Rationalisation of quantitative tooth surface loss data for epidemiological research.

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Running Title: Rationalisation of quantitative tooth surface loss data.

Summary - Recent UK National Surveys have revealed a high prevalence of tooth surface loss (tsl) due to erosion in Children and Adolescents. Although digital surface mapping and surface matching techniques may be used to quantify its progression with time, reporting tsl of individuals as a function of either mean depth loss or volume loss, this can be inadequate when transferred for epidemiological analysis. For example, a tooth displaying multiple regions of depth loss may deserve to be distinguished from a tooth with a single localised area of erosion, even though the total volume change may be the same. A potential solution, explored here, is to use both the quantitative wear data and colour coded surface representation plots generated by such methods to arrive at a single categorical wear score (1 ($\leq 5\%$ of surface exhibits tsl) to 5 ($\geq 51\%$ of surface exhibits tsl)). Two examiners independently categorised, on 2 separate occasions, the tsl of 53 maxillary incisors (26 subjects observed at baseline and 9 months). Their performance was assessed for intra and inter examiner agreement by; (a) calculating the % of agreement (b) a Wilcoxon matched-pairs signed rank test. Thereafter, in cases of disagreement a consensus score was allocated and a regression analysis of this versus the numerically derived % of the surface that had undergone change was carried out. Intra and inter examiner agreement was 100 % and 88.7 % respectively and for the inter examiner comparison $P = 0.0456$. The categorical scores and the quantitative wear data correlated linearly ($R = 0.82$).

It is concluded that the method used to rationalise the quantitative tsl data is both reproducible and reflects the quantitative data. Its use should be helpful in epidemiological tsl studies but continued vigilance is required in cases of examiner disagreement. **Keywords:** Erosion, measurement, epidemiology, ranking.

Introduction

The 1993 National Survey of Child Dental Health in the United Kingdom (O'Brian, 1994) revealed that just above 50 % of 5-6 year olds and nearly one quarter of 11 year old children exhibited dental erosion. More recently the National Diet and Nutrition Survey (2000) also revealed a high prevalence of tooth surface loss due to erosion of the order of 52 – 65 %. In later life, if unchecked, such tissue loss can result in sensitivity or pain as well as poor appearance.

At present, the assessment of progression of palatal surface tooth erosion is made by making visual comparison of the dentition with previous study casts. Although this technique is universally applied by all UK consultants in restorative dentistry, one third believe it only capable of detecting relatively gross topographical changes and none believe it to be sufficiently sensitive to detect small increments of wear that cumulatively may be of great significance (Chadwick, 1998). In an endeavour to improve upon this situation we have previously described a system of measurement that utilises silicone impressions of the dentition, recorded at different epochs, to facilitate fabrication of electroconductive replicas for mapping by means of a computer controlled probe and comparison using a surface matching and difference detection algorithm (SMADDA) (Chadwick et al., 1997). Such a technique mathematically seeks regions of coincidence and conflict between maps (or digital terrain models [DTM's]) of the same tooth, at different epochs, to determine the degree of surface loss that has occurred (Mitchell and Chadwick, 1998). We have already demonstrated that such replicas (Chadwick et al., In Press) and the mapping device used (Chadwick et al., 1997) are accurate; the SMADDA

software reliable (Mitchell and Chadwick, 1998, 1999); and the technique as a whole capable of quantifying erosion (Chadwick and Mitchell, 2001). By its very nature such an approach yields considerable quantities of numerical wear data that, in order to achieve optimum utility in both epidemiological research or in long-term monitoring of an individual's tooth wear, needs to be interpreted. Although for individual cases we have found colour-coded surface difference plots to be of help (Chadwick and Mitchell, 1999) the translation of such an approach for large-scale epidemiological research offers less information than is available with human interpretation. Potential solutions such as reporting the loss of tooth substance as function of volume loss or mean depth loss are, in the opinion of the authors, inadequate. For example, a tooth displaying multiple regions of depth loss may deserve to be distinguished from a tooth with a single localised area of erosion, even though the total volume change may be the same. Should such convenient but imperfect numerical values then go forward into any large scale epidemiological database for statistical comparison any conclusions reached may lack robustness. This paper describes a novel approach that seeks to overcome these difficulties by utilising the quantitative wear data and colour coded surface representation plots to arrive at a single categorical wear score for subsequent use in epidemiological studies. The work was stimulated by the employment of the measurement technique in an ongoing clinical study that seeks to examine the relationship between tooth erosion and dietary variables in a population of 250 school children aged 11-13 years.

