evaluation index according to the occurrence of WSL. The x-axis of the bar diagram shows the evaluation index (0%-100%) and its distribution by percentage upon evaluating WSL, prior to and after MB respectively. The y-axis shows the prevalence in %.

The incidence, the number of new cases, was highest with upper canine teeth and first premolars (71-79%), followed by lateral incisors and second premolars (59-63%). In the LJ, the incidence was highest with second and first premolars (64-76%) and lowest with incisors (22-35%) (tab. 2).

Table 2: Incidence of every single tooth and corresponding confidence intervals

To illustrate the incidence of severity according to extent and intensity of WSL after MB treatment, we only included those patients in the analysis who did not present a WSL at the beginning of the study. We examined the surfaces for each tooth.

58.8% of the newly affected tooth surfaces showed enamel demineralizations of less than 50% of tooth surfaces (EDI=1). 36.4% exhibited enamel demineralizations of more than 50% of tooth surfaces (EDI=2). 4.8% of the incidences featured demineralizations of 100% of tooth surfaces (EDI=3) (fig. 6).

Figure 6: Incidence distribution based on intensity (EDI)

16.9% of the newly affected tooth surfaces showed enamel demineralizations of 20% of tooth surfaces. The majority (40.8%) of new cases exhibited enamel demineralizations of 40% of surfaces. 22% of tooth surfaces had an incidence with a severity of 60%. The lowest incidence could be detected with enamel demineralizations of 80% (14.6%) and 100% (5.6%) (fig. 7).

Figure 7: Distribution of the incidence according to extent (%)

Logistic Regression

The probability to diagnose WSL before MB therapy is lower with female than with male patients. The risk for female patients to develop a WSL is 0.89 times lower than for male patients. With regard to tooth types, we chose tooth 11 as a reference. Teeth 12, 13, 14, 15, and 24 showed a statistically higher risk of contracting a WSL than tooth 11. The lower teeth and teeth 21, 22, 23, and 25 were found to be at a lower risk of contracting a WSL than the reference. Teeth 12, 13, 15, 21, 22, 23, 25, 34, 35, 44, and 45 ($p>0.05$) showed a similar risk of developing a WSL before MB therapy as tooth 11. The analysis based on the first model was concluded by factoring in the tooth surface as a parameter. Thereby, the risk of developing a WSL is statistically higher for the occlusal, distal and mesial surfaces than for the gingival area. Accordingly, the risk was found to be increased by a factor of 1.33-1.61 (tab. 3).

Table 3: Overview of the parameters for the logistic regression: WSL prior to MB therapy

The probability to diagnose a WSL after MB therapy is lower for female than for male patients. The risk for female patients to contract a WSL is 0.65 times lower than for male patients.

Upon regarding tooth types, we again chose tooth 11 as a reference. Teeth 12, 13, 14, 15, 22, 23, 24, 25, 34, 35, 44, 45 showed a statistically higher risk of developing a WSL than tooth 11. Hereby, the upper and lower premolars (odds ratio=1.51-2.52) were statistically conspicuous. The LJ anterior and canine teeth (31, 32, 41, 42) exhibited a lower risk of getting a WSL than the reference. Teeth 21,33, and 43 showed a similar risk as tooth 11 (p>0,05) of developing a WSL after MB therapy. Similar to the preceding analysis, the analysis based on the second model was concluded by factoring in the tooth surface as a parameter. The occlusal, distal, and mesial surfaces were found to have a statistically higher risk of developing WSL than gingival surfaces. As a result, the risk was increased by a factor of 1.24-1.37 times (tab. 4).

Table 4: Overview of the parameters for logistic regression: WSL after MB therapy

The probability of diagnosing a new WSL after MB therapy is lower for female than for male patients. The risk for female patients to develop a WSL is 0.7 times lower than for male patients.

For the analysis of the various tooth types, we again chose tooth 11 as a reference. Teeth 12, 13, 14, 22, 23, 24, 25, 34, 35, 43, 44, 45 showed a statistically higher risk of developing a WSL than tooth 11. Here, upper and lower premolars (apart from 15) (odds ratio=1.69-2.8) were found to be statistically conspicuous. The lower teeth (31 and 41) were at a lower risk of developing a WSL than the reference. Teeth 15, 21, 32, 33, and 42 showed a similar risk of developing a WSL after MB therapy as tooth 11 (p>0,05).

As with the other analyses, we concluded the third model analysis by factoring in tooth surface as a parameter. Mesial and gingival surfaces carried a similar statistical risk of developing a WSL whereas the risk for distal surfaces was slightly higher than

for mesial and gingival surfaces. The occlusal area carried the lowest risk (tab. 5).

Table 5: Overview of the parameters for the logistic regression: Incidence

Discussion

For this retrospective study, we analyzed digital, intraoral photgraphs and 9680 tooth surfaces of 121 patients that received labial MB therapy as well as standardized oral hygiene instructions. A sample size calculation was performed in collaboration with a statistician of the IMBEI. The sample size and the examined tooth surfaces are similar to those described in the literature. (tab. 1) [2, 8, 10, 11, 19, 22, 24]. The study focused on upper and lower incisors, canine teeth, and premolars because their tooth surfaces are clearly visible on frontal as well as lateral photographs in spite of the labially bonded brackets during MB therapy. However, we did not include molars in the analysis as the bands used on them impeded the evaluation of buccal tooth surfaces on lateral photographs.Benson et al. [28] showed that the analysis of digital photographs is better suited for retrospectively evaluating WSL than analog photographs. Accordingly, digital photographs allowed for a correct identification of demineralization cases in 63 % of the time, whereas with analog pictures only 47% of demineralization cases were diagnosed correctly. Previous studies of photographs have already emphasized that when evaluated graphical material used can vary deliberately due to differing exposure, saturations, and intensities [29]. This variability particularly affects the decision whether a mild or grave WSL is presented. Nonetheless, healthy enamel can easily differentiated from WSL [11], which is also the reason why we conducted the analysis in a completely darkened room. In terms of repeatability, we found that digital photographs allow for an easier repeated diagnosis of WSL than clinical inspection or light microscopic study [30, 31]. As a result, this method allows for effective documentation and analysis of the prevalence as well as severity of demineralization over a specific period of time [32].

The aim of developing new evaluation tools was to increase the repeatability of the examination whether performed by varying researchers or by the same researcher. For this purpose, a standardized procedure is beneficial for accomplishing this goal. The benefits of using the EDI are, on the one hand, the division of the labial tooth surfaces around the bracket into four areas; on the other hand, the percentaged scale division presents yet another benefit of the EDI. At this point, the EDI is not widely used, which renders a comparison with other analytical methods difficult and quite restricted [9]. The EDI evaluates WSL intensity but not its extent. As a result, even a rather small cavitation is categorized at the highest level (level 3). Hence, next to intensity, the extent is of particular interest. To deliver more accurate conclusions on the extent of lesions on the tooth surface, we chose a graticule with concentric circles with an evaluation scale in increments of 20% for further analysis. The index by von der Fehr [34] we consider unfit for the retrospective examination of WSL with photographs as it is used for light microscopic studies of extracted teeth and their evaluation of the surface condition with regard to the opacity and ,thus, the severity of WSL. This index, however, does not allow for conclusions on the extent of WSL, which is why it is only applied in in vivo examinations and in relation to other indices [2].

