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Monitoring the progression of erosive tooth wear (ETW) using BEWE index in casts and their 3D images: A retrospective longitudinal study

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ABSTRACT

Objective: To determine if the Basic erosive tooth wear index (BEWE index) is able to assess and monitor ETW changes in two consecutive cast models, and detect methodological differences when using the corresponding 3D image replicas.
Methods: A total of 480 pre-treatment and 2-year post-treatment orthodontic models ($n = 240$ cast models and $n = 240$ 3D image replicas) from 120 adolescents treated between 2002 and 2013 at the Gent Dental Clinic, Belgium, were scored using the BEWE index. For data analysis only posterior sextants were considered, and inter-method differences were evaluated using Wilcoxon Signed Rank test, Kappa values and Mc Nemar tests ($p < 0.05$). Correlations between methods were determined using Kendall tau correlation test.
Results: Significant changes of ETW were detected between two consecutive models when BEWE index was used to score cast models or their 3D image replicas ($p < 0.001$). A strong significant correlation (τb: 0.74; $p < 0.001$) was shown between both methods However, 3D image-BEWE index combination showed a higher probability for detecting initial surface changes, and scored significantly higher than casts ($p < 0.001$). Incidence and progression of ETW using 3D images was 13.3% ($n = 16$) and 60.9% ($n = 56$) respectively, with two subjects developing BEWE = 3 in at least one tooth surface.
Conclusions: BEWE index is a suitable tool for the scoring of ETW lesions in 3D images and cast. The combination of both digital 3D records and index, can be used for the monitoring of ETW in a longitudinal approach. The higher sensibility of BEWE index when scoring 3D images might improve the early diagnosis of ETW lesions.
Clinical significance: The BEWE index combined with digital 3D records of oral conditions might improve the practitioner performance with respect to early diagnosis, monitoring and managing ETW.

1. Introduction

Erosive tooth wear (ETW), which is the chemical-mechanical process of tooth surface loss caused principally by extrinsic and/or intrinsic acids, has become an important topic in dental research the last decade [1,2]. Current dietary habits involving higher consumption of acidic food and beverages explain the increasing concerns with respect to the occurrence of ETW [1], and this is reflected by the several prevalence studies of ETW that have been lately published [3–9]. In 2015, an estimation of the worldwide prevalence indicated that 30% of children and adolescents were affected by some kind of ETW [10], and in adults a multicenter study of 7 European countries indicated that 57.9% of them had at least one anterior tooth surface affected by ETW [11]. The available data suggests that ETW is a common condition and that there is an apparent increase in the worldwide prevalence [1].

On the other hand, assumptions with respect to the incidence and progression of ETW remains difficult: firstly, the available studies investigating this topic are scarce and secondly, their methodology to detect progression of ETW differs substantially [1]. For instance, only five longitudinal studies assessed ETW progression in adolescents and all of them use different age groups, indexes and follow-up times, which complicate any comparison between results [12–16]. For example, the first longitudinal study performed in 2001 used pre-orthodontic cast models found an incidence of 18% with 17.7% progression of ETW in a period of 5 years for 11 year-old adolescents [12]. Those results are difficult to compare with the results of the latest prospective

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longitudinal study done in 2016, where progression of ETW was clinically evaluated using a different age group (13–14 year-old) and a longer follow-up time (4 years) [16]. Nevertheless, despite these methodological differences present among the available longitudinal studies, all these results agree with the fact that ETW progresses in time, even after a 1.5 year period [14]. This suggests that ETW should be detected and monitored from early ages, in order to prevent and diminish any progression of ETW.

