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Quantifying increased rates of erosive tooth wear progression in the early permanent dentition.

Abstract

Objectives. To investigate if quantitative analysis of intraoral scans of study models can identify erosive tooth wear progression.

Methods. Data were collected from a retrospective longitudinal study, using pre-and post-orthodontic treatment casts of 11-13 year olds recorded at two consecutive appointments 29 months apart. Casts were digitised with intra-oral scanner TRIOS™ (3Shape, Copenhagen, Denmark) and first molar scan pairs used for analysis. Occlusal surfaces of each molar pair were visually assessed using the BEWE index as having no BEWE progression (n=42) or BEWE progression (n=54). Scan pairs were aligned and analysed for volume loss, maximum profile loss and mean profile loss in WearCompare (Leedsdigitaldentistry.com/wearcompare) using previously published protocols. Data were analysed in SPSS and not normal Mann-Whitney U test with Bonferroni correction assessed differences between progression groups. Receiver-operating-characteristic (ROC) curves were used to identify the sensitivity and specificity of quantified wear progression rates at determining visual wear progression.

Results. Surfaces with visible progression demonstrated a median volume loss of -2.19mm^3 (IQR-3.65, -0.91) compared to a median volume loss of -0.37mm^3 (IQR -1.02, 0.16) in the no visible progression group (p<0.001). Mean profile loss was -75.2μm (IQR-93.9, -61.0) and 63.2μm (IQR -82.5, -49.7) for the progression and no-progression groups respectively (p=0.018). Volume loss of -1.22mm^3 represented a

79% sensitivity and 61% specificity. The estimated area under the curve for volume loss was 0.80 (95%CI 0.71-0.89, $p<0.001$).

Conclusions. This is the first study to propose rates of high wear progression in adolescents. Limited sensitivity and specificity confirms that quantitative analysis is an adjunct tool to be used alongside history taking and clinical judgement.

Clinical Significance. The rapid advancement of digital technologies may result in improved diagnosis in erosive tooth wear (ETW). Intra-orals scans and registration software are a promising adjunct for monitoring ETW progression in clinical practice.

Key words Tooth erosion, Tooth wear, Epidemiology, Progression, Diagnostic imaging.

1. Introduction

Erosive tooth wear (ETW), known as the chemical-mechanical process of tooth wear caused by the presence of non-bacterial acids in the oral cavity [1], has been described as common with around 30% of adults [2]. Severe cases of ETW represent 2-3% of the population [2]; however, the prevalence is increasing globally and this is particularly true for younger age groups [3]. The increase in consumption of acidic/erosive food products, as is seen in many modern diets [4], may be associated with this higher prevalence [2, 5-7]. Further frequent consumption may increase the rate of ETW and could compromise the dentition function at younger ages.

There is limited evidence on the rate of physiological ETW progression. Lambrechts et al. 1989 identified a normal rate of tooth wear progression, as measured by overall reduction in crown height, of 29 μm a year in molars and 15 um in premolars in healthy young adults [8]. Rodriguez et al. 2012 reported an average of 15 μm per tooth to be a normal rate of wear over 6 months but noted that this was also below the detection limit of the measurement system [9]. O'Toole et al. 2018 observed in a randomised controlled clinical trial that altered dietary habits in a high-risk group of tooth wear patients decreased the volume loss on the central aspect of their central incisors to a rate of 0.00mm^3 over 6 months compared to 0.07mm^3 lost in those who maintained a high level of dietary acid intake [10]. These studies have used profilometric measurements of casts and the use of engineering or custom-built proprietary software to align and analyse change, all of which are difficult to apply in primary care. Intra-oral scanners have been suggested as a promising instrument that could potentially be used for the clinical diagnosis and monitoring of ETW [11]. Recently, two studies have used intra-oral scans (IOS) to assess ETW and the use of such records improved significantly the detection of ETW [12, 13]. However, intraoral scanners can also be used to digitise casts and perform 3D analysis on them. The possibility to superimpose IOS, instead of laboratory based profilometers, has the potential to overcome many diagnostic issues in primary care. However, this technology needs to be validated and rates of tooth wear progression associated with pathological tooth wear need to be determined. The aims of this study were to investigate whether wear quantification on IOS of study casts could differentiate between scans which showed visual progression compared to those that did not. The null hypothesis was that there would be no difference in the volume loss detected on sites with visible wear progression compared to those without.

