Author:
Griffith, Louise

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Development and application of a novel cervical index in an epidemiological investigation of tooth wear, recession and dentine hypersensitivity

Development and application of a novel cervical index in an epidemiological investigation of tooth wear, recession and dentine hypersensitivity

Dr. Louise Griffith

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Abstract

Objective: This thesis designed and validated a novel index to assess tooth wear and gingival recession (GR) in the cervical region, for use both in research studies and general dental practice. The index was implemented in a UK epidemiological study which investigated the prevalence of GR, tooth wear, dentine hypersensitivity (DH) and investigated risk factors for severe tooth wear.

Methods: Codes reflecting the clinical presentations of the cervical region in health and disease were defined. The index was validated by 3 trained examiners who scored buccal and palatal surfaces of eligible teeth in 42 adults. Each volunteer underwent 4 identical clinical examinations, the first and last completed by the same examiner. Subsequently, a cross-sectional observational epidemiological study recruited healthy adults who completed a questionnaire and underwent clinical assessments to determine the distribution of the codes of the index, together with the prevalence of tooth wear, GR and DH.

Results: The 'Cervical Localisation Code' was defined and focused management strategies provided for each score. For validation, 2073 tooth surfaces were scored with good intra- and inter-examiner reliability demonstrated (57 within and 201 between examiner disagreements). 791 volunteers aged 18-86 years were recruited to the epidemiological study. Participants had good oral hygiene and low levels of periodontitis but high prevalence of DH (60.5% participant-reported), GR (94.7% GR ≥1mm) and tooth wear (78% BEWE 2/3) as determined by whole mouth maximum scores. GR and tooth wear were significantly positively correlated whereas weak/no association was detected between DH and tooth wear/GR, respectively. Age was the only risk factor that was significantly associated with severe tooth wear ($p<0.001$).

Conclusions: In this large adult population tooth wear, GR and DH were highly prevalent and tooth wear was strongly associated with age. The Cervical Localisation Code presents a valuable tool for researchers and aids general dental practitioners with the diagnosis and management of these common conditions.

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Author’s declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: .... DATE: 3rd May 2020

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List of abbreviations

ADHS	Adult Dental Health Survey
BEWE	Basic Erosive Wear Examination
BMI	Body Mass Index
BPE	Basic Periodontal Examination
CEJ	Cemento-Enamel Junction
CPP-ACP	Casein Phosphopeptide – Amorphous Calcium Phosphate
DH	Dentine Hypersensitivity
DHEQ	Dentine Hypersensitivity Evaluation Questionnaire
GR	Gingival Recession
ISO	International Standards Organisation
LG	Louise Griffith
NCCLs	Non-Carious Cervical Lesions
NHS	National Health Service
OES	Orofacial Esthetic Scale
OHIP	Oral Health Impact Profile
OHRQoL	Oral Health Related Quality of Life
RDA	Relative Dentine Abrasivity
REA	Relative Enamel Abrasivity
RN	(Professor) Robert Newcombe
TWI	Tooth wear Index
VEDE	Visual Erosion Dental Examination

1. Introduction

A child born today in the UK may well live to see their one hundredth birthday (Christensen et al., 2009) and with improved oral hygiene, their chances of keeping their own vital teeth throughout life is ever-increasing (White et al., 2012). Although the preventative dentistry era has strived to bring caries and periodontitis under control, the 21st century lifestyle has brought about a new set of conditions. Tooth wear, dentine hypersensitivity (DH) and gingival recession (GR) are all now recognised as common problems that are related, with the exposure of dentine due to tooth wear and/or GR increasing the risk of DH, their common symptom (Addy, 2005).

With increase in consumption of dietary acids from those following healthy fruit and vegetable based diets, or those who turn to acidic soft drinks to quench their thirst, together with overenthusiastic toothbrushing in pursuit of the perfect smile – tooth wear is on the increase and GR rates in the young are particularly high, suggesting an increase in DH may follow.

The aim of this thesis is to evaluate a novel index for tooth wear that will also enable risk of DH to be assessed and to investigate current prevalence rates of tooth wear, GR and DH in a UK population, together with the associated risk factors. This thesis forms part of a larger study examining these conditions, together with periodontal conditions, and the associated risk factors across seven European countries.

1.1 Tooth wear

1.1.1 What is tooth wear?

Tooth wear is the loss of hard dental tissue through non-carious causes and is characterised by the loss of natural tooth surface morphology. The process is generally recognised to be multifactorial, encompassing both chemical and mechanical aetiologies (Barbour and Rees., 2006). Improved dental awareness and self-care in the developed world has resulted in many individuals retaining their natural dentition for longer (Brading et al., 2009). Thus, dental tissues must endure a greater period of exposure to mechano-chemical insults over their lifetime than those of previous generations.

Tooth wear results from three main processes: erosion, abrasion and attrition. A further process, namely abfraction, has also been suggested to play a contributory role in potentiating tooth wear, although the use of this terminology has been recently discouraged by a consensus workshop (Schlueter et al., 2019) as there is insufficient supporting evidence to justify it as a separate process

(Shellis and Addy, 2014; Fan and Caton, 2018). As there is limited evidence for this method of tooth loss as its own entity, the remainder of this section will focus on erosion, abrasion and attrition.

1.1.1.1 Erosion

Dental erosion is commonly defined as the chemical dissolution of hard dental tissues without bacterial involvement (Barbour and Rees, 2006). The acids involved in the process are divided into two major categories – intrinsic and extrinsic. Intrinsic acid refers to hydrochloric acid produced in the stomach. This gastric acid has a pH of 1-1.5 and travels up the alimentary tract to via rumination, regurgitation, involuntary gastroesophageal reflux or vomiting (Scheutzel, 1996). The regular exposure of the teeth to intrinsic acids tends to erode the palatal surfaces of the upper anterior teeth initially, although it can cause more widespread damage as the erosion progresses (Moazzez and Bartlett, 2014). Extrinsic acids encompass a broader range of sources including occupational exposure to acidic fumes with improper protective equipment, acidic medicines and, more historically, unmaintained swimming pools (Barbour and Lussi, 2014; West and Joiner, 2014). The widespread consumption of dietary acids, such as fresh fruit, fruit juices and soft drinks also contributes significantly to the prevalence of dental erosion (Salas et al., 2015), and with improved health and safety ensuring lower occupational exposure, these acids are now the most common cause of extrinsic erosion (West and Joiner, 2014).

Dental erosion is characterised by the dissolution of dental minerals and is caused by the repetition of short periods of acidic exposure (Shellis et al., 2014). Initially, on acid exposure, enamel loses minerals from its surface resulting in a softened layer which is susceptible to mechanical wear (Lussi and Carvalho, 2014). This dissolution is not purely a surface phenomenon, as once thought, but extends a few microns into the softened layer- a process termed 'near surface demineralisation' (Lussi and Carvalho 2014). This initial loss of mineral is reversible in the early stages of erosion, although the recovery of the enamel surface layer requires several hours without further acidic challenge (Seong et al., 2015). With further exposure to acid, the erosive process continues and layers of enamel crystals dissolve resulting in permanent loss of tooth substance. As the erosive lesion advances, dentine can become exposed (Shellis and Addy, 2014).

Dentine erosion is more complex than that of enamel due to the differences in its structure and higher organic content (Berkovitz et al., 2009). During erosion, peritubular and intertubular dentine are easily demineralised. Eventually the process results in an outer layer of dentine which is fully demineralised leaving the organic matrix (Breschi et al., 2002). The superficial organic matrix is proposed to have buffering potential slowing further demineralisation, forming a barrier to acid diffusion and slowing clearance of ions from the mineral surface (Barbour and Rees, 2006; Shellis et al., 2010). Chemical and mechanical insults which degrade the matrix will promote the continuation of demineralisation (Ganss et al., 2004; Lussi and Carvalho, 2014).

The erosive potential of a solution depends not only on the pH but is also strongly influenced by its mineral content – namely calcium, phosphate and, to a lesser extent, fluoride (Lussi et al., 2011). Together, the pH and mineral content determine the degree of saturation of a solution with respect to tooth mineral, which in turn determines if dissolution occurs. Tooth surface demineralisation is likely to occur in a solution undersaturated with respect to enamel or dentine, whereas dental mineral will not dissolve in a solution that is supersaturated (Barbour and Lussi, 2014). Applied to the situation of dietary acids, it is not just the pH of the consumed food or drink which is relevant, but the concentrations of calcium and phosphate ions contained within it in will determine whether the solution bathing the teeth is saturated with respect to enamel and consequently whether dissolution occurs (Lussi et al., 2011).

Although erosion is commonly considered the dominant factor in tooth wear, it often acts in synergy with another mechanism (Hunter et al., 2002). Shellis and Addy (2014) postulated that erosion in vivo can lead to loss of the enamel by two different mechanisms: physical wear of the softened surface layer (termed erosive tooth wear) and the direct loss of hard tissue from prolonged demineralisation, although this tends to only occur in more severe cases. Whichever way it contributes to loss of tooth tissue, it is evident that acidic erosion plays a key role in the initiation and progression of tooth wear and is a growing problem in the population (Johansson et al., 2012).

1.1.1.2 Abrasion

In a dental context, the term abrasion means the wearing of dental hard tissue through abnormal mechanical processes involving foreign objects or substances repeatedly contacting the teeth (Hunter et al., 2002). Although toothbrushing is an accepted prerequisite for maintaining optimal oral health, brushing with toothpaste is the most common cause of abrasive wear (Barbour and Rees, 2006). Results from both clinical and in vitro studies indicate that the abrasion of hard tissue is almost entirely related to the toothpaste, with the toothbrush itself causing very minimal damage (Addy and Hunter, 2003). The overall wear caused by toothbrushing with toothpaste seems to be influenced by many factors including the total duration, frequency and force of brushing (Addy and Hunter, 2003).

Dentine is softer than enamel and is more susceptible to abrasion once it has been exposed as demonstrated in an in-situ study by Hooper et al. (2003) in which the amount of wear caused by toothbrushing with toothpaste on a dentine sample was far greater than that observed on the enamel sample in the same intra-oral appliance. An explanation for this is that most abrasives in toothpastes are softer than enamel but harder than dentine (Addy, 2008). However, when toothbrushing without a traumatic technique and using a toothpaste that meets the International Standards Organisation (ISO) guidelines for Relative Dentine Abrasivity (RDA) and Relative Enamel Abrasivity (REA), the abrasion of dentine is clinically insignificant and there is virtually no wear to enamel (Addy and Hunter, 2003).

In summary, the literature to date suggests that abrasive tooth wear is most commonly attributed to toothbrushing with toothpaste but that providing toothpastes meet international standards for abrasivity, normal twice daily brushing regimes alone should not result in significant abrasive tooth wear.

1.1.1.3 Attrition

Attrition is physical wear caused by the action of antagonistic teeth without the presence of a foreign substance (Ganss, 2014). Incisal wear is generally attributed to attrition but wear on the buccal and lingual surfaces of the tooth can also be affected in certain malocclusions (Shellis and Addy, 2014). In vitro, the rate of attritive wear between enamel surfaces increases with both time and load (Eisenburger and Addy, 2002a) but is also dependent on the lubricant. In reality, this principle of two-body (tooth on tooth) wear cannot be distinguished from abrasive tooth wear, which involves a third body, as particles of enamel which detach during attrition could act as abrasive particles between the tooth surfaces (Eisenburger and Addy, 2002b). Furthermore, only a fraction of the mastication cycle results in direct tooth to tooth contact, without food bolus between the occluding teeth (DeLong, 2006) thus during normal function, abrasion or erosion from the food bolus are likely to play a role. Overall, given the minimal amount of time that teeth spend in contact during normal function, attrition is unlikely to impact upon the longevity of a tooth (Bartlett and Smith, 2000).

1.1.1.4 Synergistic effects of erosion, abrasion and attrition

Individual tooth wear mechanisms seldom occur in isolation. The multifactorial process and variable contribution from each mechanism result in a large array of different morphological wear patterns

(Ganss, 2014). Erosion is commonly considered the dominant factor in tooth wear and there is a general consensus that in vivo the interaction of erosion alongside an abrasive and/or attritive physical wear process is of most importance (Shellis and Addy, 2014). In vitro, softened enamel has been shown to be more susceptible to toothbrushing (Attin et al., 2007) and it has been shown that the loss of enamel differs depending on the erosive medium used to soften the samples (Voronets and Lussi, 2010). The timing of the acidic exposure is also important with an approximate 50% increase in the amount of wear reported when brushing in the presence of acid as compared to brushing after an acidic exposure (Eisenburger et al., 2003).