The diagnosis of initial stages of ETW however, is difficult to perform [17–19], and this limitation might be the first barrier for the correct monitoring of lesion progression. Therefore, there is need of chairside tools able to improve the diagnose, detection and record ETW lesions [20]. Up to date, diagnostic tools such as the BEWE index have been recommended for the recording of ETW in cross-sectional studies and at the dental practice [21]. This index has the additional advantage of providing guidance for the clinical management of patients according to their level of ETW risk, which can be low, medium or high depending on the severity reached. Despite these advantages, the criteria description that defines each level of ETW in this index provides general information, and therefore their creators do not recommend it for progression studies of ETW, where detailed information is needed [19,22]. Nevertheless, the use of this index combined with additional records such as photographs, cast models or 3D images provided by intra-oral scanners could improve its performance for the monitoring of ETW between appointments [20–23].

Previously, BEWE index demonstrated a good performance for the scoring of ETW in photographs [24] and in 3D images [23]. Recording 3D image data might improve significantly the detection and monitoring of ETW lesions based on the fact that digital images can be zoomed in, rotated and measured [25,26]. In the past decade, the use of intra-oral scanners in the dental practice has increased [27], and several brands are promoting these technologies [23,27]. A recent study demonstrated that BEWE index was reliable for the score of 3D models, and suggested that this method of record could be useful for the monitoring of progression of ETW [23]. However, up to date, their use in a longitudinal study combined with the scoring provided by BEWE index has not been tested.

The lack of longitudinal studies related with ETW and the need of improvements for the early diagnosis of ETW and between appointments monitoring have encouraged the present study. Therefore, the primary aim of this retrospective longitudinal study was to determine if BEWE index is able to assess and monitor ETW changes between two consecutive cast models, and detect methodological differences when using their 3D image replicas, and to determine the progression of ETW lesions during a two-year time period in a group of Belgian adolescents.

2. Materials and methods

2.1. Study population and ethical aspects

The target baseline cohort of this longitudinal retrospective study comprised all adolescents (age range 11–13 year olds) who were treated between 2002 and 2013 in the Orthodontic Department of the Gent University Hospital, Gent, Belgium, and who had pre- and post-orthodontic cast models available in their records. Only models from patients aged 11, 12 and 13 at baseline (pre-orthodontic model) and who had a follow-up model after a minimum time of 1.8 years and maximum time of 2.8 years, were included in this study.

Exclusion criteria for models were any absence of first permanent molars, bad quality models having presence of casting pearls or voids, broken teeth, presence of orthodontic appliances, such as brackets or orthodontic bands that could compromise the final score of the model.

This study obtained approval of the local ethical committee of the Gent University Hospital, which follows the "ICH Good Clinical practice" of the declaration of Helsinki (BC2016/0615 & 2016/0616).

2.2. Examination and score of the models

The presence and severity of ETW lesions was recorded using two indices: the BEWE index and the Erosive index (EI). EI index was previously used in a longitudinal study for the assessment of cast models [12], and for this study it was exclusively chosen in order to compare the BEWE index performance to score cast models in a longitudinal basis. BEWE index was used as suggested by Bartlett et al. [22]. For BEWE index, all permanent tooth surfaces of posterior teeth (4 sextants) were evaluated using a 4-step categorical scale (0–3). The 4 score criteria used during examination were: '0' an indication for the absence of ETW, '1' an indication for initial loss of surface texture (visually detectable), '2' an indication for distinct defect, hard tissue loss less than 50% of the surface area, and '3' an indication for hard tissue loss equal or more than 50% of the surface area (scores 2 and 3 can also involve dentin). The score of the most affected tooth per sextant represented the final sextant score. BEWE sum was calculated by adding the cumulative sextant scores of four posterior sextants.

2.3. Examiners and calibration

Two examiners (FM & LD) were educated and instructed by an experienced senior (LM) over a two-month period in relation to ETW, using photographs of diverse clinical cases of tooth wear and ETW displayed in a Power Point presentation. For calibration, each examiner was challenged to score a total of 36 cast models with different grades of ETW (not included in the study) using both indices (EI and BEWE) and in a second instance they had to score a set of 3D images of other 36 clinical cases using BEWE index. The 3D images and the cast models were scored at tooth level, by sextant or by the final BEWE sum. To determine intra-examiner agreement, every examiner had to re-score after 1 month the same casts and 3D images. The examinations of models started only after the inter-examiner agreement reached a kappa value equivalent to the cut off 0.61–0.8 or higher indicated by the scale of Landis & Koch (substantial level or higher).