The WSL index by Årtun & Brobakken [2] considers the individual tooth surfaces surrounding the bracket and, thus, can sufficiently diagnose the extent of a WSL. Moreover, Årtun & Thylstrup [35] combined their index with von der Fehr's index to draw more profound conclusions on lesion.severity.

In 1977, Cruzon and Spector devised another index for evaluating enamel opacity [36]. Mizrahi [10] modified this index to conclude on opacity severity, location, and dimension. However, this index only describes the dimension of WSL on the entire vestibular surface without generating a concise division of the areas surrounding the bracket.

The semi-quantitative index by Gorelick et al. [8] is commonly used but yet similarly unfit to conduct a more detailed and site-specific analysis. Not only do the categorizations of level 2 (mild demineralization) and 3 (severe demineralization) devolve, the index also does not divide the labial surfaces any further.

Contrary to the other methods we discussed earlier, the newly designed evaluation tool generates concise data on the extent of WSL. Other data useful for the critical evaluation of WSL, inter alia the so-called White Spot intensity and the WSL volume, are hereby not taken into account. Torlakovic et al. [37] demonstrated that the whiter a WSL, the more it expanded. The WSL volume not only describes the extent of the lesion with respect to the surface but also considers the depth of penetration. Torlakovic et al. [37] asserts that the traditional WSL index by Gorelick et al. is only a weak indicator of the actual depth of demineralization. From this assertion we reason that, even if a WSL concerns an expansive surface, it does not automatically coincide with deeply penetrated enamel. In the context of the clinical evaluation of WSL, we are still not able to describe WSL volume, which can only be determined on extracted teeth. Lesion depth can nonetheless be essential for performing potential WSL therapy if necessary.

The standardized procedure of this examination, which digitally adapts each photograph to the evaluation tool, allows for obtaining reproducible results regarding the extent of WSL. Other studies, which, above all, make use of the different refractive properties of a healthy enamel and the demineralization body, have attempted to establish a correlation to the lesion's depth. Thereby, polarized, fluorescent light sources and spectrophotometric measuring devices appear potentially well-suited for generating evident results regarding WSL formations in the future [26, 29, 37-44]. We find that WSL classification alongside with an extension index that is combined with a method that allows for conclusions on lesion depth possibly constitutes a useful tool for the diagnosis of labial WSL and ensuing therapeutic decisions.

In comparable studies, Mizrahi [10] discovered a prevalence of 72.3% of WSL with examined patients prior to MB treatment, Pancherz & Mühlich [21] of 70.4%. Enaia et al. [11] and Årtun & Brobakken [2] declared that 32.3% or 50.3% of the patients already had at least one previously damaged tooth prior to treatment. Merely Lovrov et al. [9] found that only 2.5% of the examined patients in their cohort had a WSL level >1. The cohort we examined accounted for a prevalence prior to MB treatment of 69.4%.

In the course of MB treatment, we observed a continuous increase of WSL. 97.5% of our patients presented WSL on at least one tooth surface after MB treatment. A clinical study that classified WSL with quantitative light-induced fluorescence (QLF) calculated a prevalence of 97% after MB treatment [26]. Ogaard [19] (96%), Mizrahi [10] (84%), Enaia et al. [11] (73,5%), and Banks & Richmond [24] (73%) came to results that were equally high. In contrast, Gorelick et al. [8], Geiger et al. [17], and Lovrov et al. [9] discovered that 49.6%, 33.8%, 32.3%, and 22.6% of the patients respectively had a WSL after MB therapy. The great variance of the occurrence of WSL between the studies mentioned above mainly derives from differences in their analytical approach [13]. The represented analyses detected the degree of demineralization above all by using visual-clinical inspection. Boersma et al. [26] discovered that all visually detected WSL were also correctly identified by using the QLF method. Furthermore, this method turned out to be more sensitive than visual examination when it came to an early diagnosis of WSL. Thus, the light-induced fluorescence (QLF) detected more WSL than the visual method. However, applying the QLF method is far more elaborate. The design of the study is another factor of influence. Retrospective examinations offer the advantage that a patient population can be re-examined quickly. In addition, the results represent the emergence of WSL that appeared in the orthodontic practice with routine treatment [11]. Data such as social origin, additional fluoridations, or the duration and regularity of MB treatment have not been included in the evaluation. On the basis of prospective examinations, we can further evaluate other factors. This may result in the anterior exclusion of patients with a bad or improvable oral hygiene or of patients with an already existing WSL from the study [45]. Another observation is the so-called Hawthorne effect, which implies that a patient's self-motivation considerably increases by participating in a study. This may ultimately have positive implications for their oral hygiene [46].

Another essential difference that may explain the variance between the studies is the selection of the teeth subject to examination. Similar to our study, the majority of researchers analyzed the UJ and LJ anterior and canine teeth as well as the first and second premolars that were provided with a bracket [2, 10, 21, 24]. Lucchese et al. [22], Lovrov et al. [9], and Ogaard [19], however, also examined the banded molars. The inclusion of canine teeth, premolars, and molars significantly increases the probability to diagnose a WSL. As a result, the percentaged data of WSL prevalence cannot be compared to other studies such as Enaia et al. [11], which solely analyzed the upper anterior teeth. Moreover, methodological variations occur on account of the use of different WSL indices, bracket and bonding matierals, oral hygiene measures, and treatment durations. However, the broad age range among patients and, potentially, their varying ethnic backgrounds can similarly result in these variations [47, 48].

In our patient population, 74.1% of female patients presented a WSL prior to and 96.5% after MB therapy. In comparison, we diagnosed at least one tooth with a WSL for 65.1% of male patients prior to and 98.4% after MB therapy. One plausible cause for the higher number of female patients with WSL at the beginning of the treatment is most likely a past tooth eruption. The affected tooth is longer exposed to oral cavity and thus bears a higher risk of developing a WSL for patients of the same age group. [21]. The gender difference in developing a WSL prior to MB therapy is statistically insignificant. However, after MB therapy, the difference is statistically conspicuous (p=0,049) as more male than female patients present a WSL. The logistic regression of this study thereby refers to all tooth surfaces. Therefore, we conclude that at any point in time, more tooth surfaces of males than females have been affected, even though fewer male patients presented a WSL. These results also correspond to the findings of Mizhari [10] and Zachrisson & Zachrisson [49] who observed worse oral hygiene or compliance with male than with coeval female patients during orthodontic treatment.