Fewer studies have examined the effects of combined erosion and attrition, however Vieira et al. (2006) found that exposing bovine enamel to citric acid increases the depth of tissue loss from simulated attritive wear, when compared to specimens subjected to erosion alone. Similarly, dentine has also been shown to be more susceptible to attritive wear in vitro when it has received a pretreatment with acid (Li et al., 2011). However, the presence and nature of the lubricant between the opposing teeth also plays an important role. Eisenburger and Addy (2002b) reported a decrease in attritive damage in the presence of dilute acetic or citric acid which was attributed to the acid erosion smoothing the enamel, decreasing the friction between the surfaces and dissolving any fractured enamel particles which could pose an abrasive threat.

Thus, evidence supports erosion as the most important factor in tooth wear, the softening of hard tissue by acids resulting in their increased susceptibility to other types of wear.

1.1.2 Diagnosis and management of tooth wear

As described above, tooth wear can result from a vast array of chemical and physical processes. Diagnosing the main aetiological factors and implementing steps to eliminate these is key to successful management of the condition (Lussi and Hellwig, 2014).

1.1.2.1 Clinical diagnosis of tooth wear

There can be difficulty in determining the separate aetiologies of tooth wear from clinical presentation alone, as they frequently occur simultaneously and can manifest in many differing representations (Lussi et al., 2011; Wetselaar and Lobbezoo, 2016). The diagnostic process should therefore include both identification of intraoral characteristics of wear and a thorough history enquiring about general health, diet and other habits. (Ganss and Lussi, 2014).

Erosion is difficult to diagnose when in the early stages as there are few clinical signs and limited symptoms (Lussi and Jaeggi, 2008). Characteristic signs of enamel erosion include a smooth, glazed or dull appearance (Lussi et al., 2011). For smooth surfaces, convex areas appear flattened or concavities form with a tendency for the width to exceed the depth of the lesion (Ganss and Lussi, 2014). Initial lesions are located coronal to the cemento-enamel junction (CEJ) with a preserved border of enamel along the gingival margin, it is suggested that this is due to the neutralising effect of crevicular fluid (Ganss and Lussi, 2014). The initial features of occlusal and incisal surfaces are similar to those of smooth surfaces; further progression on these surfaces leads to rounding of cusps and incisal edges and proud-standing restorations. In more severe cases occlusal morphology is lost completely and dentine may be exposed (Ganss and Lussi, 2014). Anteriorly, incisal edges become progressively more translucent and chipping may occur (West and Joiner, 2014).

It can be difficult to distinguish occlusal erosion from attritive/abrasive lesions. However, attritive wear tends to result in flat glossy lesions with sharp margins (Ganss, 2014; Carvalho et al., 2015a) and the process creates equal wear and corresponding facets on opposing teeth (Shellis and Addy, 2014). Other intraoral signs which may be suggestive of an attritive cause include frictional keratosis on the buccal mucosa and fracture lines in teeth or restorations (Rees and Somi, 2018). Erosion and abrasion often occur simultaneously on both the flat surfaces and at the cervical region making it very difficult to diagnose as abrasion alone. Non-carious cervical lesions (NCCLs) is a term often used to refer to loss of tooth tissue at the cervical margin that is unrelated to caries (Osborne-Smith et al., 1999; Fan and Caton, 2018). Many researchers consider NCCLs to have a multifactorial origin – with prominent contributions from erosion and abrasion (Bartlett and Shah, 2006).

In conclusion, tooth wear almost always occurs as a result of a combination of chemical and physical insults, and the morphology of defects may vary depending on the predominant cause. Due to this multifactorial nature of tooth wear, a thorough history of patient diet and lifestyle habits is necessary to inform the diagnosis. Importantly, identifying and eliminating the cause ceases the progression of tissue loss (Ganss and Lussi, 2014).

1.1.2.2 Management techniques

Prevention is the essential first line management of tooth wear (Johansson et al., 2012). This includes counselling and educating the patient with regards to aetiological factors and appropriate preventive measures/agents (Wetselaar and Lobbezoo, 2016). The need for frequent application of preventive agents makes home care products a desirable option (Huysmans et al., 2014). Fluoride has long been used in products for the prevention of caries, however monovalent fluoride toothpastes (sodium fluoride and sodium monofluorophosphate) only have limited anti-erosive capacity unless used at high concentrations (Hara et al., 2009; Huysmans et al., 2014). Any protective effect from fluoride is limited to the surface or near surface layer of enamel as there is no sheltered area in the erosive process, unlike the subsurface carious lesion (Lussi and Carvalho, 2015). Fluoride ions are adsorbed onto the tooth surface which reduces the solubility to a limited extent. The fluoride in solution surrounding the tooth plays a more effective role at inhibiting further demineralisation, by saturating the solution to maintain an equilibrium and prevent further dissolution of tooth mineral (Lussi and Carvalho, 2015).

There is now good evidence for the efficacy of stannous containing fluoride products for the prevention of tooth wear. Following use of these products a tin-rich layer forms on both eroded and non-eroded enamel surfaces which is less susceptible to dissolution (Lussi and Carvalho, 2015). This layer is deposited on first use, accumulates with daily application and is retained for hours (Khambe et al., 2014). In situ, stannous-containing toothpastes have been shown to significantly reduce enamel loss as compared to control pastes (Huysmans et al., 2011; Hooper et al., 2014; West et al., 2017). Stannous fluoride mouthrinses have also been developed and shown to be more effective than those containing sodium fluoride (Ganss et al., 2010), with solutions containing titanium tetrafluoride which work in a similar way to tin-containing products (Lussi and Cavalho, 2015) being shown to be equally as effective as stannous fluoride solution in the reduction of enamel erosive-abrasive wear in situ (Stenhagen et al., 2013).

Preventative products may also be applied professionally, such as fluoride varnishes which increase the fluoride content of the enamel surface (Carvalho et al., 2015b) and provide a mechanically protective layer (Vieira et al., 2005). Fluoride varnish has been shown to effectively reduce progression of erosive wear and combined erosive and abrasive wear in situ, however, detachment of the varnish layer due to toothbrushing was demonstrated (Vieira et al., 2007). It is likely that the varnish layer would be lost even more rapidly on chewing surfaces, making regular application a necessity. In another study the varnish that provided the best enamel protection was the one which had optimal mechanical retention but least deposition of fluoride (Duraphat®) (Carvalho et al., 2015b), suggesting that the physical barrier may be more closely linked with protection than fluoride layer formed by such varnishes. These findings indicate that professional application of fluoride varnishes for protection need to be carried out regularly making it a less cost-effective option than use of home care products.

The regular monitoring of tooth wear in clinical practice, utilising clinical indices, study models and intra-oral photographs, allows for detection of tooth wear progression (Bartlett et al., 2008; Wetselaar and Lobbezoo, 2016). In severe cases, restorative therapy may be required to treat tooth wear, to address pain/sensitivity symptoms or restore aesthetics and function but this should only be used in conjunction with prevention, as long-term success depends on the causative factors being brought under control (Carvalho et al., 2015a). In general, restorative work should be minimally invasive and 'additive' rather than 'subtractive' where possible, utilising bonded restorations rather than heavily preparing teeth (Johansson et al., 2012).

In summary, given the finite lifespan of all restorative work placed in the oral environment, early diagnosis and prevention are the key to avoid development of severe tooth wear requiring complex restorative rehabilitation. Preventing the initiation and progression of erosive tooth wear with home care products, such as toothpastes containing stannous fluoride, or mouthrinses containing titanium tetrafluoride, is an attractive option due to increasing evidence of their efficacy, their widespread use and low cost.

1.1.3 Prevalence of tooth wear

Measuring the frequency of conditions such as tooth wear and capturing how they vary over time or among differing populations is an important step in the discovery of potential causes, the extent of the problem and assessing effective methods for prevention and management. Frequency can be measured as prevalence or incidence. Prevalence reflects the existing cases of a disease, in a certain population, at a certain time. Incidence represents the number of new cases of disease within a specified time-period and can be expressed as a risk or incidence rate (Noordzij et al., 2010). The way that prevalence, incidence rate and risk are calculated is shown in Figure 1.1.

$$\textbf{Prevalence} = \frac{\text{Number of subjects having the disease at a time point}}{\text{Total number of subjects in the population}}$$

$$\textbf{Risk} = \frac{\text{Number of subjects developing the disease over a time period}}{\text{Total number of subjects followed over that time period}}$$

$$\textbf{Incidence rate} = \frac{\text{Number of subjects developing the disease}}{\text{Total time at risk for the disease, for all subjects followed}}$$

Figure 1.1 Equations to calculate prevalence, risk and incidence rate (Noordzij et al., 2010).

Prevalence is influenced by the number of incident cases, the deaths and recoveries. This relationship is illustrated in Figure 1.2. Tooth wear is highly unlikely to result in death and is an irreversible process, meaning that damage from tooth wear accumulates with age. However, in an epidemiological study relying on clinical diagnosis, a successfully restored but previously worn tooth might be charted with no wear or excluded from scoring, the equivalent of 'recovery'. Thus, the prevalence of tooth wear will increase as incident cases are added and decrease after successful restorative treatment or if the case passes away. Given that we have an aging population (Office for National Statistics, 2019a) and our clinical guidance promotes preventative measures to conserve teeth, with restorative ones used for more severe cases, one could speculate that the prevalence will continue to grow, and there is evidence that erosive tooth wear is on the rise (Jaeggi and Lussi, 2014).

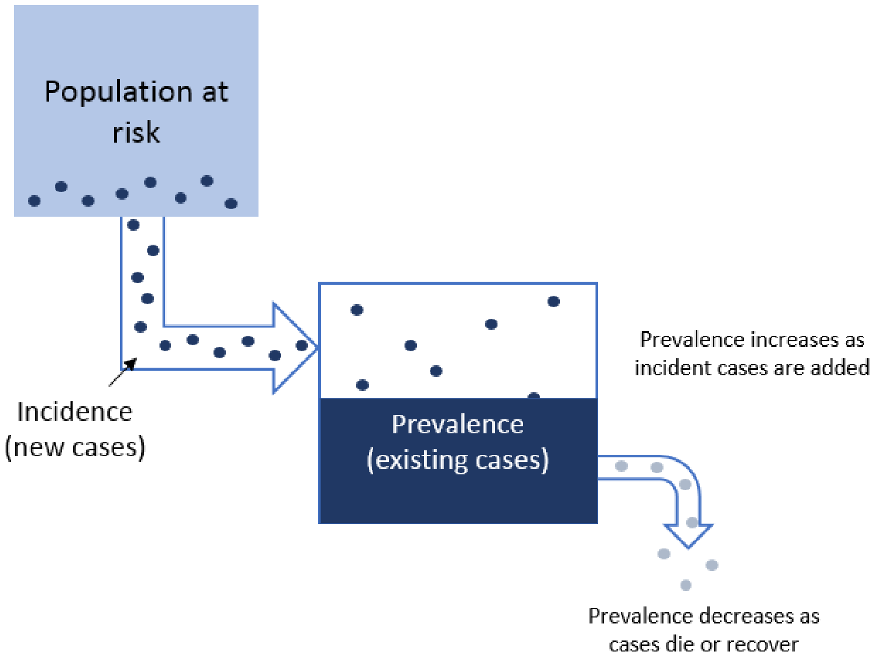

Figure 1.2 Diagram showing relationship between incidence and prevalence. Adapted from (Noordzij et al., 2010).

1.1.3.1 Prevalence figures

There are relatively few studies on the prevalence of tooth wear conducted within the adult population, with more being undertaken on children and adolescents (Van't Spijker et al., 2009). This may reflect the difficulty of recruiting adults for large cohort studies.

Prevalence figures for tooth wear in the limited studies on adults that exist vary from 20%, reported in the control group of a study looking at tooth wear in wine tasters (Mulic et al., 2011), to 100% in university students (Fares et al., 2009), a difference that likely reflects the population studied and/or the methods of assessment used. In the UK the most recent Adult Dental Health Survey (ADHS) in 2009 including England, Wales and Northern Ireland reported that overall the prevalence of tooth wear extending into dentine was high – with 77% of adults showing some wear in their anterior sextants. In comparison to the previous ADHS in 1998, moderate tooth wear had increased from 11% to 15% (White et al., 2012) and there was an increasing proportion of younger adults with moderate wear (Steele and O'Sullivan, 2011). The limitations of this study, however, are that only 12 anterior teeth were scored which might not be representative of the entire mouth.