2. Materials and methods

Previously collected data from pre- and post-orthodontic treatment casts belonging to 120 adolescents (age range 11-13 years at pre-treatment cast) with an interval median time of 29 months (±3.4) between the pre-and post-treatment model were used for selection proposal (Ethical committee reference number: BC2016/0615 & 2016/0616). Orthodontic patients were chosen as a convenient sample as long-term storage of orthodontic models and records facilitated a convenient longitudinal data set. Treatment casts at baseline and follow-up were digitised using a confocal intra-oral scanner TRIOS™ (3Shape, Copenhagen, Denmark) according to the manufacturer's scanning instructions.

The occlusal surfaces of the first molars were visually assessed and scored using the BEWE index [13]. Any surface showing an increase in BEWE score was categorised into the progression group whereas surfaces with the same BEWE score over the 2-year period was categorised into the non-progression group. All visual assessment was performed by a single operator (FM).

Volumetric analysis for power calculation was performed on a pilot sample of 10 surface pairs with visible wear progression and 10 surface pairs without wear progression. An effect size of 0.88 was observed between groups. Assuming $\alpha = 0.05$ and at 95% power, a minimum of 29 cases were needed to be included per group to observe differences between groups.

The IOS scan of each occlusal molar surface was aligned and measured individually in WearCompare (www.leedsdigitaldentistry.com/WearCompare) using a previously validated selective surface alignment protocol [14, 15]. Initially a global alignment between the two scans at separate time points was performed to bring the two scans into closer approximation. A more refined iterative closest point alignment was then performed aligning only on areas which were less likely to have experienced wear progression (the buccal and lingual surfaces of the molars). Alignment quality was assessed by analysing the percentage of data points within these reference areas as being within 25 microns of each other. Figure 1 illustrates the protocol used to superimpose the sample and quantify the ETW. Volume change (in mm^3) was the primary measurement outcome. Volume change per mm^2, the maximum point loss (µm) and the mean profile loss (µm) were also recorded as secondary measurement outcomes.

Scan pairs were excluded from analysis if the baseline or sequential scan was missing, incomplete data on the IOS, blebs/errors on the cast, restorations involving ≥ 50% of the surface, or if there were any alterations which would affect the reference alignment protocol of the scan (e.g. orthodontics, partial eruption). The final data set to be analysed were first molar surfaces which did not have visual progression and first molar surfaces with visual progression. More than one molar per participant was included in some cases.

A single investigator was trained in the use of the software and performed all alignments and measurements. To assess intra-operator reproducibility (ICC), a single pair of scans, not used in the study protocol were aligned 15 times and the volume loss between the scans recorded. The mean volume loss noted was 5.39 (0.34 SD) and the ICC between readings was excellent at 0.99 (CI: 0.96-1.00; $p<0.001$)[16].

The final sample of 42 surface pairs without wear progression and 54 surface pairs with wear progression were then aligned, analysed and measurements recorded Volume change (mm^3), volume change/ mm^2 (mm), maximum point loss and mean profile loss.

Data were analysed using SPSS version 25 (SPSS Inc., Armonk, NY). To assess the sensitivity and specificity of software performance at identifying the visual progression, receiver operating characteristic (ROC) curves were drafted and the area under the curve was estimated. The distribution of the data was assessed visually using boxplots and histograms. Data were not normally distributed and are therefore presented using medians and interquartile ranges (IQR). A Mann-Whitney

U test with Bonferroni correction was used to analyse differences between groups (progression and no progression), with a significance level set at $p<0.001$.

3. Results

3.1 Demographics

The average time between scans was 29.5 months (3.5 SD; range 24-35 months) within 32 adolescents (Table 1: age range at baseline 12-13, 20 females, 12 males). There were no statistical differences in the age, gender or mean period scans from the progression and no progression group.

3.2 Quantitative Analysis

The median volume loss (mm^3) on occlusal surfaces of the progression group was -2.19 mm^3 (IQR -3.65, -0.91) and non-progression was -0.37 mm^3 (IQR-1.02, 0.16), ($p<0.001$). When volume loss was standardised per mm ^{2}, the volume loss was -0.025 mm^2 (IQR -0.048, -0.012) for the progression group and -0.005 mm^2 (IQR-0.13, 0.002) for the non-progression group ($p<0.001$). The full quantitative analysis results showing volume loss, standardised volume loss per mm^2, maximum point loss and mean profile loss are reported in Table 2 according to the progression and no progression group. Overall the volume loss (in mm^2 and mm^3) differed significantly between groups, whereas the maximum point loss and mean profile loss did not.