The evaluation of WSL prevalence prior to MB therapy with respect to each individual tooth showed a symmetric distribution of WSL on the different quadrants of the same jaw. The first and second premolars of UJ and LJ were more strongly affected than canine teeth or lateral incisors of the same jaw. The central incisors exhibited the lowest prevalence both prior to and after MB treatment. For teeth 14 and 24, the binary logistic regression resulted in a statistically increased risk to develop a WSL prior to MB therapy. In comparison, the lowest risk was calculated for the LJ anterior and canine teeth. After MB therapy, the highest risk of diagnosing a WSL remains with teeth 14 and 24. Furthermore, there is a statistically increased risk of developing a WSL for teeth 12, 22, 13, 23, 15, 25, as well as for the first and second premolars of the LJ. These results correspond to the findings of other studies for the lower teeth [2, 8, 17, 19, 22]. The anatomic proximity to the excretory duct of the salivary glands of the glandula submandibularis as wells as sublingualis seems to be mainly responsible for the low prevalence in the lower anterior teeth [50]. In their evaluation, Pancherz & Mühlich [21] discovered an accumulation of changes in the enamel on the upper central and lateral incisors prior to MB treatment. A past eruption of the remaining upper anterior teeth and the resulting longer exposure to oral cavity [21, 51] was stated as possible causes for these changes. Moreover, they also diagnosed an increase of demineralization's on the lateral incisors after MB treatment [2, 8, 10, 17, 49]. The lateral incisor seems to be particularly predisposed due to its smaller clinical crowns. After pasting the bracket, there only remains a small space to the marginal Gingivasaum. This area is hardly accessible for oral hygiene and thus entails a higher demineralization risk [19]. Another study emphasized that the use of loops to fill gaps, as well as hooks, and elastics in MB therapy considerably increases plaque retention between lateral incisors and canine teeth [2]. Furthermore, they argued that tooth shape and particularly the mesial concavity of the lateral incisivus was a decisive factor that contributed to an increase in plaque retention [2]. We usually did not use loops on our patients. In only seven cases, we used so-called closing loops that served to retract the anterior teeth after distalizing the canine tooth. The results of our study are also affirmed by the results found by Lovrov et al. [9] who proved that. in the upper jaw the first premolars have the highest prevalence of WSL both before and after MB treatment. Tufekci et al. [52] examined the prevalence of WSL after wearing the MB appliance for 6 and for 12 months and could not detect a difference between the various tooth types. The present MB appliance does not allow for an accurate identification of labial WSL, , which renders an evaluation difficult in this case [47].

A final evaluation of prevalence allowed for an analysis of the different tooth surfaces surrounding the bracket. The risk to developing a WSL before MB treatment was statistically higher for occlusal, distal, and mesial surfaces in comparison to gingival tooth surfaces. After MB therapy, the distal surface is more often affected than mesial, occlusal, and gingival surfaces. Cariology attributes the highest susceptibility to cavity to the approximal tooth surfaces, which more often concerns the distal than the mesial surface [53]. Comparable orthodontic studies attributed the highest risk to contract a WSL to gingival tooth surfaces [8, 49]. The gingival area is normally the smallest tooth surface, which facilitates plaque retention [2, 24]. Similar to our own patient population, Robertson et al. [25] describes a tendency to incisal and occlusal demineralizations. This nontypical distribution corresponding to literature does not derive from a systematic mistake. Firstly, Robertson et al.'s [25] results were collected by two independent researchers; and secondly, there existed a high intra-rater reliability. It can therefore be concluded that WSL prevalence in both patient populations was focused on the incisal quadrants. WSL incidence in our patient population amounted to 29%. This means that 29% of the patients, who have had no WSL prior to MB treatment, exhibited a demineralization after MB therapy on at least one tooth surface. Compared to the incidence discussed in literature, this constitutes a relatively small number of newly affected tooth surfaces. The analysis by Banks & Richmond [24] shows a considerably higher incidence: 74% of the patients had a WSL after MB treatment for the first time. In their patient population, Pancherz & Mühlich [21] diagnosed new or enlarged enamel lesions in 62% of the cases [21]. In Enaia et al.'s [11] retrospective study, 60.9% of the examined upper anterior teeth had a WSL after MB therapy. Gorelick et al. [8] examined 121 patients in total and thereby detected an incidence of 49.6%. Only Chapman et al.'s [13] study showed a lower incidence (36%). They only examined the digital photographs of the upper teeth 14-24. In analogy to evaluating the prevalence prior to and after MB treatment, there is a wide variability between the different studies. The analytic approach, the number and type of the examined teeth, and the WSL index used for diagnosis only allow for a limited comparison of the incidence in the studies at hand.

In this study, 23.2% of the female patients presented a WSL for the first time on at least one tooth after MB therapy whereas the incidence amounted to 33.9% with male patients. We consider this difference statistically insignificant. We acknowledge that this result does not correspond to Gorelick et al.'s [8] conclusions (incidence of 44% for male and of 55% for female patients). However, it is important to note that Gorelick et al.'s [8] patient population consisted of 49 boys and 72 girls, which impacted their result deliberately. Ogaard [19] also did not detect a statistically significant gender variation. Boersma et al. [26], on the other hand, discovered a statistically significant difference between the incidence of male (40%) and female (22%) patients.

The evaluation of new post-therapy WSL on different types of teeth in the UJ came to the result that canine teeth and premolars had the highest WSL incidence (71-79%). On the lateral incisors of the UJ, we diagnosed a new labial WSL on at least one tooth surface in 61-63% of the cases. In the LJ, the first and second premolars are most often affected (64-76%). Thereby, the premolars (aside from 15) of the UJ and LJ are statistically conspicuous. Similar to the prevalence, the results of the UJ here diverge from those discussed in literature. In their study, Banks & Richmond [24] detected the highest susceptibility to WSL for the lateral incisors and the canine teeth of the UJ. They also implied that using so-called "solder arch hooks" (hooks soldered on the archwire) complicates oral hygiene and contributes to an augmentation of WSL. This finding also corresponds to the results of other studies and allows for the conclusion that small tooth surfaces between the bracket and marginal gingiva increase the accumulation of plaque as well as food remains and, thus, the demineralization risk [2, 8, 17]. Another substantial factor for the development of new WSL in the UJ anterior teeth area seems to be the age at the beginning of MB treatment [54]. Starting therapy at a pre-pubertal age (9-12 years) was associated with a higher WSL risk [13].

In principle, it can be stated that the development of new WSL is symmetrically distributed on the left and on the right of the jaw. The studies at hand thereby correspond to the results of this study with respect to the incidence of the UJ as well as the LJ premolars and canine teeth. The high disposition of the lateral incisor could not be proven in this study. One reason for this might be the particular approach to acknowledge this risk and amend oral hygiene instructions accordingly, which can result in the reduction of plaque retention in this area. Furthermore, the use of hooks or loops between canine teeth and lateral incisors created additional retention sites. We only used these tools with 7 out of 121 patients in our cohort. Thus, the risk of demineralization on the lateral incisors was lower.