Bartlett et al. (2013) conducted the first epidemiological study to assess the prevalence of tooth wear across multiple countries in Europe. Tooth wear was assessed for all eligible teeth of 3187 young adults aged 18-35 in 7 countries and recorded using the Basic Erosive Wear Examination (BEWE) (Bartlett et al., 2008). Overall, 29% of participants exhibited distinct tooth wear on at least one surface in the mouth (BEWE 2 or 3). Large differences were found between countries and the highest levels of tooth wear were observed in the UK, where 54.4% participants showed distinct tooth wear on at least one tooth surface.

Tooth wear is presumed to accumulate with age as, apart from at very early stages, it is an irreversible process. However, there are few studies which have reported longitudinal data for the progression of tooth wear so the rate of accumulation of wear is as yet unknown. Lussi and Schaffner (2000) conducted a study to assess the progression of tooth wear in 55 participants over a 6-year period. It was demonstrated that both the older (46-50) and younger (26-30) age group presented with increased tooth wear at the 6-year follow-up and this increase was more marked in the older age group. This finding is supported by the systematic review carried out by Van't Spijker et al. (2009) who concluded that, when the studies are reviewed together, there is a tendency to develop more tooth wear with age.

In summary, tooth wear is highly prevalent in the adult population and results from the UK ADHS suggest it is increasing. Data suggests that tooth wear accumulates with age, as would be expected from an irreversible process, but current data on the rate of progression is limited.

1.1.3.2 Difficulties in interpreting prevalence figures

There are several challenges when attempting to interpret the results of epidemiological tooth wear studies, due to the differing examination standards and the different groups examined.

One of the major differing factors in prevalence studies reflects the cohort. This varies not only in number of examined individuals but also their age, gender and geographical location. In a study of

18 year olds in Oslo, 38% of the 1,456 subjects examined exhibited an erosive lesion on at least one tooth (Mulic et al., 2012a). By contrast, a population of a similar age in Sweden were found to have a much higher prevalence of erosion where 75% of the 494 individuals exhibited erosive tooth wear on their incisors or molars (Isaksson et al., 2014). However, these differences are unlikely to be purely down to geographical location as the method of tooth wear scoring also differed. As indicated above, prevalence figures have been shown to increase with age (Van't Spijker et al., 2009), indicating that care must be taken when interpreting prevalence figures where the study group is not representative of the general population.

As indicated above, studies also often use different examination standards for the measurement of tooth wear such as differing indices, full or partial mouth recordings and the examination of all tooth surfaces or specific surfaces only (Berg-Beckhoff et al., 2008; Ganss et al., 2011; Van't Spijker et al., 2009). The inconsistency of scored surfaces/teeth makes comparisons difficult as it is not possible to tell the extent of wear which occurred on the non-scored surfaces, which could result in an under or overestimate of total wear. The abundance of indices which have been used in epidemiological studies of tooth wear also makes comparison of data problematic, if not impossible (Van't Spijker et al., 2009; Ganss et al., 2011). The Tooth Wear Index (TWI) (Smith and Knight, 1984), and derivatives of this index, are frequently cited in the literature. This index involves a detailed description of the clinical appearance of wear but does not allude to the aetiology. Van't Spijker et al. (2009) converted the scores of the articles included in their systematic review into TWI to enable them to carry out comparisons but concluded that it was a relatively crude index which favoured higher levels of tooth wear. To address the issues encountered and to try and halt the development of further indices the BEWE was introduced in 2008 (Bartlett et al., 2008). It is designed to be simple and easy for use by general dental practitioners, whilst also allowing re-analysis and integration of results from existing studies.

Not only are there differences in the method used to score tooth wear between studies, there is also evidence that inter-examiner reproducibility is poor when relying on the diagnosis of dentine exposure (Holbrook and Ganss, 2008). Moreover, the definition of tooth wear itself is not clear and can be interpreted differently in different countries with Europeans historically putting greater emphasis on the erosive component than Northern American colleagues (Bartlett et al., 1999; Bartlett, 2005). These differing interpretations of the same clinical appearance may result in varied prevalence figures. Study figures must also be interpreted carefully as some studies quote prevalence figures per individual and others per tooth surface (Jaeggi and Lussi, 2014).

The aforementioned variability across studies make it difficult to draw conclusions about the prevalence of tooth wear and capture accurate population prevalence figures, either worldwide or in specific populations. However, it is clear that the prevalence of tooth wear in the adult population is high, appears to be on the rise and it seems to increase with age. Further large-scale epidemiological studies using standardised indices across a wide population are required in order to establish a more representative view of the current situation.

1.1.4 Why tooth wear is an issue for patients

The symptoms of tooth wear vary widely and indeed affected patients can present asymptomatically (Al-Omiri et al., 2006). However, for many patients a worn dentition can present with problems such as pain, functional impairment and poor aesthetics (Wazani et al., 2012).

As tooth wear progresses and enamel is eventually lost, the dentinal-pulp complex responds by depositing reactionary and reparative dentine which obturate the dentinal tubules as a protective mechanism (Ganss, 2014). However, if the rate of wear exceeds this reparative capacity the possible sequelae are pain, pulpal inflammation and necrosis. The prevalence of endodontic sequelae has not been extensively studied but it is estimated to affect approximately 10% of patients with severe tooth wear (Sivasithamparam et al., 2003). Pain can also occur as a result of DH in response to an environmental trigger if dentine is exposed and tubules are opened so that they are patent from the oral environment to the pulp (Absi et al., 1987). In a European epidemiological study with over 3000 participants, a significant association was found between those with erosive tooth wear and those presenting with DH (West et al., 2013a).

However, for most patients, aesthetic concerns tend to dominate over any functional ones (Wazani et al., 2012). Straight, white teeth are increasingly considered the beauty ideal and tooth wear not only alters the tooth morphology but also can cause yellowing due to deposition of tertiary dentine. Wazani et al. (2012) analysed the signs and symptoms of a group of patients with tooth wear who had been referred into the hospital setting. Of the 290 patients included, aesthetic concerns were the most common presenting complaint (59%) followed by sensitivity (40%).

The degree to which pain or compromised aesthetics arising from tooth wear impacts on patients' wellbeing and function is important. The Oral Health Impact Profile (OHIP) is a specifically developed questionnaire which is an instrument that is frequently used to assess patient's perception of the social impact of their oral health on their wellbeing (Slade, 1997). Using the Dutch version of OHIP it was demonstrated that oral health related quality of life (OHRQoL) was significantly impaired for the patients with visible tooth wear when compared with the healthy controls. Moreover, the negative impact upon quality of life was comparable with that reported by edentulous subjects in the study (Papagianni et al., 2013). These findings were supported by a more recent study in which OHRQoL was assessed using OHIP-14 results from 5654 dentate adults nationwide across the UK (Li and Bernabé, 2016). In this study, severe tooth wear was negatively associated with psychological impacts on people's life and this was particularly pronounced in the scores for psychological discomfort and psychological disability.

For specific concerns regarding appearance, a separate questionnaire has been developed: the Orofacial Esthetic Scale (OES) (Larsson et al., 2010; Wetselaar et al., 2015). This instrument was used to assess self-perceived aesthetics in those with and without self-reported tooth wear in a Dutch study population (582 subjects) and using this it was found that those with tooth wear were significantly less satisfied with their orofacial aesthetics (Wetselaar et al., 2015). For patients reporting aesthetic issues or pain due to their tooth wear, OHIP and OES scores have been shown to significantly improve after restorative treatment involving full rehabilitation using composite restorations and increasing the occlusal vertical dimension (Sterenborg et al., 2018).

In conclusion, it is important that dentists recognise that tooth wear is not only an objective clinical characteristic but also can have great impact on the quality of life of the patient.

1.2 Gingival Recession (GR)

1.2.1 What is GR?

GR is defined as the apical migration of marginal gingival tissues with respect to the CEJ (Cortellini and Bissada, 2018). In a healthy periodontium the gingival margin is positioned 0.5 to 2.0mm coronal to the CEJ (Loë et al., 1968; Newman et al., 2014). GR is associated with clinical attachment loss and the presence of underlying bony dehiscence (Smith, 1997), resulting in exposure of the root surface. The cementum covering the root surface is rapidly lost exposing radicular dentine (Bevenius et al., 1994; West et al., 2013b). GR tends to increase throughout life (Kassab and Cohen, 2003) with GR of ≤3mm suggested to be physiological attachment loss commensurate with age (Lamster et al., 2016).

GR may occur in periodontal health at sites with normal sulci and undiseased interdental crestal bone, or may occur pathologically in periodontal disease at sites where alveolar bone has been lost (Tugnait and Clerehugh, 2001). Several anatomical factors increase the risk of recession development including a reduced thickness of the overlying buccal bone plate, abnormal tooth position in the arch and a thin gingival phenotype (Cortellini and Bissada, 2018). However, proceedings from the recent periodontology world workshop, which established the new classification of periodontal diseases, concluded that any amount of gingiva (thickness and width) is sufficient to maintain periodontal health if optimal oral hygiene is achieved (Jepsen et al., 2018).

The aetiology of GR is still unclear (Cortellini and Bissada, 2018) and its presence in patients with both poor and good standards of oral hygiene suggests that the aetiology is complex and multifactorial (Joshipura et al., 1994).

1.2.1.1 GR in health

Toothbrushing is a prerequisite for maintaining oral health (Public Health England, 2017). However, improper toothbrushing has been recognised as a contributory factor towards GR for many years (Jati et al., 2016) although the majority of studies have been observational in nature and so cannot show causation.

In an attempt to clarify the role of toothbrushing in GR, Heasman et al. (2015) conducted meta-analysis of evidence for the occurrence of GR as a consequence of traumatic toothbrushing. Only 2 studies were similar enough to allow quantitative meta-analysis and these both assessed how current sites of recession responded to a manual or powered toothbrush over a 12-month period (McCracken et al., 2009; Graetz et al., 2013). Results suggested that for patients with non-inflammatory recession sites, the use of either a manual or powered toothbrush may prevent recession progression. More recently executed randomised control trials also looking at sites of pre-existing GR support these findings, showing significant reduction in recession sites with the use of either a powered or manual toothbrush (Dörfer et al., 2016; Sälzer et al., 2016).

In the study by Heasman et al. (2015) a further 17 studies fulfilled the systematic review criteria for assessment qualitatively, and this analysis on the available data revealed that the most frequent toothbrushing factors associated with development and progression of GR are toothbrushing frequency, brushing technique and toothbrush bristle hardness (Tezel et al., 2001; Daprile et al., 2007; Chrysanthakopoulos, 2011). More recent cross-sectional studies have also suggested an association between overzealous toothbrushing habits and the presence of GR (Chrysanthakopoulos, 2014; Mythri et al., 2015; Seong et al., 2018a).

Confusingly, data from the quantitative and qualitative analysis seem to conflict (toothbrushing resolving GR in the former and causing it in the latter), this may be due to the differing study designs. The participants in the quantitatively analysed studies were recruited as they had GR which they might have been motivated to resolve, they were aware that they were taking part in a GR study and would be likely to follow study guidance regarding toothbrushing. By contrast participants recruited to cross-sectional studies are not instructed about toothbrushing, instead data regarding their self-reported toothbrushing habits is obtained together with their GR scores at that time, thus their toothbrushing habits as recorded are not directly influenced by study participation, but the studies are unable to show causality. Further randomised controlled clinical trials are needed to ascertain whether toothbrushing factors predispose to or are just associated with GR.

GR can also be induced by mechanical trauma from objects other than toothbrushes, such as impaction of foreign bodies against the gingiva, gingivitis artefacta, compromised biological width and occlusal trauma (Tugnait and Clerehugh, 2001; Jepsen et al., 2018). Orthodontic repositioning of the dentition may initiate or progress recession defects during or after treatment (Cortellini and Bissada, 2018) and mandibular incisors seem to be the most vulnerable (Renkema et al., 2013). Low level evidence suggests that proclination or movement of incisors beyond the osseous envelope of the alveolar process increases likelihood of developing GR (Joss-Vassalli et al., 2010). However, orthodontics can also be used to move buccally positioned teeth in a lingual direction, decreasing the risk of future recession (Jati et al., 2016).