Materials and method

Data acquisition - The data set used in this study consisted of a total of 53 pairs of electroconductive replicas of the palatal surfaces of maxillary central incisors of 26 subjects observed at baseline and nine months thereafter. These were drawn from an ongoing study that sought to examine the relationship between dietary variables in a population of school children aged 11-13 years. Each replica was formed from an impression of the tooth's surface recorded, at either baseline or nine months, in an addition cured silicone impression material (President, Coltene, Switzerland) within a special tray. To render these electroconductive the surface of the silicone impression was painted with a high silver content electrical paint (RS Silver Paint, RS Components, Corby, Northants, UK). Once dry a further coat was applied and two hours later a layer of a cyanoacrylate based gel material (Zapit®, Dental Ventures of America Inc., USA) was applied to back up the painted surface and reinforce it. This was chemically hardened according to the manufacturer's instructions. In order to increase the thickness of the resultant replica, to facilitate both handling and mounting upon the mapping device, this was further backed up with die stone (Miles Dental Products, South Bend, IN, USA), mixed according to the manufacturer's recommended powder: liquid ratio, before being removed from the impression. Thus, upon removal from the impression, an electroconductive replica resulted whose surface was composed of a layer of silver paint conforming to the surface dimensions of the tooth under investigation as captured by the impression. Previous work had established the high degree of accuracy afforded by this technique (Chadwick et al., In Press).

Each replica was transferred to the mapping device that was a development of that described by Chadwick et al. (1997). It had been manufactured by the Medical Physics Department of Ninewells Hospital, Dundee, UK to BS EN ISO 9001 (1994) and consisted of a precision x, y table (Daedal, Pittsburgh, USA) motorised by the addition of two computer controlled stepper motors (RS Components Ltd., Corby, UK) that controlled precisely the position of the table in the horizontal x, y planes. In addition, a third geared stepper motor under computer control, mounted perpendicular to the motorised table, governed the position of an electrical probe relative to the specimen. The probe was manufactured from tungsten carbide wire of 125 μm diameter (Clark Electromedical, Pangbourne UK) and formed part of a feedback loop such that on coming into close proximity with an electrically conductive specimen, wired into the specimen chamber on the x, y table, it ceased its downward travel in the z direction and retracted 50 μm before moving on to the next measurement point. All such data was computer logged and, to minimise the effects of backlash in the stepper motors, measurement was only undertaken when the stepper motors were driving the stage in the positive x and y directions. The positioning and measurement resolution in the x, y and z planes was ± 2.5 μm . Throughout this work the x and y intervals, at which the elevation (z co-ordinate) of the replica was determined, were set at 150 μm .

Comparison of surfaces - The resultant data files for each tooth at baseline and nine months, that comprised a series of Digital Terrain Models (DTM's) consisting of many x, y and z-co-ordinates (generally around 50 x 50 points in size (150 μm apart) giving 2,500

data points in all within a grid of 7.5 mm x 7.5 mm) for each replica were then compared using a SMADDA. This utilised a least squares approach to surface matching in which the surfaces being compared were moved mathematically so that the surface of one DTM was superimposed upon that of another for comparative purposes. To this end each surface model was described by a set of Cartesian co-ordinate triplets, i.e. a set of (x, y, z) values. The two sets of co-ordinates represented the same original surface as replicated on different occasions. The sum of squares of the surface separations in the vertical direction of these points was minimised in the solution. Making initial estimates of the various parameters required to implement this namely; rotations and translations about x, y and z of the DTM's achieved this. Further continuous refinement of these parameters ensued until the vertical separations between the DTM's were minimised. Full accounts of the mathematics involved in this procedure are given in Mitchell and Chadwick; 1998 and 1999. In summary however, the fundamental aim of the procedure is to find that spatial relationship between the co-ordinate systems, which brings the surfaces into closest co-incidence. To achieve this end those points at which the separation was greater than a pre-defined quantity (set at 50 μm for this work), at which obvious distortion was defined for the purposes of the program to occur, were excluded to facilitate the superimposition process. Once the co-ordinate systems were approximated however, these points were then included in the final wear analysis.

Presentation and rationalisation of the quantitative wear data – For each tooth compared in this way the amount of tooth surface loss was expressed as the overall percentage of the mapped surface that had undergone change with a breakdown of this figure in ten

incremental bands of 15 μm . A computer program, written using the GS Scripser facility within the contouring and 3D surface mapping program Surfer™ (Surfer for Windows, Version 6, Golden Software Inc., Colorado, USA) also permitted visualisation of this data as colour coded surface plots that indicated both the magnitude and location of the surface loss.