Finally, we analyzed the various tooth surfaces around the bracket for examining the incidence. The logistic regression analysis thereby resulted in a statistically increased risk of developing a new WSL for the distal tooth surface. For the mesial and gingival surfaces, the risk of diagnosing a new WSL during MB treatment is equally high, while the occlusal surface bears the lowest risk. We can conclude from epidemiological studies on caries incidence that the risk of diagnosing a new cavity is higher on the approximal tooth surfaces, regardless of an MB appliance [53]. The result of this study suggests that the presence of an MB appliance results in an increased tendency for developing a new WSL on the gingival tooth surface [25].

Nevertheless, this hypothesis has to be considered with reservations as it can only be confirmed through a control group without MB appliance. Banks & Richmond [24] concluded that almost 2/3 of the newly developed WSL were located in the gingival tooth area. The small area between the gingival seam and the bracket thus represents an increased risk of plaque retention. The knowledge of these risk factors influences the orthodontists' approach to the adhesive bonding of brackets and oral hygiene instructions. As a consequence, a reduction of the effects of the MB appliance on the development of new WSL is to be expected.

Conclusion

Labial MB treatment induces a high risk of developing WSL, particularly on canine teeth and premolars. The extent of labial WSL was evaluated concisely based on our specially developed evaluation index (graticule with concentric circles) and was clearly proven by simple handling and high intra-rater reliability. As a result, this method allows for precise quantification and is thus well suited for comparing the development of WSL with various labial MB appliances.

Abbreviations

White Spot Lesions (WSL)

multibracket appliance (MB)

Enamel Decalcification Index (EDI)

upper (UJ) and lower jaws (LJ)

tooth surfaces (TS)

Quantitative light-induced fluorescence (QLF)

gingival (g)

mesial (m)

distal (d)

occlusal (o)

Intraclass Correlation Coefficient (ICC).

Declarations

Ethics approval and consent to participate:

All investigations and procedures were conducted according to the principles expressed in the Declaration of Helsinki. Ethical approval for the retrospective study was not required. The Ethics Committee letter, supporting that statement, is added separately.

Consent for publication

Not Applicable.

Availability of data and materials:

The data used for analysis has been referenced in the text or tables of the paper.

Competing interests:

The authors declare that they have no competing interests.

Authors' contributions:

CE was the principal investigator and participated in the design of the study. CE and DO selected the patient's data for the study and contributed in writing the manuscript. HW designed and organized the whole study and was a major contributor in writing the manuscript. IS, as statistician, analyzed and interpreted the data. LH was the data manager and prepared the database and contributed to writing the manuscript.

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Tables

Table 1: Literature overview of the corresponding parameters for analyzing the prevalence and the incidence of WSL after MB treatment

Author (year)	Number of patients	teeth	Tooth surfaces	Used index	Prevalence	Incidence	Diagnosis
Lucchese et al. (2012)	191	UJ and LJ anterior teeth, posterior teeth (16-26,36-46)	4584	Gorelick et al.	40-43%	n.s.	Visual inspection
Enaia et al. (2011)	400	UJ anterior teeth (12-22)	1600	Gorelick et al.	73.5%	60.9%	Intraoral photography
Lovrov et al.(2007)	53	UJ and LJ anterior and posterior teeth (17-27,37-47)	1414	Gorelick et al.	26.4%	24.9%	Intraoral photography
Pancherz and Mühlich (1997)	108	UJ anterior teeth and premolars (15-25)	794	Modif. Gorelick	62.0%	49.6%	Intraoral photography
Banks et al.(1994)	80	UJ and LJ anterior and posterior teeth (15-25 a. 35-45)	4728	EDI	n.s.	74%	Visual inspection
Øogard et al.(1989)	51	UJ and LJ anterior and posterior teeth (16-26 a. 36-46)	1224	Modif. Gorelick	96%	n.s.	Visual inspection
Årtun and Brobakken (1986)	120	UJ and LJ anterior and posterior teeth (15-25 u. 35-45)	2400	Cavity index by von der Fehr and modif. Gorelick	52.5%	n.s.	Visual inspection
Mizrahi et	269	UJ and	5758	Modified	84%	n.s.	Intraoral

al. (1982)	LJ anterior teeth and premolars	Index by Curzon and Spector	photography

Table 2: Incidence of every single tooth and corresponding confidence intervals

Tooth	Confidence Interval 95%		Incidence
	Lower boundary	Upper boundary	
11	0.3668	0.5931	**48%**
12	0.4869	0.7194	**61%**
13	0.5975	0.8323	**73%**
14	0.5682	0.8176	**71%**
15	0.4441	0.7231	**59%**
21	0.4345	0.6543	**55%**
22	0.5192	0.7312	**63%**
23	0.6671	0.8753	**79%**
24	0.5815	0.8365	**73%**
25	0.4725	0.7357	**61%**
31	0.1757	0.3321	**25%**
32	0.2165	0.3885	**30%**
33	0.4233	0.6357	**53%**
34	0.6042	0.8171	**72%**
35	0.6179	0.8477	**75%**
41	0.1527	0.3068	**22%**
42	0.2683	0.4456	**35%**
43	0.4990	0.7014	**60%**
44	0.6467	0.8473	**76%**
45	0.5069	0.7570	**64%**

Table 3: Overview of the parameters for the logistic regression: WSL prior to MB therapy

	Hypothesis testing		Odds Ratio	95% Wald confidence interval for Exp(B)	
Parameter	df	Sig.	Exp(B)	Lower value	Upper value
(Constant term)	1	.017	.063	.006	.608
Male	.	.	1	.	.
female	.1	.655	.887	.523	1.054
tooth 11	.	.	1	.	.
tooth 12	1	.329	1.202	.831	1.739
tooth 13	1	.850	1.039	.701	1.540
tooth 14	1	.033	1.569	1.036	2.377
tooth 15	1	.562	1.139	.733	1.771
tooth 21	1	.377	.894	.696	1.147
tooth 22	1	.841	.966	.690	1.353
tooth 23	1	.760	.936	.611	1.433
tooth 24	1	.010	1.775	1.146	2.748
tooth 25	1	.968	.989	.578	1.693
tooth 31	1	.000	.081	.029	.225
tooth 32	1	.000	.177	.089	.351
tooth 33	1	.016	.566	.356	.900
tooth 34	1	.580	.869	.529	1.428
tooth 35	1	.168	.636	.334	1.210
tooth 41	1	.000	.075	.030	.184
tooth 42	1	.000	.129	.059	.281
tooth 43	1	.000	.311	.174	.555
tooth 44	1	.614	.885	.551	1.421
tooth 45	1	.293	.740	.422	1.298
surface o	1	.000	1.605	1.266	2.035
surface d	1	.001	1.325	1.115	1.574
surface m	1	.000	1.441	1.222	1.700
surface g	.	.	1	.	.
age	1	.134	1.110	.968	1.273

treatment time	1	.972	.996	.778	1.275

Table 4: Overview of the parameters for logistic regression: WSL after MB therapy