Overall, GR in health is a common finding which appears multifactorial and is still not fully understood. Anatomical, traumatic and iatrogenic factors are all associated but further research is needed to demonstrate causality.

1.2.1.2 GR in disease

GR has historically been associated with poor oral hygiene, periodontal diseases and their management (Yoneyama et al., 1988) and the impact of smoking will be discussed later in section 1.4.2.3. Sarfati et al. (2010) found that gingival bleeding was significantly associated with sites of GR, postulating that the inflammatory reaction to plaque biofilm may induce GR. Inflamed sites of GR may be plaque retentive, causing further progression of the defect, as they can be painful to brush and so are avoided when cleaning (Miranda-Rius et al., 2018). Clinical attachment loss is a well-known consequence of periodontitis progression associated with alveolar bone destruction and apical migration of the junctional epithelium and is seen clinically as periodontal pocketing and GR (Beck and Koch, 1994; Tugnait and Clerehugh, 2001). GR associated with periodontitis may occur on all surfaces of the teeth due to the loss of interproximal and circumferential alveolar bone (Tugnait and Clerehugh, 2001). Recession occurring due to poor oral hygiene may predominantly affect the posterior dentition as these teeth are more easily missed during the brushing cycle (Seong et al., 2018a).

Treatment of oral diseases can also lead to iatrogenic GR. Paradoxically, treatment of periodontitis will often result in recession as the inflammation subsides resulting in shrinkage and apical migration of the gingival tissues (Badersten et al., 1984); successful treatment in the clinician's eye but often an undesirable aesthetic outcome for the patient. Root surface instrumentation of shallow pockets, however, has been shown to cause attachment loss and consequent GR and is therefore deemed inappropriate (Lindhe et al., 1982). The placement of cervical restorations could also contribute to GR defects with a recent systematic review reporting that intrasulcular restorative margins at sites with minimal or no gingiva are more likely to be associated with GR and inflammation (Kim and Neiva, 2015). Although both dental procedures may cause unwanted GR, for periodontitis it may be an unavoidable sequalae of the successful treatment so patients must be forewarned. Restorative work in the cervical region may be avoided for NCCLs with the use of topical agents if DH is the main complaint and aesthetics are not an issue, see section 1.1.2.2. In summary, it is important that the risk of inducing GR is considered during treatment planning yet often it is an unavoidable consequence of the required treatment.

1.2.2 Diagnosis and management of GR

GR is diagnosed visually by measuring from the CEJ to the gingival marginal tissues, using the millimetre markings on a periodontal probe (Elashiry et al., 2019). Although in theory a simple measurement, its reliance on the CEJ as a reference point may undermine its accuracy as difficulties are encountered when the CEJ is no longer discernible (Smith, 1997). The CEJ recedes coronally in areas damaged by abrasion or erosion (Smith, 1997) and exposure of coronal dentine in these defects can produce a line which is commonly mistaken for the anatomic CEJ (Zucchelli et al., 2006). Other possible landmarks have been proposed such as the clinical crown height (Volchansky and Cleaton-Jones, 2001) and a gingival margin-papillae measurement (Handelman et al., 2018) both of which have their shortcomings. Thus, measuring from the CEJ to the gingival margin is still the accepted standard.

Management of GR tends to focus on prevention and monitoring. In patients with GR resulting from periodontitis, the underlying periodontal disease must be stabilised to prevent further clinical attachment loss. For those with GR on an otherwise healthy periodontium, modifiable risk factors should be addressed by educating the patient and supporting them to make the required behaviour changes, such as changing traumatic toothbrushing habits or removing peri-oral piercings. (Merijohn, 2016; Miranda-Rius et al., 2018). A recent meta-analysis explored the long-term outcomes of untreated GR defects (Chambrone and Tatakis, 2016) and the authors concluded that when GR sites are left untreated in patients with good oral hygiene they have a high likelihood of progression. Therefore, regular monitoring of GR is important to identify any sites which are progressing. The main indications for root coverage procedures are aesthetic complaints or DH symptoms (Tugnait and Clerehugh, 2001).Merijohn (2016) suggests an individual should be considered a candidate for mucogingival surgery if there is documented progressive GR, persistent gingival inflammation and clinical attachment loss > 5mm. A range of surgical procedures to treat GR exist which can be broadly classified as pedicle flaps, free grafts or guided tissue regeneration procedures (Shkreta et al., 2018). Successful surgical management is largely related to the prior elimination of aetiological factors and the selection of an appropriate surgical technique considering anatomical variables such as the size of defect and width of keratinised gingiva available. It is widely reported that GR defects associated with loss of interdental attachment have a reduced potential for full root coverage following mucogingival surgery (Cortellini and Bissada, 2018). Currently, the accepted gold standard is a combination of subgingival connective tissue graft and a coronally advanced flap (Chambrone et al., 2010).

1.2.3 Prevalence of GR

GR affects a significant proportion of the adult population (Heasman et al., 2015) yet there is great variation in prevalence figures which range from 30-100% (Miranda-Rius et al., 2018), reflecting the differences in populations studied and how GR has been defined (Litonjua et al,. 2003). In studies which report GR where the participants studied have at least one site with ≥1mm, figures are generally high. In an urban Brazilian study population aged 14 years and over, of the 1,460 individuals examined, 83.4% had at least one site of GR ≥1mm (Susin et al., 2004). This is a similar figure to that reached when a group of Spanish dental students were studied and 85% had at least one tooth with GR ≥1mm (Matas et al., 2011). The authors concluded this high prevalence was likely due to the excellent oral hygiene of the subjects under study, whereas in the Brazilian population the risk factors identified for the GR observed were more in line with periodontal disease. More recently, secondary analysis on a study involving 350 young adults in the UK revealed that 100% of participants exhibited GR of ≥1mm on at least one tooth (Seong et al., 2018a) with good oral hygiene anteriorly and poorer oral hygiene posteriorly being implicated as risk factors. In studies which record GR as greater gingival loss than the ≥1mm, prevalence figures are unsurprisingly lower. The prevalence of GR of >3mm among young Greek adults was 64% (Chrysanthakopoulos, 2014), and in the study by Seong et al. (2018a) although 100% had GR of ≥1mm on at least one tooth, only 42% had a maximum GR site of 4-8mm (Seong et al., 2018a).

As indicated in the studies reported above, GR can affect individuals from a young age and accumulates throughout life (Serino et al., 1994; Litonjua et al., 2003). Albandar and Kingman (1999) examined a large sample from the US population ranging from 30-90 years of age. Results showed that GR increased gradually with the age of the cohort, with a prevalence of 37.8% GR of ≥1mm in the 30-39 year olds which more than doubled to a prevalence of 90.4% in the 80-90 year olds. When using the cut off GR >3mm, these figures were 4% and 40% respectively. The extent of teeth affected averaged 8.6% in the 30-39-year-old group and 56.3% in the 80-90 year old group, demonstrating that both the prevalence and extent of GR increases with age.

As discussed previously, GR occurs in those with both good and poor oral hygiene and differences in prevalence figures between these groups have been demonstrated. Between 1969 and 1990 a longitudinal study was conducted on a Norwegian population with good oral hygiene practices and a Sri Lankan population with suboptimal oral hygiene (Löe et al., 1992). Similar to the studies discussed above, it was found that GR increased with age in both groups during the 20 years of the study (Serino et al., 1994; Albander and Kingman, 1999; Litonjua et al., 2003). Prevalence figures in both groups were shown to be high by 30 years of age, however there were differences between them as more than 70% of Norwegians as compared to 90% of Sri Lankans exhibited one or more sites with GR of ≥1mm (Löe et al., 1992). A further finding in this study was that in the Norwegian cohort with good oral hygiene, GR was heavily concentrated on the buccal surfaces of the teeth, which is consistent with the literature (Matas et al., 2011; Seong et al., 2018a). The Sri Lankan cohort also exhibited GR predominantly buccally but a much larger proportion of the interproximal and lingual surfaces were also involved. The authors concluded that although prevalence of GR was reasonably comparable at younger ages for these two cohorts, the severity and extent of GR was much higher in the Sri Lankan population (Löe et al., 1992). Together, this data implies that poor oral hygiene results in more widespread GR, both on a population and individual level, than good oral hygiene.

The majority of literature suggests that males are more frequently affected by GR than females. Toker and Ozdemir (2009) examined 831 subjects in a Turkish hospital setting and their results found that the prevalence of GR was significantly higher for male than female subjects, affecting 82% and 76% respectively. A significantly higher proportion of males than females were also affected by GR in an American study involving 9689 adults (Albandar and Kingman, 1999). Further prevalence studies based in Greek, Brazilian and UK populations have all also reported a higher prevalence for the male gender (Susin et al., 2004; Chrysanthakopoulos, 2014; Seong et al., 2018a). It has been indicated that males generally maintain a lower standard of oral hygiene than females (Addy, 1990; White et al., 2012), however as GR can be a consequence of both good and poor oral hygiene, it is difficult to draw conclusions as to why males appear to be more affected.

Collectively, data to date suggests that GR is universal. When interpreting these figures, however, attention must be given to the difficulties in diagnosing dentine exposure in the cervical region, especially once the CEJ is no longer distinguishable, which can lead to measurement inaccuracies (Holbrook and Ganns, 2008). In addition, care must be taken when comparing studies as the definition of GR for each can vary. Since GR ≤3mm can be interpreted as a physiological consequence of aging (Lamster et al., 2016), it could be argued that only GR above this value is clinically relevant. However, GR is a condition which progresses with age therefore a recording of ≤3mm in younger subjects is unlikely to solely reflect the aging process, implicating other aetiological factors. For this study we look at GR ≥1mm as we are including the younger population and it could indicate a tendency towards further GR in the future. Moreover, the slightest exposure of radicular dentine can cause DH, which is also under investigation in this thesis, therefore the recording of GR ≥1mm will allow analysis of this association.

In summary, GR is undoubtably common, tends to increase with age and given the increasingly dentate aging population, is likely to rise in the future.

1.2.4 Why GR is an issue for patients

Some patients may experience GR with complete unawareness of the condition (Kassab and Cohen, 2003) however for many patients, it is a cause of anxiety for reasons including resulting sensitivity (see section 1.3) and fear of losing the teeth (Smith, 1997). Aesthetic distress caused by GR, particularly in patients with a high smile line, is a common patient concern (Merijohn, 2016). The exposed root surface is usually a darker shade than the crown of the teeth and the resulting uneven contour of gingival tissues may result in an asymmetrical appearance, both of which cause concerns about dental appearance (Tugnait and Clerehugh, 2001). Further concerns stem from the adage of 'becoming long in the tooth' and patients may therefore interpret GR as an undesirable sign of aging (Smith, 1997; Merijohn, 2016). The exposed radicular dentine is susceptible to both carious and non-carious attack which can cause pain and necessitate further dental treatment (Cortellini and Bissada, 2018).

Overall, GR is the consequence of many aetiological factors the extent to which each has contributed is difficult, if not impossible, to establish. The high prevalence of GR in both healthy and periodontally involved dentitions and the problems of pain and aesthetics it causes patients highlights the need for further research.

1.3 Dentine hypersensitivity (DH)

1.3.1 What is DH?

DH is characterised by a sharp, transient pain which results from the stimulation of exposed dentine, typically in response to evaporative, thermal, tactile, osmotic or chemical stimuli (Holland et al., 1997; Rees and Addy, 2002). DH is diagnosed when the pain cannot be attributed to any other form of dental defect or disease (Canadian Advisory Board on Dentin Hypersensitivity, 2003). For DH to occur, there must be dentine exposure which can either occur as a result of hard or soft tissue loss (Addy, 2002) and the dentinal tubules must be patent from the oral environment to the pulp (Absi et al., 1987). These two processes are commonly referred to as lesion localisation and lesion initiation (West et al., 2014) which are explored further below.

During lesion localisation, dentine is exposed by either loss of the overlying enamel or cementum. Coronal dentine exposure can occur following erosive, abrasive and attritive tooth wear, as discussed in Section 1.1.1. By contrast, radicular dentine is most commonly exposed due to GR, the causes of which are covered in Section 1.2.1. Previously the term 'root sensitivity' was proposed as a different entity to DH (Sanz and Addy, 2002) however as there is no evidence of differences between coronal and radicular DH (West et al., 2013b), both will be included under the umbrella definition of DH for this thesis.