2.4. Cast examination

The scoring of the cast models was made under standard illumination (LED light source) in the same room. Only the visible surfaces of the permanent dentition of the posterior sextants, with exception of third molars and partially erupted teeth were evaluated. Anterior sextants were excluded due to aesthetic modifications that some orthodontic patients received at the end of the treatment. In addition, the presence of different types of tooth wear such as wedge-shaped defects, attrition (matching facets, flat, and sharp bordered) and abrasion were not considered as affected (score 0 in both indices), when the role of this type of wear was major and no typical features of acidic interaction were present.

2.5. 3D image examination

3D image replicas from the cast models at baseline and follow-up were obtained from a confocal intra-oral scanner TRIOS ™ (3Shape) and were transferred to the software Preview 8.1 (OSX10.11.4), which allowed the zooming in, rotation and inclination of the images during examination of the models (Fig. 1). The same examiners and parameters described for the cast models were used to score 3D images. Score procedure was performed 1 month after the cast examination and the examiners did not have access to the previous scores given for the cast models.

2.6. Data management and statistical analysis

The presence of ETW was determined using as cut-off BEWE sum > 0 and EI > 0. For inter-method agreement, BEWE sum and the

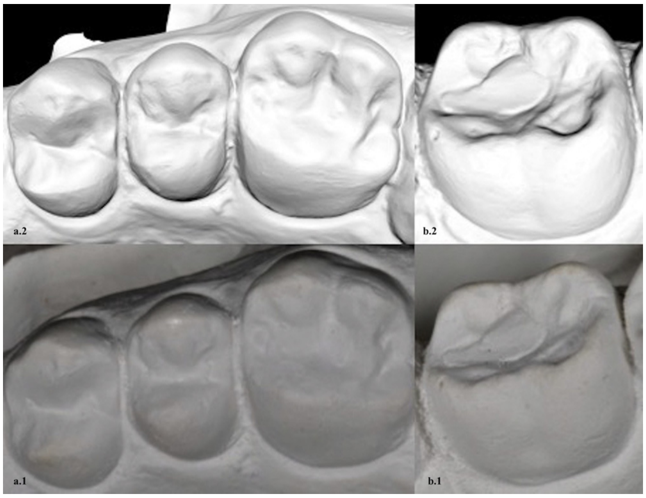

Fig. 1. Illustration of Cast record with correspondent 3D image replica.
Case a. 2.4 BEWE = 1; 2.5 BEWE = 0 and 2.6 BEWE = 1 (a.1: Cast a.2: 3D image replica).
Case b. BEWE = 3 (b.1: Cast b.2: 3D image replica).

scores obtained by each posterior sextant were analysed separately. Additionally, changes according to the level of risk were determined by the cut-off criteria originally proposed by Bartlett et al. [22], which uses BEWE sum > 2–8, BEWE sum > 8–13 and BEWE sum > 13–18 as indicators for low, medium and high risk respectively [22]. Incidence, distribution and progression of the lesions between baseline and follow-up were analysed using the aforementioned cut-offs, the mean BEWE sum and using the total number of affected teeth for each BEWE criterium (BEWE = 0, = 1, = 2 and = 3).

Data were analysed using IBM SPSS v. 22.0 and v. 24.0 (SPSS Inc., Armonk, NY.). Intra and inter- examiner reliability was calculated using kappa coefficients. Overall, descriptive statistics were performed and to compare methods of scoring (EI, BEWE in cast and BEWE in 3D models) Wilcoxon Signed Rank test, Paired sample test and Mc Nemar test at significance level of $p < 0.05$ were used. Correlations between methods (significance level $p < 0.01$) were determined using Kendall tau correlation test.