	Hypothesis testing		Odds Ratio	95% Wald confidence interval for Exp(B)	
Parameter	**df**	**Sig.**	**Exp(B)**	**Lower value**	**Upper value**
(Constant term)	1	.945	.938	.153	5.764
male	.	.	1	.	.
female	1	.049	.645	.417	.999
tooth 11	.	.	1	.	.
tooth 12	1	.000	1.846	1.388	2.456
tooth 13	1	.000	1.950	1.377	2.762
tooth 14	1	.000	2.379	1.657	3.414
tooth 15	1	.013	1.506	1.090	2.080
tooth 21	1	.291	1.126	.903	1.403
tooth 22	1	.001	1.688	1.294	2.281
tooth 23	1	.000	2.474	1.771	3.455
tooth 24	1	.000	2.524	1.763	3.613
tooth 25	1	.000	2.005	1.383	2.907
tooth 31	1	.000	.213	.141	.321
tooth 32	1	.000	.387	.265	.567
tooth 33	1	.928	.983	.679	1.424
tooth 34	1	.000	2.161	1.464	3.189
tooth 35	1	.004	1.797	1.201	2.689
tooth 41	1	.000	.226	.146	.350
tooth 42	1	.000	.417	.285	.610
tooth 43	1	.771	1.061	.712	1.581
tooth 44	1	.000	2.120	1.465	3.068
tooth 45	1	.000	2.042	1.370	3.046
surface o	1	.007	1.235	1.058	1.441
surface d	1	.000	1.372	1.218	1.547
surface m	1	.000	1.331	1.182	1.498
surface g	.	.	1	.	.
age	1	.582	1.033	.921	1.159

treatment time	1	.133	.878	.741	1.040

Table 5: Overview of the parameters for the logistic regression: Incidence

	Hypothesis testing		Odds Ratio	95% Wald confidence interval for Exp(B)	
Parameter	df	Sig.	Exp(B)	Upper value	Lower value
(Constant term)	1	.430	.938	.153	5.764
male	.	.	1	.	.
female	1	.055	.697	.483	1.007
tooth 11	.	.	1	.	.
tooth 12	1	.003	1.730	1.210	2.475
tooth 13	1	.001	2.172	1.402	3.365
tooth 14	1	.027	1.688	1.060	2.688
tooth 15	1	.497	1.165	.749	1.814
tooth 21	1	.100	1.287	.953	1.739
tooth 22	1	.001	1.860	1.295	2.672
tooth 23	1	.000	2.474	1.771	3.455
tooth 24	1	.000	2.799	1.797	4.361
tooth 25	1	.012	1.851	1.147	2.986
tooth 31	1	.008	.482	.281	.826
tooth 32	1	.336	.783	.476	1.289
tooth 33	1	.060	1.561	.981	2.483
tooth 34	1	.000	2.796	1.697	4.608
tooth 35	1	.002	2.428	1.387	4.251
tooth 41	1	.009	.469	.266	.829
tooth 42	1	.670	.906	.575	1.426
tooth 43	1	.001	2.313	1.437	3.721
tooth 44	1	.000	2.568	1.589	4.152
tooth 45	1	.000	2.725	1.552	4.787
surface o	1	.395	.930	.786	1.100
surface d	1	.022	1.157	1.021	1.310
surface m	1	.670	1.030	.900	1.179
surface g	.	.	1	.	.
age	1	.055	.911	.828	1.002

treatment time	1	.095	.876	.750	1.023

Figures

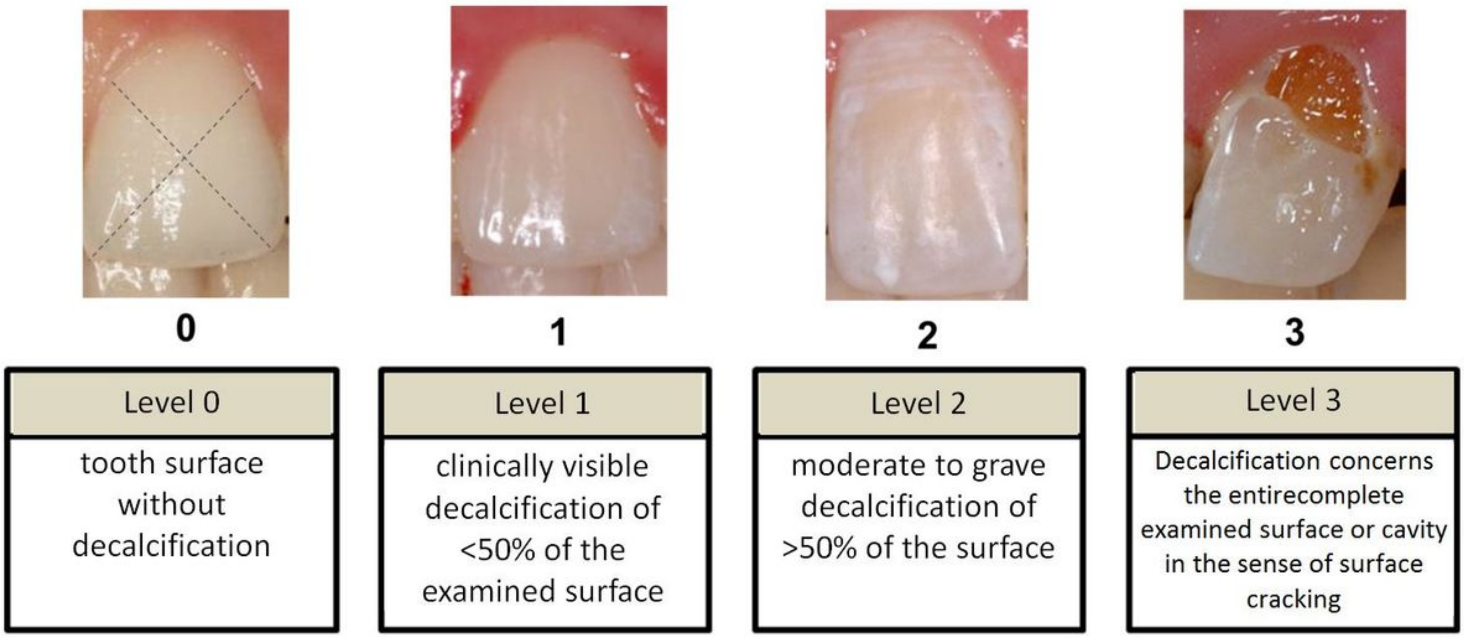

Figure 1

Description of the des Enamel Decalcification Index (EDI) by Banks & Richmond in order to measure the intensity of White Spot Lesions.