Once dentine is exposed, for DH to occur the lesion must be initiated so that the dentine tubules are open. The surface of exposed dentine may consist of patent tubules or it may be coated by a smear layer of oral debris, such as calcium or constituents of toothpaste (West et al., 2013b). The smear layer can be removed by acidic drinks (Prati et al., 2003) and this acid attack softens the dentine surface (Addy, 2002) increasing its susceptibility to abrasive insult, leading to further loss of dentine and exposure of wider tubules. Most research on and, therefore, conclusions about lesion initiation are based on studies in vitro due to the difficulties imaging and measuring tubule exposure in vivo and the ethical implications of cutting cavities to induce DH.

Sensitive dentine has been shown to differ from non-sensitive dentine in both the number and diameter of open tubules present. Absi et al. (1987) used scanning electron microscopy and penetrating dye in vitro to demonstrate that hypersensitive dentine samples had 8 times the number of open tubules and 2 times wider tubule diameter when compared to non-sensitive samples. In addition, Rimondini et al. (1995) examined replica study models from both sensitive and non-sensitive teeth under a scanning electron microscope and discovered that non-sensitive dentine tended to have a thicker, amorphous smear layer when compared to the sensitive samples.

Occlusion of dentine tubules can occur by either endogenous or exogenous means. Brushing with an occluding toothpaste will deposit toothpaste ingredients in tubule orifices (Prati et al., 2002) and is one of the main mechanisms adopted by DH treatments. However, there is also evidence that exposed dentine will repair with the formation of reactionary or reparative dentine to block patency from the oral cavity to the pulpal tissues (Ganss et al., 2014).

1.3.1.1 Accepted mechanism of DH

Three main theories have been proposed to establish the mechanism of DH: The direct innervation theory, odontoblast receptor theory and the hydrodynamic theory. For the purposes of this thesis, only the most widely accepted theory- the hydrodynamic theory - will be discussed.

The hydrodynamic theory was first proposed by Gysi in the 19th century (Gysi, 1900) and was further evidenced by Brännström in a series of studies in the 60s (Brännström, 1963; Brännström, 1986). This theory proposes that external stimuli applied to the dentine surface, such as cold, hot, tactile or osmotic pressure, trigger a change in the flow rate of dentinal fluid within the tubules. The basis of the theory was the observation that outward fluid flow along dentinal tubules increased after certain stimuli were introduced, which in turn was responsible for nociceptor activation in the pulp (Brännström, 1963). In vivo, this increased rate of fluid flow induces a pressure change across the dentine which increases neural activity at either the pulp-dentine border or within the dentinal tubules (Matthews and Vongsavan, 1994). Intradental myelinated A-β and some A-δ fibres are thought to respond to this hydrostatic pressure change in the dentinal tubules, resulting in the characteristic sharp pain of DH (Närhi et al., 1992).

Depending on the trigger for DH, fluid movement within the dentine tubules can take place in either an outward and inward direction (Orchardson and Cadden, 2001) yet it has been found that intradental nerves are more readily excited and thus more action potentials are generated by outward than inward fluid flow (Matthews and Vongsavan, 1994). The application of both cold and evaporative stimuli to the dentinal surface will cause contraction of dentinal fluid, reducing its volume and leading to outward fluid flow (Brännström, 1986), whereas thermal stimuli are thought to cause inward fluid flow. This explains why DH in the literature appears to be most commonly reported in association with cold stimuli (Clayton et al., 2002; Rees and Addy, 2004; Mantzourani and Sharma, 2013). The relationship between lumen diameter and fluid flow is explained by Poiseuille's Law which states that the rate of fluid flow within tubules is proportional to the fourth power of the radius (r^4). For DH, this means that doubling the diameter of a dentinal tubule will increase fluid flow 16-fold (West et al., 2014). This, coupled with the findings that extracted teeth with sensitive dentine had many more and wider tubules compared to non-sensitive teeth (Absi et al., 1987), further supports the theory that fluid movement is responsible for DH pain.

Further evidence for the hydrodynamic theory comes from the products developed on this basis which are designed to occlude dentine tubules and therefore should, if the theory is correct, diminish DH symptoms. As most of these studies are carried out in situ using tooth samples rather than vital teeth to demonstrate tubule occlusion, they cannot directly show decrease in pain. However, a small number of studies have used replica techniques which utilise an impression material which is able to finely discriminate the surface topography of the dentine of vital teeth and are able to record whether tubules are patent or occluded. Such techniques enable the visualisation of dentine in vivo and the detection of associated pain and in this way tubule occlusion has been shown to inversely correlate with pain scores (Seong et al., 2018b). However, these techniques still require further work to improve accuracy. The success of occluding products, which reduce fluid flow in the tubule lumen, in treating DH provides further evidence to support the hydrodynamic theory.

1.3.2 Diagnosis and management of DH

1.3.2.1 Diagnosis

An accurate diagnosis of DH is key for its successful management. It is, by definition a diagnosis of exclusion and so other forms of dental defect or disease must be omitted as potential causes of the pain experienced (Canadian Advisory Board on Dentin Hypersensitivity, 2003). Many conditions share the symptoms of DH such as caries, chipped or fractured teeth and restorations, marginal leakage around restorations, cracked tooth syndrome, palatal-gingival grooves and vital bleaching (Addy, 2002; West et al., 2014). Some patients also report severe pain on initial stimulus followed by a lasting dull ache. These rarer cases have been suggested to be more likely due to pulpal inflammation requiring different management strategies such as endodontics or removal of the tooth (Addy, 2002).

Tactile, cold and evaporative air stimuli are the recommended test stimuli for diagnosing DH due to their controllable nature (Holland et al., 1997). The evaporative air stimulus is accessible to all dental practitioners as it is easily performed with the triple air syringe on a standard dental unit, whereas to deliver a controlled tactile stimulus a calibrated pressure-sensitive probe must be utilised, such as the Yeaple probe (Polson et al., 1980). Self-reported questionnaires are also frequently used to assess DH symptoms, although these are recommended alongside clinical assessments as under or over-reporting are common due to the subjective nature of perceived pain, the episodic presentation of DH symptoms and misdiagnosis of other similar pain by the participant, for example reversible pulpitis (Chabanski and Gillam, 1997; West et al., 2014).

1.3.2.2 Management

After reaching a diagnosis of DH and excluding alternative or additional causes of dental pain, the next step is to identify and eliminate aetiological and predisposing factors before providing treatment based on the individual need (West et al., 2014). Treatments for DH can be classified according to their mode of delivery as professionally applied or home use. Two main treatment modalities exist, namely: nerve stabilisation/desensitisation and occlusion of exposed dentine tubules (Mantzourani and Sharma, 2013; West et al., 2014).

The main agent used for nerve desensitisation are potassium salts which are thought to diffuse along dentinal tubules and increase the local concentration of extracellular potassium ions to a level which stabilises and inactivates the intradental nerves at the pulpal ends of the tubule (Orchardson and Gillam, 2006). Ajcharanukul et al. (2007) demonstrated in vivo that potassium ions applied to exposed dentine of human volunteers could cause a transient block of impulse conduction in nerve endings. However, clinical trials testing potassium-based toothpastes showed that it took at least two weeks of twice daily use to provide measurable reductions in DH (Davies et al., 2010). There is much debate on the efficacy of potassium-based desensitising toothpastes with a recent systematic review (West et al., 2015) concluding that potassium salts have a lack of proven effectiveness and therefore could not be recommended for DH treatment.

Currently dentinal tubule occlusion is the favoured treatment modality for DH as these have been shown to provide instant relief (West et al., 2013c). The effectiveness and longevity of occluding agents depends on their resistance to removal mechanically or by acid (West et al., 2014). A vast range of products are now available with different active ingredients. Strontium salts, arginine and calcium carbonate, stannous fluoride, calcium sodium phosphosilicate, oxalates and casein derivatives are all efficacious occluding agents which have been successfully shown to decrease DH symptoms (West et al., 2014; West et al., 2015) to varying degrees. Recent systematic reviews suggest that arginine-based medicaments are superior (Yan et al., 2013) with less evidence to support the efficacy of strontium containing products (Bae et al., 2015; Magno et al., 2015).

It has been suggested that the treatment of DH should begin with an at-home, non-invasive method, such as a desensitising dentifrice (West, 2008). When this fails to satisfactorily treat the experienced DH then professional treatments may be indicated. Varnishes applied in the surgery have shown promising results, although their efficacy is limited to the duration for which they remain on the dentine surface (Olusile et al., 2008). Restoring the exposed dentine is a further option to the clinician, although traumatic brushing habits should be tackled first to ensure their longevity (West et al., 2014) and consideration must be given to the gingival tissues (see Section 1.2.1.2). A further option available in surgery is Nd:YAG laser irradiation, which works to coagulate proteins in the dentinal fluid and thus reduce the permeability of the tubules (Goodis et al., 1997). However, recent systematic reviews and meta-analysis have concluded that there was insufficient evidence base to clinically recommend the use of lasers to treat DH (Sgolastra et al., 2013) and the placebo effect may play a role (Sgolastra et al., 2011).

In summary, the majority of management strategies for DH focus on pain relief by treating the exposed dentine, and home use products are increasingly popular as the effects of professionally applied treatment may not last until subsequent dental visits. Although these topical treatments are effective in relieving symptoms, it is important that the aetiology of the condition is also addressed in order to prevent perpetuation of the condition.

1.3.3 Prevalence of DH

Prevalence figures for DH in the literature vary widely, ranging from 1.34% (Bamise et al., 2007) to as high as 98% (Chabanski et al., 1997) in periodontal patients. This huge disparity reflects differences in populations studied, such as the periodontal status of participants – those with periodontitis presenting with higher levels of DH (Taani and Awartani, 2002), and the study methodologies utilised. Holland et al. (1997) set out guidance on how to conduct clinical trials on DH in order to try and standardise methodology. It was stated that at least 2 hydrodynamic stimuli should be used (tactile, cold or evaporative air), the least severe applied first with appropriate interval between applications, and that the overall assessment of the subject's DH can be captured via questionnaire.

Data suggests that DH is prevalent from a young age and is on the rise (Olley and Sehmi, 2017). A recent European study of 18-35 year olds reported a DH prevalence of 42% (West et al., 2013a). As discussed in previous sections, GR and tooth wear are both risk factors for DH and their prevalence increase with age. It could be expected, therefore, that DH experience would also follow this pattern with higher prevalence in the older population. However, a questionnaire-based study of 507 patients attending general dental practices in the UK reported the highest prevalence was in those aged 30-39 years (Gillam et al., 1999), with the prevalence of DH declining after this point, as the age of the participant increased. This trend was also seen in an Australian study where clinical and questionnaire-based data was collected for 12,692 adults attending private dental practice, with the 30-49 years experiencing the highest rates of DH, and elder patients less affected (Amarasena et al., 2011). This finding of a peak in the middle-aged population and subsequent decline may be explained by age-related changes in the pulpodentinal complex, such as the deposition of reparative dentine which leads to reduced dentine permeability and decreased pulp chamber size (West et al., 2014; Lamster et al., 2016). Consideration must also be given to the possibility that these individuals have developed more effective coping mechanisms, such as avoidance of certain foods, over their lifetime and as such their experience of DH has diminished (Gillam et al., 2002).

In terms of gender, globally studies show a slightly higher prevalence of DH in females than males (Gillam et al., 2001; Addy, 2002; Azodo and Amayo, 2011; Haneet and Vandana, 2016; Liang et al., 2017). Possible reasons for this trend have been proposed such as women being more likely to seek professional advice compared to men (Ramlogan et al., 2017) or are more likely to have regular toothbrushing habits from a younger age (Dowell et al., 1985) which can in turn lead to GR, tooth wear and consequently DH (see sections 1.1.1.2 and 1.2.1.1). This finding, however, is not absolute and a more recent large-scale epidemiological study based in Europe found no significant difference between genders (West et al., 2013a).