3.3 ROC analysis

The ROC curves in Figure 2 and Table 3 demonstrate the diagnostic ability for each measurement metric. Analysing volume loss measurements on IOS scans resulted in an estimated area under the curve of 0.80 (95%CI 0.70-0.89, $p<0.001$) and similar to the volume loss per mm^2 of 0.79 (95% CI 0.69-0.88, p<0.001). The ROC curve of 0.64 for mean profile loss (95% CI: 0.53-0.75, p=0.018), indicates a poor diagnostic capability. The area under the curve for maximum point loss was 0.61 (95% CI: 0.50-0.72, p=0.053), which also indicates a poor diagnostic capability. Table 3 demonstrates the sensitivity and specificity of the discrimination threshold. A cut off point of -1.22 mm^3 was associated with a sensitivity of 79% and a specificity of 61% of predicting visible ETW progression over 2 years.

4. Discussion

Volumetric tissue loss observed using intra-oral scans over the two-year period was statistically different between progression and non-progression groups based on the visual assessment. A detected wear of ≤ -1.22mm^3 on the occlusal surfaces of first molars was observed to have a sensitivity of 79% and a specificity of 61% of diagnosis of visible wear progression. Volume loss also indicated that quantitative tooth wear progression using intraoral scanners is a feasible aid for diagnosing increased rates of ETW progression over this time period.

Molar surfaces with visual wear progression were observed to have an average loss of -2.19mm^3 over the two-year period compared to -0.37mm^3 of loss for those without visual wear progression. Although wear does not always progress at a constant rate, this would correspond to -0.55mm^3 in the high progression group and -0.09mm^3 in the low progression group over a 6-month period. Pintado et al., 1997 observed a volume loss of 0.047mm^3 over two years on molar occlusal surfaces, again on healthy adults [17]. Tantbirojn et al. 2012 observed volumetric loss of -0.18mm^3 in adults with GERD (n=12) compared to a volumetric loss of -0.06mm^3 in control patients (n=6) over 6 months [18]. However, the same author analysed and averaged wear over the whole mouth. The mean profile loss in our low progression group was 63 μm and 75 μm in the high progression group over 2 years. Lambrechts et al. 1989 estimated an annual rate of 29μm on molars on low progression groups [8]. More recently Rodriguez et al. 2012 observed an average wear rate of 15μm over 6 months [9]. This study and others did not observe statistical differences between a high progression group and a low progression group when calculating average profile loss [9, 17, 19]. Unfortunately, direct comparison between other studies is difficult due to different methods of analysis over different time periods [18]. The majority of alignment techniques have focused on a best fit or least mean squares registration which can underestimate the wear [15]. It is, however, interesting to see that the wear quantified in the control groups were relatively similar.

It is also difficult to compare studies due to the differences in the measurement metrics. For profile loss, large differences are averaged out over the entire surface and can pose problems when detecting localised wear. A moderate AUC value was observed using this measurement metric. No differences were observed between groups in this study when the maximum point loss data was used. A poor, non-significant AUC value was also observed. As the maximum point loss relies upon a single data point, measurements are susceptible to outliers or process errors. Based upon this data, the use of the maximum point loss with IOS data on casts cannot be recommended. Volumetric wear analysis reported the highest AUC value. Other groups using volumetric analysis were also able to observe differences between groups [10, 18]. The difficulty with using volumetric analysis is that the size of the surface is not standardised. A larger surface will show a higher wear value than a smaller surface even if the proportional reduction is the same. Two volumetric measurements are reported in this study. One reports the total volumetric loss over the whole surface and this has advantages in that it gives an overall volume and localised wear defects do not get averaged out over the surface. The disadvantage is that it is not standardised. A standardised volume loss per squared mm of analysed surface is also presented. Although this increases comparability across surfaces it is a less tangible measurement metric when used for patient education. Both measurement metrics offer good predictive values.