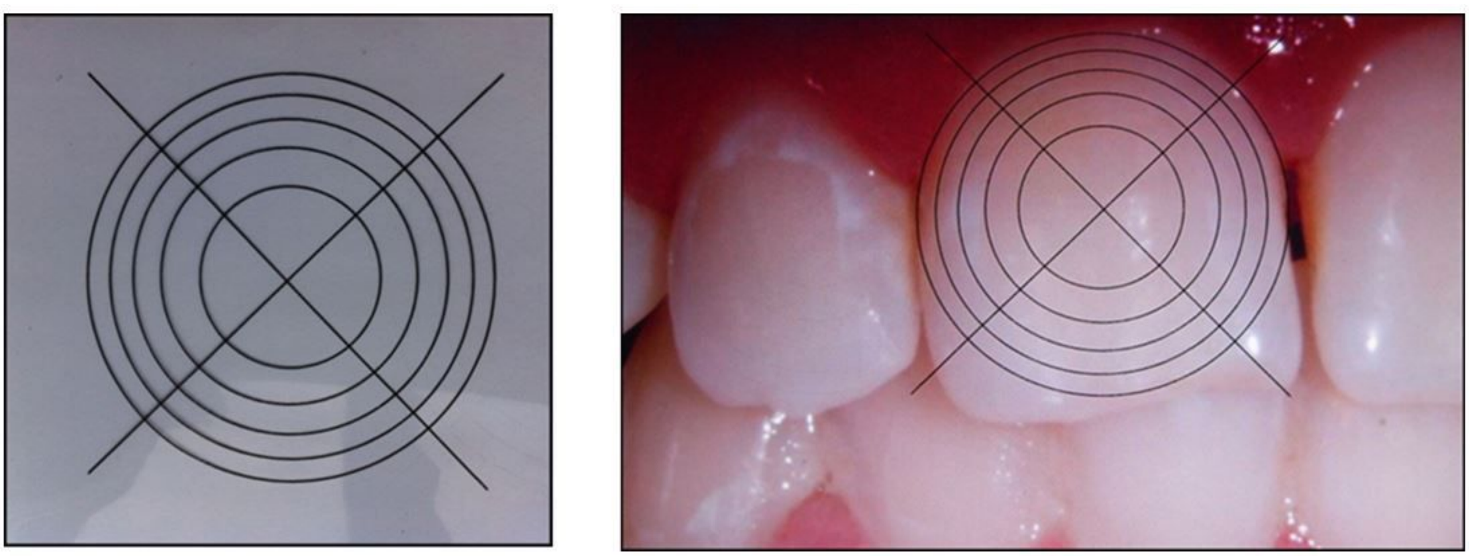

Figure 2

Evaluation tool with graticule and concentric circles printed on film and evaluation with the polyester film adapted and fitted to the tooth.

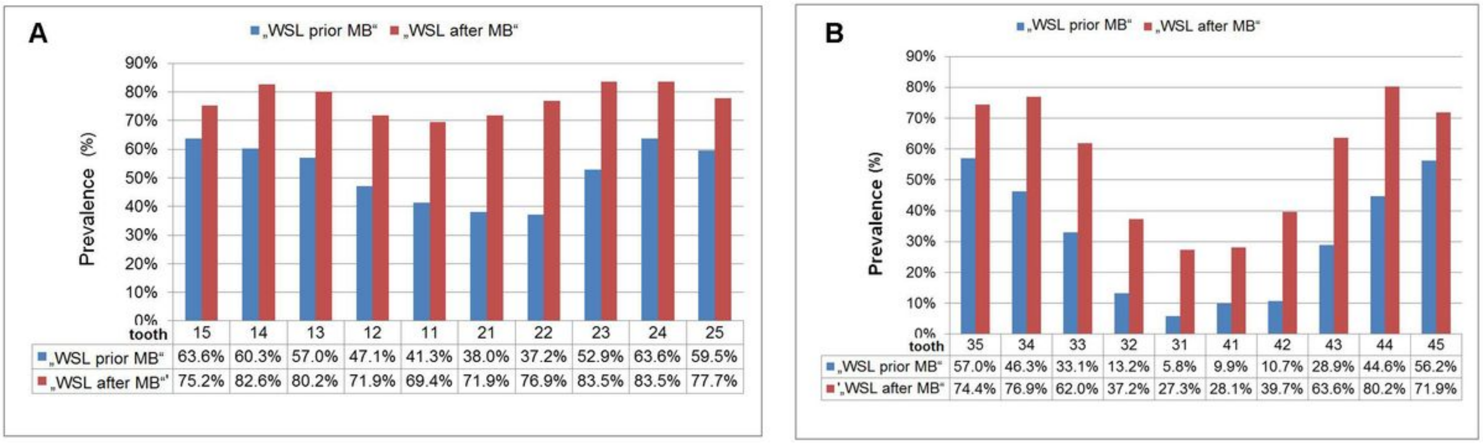

Figure 3

a and b: Bar diagrams describing the prevalence of WSL of upper teeth a) and lower teeth b). The x-axis divides the examined teeth according to the time of their examination (WSL prior to MB; WSL after MB). The y-axis displays the percentage that corresponds to the occurrence of WSL; only the positive results (WSL=1) were included.