Further variation arises from study methodology with self-reported prevalence of DH often varying considerably from clinical findings. A recent study conducted on 389 patients in Brazil found 42% self-reported prevalence of DH compared to an 89% diagnosed prevalence when the same subjects were examined clinically (Barroso et al., 2019). By contrast, Liang et al. (2017) examined 1320 patients in China and noted the opposite had happened, with 34% reporting DH via a questionnaire but only 26% diagnosed clinically. One of the main problems encountered when evaluating self-reported DH is the lack of reliability and consistency due to the subjective nature of perceived pain and the episodic presentation of DH symptoms (Chabanski and Gillam, 1997; West et al., 2014). Further, it is possible that other dental conditions may be responsible for the perceived pain reported on questionnaires, resulting in a higher self-reported prevalence of DH than clinically elicited (Flynn et al., 1985). On the other hand, clinically applied stimuli are not an exact reproduction of typical daily stimuli associated with DH and therefore may evoke responses in those who do not normally suffer DH, or vice versa (Fischer et al., 1992). As both approaches have shortfalls, a combination of both self-reported and clinically elicited data is likely to provide a more accurate representation of true DH prevalence.

In summary, DH is a common condition affecting subjects of all ages. The heterogeneity of study methodologies makes interpretation of prevalence figures difficult and further research is still needed involving large, representative populations and using both clinical and questionnaire-based data collection, to facilitate a better understanding of the bigger picture.

1.3.4 Why DH is an issue for patients

DH has been described as one of the most painful yet poorly managed chronic ailments of the dentition (Chalas et al., 2015) with significant negative effects on the quality of life of those affected (Boiko et al., 2010; Bekes and Hirsch, 2013; Baker et al., 2014). Affected individuals may need to make lifestyle changes to ease the tangible frequent discomfort, such as avoiding chilled food and drink and taking care when breathing in cold weather. 28% of 782 young European adults who declared suffering with DH via a self-completed questionnaire, also reported that the effect of DH was important or very important to them (West et al., 2013a). A specific questionnaire has been developed and validated as a tool to determine the impact of DH on quality of life, namely the Dentine Hypersensitivity Evaluation Questionnaire (DHEQ) (Boiko et al., 2010). This is a self-complete questionnaire with a full and shortened form and focuses on different impact subscales such as emotional impact and restrictions (Boiko et al., 2010).

For individuals seeking treatment for DH, the impact on the quality of life has been shown to be similar to those suffering from chronic temporomandibular disorders (Bekes et al., 2009). The condition has been found to impact on drinking, eating, toothbrushing, social interaction and self-identity (Boiko et al., 2010). In one study of 277 patients, 28% of participants could not drink cold water and 26% could not eat ice cream without discomfort due to their DH, whilst 9% found that it hindered their toothbrushing (Gillam et al., 1999). The latter is a cause for concern as this could have a knock-on effect on periodontal health. Moreover, DH has also been shown to significantly hinder the quality of life of those undergoing supportive periodontal care (Goh et al., 2016).

Comparatively, there has been little research on DH from the patient's perspective with more studies recording response to stimulus in a clinical setting (Baker et al., 2014) although recording this qualitative data is essential to understand the impact of the condition on everyday life.

1.4 Risk factors for tooth wear, GR and DH

As the above sections have indicated, tooth wear, GR and DH are all linked – with the latter being their common symptom. This was confirmed in the findings of the largest European based epidemiological study to date looking at risk factors for DH and NCCLs on 3187 participants which found association between DH and tooth wear, and DH and loss of attachment (Bartlett et al., 2013; West et al., 2013a). Identifying the individual and common risk factors for these conditions is important to allow for a preventative approach to their management. This section aims to explore the evidence to date.

1.4.1 Biological risk factors

Several risk factors for the oral conditions under investigation are dependent on our biotype and phenotypic expression, making these risk factors non-modifiable or only partially modifiable. Saliva is the main biological factor for the prevention of dental erosion (Johansson et al., 2012). Its role is multifunctional, acting directly to dilute, neutralise and clear acids whilst also providing a reservoir of calcium, phosphate and fluoride ions which reduce demineralisation rate and enhance remineralisation (Hara and Zero, 2014; Dawes et al., 2015). The flow rate is important as it determines how quickly the dietary acidic challenge is diluted and cleared from the oral cavity, thus decreasing its erosive potential. Saliva also plays a role in forming a protective covering on the tooth surface – the acquired pellicle. The pellicle is semi-permeable, providing partial protection against acidic challenges by reducing calcium and phosphate release from enamel (Hannig and Hannig, 2014). Sites of erosion in the mouth are saliva dependent (Young and Khan, 2002). Teeth that are bathed mostly by mucous saliva are more prone to erosion, as mucous saliva lacks the buffering capacity and high flow rate of serous saliva, which is required for acid clearance (Dawes, 1987). Among the main causes of decreased salivary flow are aging, radio and chemotherapy and systemic diseases. Several drugs also induce xerostomia and, irrespective of the nature of the drug, the number of medications taken daily linearly reduces the secretion of saliva (Salum et al., 2018).

Overall, factors which affect saliva flow are also likely risk factors for erosive tooth wear. As erosion is a dominant factor in both the localisation and initiation of DH lesions, saliva may also be protective for DH.

For DH, the main biological protection is the smear layer which provides more than 80% of the resistance to dentine tubule fluid flow following the exposure of dentine (Pashley, 2013) and the dissolution of this layer is directly related to DH lesion initiation (section 1.3.1). Non-sensitive exposed dentine has been shown to have a thicker, amorphous smear layer (Rimondini et al., 1995). which protects against DH symptoms by blocking tubules.

Anatomically, the relative thickness and positioning of both the hard and soft tissues may play a role in the aetiology of these conditions. Periodontally, a thin phenotype has been shown to increase the risk for developing GR (Cortellini and Bissada, 2018) as has unfavourable tooth positioning in the alveolar bone, resulting in little or no keratinised tissue buccally (Tugnait and Clerehugh, 2001). Gingival phenotype is assessed by observing the shine-through of a periodontal probe, as an indication of gingival thickness. If the probe is visible through the sulcal tissues the phenotype is classified as thin (≤1mm), whereas a thick phenotype is when the probe is not visible (>1mm) (Jepsen et al., 2018). Studies have reported males to be more predisposed to thicker gingiva than females (Rathee et al., 2016) with overall thinner gingival thickness around the canines (Cortellini and Bissada, 2018).

As GR is a prerequisite for lesion localisation in radicular dentine, teeth which are more predisposed to GR – namely canines and premolars- are also associated with DH (Addy et al., 1987; Addy, 2008), although this could be due to the fact these areas receive more attention in the brushing cycle (Macgregor and Rugg-Gunn, 1979).

1.4.2 Modifiable, behavioural and lifestyle risk factors

1.4.2.1 Oral hygiene

The links between toothbrushing and GR, and toothbrushing and tooth wear are still under debate (see sections 1.2.1.1 and 1.1.1.2) although traumatic brushing technique has been associated with increased risk of DH (West et al., 2013a). In vitro, brushing with a heavier force has been shown to expose more tubules than lighter toothbrushing techniques, suggesting that it could be beneficial for DH patients to brush more gently to reduce the permeability of the dentine (Sehmi and Olley, 2015). Soft and extra soft brushes have also been suggested to be safer for the soft tissues (Ranzan et al., 2018), although they have been found to lead to more abrasive wear on hard tissues than harder bristle brushes in vitro (Dyer et al., 2000; Bizhang et al., 2016). Possible explanations for this include increased retention of dentifrice on filaments with a smaller diameter and their capacity for greater flexion, increasing the contact area between filament and tooth (Bizhang et al., 2016).

Studies that have investigated the effect of the dominant hand also support toothbrushing as a risk factor for DH. In a cross-sectional study looking at the distribution of DH in 92 patients, the dominant factor affecting DH was side of the mouth, with more DH present on the left-hand side as 86 of the subjects were righthanded (Addy et al., 1987) and therefore may scrub this area preferentially. However, a recent large-scale European study found no clear relationship between tooth wear or DH and the dominant hand (Bartlett et al., 2013; West et al., 2013a).

Newer evidence suggests that the longstanding advice given by dental care professionals to delay brushing after meals to protect against tooth wear may not be substantiated (Lussi and Carvalho, 2014; O'Toole et al., 2017;). In vitro and in situ, a statistically significant reduction in tooth wear has been shown when delaying brushing for 60 minutes after an acidic challenge, although there was still substantial enamel loss when brushing after this time (Jaeggi and Lussi, 1999; Attin et al., 2001). This finding suggests that the clinical protective effect of delaying toothbrushing may not be substantial (Lussi and Carvalho, 2014). This is supported by the finding of O'Toole et al. (2017) who reported no significant association between clinically detected tooth wear and those who reported toothbrushing within 10 min of acid intake, once adjustments had been made for dietary factors. Similarly, in the European population-based study of 3,187 adults from 7 countries, there was no association observed between the waiting period for toothbrushing after breakfast and tooth wear or DH (Bartlett et al., 2013; West et al., 2013a). However, a significant link between the type of toothbrush used and tooth wear was found, suggesting that changing damaging brushing habits may be more important to prevent tooth wear than asking patients to wait before brushing their teeth.

Interestingly, to date there appears to be little research looking at the tooth which is brushed first in the mouth in association with these conditions. Given that toothpaste is the main abrasive factor and the majority of it is likely to be deposited at the first site the toothbrush comes into contact with, it is possible that this could be a risk factor for DH through abrasion of either hard or soft tissues.

1.4.2.2 Diet

Dietary acids are well known risk factors for both DH and tooth wear (Lussi et al., 2011; West et al., 2013b). In the pan European study of 3187 adults, all acidic dietary items studied were associated with DH and tooth wear, especially fresh fruit and isotonic energy drinks (Bartlett et al., 2013; West et al., 2013a). A similar finding was reported in a Brazilian adult population where tooth wear was particularly associated with wine and alcoholic beverages and DH with the consumption of acidic fruits and juices (Yoshizaki et al., 2017).

Not only the frequency of acid intake but also its timing in relation to meals has proved to be important in relation to tooth wear. In a recent case-control study with 600 participants, 300 with tooth wear and 300 age-matched controls, fruit intake between meals but not with meals was associated with tooth wear. Interestingly, acidic drinks maintained a strong association regardless of when they were consumed (O'Toole et al., 2017). In this study, prolonged fruit eating and alternate habits, such as swishing or holding beverages prior to swallowing, were also strongly associated with tooth wear suggesting that the contact time between acids and the tooth surface is highly important. Other studies have also found that the manner in which dietary acid is consumed can affect the duration and localisation of the acid attack (Johansson et al., 2004; Shellis et al., 2005). Johansson et al. (2004) measured the intraoral pH on tooth surfaces after different methods of drinking an acidic drink. Holding the drink in the mouth before swallowing led to the largest pH drop, followed by taking long drawn-out sips of the drink.

The erosive capacity of dietary acids further depends on the chemical composition including pH, acid type and buffering capacity. The mineral content of the food/drink (calcium, phosphate and fluoride) affects the degree of saturation of the fluid surrounding the tooth with respect to the mineral of the hard tissues and therefore determines whether or not dissolution occurs (Zero and Lussi, 2005). Increasing the temperature or the flow rate of the foodstuff has been found to increase its erosive capacity in vitro (Barbour et al., 2006; O'Toole and Mullan, 2018) which suggests that the method of consumption – such as swilling alcoholic beverages or having hot fruit teas – could influence DH localisation, through erosive tooth wear, and initiation via removal of the smear layer. This is supported by the findings of Rees et al., (2006) who tested a range of fruit teas in vitro reporting that all were sufficiently acidic to remove the smear layer.

There is an established role between dietary acids, erosive tooth wear and consequent DH. As this aspect of tooth wear is both modifiable and preventable, delivering evidence-based dietary advice to patients and supporting them to change their behaviours may prevent or delay progression of these damaging conditions.

1.4.2.3 Behaviour and lifestyle

When looking at tooth wear and DH in the aforementioned European study, the two most associated risk factors for tooth wear were the regular use of antidepressants/sleeping medications and gastroesophageal reflux/vomiting. For DH, these risk factors also had the most highly marked associations alongside smoking (Bartlett et al., 2013; West et al., 2013a). Medicines have long been recognised as having an erosive potential, especially those with low pH or those that decrease saliva flow (see section 1.4.1) (Hellwig and Lussi, 2014). Smoking is recognised as a risk factor for GR (Merijohn, 2016) with several epidemiological studies identifying associations between GR and those who smoke (Susin et al., 2004; Toker and Ozdemir, 2009). In the European study, there was a strong association between smoking and GR and a further link between smoking and DH was also detected (West et al., 2013a). This association between DH and smoking likely reflects the increased exposure of radicular dentine due to GR.