There were limitations in this study. Single tooth analysis is time consuming and it was not within the scope of this study to perform analysis on each surface of the dentition. The occlusal surface of the lower first molar is a known index surface when assessing ETW [20]. There are also several published and validated protocols assessing the occlusal surfaces of the molar teeth [14]. Wear rates reported may or may not be generalizable to other surfaces and this will need to be an area for further research. The comparison of visible wear progression as the gold standard is fundamentally flawed as non-localised wear could have occurred over the entire surface which was not detected by the human eye. Secondly, there were high standard deviations (SD) and positive values in the data representing tissue "gain". Although these are consistent with previous observations reported in the literature [9, 17, 21] and could be a simple reflection of true biologic variations of the tooth surfaces, they are possibly an error in the data capture and analysis process. Erroneous positive values are a known error when using a free-form 3D scan alignment process [15]. The alignment is performed by minimising the mesh distance error between each corresponding data point [21]. This will spread errors evenly over positive and negative deviations until a "best fit" is obtained. If the algorithm decides that the absolute distance between the two datasets is optimally minimized by causing a positive deviation in one area to counteract a large negative deviation in another, it will align the two scans in this way, regardless of the clinical outcome. This is to a large extent overcome by aligning on reference areas less likely to have changed but positive errors will still occur directly impacting on the sensitivity and specificity of the process [15]. Thirdly, IOS on study cast models were used as opposed to direct intraoral scans. Although this offers advantages, such as, being able to ensure an accurate scan there are several disadvantages. In addition to errors in the image processing of an intraoral scan there are also errors in the impression and pouring of a cast which has been estimated to be in the order of 15 μm [9]. It is unknown whether the rates of wear on orthodontic patients are different to that of patients who have not undergone orthodontic treatment and this is a limitation of the study. The movement of teeth into positions where the occlusal forces may be unevenly distributed during periods of treatment may exacerbate wear progression rates on those areas. However, as tooth wear is a relatively slow process unless there is an underlying acid involved this may be unlikely to have a significant impact unless previous risk factors were already present. Cunha-Cruz et al., 2010 did not find a direct association between TW and patients wearing orthodontic appliances [22]. Nevertheless, in Belgium 50% of adolescents are being treated or are still under orthodontic treatment [23]. The results of this investigation can be generalized to this group within the limitations of the study. Finally, a good sensitivity but a moderate specificity was observed for intraoral scans as a diagnostic tool. This would ideally be improved through improved technology and a more accurate registration system. However, if enhanced preventive treatment and not restorative treatment, is the outcome of diagnosis, including more false positives in a prevention programme is unlikely to impart harm.

Bearing these limitations in mind, this study demonstrates for the first time that there are significantly different increased rates of volume loss in those with visible ETW progression and compared to those with no wear progression. The recommended value for diagnosing a high rate of ETW progression in adolescents, from results observed in this study is -1.22mm^3 over a two-year period. Using this cut-off as the point at which to engage on a preventative programme may delay visible tooth wear progression, although this would have to be confirmed with longitudinal clinical studies, ideally in multiple age groups controlling for risk factors. This also requires further testing with shorter time periods as we know that wear is non-linear [24]. The technique is still developing. The resolution of the IOS is still inferior to that of a laboratory scanner or profilometer. However, this is likely to improve as future technology improves. Scans were also done on casts and direct intraoral measurements may have improved sensitivity of the analysis. Lastly, the alignment process still introduces a large amount of subjectivity and operator error. It is likely that the use of machine learning will help reduce the human error in the future. Further research is required is to establish the true accuracy of IOS for quantifying ETW and in improving the accuracy of the registration technique.

Conclusions

Volumetric analysis of dental tissue loss resulted in a good AUC of 0.80 (95%CI 0.70-0.89, p<0.001). A cut off point of -1.22 mm^3 was associated with a sensitivity of 79% and a specificity of 61% of predicting visible erosive tooth wear progression over 2 years. However, as the standard deviations for measurements are large, quantitative measurement of wear using intraoral scans remains a tool to be used as an adjunct to history taking and clinical judgement.

Foot Notes Figures

Figure 1. Graphical description of alignment protocol using WearCompare. (A) Initial alignment of baseline and follow-up scans is provided automatically by the software; (B) Red line is drawn to outline the occlusal surface that aims to be measured, and references areas (in yellow) are chosen to perform a selective surface alignment; (C) Measurement plane perpendicular to the occlusal plane activated; (D) Resulting color distance map of superposition with metrics information included.

Figure 2. ROC curves predicting visible progression against rates of volume loss, mean profile loss and maximum point loss over the study period. The highest Area Under the Curve (AUC) was observed for volume loss progression rates (dark blue line).

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