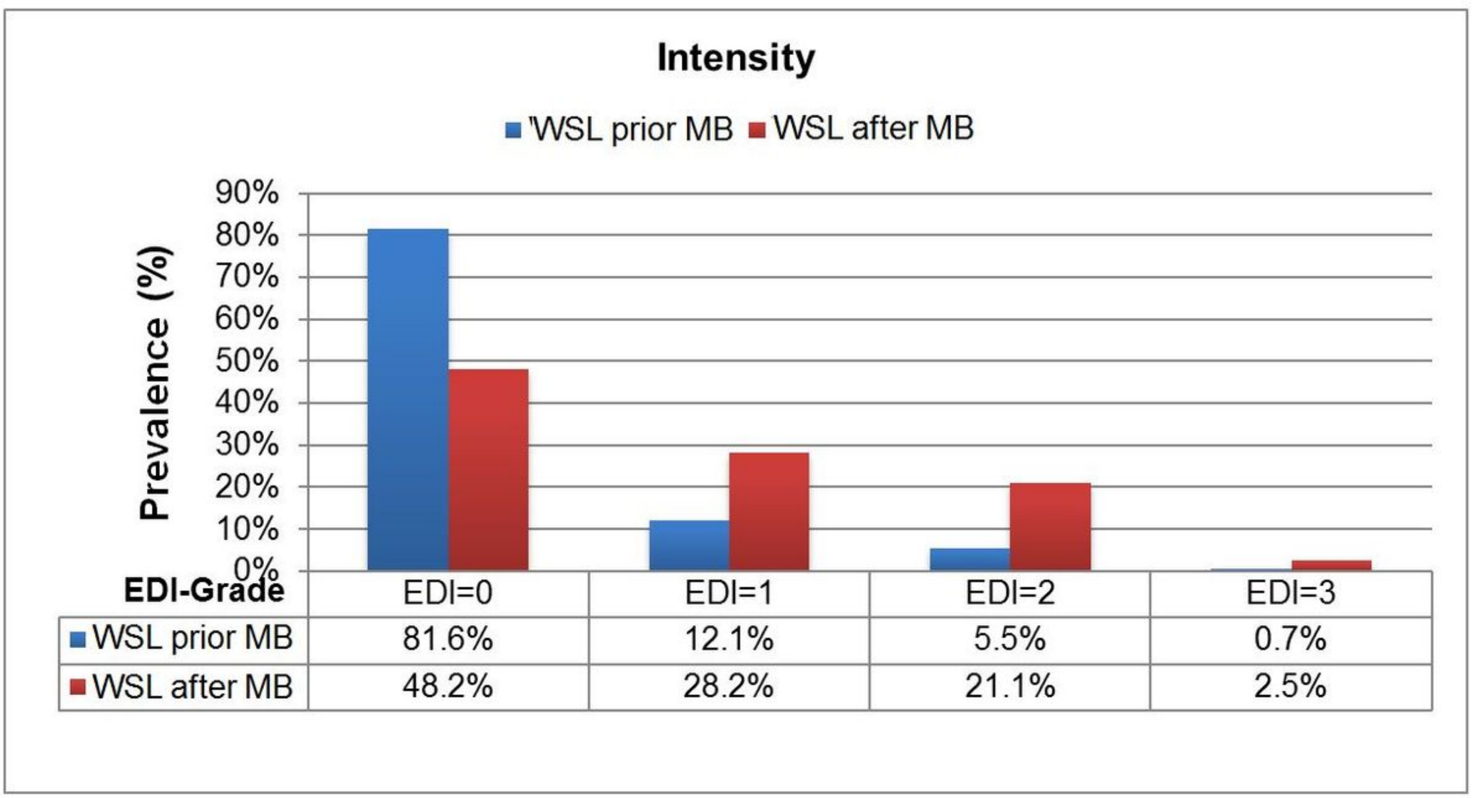

Figure 4

Bar diagram describing the WSL prevalence distributed by percentage of intensity (with Enamel Decalicification Index, EDI). The x-axis shows EDI levels 0-3 and their percentage of the WSL evaluation prior to and after MB. The y-axis specifies the prevalence in %.

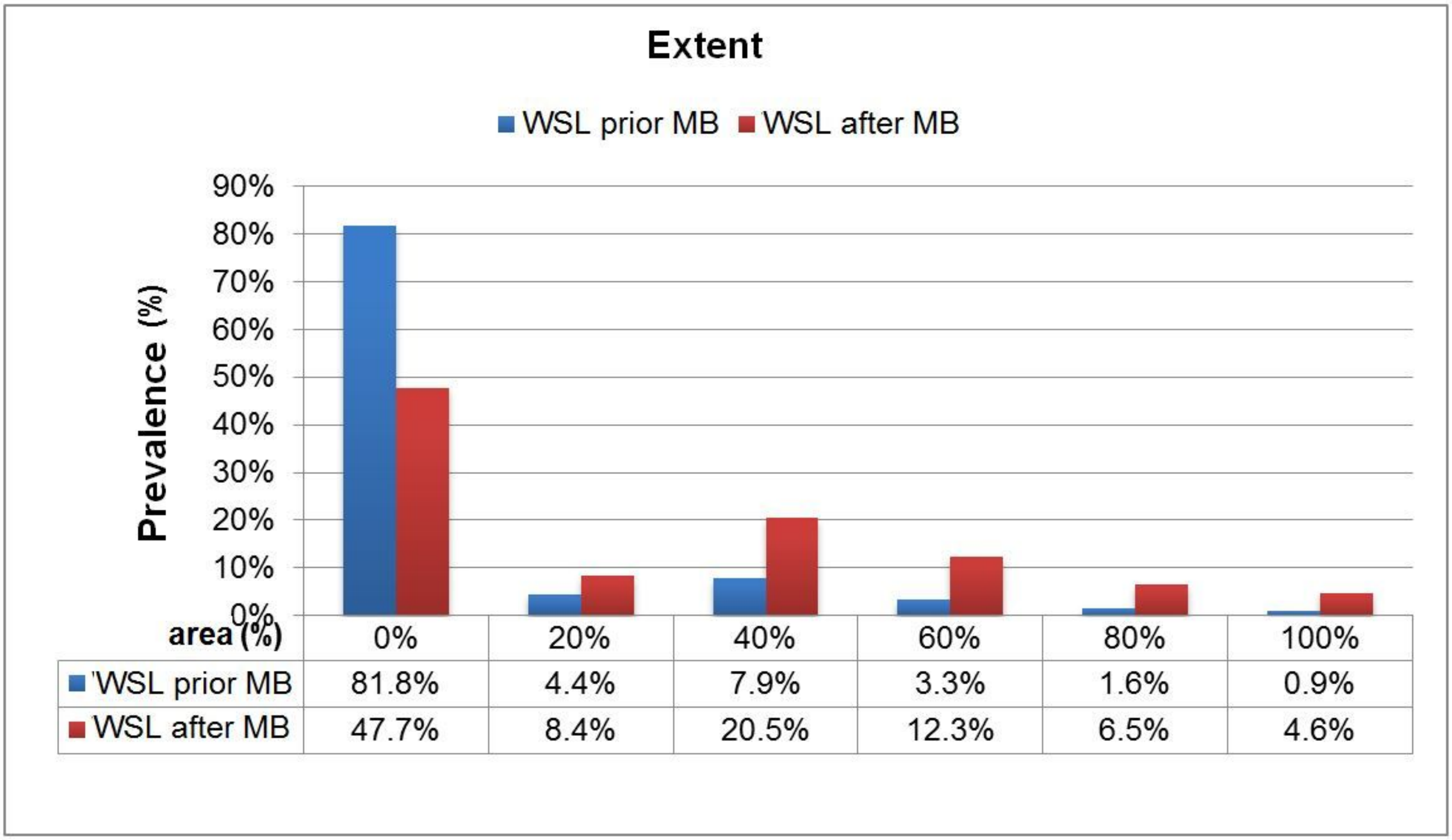

Figure 5

Percentaged distribution of the evaluation index according to the occurrence of WSL. The x-axis of the bar diagram shows the evaluation index (0%-100%) and its distribution by percentage upon evaluating WSL, prior to and after MB respectively. The y-axis shows the prevalence in %.