The impact of physical exercise on oral health has been a more recent topic of interest. Dental erosion is common in exercising young adults and was also found to associate with decreased stimulated salivary flow rate (Mulic et al., 2012b). Further, frequency of exercise per week was identified as a risk factor for dental erosion in a study population of amateur runners (Antunes et al., 2017). Isotonic energy drinks, which are regularly consumed by athletes in endurance events, have also been associated with both DH and tooth wear (Bartlett et al., 2013; West et al., 2013a).

Swimming, in particular, puts athletes at high risk of erosion due to the possible acidic chemicals (chlorine gas) used to maintain pool cleanliness. Case reports of severe erosion resulting in near entire loss of enamel demonstrate the potential damage that can be caused by poor pool maintenance (Dawes and Boroditsky, 2008), yet strict regulations make these a rare occurrence. However, competitive swimmers who used a well-maintained pool for training over 19 hours per week have still been shown to be at increased risk of erosion, even when the pH of the pool water was neutral (Buczkowska-Radlińska et al., 2013). It was suggested this may be related to undersaturation of pool water with respect to hydroxyapatite, making competitive and regular swimming a possible risk factor for erosion.

1.5 Rationale and aim

It is well documented across the literature that GR, DH and tooth wear are common and literature suggests that the latter two, are increasing. However, to accurately capture the magnitude of these dental conditions, claims of ever-increasing prevalence need to be confirmed by robust large-scale epidemiological studies. Furthermore, the relationship between GR, tooth wear and DH is complex and, as yet, not fully understood. The lack of consistent evidence for the causal effect of some risk factors identified for these common conditions, together with the undesirable impacts they have on health, highlights the need for more research in this area. Current preventative guidance remains unclear and urgent attention is needed to develop evidence-based preventive advice for clinicians, to help reduce the scale and severity of symptoms for their patients.

In a previous study carried out in 2011 across 7 European countries, data for adults aged 18-35 years was collected, capturing a snapshot prevalence of these conditions in young adults (Bartlett et al., 2013; West et al., 2013a). This thesis forms part of the follow-up European epidemiological study expanded to determine the prevalence of GR, DH, tooth wear and periodontal conditions together with associated risk factors in adults of all ages across 7 countries. The data presented here is that obtained for the UK for which I was the lead dentist, although I was also involved in setting up and training dentists for data collection in the other six European countries (Germany, Italy, Portugal, Republic of Ireland, Spain, Switzerland). In the interests of focus, this thesis is restricted to data on tooth wear, DH, GR and associated risk factors. The data is separated into 2 research chapters with associated aims and objectives. The first describes the testing of a novel index developed specifically for this study, and the second explores the prevalence and risk factors for tooth wear, DH and GR for the study population in the UK.

2. A novel index for tooth wear in the cervical region

2.1 Introduction

Tooth wear indices serve to capture and classify the severity of dental hard tissue loss, for use in prevalence studies, aiding diagnosis, indicating risk factors and helping management of the condition. Tooth wear is an aetiologic agent for DH (Addy et al., 1987), and often occurs in combination with GR (West et al., 2013a). Recording both the localisation of the tooth wear and any accompanying GR would assist the clinician in interpreting the aetiology and risk of associated DH symptoms related to soft tissue loss (gingival recession) or hard tissue loss (tooth wear).

There are numerous tooth wear indices published in the literature, yet the variety of their scoring criteria often renders studies using different indices incomparable and has resulted in difficulties evaluating the overall status of the condition (Berg-Beckhoff et al., 2008). Further, many tooth wear indices are based on the perceived aetiology of the defect which often leads to confusion as tooth wear mechanisms seldom happen in isolation. The Basic Erosive Wear Examination (BEWE) was introduced to overcome these problems, designed to be simple and easy to use by general dental practitioners, whilst also allowing re-analysis and integration of results from existing studies (Bartlett et al., 2008).

In order to gain maximum information about the distribution of tooth wear in the oral cavity, the European study conducted in 2011 (Bartlett et al., 2013; West et al., 2013a; Seong et al., 2018a) used the BEWE to provide a separate severity score for each surface of the tooth rather than a score for each sextant, as normally used in general practice. As described by Seong et al. (2018a), a localisation code was used to indicate the area of the tooth affected by tooth wear, however it was found that the application of the localisation code was confusing. Codes could overlap in some clinical scenarios, leaving the score subject to examiner interpretation; but without a mechanism to record localisation, the BEWE severity code does not allow us to appreciate whether the scored tooth wear is localised occlusally/incisally, or if it is focused in the cervical region. The BEWE severity score also lacks information on dentine exposure but rather focuses on the overall surface area of the tooth affected. This focus on surface area recognises that the distinction between lesions restricted to the enamel and dentine is difficult in the cervical region (Holbrook and Ganss, 2008) yet, the presence of dentinal exposure is a requirement for the accurate diagnosis of DH. Given these limitations of the BEWE, it was recognised that the development of a new index with a focus on tooth wear in the cervical region was warranted.

Based on the identified need a novel index: ‘Cervical Localisation Code’, has been designed specifically to assess tooth wear in the cervical region and its association with GR and DH. This index records exposure of radicular dentine (GR) and tooth wear on the anatomical crown or root in the cervical region, recognising the multifactorial aetiology of dentine exposure which could lead to DH in this region. Recording both the localisation of the tooth wear and any accompanying GR assists the clinician in interpreting the aetiology and risk of associated DH symptoms related to soft (GR) or hard tissue loss. In separating out aetiological factors, the clinician will be encouraged to address all contributory causes and tailor their management strategy accordingly.

The Cervical Localisation Code is deliberately simple, enabling it to be accessible to all practitioners in general dental practice and the descriptions have been designed to be reproducible under varying conditions for example magnification, light and hydration state of the tooth. The index was developed specifically for use in a large-scale epidemiological study focusing on clinical conditions affecting the cervical region (see Section 3) but it has been designed for use both as an epidemiological and clinical tool - highlighting the possible aetiology of any lesions and enabling focus on the individual patient’s needs. It will also be valuable in clinical trials of preventive measures. Importantly, a management section is incorporated which has been developed to provide the clinician with focused prevention and management strategies for each index score.

In the future, it is the intention to implement this index nationally in the primary care setting to help focus management of the cervical area.

2.2 Aims and Objectives

Principal aim:

To devise, describe and validate an index for the classification of the cervical region in research studies and general dental practice, with proposed interpretation and management options for the different codes.

Objectives:

1. To devise an index to allow classification of the cervical region with respect to hard and soft tissue defects.
2. To determine the validity and reproducibility of the index by analysing inter and intra-examiner agreement.
3. To create a management tool detailing prevention and management strategies for conditions affecting the cervical region, for use by general dental practitioners.

2.3 Method

2.3.1 Development of the index

The Cervical Localisation Code was developed by a group, consisting of academics, clinicians and specialists in Restorative Dentistry. The group was tasked with establishing a set of codes to reflect the different clinical presentations of the cervical region, in health and with hard and soft tissue loss in NCCLs. After defining the codes in descriptive terms, an interpretation of the hard and/or soft tissue loss was determined followed by describing a management section for each code (Appendix 1).

The final code descriptions (Table 2.1) were agreed after discussion, debate and voting, achieving a 75% or above majority vote for consensus within the clinical research team, according to current protocol (Doust et al., 2017). Once determined, the codes were then tested in a validation study.

Table 2.1 Cervical Localisation Code.

Code	Description
0	No gingival recession, **and** No distinct tooth wear on crown in cervical region
1	No gingival recession, **and** Distinct tooth wear on crown in cervical region
2	Gingival recession with or without distinct tooth wear on root in cervical region, **and** No distinct tooth wear on crown in cervical region
3	Gingival recession with distinct tooth wear on root in cervical region, **and** Distinct tooth wear on crown in cervical region
Key notes for interpretation of code: • **Distinct tooth wear** = a 'step' or 'scooped-out' defect, visible to the eye and detectable when running a probe over the tooth surface • **Crown =** anatomical crown • **Root =** anatomical root	

2.3.2 Study Design

The study was a cross-sectional observational, epidemiological validation study that took place within the University of Bristol Dental Hospital. Study participants were healthy adult volunteers aged 18 or over, recruited from restorative hospital clinics. Eligibility criteria were kept to a minimum to be as inclusive as possible.

A total of 42 volunteers who provided informed consent to participate and fulfilled the inclusion and exclusion criteria underwent four identical clinical examinations performed independently by three investigator dentists. The final examination was carried by the same dentist who completed the first examination, with an interval of at least 30 minutes in between and without reference to their previous score, allowing assessment of intra-examiner agreement. Participants were randomised equally into examination regimens using a block randomisation scheme. The investigator dentists were assigned for the course of the study and each was given an examiner ID which was not disclosed to the statistician.

Ethical approval was gained from the London - Queen Square Research Ethics Committee (REC Reference: 18/LO/1418; IRAS ID: 225373) and this study was carried out in accordance with good clinical practice guidelines.

2.3.3 Selection of participants

Patients attending the University of Bristol Dental Hospital clinics for a scheduled appointment were invited to take part in the study by a member of the research team who supplied them with a participant information sheet (Appendix 2). Those who agreed to take part in the study gave informed consent (Appendix 3). To be included in the study, participants had to satisfy all inclusion criteria and not meet any exclusion criteria (Table 2.2).

Table 2.2 Inclusion and exclusion criteria.

Inclusion criteria for participants
1. Healthy participants of either gender who are attending an appointment with a dental professional.
2. Aged 18 or over.
3. Understand and are willing, able and likely to comply with all study procedures and restrictions.
4. Accept the form of the study and signs a declaration of informed consent.
5. Have a minimum of 10 teeth not including implants or teeth with crowns or bridges.
Exclusion criteria for participants
1. An employee and/or a family relative of the investigator dentists.
2. Anyone who in the investigator’s opinion is not suitable to take part in the study.

2.3.4 Clinical assessment

Once enrolled on the study, each participant was randomised to an examination regimen detailing which dentist would be repeating the examination (Table 2.3). The participant then underwent identical examinations with each of the 3 investigator dentists who scored the Cervical Localisation Code (Table 2.1) both buccally and palatal/lingually on all eligible tooth surfaces in both arches. The examination was completed without the use of magnification, tooth surfaces were dried with a triple air syringe or cotton roll prior to examination with a dental mirror and good lighting. When scoring the code, the dentists’ attention was drawn to the key notes which detailed instructions for the correct interpretation of terminology. A further column detailing clinical interpretation alongside an example image were also provided as part of the index to aid scoring (Appendix 1). Excluded teeth were wisdom teeth and those with gross caries. Tooth surfaces covered by extra-coronal restorations in proximity of the CEJ or fixed orthodontic appliances were also excluded. Data for each examination was entered onto the clinical form (Appendix 4). The investigator who completed the first examination then repeated the examination again, at least 30 minutes after the initial examination and without reference to their previous scores. The three investigators dentists were a general dental practitioner, a restorative specialist and a periodontal specialist who were unable to confer with one another throughout to ensure that all scores were derived independently. All data remained anonymous and the participant was only identifiable by a screening ID number.

Table 2.3 Examination regimen to determine sequence of clinical examinations.

Examination Regimen	Investigator Dentist Order
1	A – B – C – A
2	B – C – A – B
3	C – A – B – C

2.3.5 Statistical analysis

All data from the clinical scoring was entered and transferred to statistical software (IBM SPSS Statistics, version 24) for analysis by the study statistician (RN) who carried out all the statistical analyses. 42 participants were seen by the 3 investigator dentists (labelled A, B and C). Fourteen of the 42 participants were scored by the 3 dentists in the sequence A – B – C – A. Another 14 were scored by the 3 dentists in the sequence B – C – A – B. The remaining 14 were scored by the 3 dentists in the sequence C – A – B – C.

The intra-observer variation for any tooth site or for the whole mouth maximum score was quantified by a standard deviation estimate s. The 95% confidence interval for s ran from 0.819s to 1.284s. Thus, this study size enabled estimation of within-observer variation as being between 18.1% lower than and 28.4% greater than the point estimate.