3. Results

3.1. Descriptive

Pre-orthodontic models from 400 patients (age range 11–13 years) treated between 2002 and 2013 were retrieved in the hospital records. From these models, a total of 120 patients presented a baseline (n = 120) and a follow-up cast (n = 120) that fulfilled correctly the inclusion criteria of the study (model quality, age and time between models). Therefore, the final sample size used for statistical analysis was 480 records (n = 240 cast models and n = 240 3D image replicas). These 480 records provided 1920 posterior sextants (n = 960 cast model sextants and n = 960 3D image sextants).

The reasons for exclusion were age and time between models (n = 262), absence of first molars in the follow-up models (n = 11), MIH (n = 2), orthodontic bands (n = 2), and cast voids (n = 3).

Mean age of the included adolescents at baseline was 12.78; SD 0.68 (age range 11–13 years old) and 15.1; SD 0.60 at follow-up (age range 13–16). The mean time between baseline and follow-up was found to be 2.52 years; SD 0.3. Gender distribution, age and time between models did not differ significantly.

Table 1
EI and BEWE index correlation in cast models scoring in a longitudinal model.

	Mean BEWE sum ± SD	Mean EI ± SD	Kendall's tau correlation
Baseline	1.34 ± 1.44	6.73 ± 8.72	0.86*
Follow-up	2.48 ± 1.89	12.5 ± 14.39	0.77*
Difference between models	+1.14 ± 1.19	+5.77 ± 11.47	0.59*

There is a significant higher mean BEWE and EI in follow-up models (Wilcoxon signed rank test z- = 7.605; $p < 0.001$ for BEWE sum mean and Z = -6.402; $p > 0.001$ for EI).
* $p < 0.001$.

3.2. Reproducibility of examiners and BEWE index for cast and 3D models

Intra-examiner reliability for EI and BEWE on cast models was considered almost perfect and substantial (unweighted Cohen's kappa), being 0.82 (EI) – 0.95 (BEWE) for FM and 0.72 (EI) – 0.91 (BEWE) for LD. The inter-examiner reliability was 0.86 and 0.95 for EI and BEWE, respectively. For 3D replicas, intra-examiner reliability was considered almost perfect according to Landis & Koch scale, being 0.96 (FM) and 0.88 (LD) and substantial for the inter-examiner reliability, ranging from 0.80 to 0.73 (unweighted Cohen's kappa).

The results using BEWE index for cast models at baseline and follow-up, were significantly correlated with the scores obtained with EI index ($p < 0.05$; Table 1).

3.3. Inter-method differences

Table 2 shows inter-method differences between the combination of BEWE-cast or BEWE-3D images. Overall, BEWE index scored significantly higher when performed on 3D replicas. The percentage of agreement of 3D images was 88.4% at sextant level for erosion detection (BEWE > 0) when scores for cast models were used as standard reference, and the 3D method detected more BEWE 1 when compared to cast. The inter-method agreement using posterior sextant score distribution (Table 3) was considered as substantial and higher; however, the agreement level decreases to moderate when BEWE sum is used to compare methods differences (Kappa = 0.53 between baseline models and Kappa = 0.59 between follow-up models).

3.4. Incidence, progression and distribution of ETW

Prevalence of ETW and risk level changes in the follow-up period are shown in Table 4. After two years, incidence of ETW was 13.3% when 3D replicas were scored and 20.8% when using casts. Progression of ETW using the 3D method was observed in 60.8% (n = 57) and in 67.1% (n = 49) using the cast method. At baseline the majority of patients had a BEWE sum score in the range of BEWE sum = 0 or BEWE sum = 1–2 (no risk). After two years a higher percentage of patients were located among the BEWE sum = 3–8 (medium risk), but no high-

Table 2
Inter-method comparisons of mean BEWE sum and correlations.