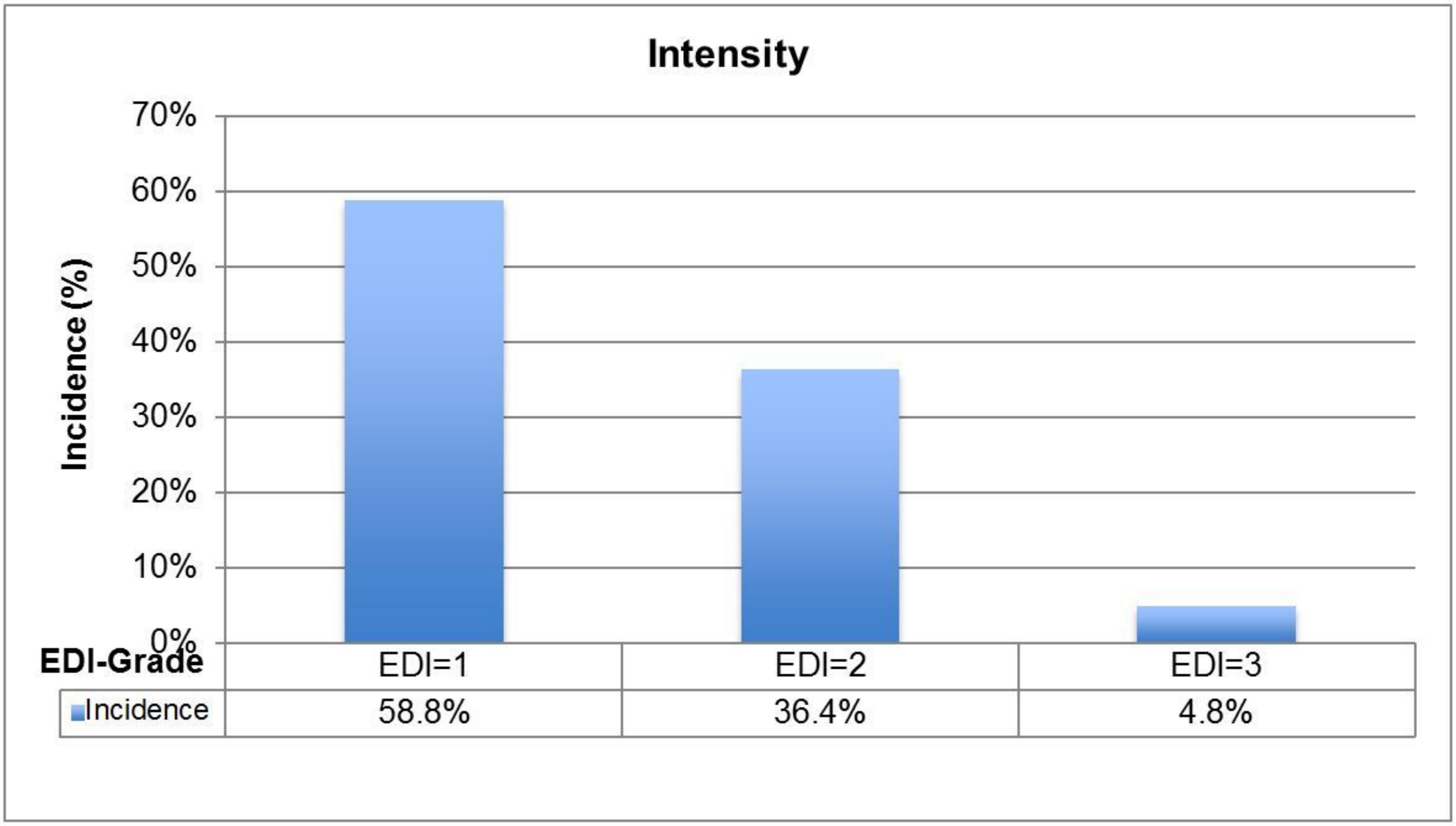

Figure 6

Incidence distribution based on intensity (EDI)

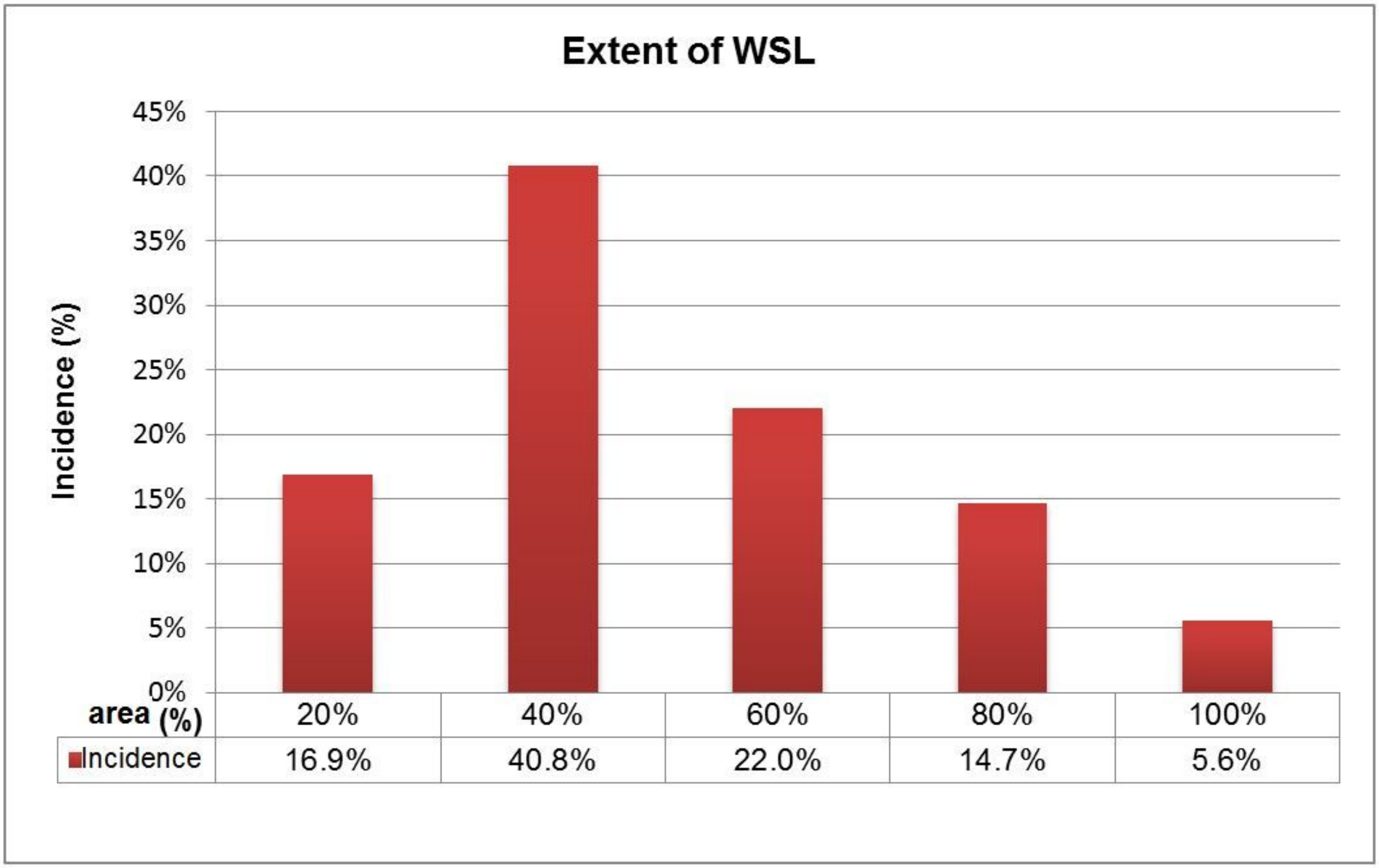

Figure 7

Distribution of the incidence according to extent (%)