Two examiners (RGC & SW) independently viewed each colour coded surface plot on two separate occasions and categorised the severity of the tooth surface loss on a five point scale according to predefined criteria (Table I) developed for this work. Where the percentage overlap of the surfaces being compared, using the SMADDA, was low (i.e. less than 66 %) the wear analysis was rejected and the replicas remapped to ensure maximum overlap. An overlay template, consisting of a marked square that occupied an area equal to 5 % of the tooth surface, was utilised to determine the proportion of the surface exhibiting tooth surface loss on the colour coded surface plot. This figure was then used to assign a wear category (Table I). The categories allocated by each examiner were subsequently assessed for intra and inter examiner agreement by both calculating the % of agreement and performing, in the case of only the inter examiner assessment, a Wilcoxon matched-pairs signed-ranks test, for the null hypothesis that there was no difference in the categories allocated by the examiners. Where disagreement occurred the examiners discussed their findings and reached a consensus on the most appropriate category to allocate. To further test the robustness of this approach a regression analysis of the agreed categorical wear severity score versus the numerically derived percentage of the mapped surface that had undergone change was carried out.

Results

Of the 53 pairs of electroconductive replicas evaluated the examiners agreed with each other on 47 occasions, with all cases of non-agreement differing by one category only, giving an 88.7 % level of agreement. The level of intra examiner agreement was 100 %.

A further, more rigorous comparison of the inter-examiner level of agreement by means of the Wilcoxon matched-pairs signed ranks test, gave a P value of 0.0456. This lies on the border of statistical significance at the 5 % threshold of statistical significance.

A regression analysis of the agreed categorical wear severity score versus the numerically derived percentage of the mapped surface that had undergone change revealed that these two quantities were strongly linearly related ($R = 0.82$).

Discussion

This investigation sought to develop and evaluate a means of rationalising complex quantitative wear data, relating to palatal erosion, by a categorical approach to facilitate epidemiological research. This was necessary because although a quantitative approach yields much valuable data certain situations arise where, if either the volume of wear or mean depth loss were to go forward for epidemiological purposes any conclusion reached may lack robustness. Such an event may arise where two teeth have apparently the same

quantity of wear but in reality this may be attributed in one case to a localised pit of wear and in the other a slight generalised depth of loss over the majority of the tooth surface.

Most epidemiological studies to date, that have examined tooth surface loss, have utilised subjective ranking scales, of increasing severity of tooth surface loss, based upon direct visual assessments of the tooth surface. Although of value they lack the ability of quantitative methods to detect small increments of wear that in themselves may be of little significance but cumulatively may be of great significance (Chadwick, 1998). Of these the most commonly used are the Tooth Wear Index (Smith and Knight, 1984) and the Ryge System. The latter, based upon operational criteria, as well as assessing the severity of wear indicates the need for treatment (Ryge and Snyder, 1973). Although this latter system is derived from the well respected criteria, of the same name, used to evaluate the clinical quality of restorations where the overall level of inter-examiner agreement was reported as 92 % (Ryge and Snyder, 1973), no analogous data is available when applied to erosion assessment. On the other hand, data relating to the reproducibility of the Tooth Wear Index is available and cites a mean reproducibility score of 79.5 % (Smith and Knight, 1984). According to Lussi (1996) any index that assesses clinical erosive lesions must: (1) clearly differentiate between various grades of severity, (2) exhibit good inter and intra examiner agreement and (3) be sensitive enough to monitor changes of severity over time in longitudinal investigations. Although the available indices satisfy the first two criteria they lack sensitivity and it is this lack of sensitivity that probably accounts for the higher level of inter-examiner agreement (88.7 %) obtained in this study as compared to the Tooth Wear Index (79.5 %) (Smith and Knight, 1984). In other words the quantitative approach provides a greater degree of

evidence on which to base the allocation of a categorical wear score than direct visual examination. The need however, for vigilance in the allocation of such a score is emphasised by the less than perfect inter-examiner level of agreement with the Wilcoxon matched pairs signed rank test ($p = 0.0456$) bordering upon a statistically significant difference in the allocation of scores by each examiner. Despite a high level of inter examiner agreement (88.7 %), and the fact that on 47 out of 53 occasions the examiners agreed differing by only one category when not in accord, the need for a consensus in cases of doubt is underscored by these results. It is however, pleasing to note that where sought the categorical wear score correlates well ($R = 0.82$) with the quantitative wear data illustrating how well this approach rationalises such complex data.

Conclusion

It is concluded that the method used to rationalise and interpret the quantitative tooth surface loss data is both reproducible and reflects the quantitative data. Its use should be helpful in epidemiological tooth surface loss studies but continued vigilance is required in cases of examiner disagreement.

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Table I : The criteria used to categorise the severity of wear as indicated on colour coded surface difference plots generated by quantitative wear analysis.

Category	Criteria
1	Majority of surface unchanged with 5 % or less exhibiting tooth surface loss.
2	Majority of surface unchanged with 6 – 15 % exhibiting tooth surface loss.
3	Majority of surface unchanged with 16 – 25 % exhibiting tooth surface loss.
4	26 – 50 % of the surface exhibits tooth surface loss.
5	51 % or greater of the surface exhibits tooth surface loss.

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