	Cast	3D Image	Correlation+
Baseline			
Mean BEWE sum ± SD	1.34 ± 1.44*	1.82 ± 1.56*	0.802+
BEWE sum range	*0–6*	*0–6*	
Follow up- after 2 years			
Mean BEWE sum ± SD	2.48 ± 1.89*	2.90 ± 1.75*	0.822+
BEWE sum range	*0–8*	*0–8*	

a) Difference according to Wilcoxon Signed Rank test comparing mean BEWE sum differences between 2 methods of scoring ($p < 0.05$*);
b) +Inter-method correlations according to Paired sample ($p < 0.001$).

Table 3
Inter-method agreement according to sextant score distribution.

	Sextants scores distribution			
	Cut-off BEWE = 0	Cut-off BEWE = 1	Cut-off BEWE = 2	Cut-off BEWE = 3
Cast sextant (n = 960)	542(56.7%)	379(39.5%)	37(3.9%)	2(0.2%)
3D sextant (n = 960)	447 (46.6%)	462(48.1%)	49(5.1%)	2(0.2%)
Kappa Value	0.80	0.64	0.73	1
Inter-method agreement (%)	77.1%	88.4%	86.4%	100%

% of agreement calculated using cast scores as standard reference.
Per method a total of 960 posterior sextants were scored.

Table 4
ETW risk and prevalence determined by BEWE index according to method type at baseline and follow-up.

		Prevalence (BEWE sum > 0)	No risk (BEWE sum 1–2)	Low risk (BEWE sum 3–8)
Cast (n = 120)	Baseline	73 (60.8%)*	46 (38.3%)	27 (22.5%)*
	Follow-up	98 (81.7%)	41 (34.2%)	57 (47.5%)
3D Image (n = 120)	Baseline	92 (76.7%)*	56 (46.7%)	36 (30.0%)*
	Follow-up	108 (90.0%)	40 (33.3%)	68 (56.7%)

BEWE sum > 8 Not present.
* Baseline value differ significantly with follow-up according to Mc Nemar test ($p < 0.05$).

risk levels were found in the entire study.

Independent of scoring method, the prevalence of ETW (BEWE sum > 0), mean BEWE sum and severity recorded at baseline increased significantly after 2 years (Tables 2 and 4). The given BEWE scores for 3D images were significantly correlated and higher than cast models scores ($\tau b = 0.68$ $p < 0.001$ at baseline and at follow-up $\tau b = 0.7$ $p < 0.001$).

Distribution of the lesions by severity reached per tooth at baseline and at follow-up is shown in Fig. 2. Overall, at tooth level the lower first permanent molars were the most affected and the only tooth surface that reached BEWE = 3 after 2 years.

3.5. *Effect of gender and age in ETW progression*

The mean BEWE sum and progression compared by gender did not differ significantly at baseline and at follow-up. Having BEWE 2 or higher at baseline was the only associated variable with higher risk of ETW after 2 years (OR: 8.04; 95%CI: 1.53–42.19, $p < 0.05$).

4. Discussion

To the best of our knowledge, this is the first study evaluating the use of BEWE index combined with cast models and 3D images to assess the monitoring of ETW in a longitudinal study. In this study, the retrospective model was chosen due to availability of orthodontic casts present in the hospital records. This resulted in a convenient sample in order to determine whether or not the combination of BEWE index with records, such as cast models and 3D images, is able to detect and monitor progression of ETW lesions between follow-ups. Nevertheless, this way of sampling could be considered as the first limitation of the study by the simple fact that it does not give us a direct comparison with the clinical situation were the detection of the lesions is not limited into a grey colour scale as in the present study. As past records were used, the clinical situation could not be assessed. In some of the cases photographs were available; however, those records were not taken with the intention to detect erosion. The use of clinical data as standard reference in a prospective clinical study will be considered for further research. A second limitation is that the major part of the population included in this study presented low rates of ETW severity, which might facilitate a good agreement between the methods. A larger sample with a wide and varied range of severity could solve this issue. However, prevalence studies show that this low severity situation is also present using larger samples [28]. Additionally, it seemed that anterior teeth were often aesthetically modified in the follow-up and due to this reason, they were not considered in the screening, which could result in an underestimation of the final results. Therefore, any interpretations and/or extrapolation of the results to the clinical situation should be done strictly within this context. Despite these limitations, the results obtained suggest that BEWE index together with records such as cast models or 3D images is able to monitor and detect ETW progression in a longitudinal model.

The BEWE index was created to score cast models as well [22], but it was never studied with longitudinal data. Therefore, to be able to use the BEWE scores on cast models as a reference standard, it was mandatory to validate the index. That is the reason why BEWE scores were first compared with the scores given by the EI index. The EI index was used in the only existing study regarding progression of ETW using pre- and post- orthodontic cast models [12]. Results show that both indices were strongly correlated, indicating that BEWE index, despite not being an index of choice for progression studies [22], was able to detect progression between two consecutive cast models with a similar accuracy to the EI index.

The main finding of this study was that BEWE index was able to assess ETW and detect changes after two years period when combined with both cast models or 3D images. The score in cast and 3D models showed correlated results respect to prevalence, incidence, progression and distribution of the lesions at baseline and at follow-up. After two years of follow-up, the increase in ETW was similar for both methods; however, the obtained scores for 3D images were higher than the ones obtained for cast models. This inter-method difference was mainly caused by a higher probability of the BEWE index to detect minimal changes at the tooth surfaces in 3D images. This is in line with the recent findings of Alaraudanjoki et al. [23], where BEWE index was shown to be more sensitive at the moment to detect early lesions when using 3D images than using clinical examinations. A reason for this higher sensibility is that the 3D images allow the examiner to rotate and zoom up the lesions, improving their capacity to detect minimal changes of dental structures. This finding indicates that the use of scans could facilitate the early detection of ETW lesions, which has been several times described as difficult [23,29]. Any improvement on the detection of ETW at their most early stages could improve the diagnosis, monitoring and prevention, and as a consequence diminish the progression of ETW lesions in patients. Further studies should aim towards the application of direct intraoral scanning for the detection and follow-up of erosive lesions in-vivo. Since intraoral scanners are on the way to becoming wide spread equipment, this would be an interesting supplementary application.

4.1. *Incidence, progression and distribution of ETW*

Considering only the 3D image scores, the incidence and progression of ETW in this study was 13.3% and 60.8% respectively, and none of the cases were considered at high risk of ETW after 2 years. However, at tooth level, a few adolescents (n = 2) scored the most severe criterium (BEWE = 3) during the follow-up period, meaning that severe cases of ETW could appear during adolescence. This indicates that practitioners should be aware of the presence of the condition at these ages, and should detect ETW at their most initial stages to prevent further deterioration of the tooth surfaces.

The distribution of the lesions presented in Fig. 2, is similar to the

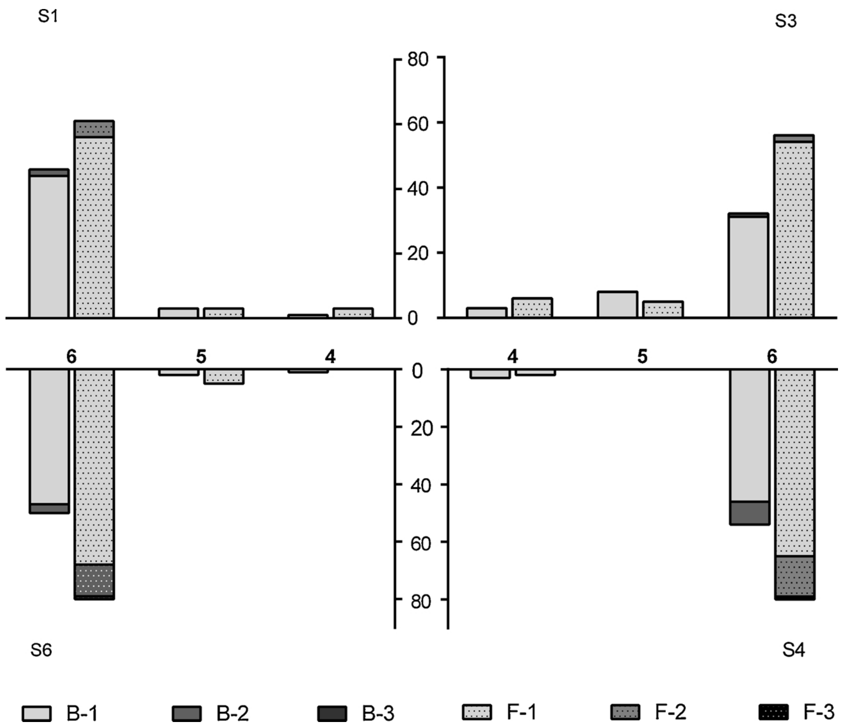

Fig. 2. Distribution and progression of ETW determined by BEWE criteria using 3D models.
Legend: Number of affected tooth within each BEWE criteria at B = Baseline (B-1 = BEWE 1; B–2 = BEWE 2 and B–3 = BEWE 3) and F = Follow-up 2 years later (F-1 = BEWE 1; F–2 = BEWE 2 and F–3 = BEWE 3).
4 = First premolar; 5 = Second premolar and 6 = First molar of each sextant.

one observed in other longitudinal studies, independent of the index used [12–16]. The most affected teeth were the lower first molars, and this was the only tooth that reached BEWE = 3 at follow-up. The longer exposure of this tooth in the oral cavity, could be an explanation for this outcome, and as proposed by Ganss et al. [12], it thus should be considered as a 'marker tooth' [12]. From the most recent longitudinal clinical study performed, an incidence of 76% and a progression at individual level of 30% in 4 years for 13–14 year-olds was shown [16]. Six years before, in the Netherlands a progression of 56.3% and 44.9% was found for 11 and 12 years old respectively in three years [15]; and in the UK the progression was observed in 47.7% of the cases [13]. A much lower incidence and progression was shown in 2001 in Germany for the only existent longitudinal study performed with casts [12]. The present results differ substantially with this study, and the final scores obtained using the same index (EI index) are 18 times higher than the ones presented 11 years ago (mean age 15 year-olds). These differences might be explained by the fact that the previous study was performed 16 years ago and assessed generations before 2000 [12], where different nutritional habits were present and the worldwide consumption of acidic beverages was lower than at present [2]. This might be interpreted as an increment of ETW cases, nevertheless, assumptions and comparisons with the present data and the one obtained by the aforementioned longitudinal studies remains difficult due to the different ages, follow-up times and different index criteria used to assess ETW.

5. Conclusions

In conclusion, the present results indicate that the combination of BEWE index with records such as cast or 3D images can be used for the monitoring of ETW in a longitudinal approach. Furthermore, BEWE index showed a higher probability of detecting initial changes on tooth surfaces in 3D images when compared to cast models. This could indicate that the use of this digital data might improve the early diagnosis of ETW lesions. Due to magnification and orientation possibilities, 3D scans allow a more frequent detection of ETW lesions, and further benefits include easy storage and data exchange. After two years there was a progression of lesions up to 67% that in few cases reached severe grades of destruction at tooth level. The latter indicates the need of monitoring and an earlier detection of ETW, which should start during the adolescence, in order to prevent and avoid progression of ETW lesions.

Role of authors

Study design: Francisca Marro, Wolfgang Jacquet and Luc Martens
Performed the examination: Francisca Marro and Liesa De Lat
Analyzed the data: Wolfgang Jacquet and Francisca Marro
Wrote the paper: Francisca Marro, Luc Martens and Peter Bottenberg

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