The four codes were treated as separate diagnostic categories, with no implied gradation or progression. Both random and systematic variation between and within examiners was quantified. Intra-examiner variation was assessed by comparing the first and final scores. Inter-examiner variation was assessed by comparing the 1st, 2nd and 3rd scores in a two-way analysis of variance model.

Kappa statistics were calculated for intra-examiner agreement. Disagreements between repeat scorings by the same examiner were also identified by producing a crosstabulation. The 6 possible disagreements were as follows: 0&1, 0&2, 0&3, 1&2, 1&3, 2&3. On the null hypothesis of no agreement whatsoever between the two scorings, the two ratings would be statistically independent. The numbers of each of the 6 possible types of disagreement were set alongside "expected" numbers of disagreements calculated on the null hypothesis of independence using pooled marginal frequencies. Actual ÷ expected disagreement ratios were calculated for each type of disagreement. An actual ÷ expected ratio approaching 1 indicated poorly repeatable discrimination between the two scores concerned.

Similar crosstabulations were constructed to find disagreements between scorings by each pair of examiners. These were post-processed in a similar way, combining disagreement data for each of the 3 pairs of examiners.

2.4 Results

All forty-two participants who gave informed consent completed the study, amounting to a total of 2352 possible tooth surfaces, 2073 of which were scored and 279 excluded.

Table 2.4 relates the initial scores and repeated scores by the same examiner. The distributions at rescoring, shown in the final row, were very similar to those at the initial scoring shown in the final column. 97.3% of sites (2016) were rated identically when scored and rescored by the original examiner, these agreements are highlighted in green. By far the most common score was 0 (67%), followed by 2 (22%). Scores 1 and 3 were less abundant, with code 3 only amounting to 3% of all scores.

Table 2.4 Scores at initial and repeated scorings by the same examiner, based on combined data from all examiners for all 42 participants.

		Repeated score (30 min later)				Total count for initial scoring
		0	**1**	**2**	**3**	
Initial Score	**0**	1377	6	6	0	1389
	1	4	151	4	0	159
	2	12	3	426	11	452
	3	1	0	10	62	73
	Total count for repeated scoring	1394	160	446	73	2073

The kappa statistic for intra-examiner agreement was 0.9445.

Table 2.5 summarises the intra-examiner disagreements, obtained by comparing initial and repeated scores for all 3 examiners together, for all 42 participants. The highest actual disagreement counts are for scores 2 & 3 and for scores 0 & 2 and the lowest for scores 1 & 3 and 0 & 3. When judged in relation to the abundance of scores of 0 or 2 and the scarcity of scores 3 and 1, the greatest rate of disagreements was between scores of 2 and 3. The actual ÷ expected ratio for this disagreement combination was closer to 1. This applied similarly for all 3 examiners.

Table 2.5 Intra-examiner disagreements for study population- all 3 examiners combined.

Disagreement between scores	Disagreement count		Actual ÷ expected
	Actual	Expected	
0 & 1	10	214	0.047
0 & 2	18	603	0.030
0 & 3	1	98	0.010
1 & 2	7	69	0.101
1 & 3	0	11	0.000
2 & 3	21	32	0.664

Table 2.6 summarises the inter-examiner disagreements between pairs of examiners, obtained by combining disagreement results for examiners A & B, B & C and C & A. Similar to the intra-examiner data, in absolute terms the highest disagreement counts were for scores 2 & 3 and for scores 0 & 2, but when judged relative to the overall frequencies of each score, the greatest rate of disagreements was between scores of 2 and 3. This pattern was seen across all 3 pairs of examiners. Once again, the combination of disagreements which occurred least frequently were 1 & 3 and 0 & 3. The kappa scores for inter-examiner agreement were 0.9236 examiner 1 vs 2, 0.9468 examiner 2 vs 3, 0.9350 examiner 3 vs 1.

Table 2.6. Pairwise disagreements between all 3 examiners combined.

Disagreement between scores	Disagreement count		Actual ÷ expected
	Actual	Expected	
0 & 1	43	659	0.065
0 & 2	53	1784	0.030
0 & 3	6	309	0.019
1 & 2	37	211	0.176
1 & 3	2	37	0.055
2 & 3	60	99	0.606

The management tool designed for use in general practice is shown in Appendix 1. It is broken down into easy-to-follow bullet points of prevention and management strategies, based on which code has been scored.

2.5 Discussion

This study devised and investigated a novel index designed both for epidemiological studies, such as the follow-on study described in the subsequent chapter (Section 3), and to aid clinical management of the cervical region. Development of the Cervical Localisation Code addressed the common problem of identifying and classifying hard and soft tissue loss at the cervical region and detailed consequential management of the conditions for general dental practice use. The code was designed to be easy and straightforward to record, capturing changes in all hard and soft tissue that are possible. The definitions of the codes were pondered at length, discussed and voted upon to reach consensus opinion according to current protocol (Doust et al., 2017).

The aim was to ensure that all four codes in the index were distinguishable as separate clinical entities which could be reproducibly scored by different clinicians. The results indicate that the index satisfied these aims, with the good intra-examiner and inter-examiner reproducibility demonstrated for all scores, although a level of disagreement was observed between examiners as expected, for codes 2 and 3.

Scores 2 and 3 distinguish between GR with or without cervical tooth wear restricted to the anatomical root (code 2), and GR where cervical tooth wear of both the anatomical crown and root is evident (code 3). For these scores, the actual ÷ expected disagreements were in the region of 0.6 for both intra-examiner and inter-examiner assessment, indicating examiners experienced some difficulties in discriminating between these codes. Clinically, this could be reflected in the difficulties in determining the position of the CEJ once there has been GR or more problematically with cervical tooth wear as GR leads to loss of root surface cementum, with further damage to the region by abrasive or erosive tooth wear leaving the CEJ indiscernible (Bevenius et al., 1994; Smith, 1997). The loss of this anatomical landmark demarcating the boundary between the root and crown makes codes 2 and 3 harder to distinguish. In addition, once enamel has been lost, further coronal tooth wear can result in a clear demarcation separating the coronal dentine and enamel which can be mistaken for the anatomic CEJ (Zucchelli et al., 2006) which could also lead to erroneous scores if the anatomical crown and root are wrongly identified. Moreover, wide but shallow cervical tooth wear may have been more difficult to detect than typical wedge-shaped defects.

The difficulty identifying the correct anatomical CEJ in areas of GR is not a new clinical issue in dentistry. Several researchers have suggested ways to arrive at a correct diagnosis, from using the CEJ measurements on adjacent or contralateral teeth (Cairo and Pini-Prato, 2010) to careful observation under magnification to distinguish the more curved and convex CEJ from a flatter abrasion line (Zucchelli et al., 2006). For the purpose of this index, perhaps it must be made more obvious that a distinct defect is required both on coronal and radicular dentine in order to score a 3. One might expect that a code 2 should have the CEJ still intact whereas for a code 3 it will have disappeared, however as we define that there must be a distinct defect for a code 3 to be scored, the CEJ may have also already been lost in a code 2.

Clinically in practice the management for both code 2 and 3 is similar, with code 3 focusing more on dietary advice due to the likely erosive component. This discrepancy in scores will mean that practitioners need to use lifestyle questions to decide if there is a likely dietary or abrasive element which needs addressing in which case a score of 3 is more appropriate. For its use in clinical research, this distinction is of greater importance and so guidance should be given during the examiner training and calibration phase of the study which focuses on how to relocate the original CEJ in its absence, majoring on the need for magnification. This level of training, whilst essential for a clinical trial, could also be straight forward in general practice as a large number of clinicians now wear loupes.

According to the literature, the current gold standard for assessing tooth wear internationally is the BEWE (Bartlett et al., 2008), although there are relatively few studies looking at the reliability of this scoring system. Mulic et al. (2010) compared the BEWE to the Visual Erosion Dental Examination (VEDE), another erosive tooth wear index. The obtained values for inter- and intra-examiner agreement showed that they were similar for both indices, although only erosive tooth wear was considered. Dixon et al. (2012) compared the BEWE to the TWI (Smith and Knight, 1984) demonstrating similar distribution of both scores. They concluded, however, that there was unacceptable variation both when assessing intra- and inter-examiner agreement for the BEWE and therefore could not recommend its use. More recently, Olley et al. (2014) investigated whether the cumulative BEWE score for a whole mouth provided accurate representation of the scores as recorded separately on all tooth surfaces. In this study the BEWE was used to record all forms of tooth wear although the examinations were carried out by a single examiner with intra-examiner agreement only assessed once in every ten patients, immediately after initial assessment. Results showed that the cumulative score related well for tooth surfaces with early or distinct wear but less so for BEWE 1 (early wear affecting enamel) and BEWE 3 (wear affecting >50% surface area). The methodology described above for the Cervical Localisation Code is arguably more robust than this most recent validation study for the BEWE, with three examiners completing the assessments and intra-examiner agreements measured after a significant break so that answers could not just be replicated from the initial scoring session. Further the promising agreement of scores makes its validity comparable, if not superior, to the BEWE whilst also providing additional information regarding the soft tissue status associated with cervical defects.

As the Cervical Localisation Code is novel in recording the presence and absence of both tooth wear and GR, it cannot be directly compared in a validation study to the BEWE or any other index that only records tooth wear. Tooth wear in the presence of GR defects alone has previously been considered in an index by Pini-Prato et al. (2010), in the context of mucogingival surgery outcomes. They describe a classification of dental surface defects in areas affected by GR (but not in gingival health), focusing on the presence or absence of the CEJ and whether there is a distinct dental step defect caused by abrasion. In the validation study by Pini-Prato et al. (2010), intra-examiner agreement was high but inter-examiner agreement was only moderate, perhaps reflecting the same difficulties encountered in the current validation study regarding the correct location of the original CEJ and deciding what counts as a distinct dental defect. The Cervical Localisation Code not only assesses the root surface but also records the presence or absence of tooth wear on the anatomical crown when there is clinical gingival health, making it a more suitable alternative for patients in general dental practice rather than those anticipating periodontal surgery, and encompasses NCCLs in general rather than one aetiology of NCCL.

The specific use of the Cervical Localisation Code to record GR and tooth wear in DH studies would give the advantage over the BEWE that it allows analysis of whether hard or soft tissue loss (or both) is most commonly associated with DH symptoms in the cervical region. Currently, guidance on the conduct of DH trials is set out by Holland et al. (1997) with the main focus on how to record DH - the hydrodynamic stimuli which should be used (at least two of tactile, cold or evaporative air) and the use of questionnaires to capture overall experience. Introducing the Cervical Localisation Code as a gold standard in DH studies to record the clinical presentation of teeth with DH symptoms will allow the potential aetiology of the symptoms to be assessed as well as encouraging standardisation of how GR and tooth wear are detailed in these studies, allowing easier comparison.

The management section of the Cervical Localisation Code has been designed to aid dental practitioners in primary dental care and it is suggested that it will complement the use of the BEWE in general practice. The joint use of these codes would give a better appreciation of where tooth wear is located, with the BEWE giving an indication of general severity of wear across the whole tooth surface or mouth, while the Cervical Localisation Code can be used to record more detail of specific lesions as it also notes any soft tissue defect which may be associated, providing more descriptors for aetiological factors. The management guide for each code encourages practitioners to recognise the possible aetiology of lesions at an early stage, allowing a preventative approach to halt their progression and ideally avoid the need for invasive restorative intervention. It is recognised that ideally a wider range of stakeholders should have been involved in the development of the index, such as focus groups with patients and general dental practitioners, given its recommended role in primary dental care.

In this validation study, the Cervical Localisation Code has been used reproducibly by three independent examiners with agreement scores superior to other studies investigating similar indices in the literature. It has a place both in general dental practice, guiding practitioners in recognising and recording NCCLs, something sadly lacking currently, and providing the appropriate management of each clinical scenario, and further has a place in clinical studies investigating tooth wear, DH or GR. However, it is acknowledged that codes 2 and 3 can be difficult to distinguish. The next step is to utilise this index in a large-scale study to establish the distribution and frequency of each code in the general population to complement the current literature.

3. Meribel Study - An observational, cross-sectional epidemiological study to investigate GR, DH, tooth wear and the associated risk factors

3.1 Introduction

It is well documented across the literature that tooth wear, DH and GR are common. Within the UK however, there are limited large data sets which explore their prevalence. The ADHS is a good resource which aims to capture the condition of dental health of the adult population and how it is changing, which has been conducted approximately every 10 years since 1968 (O'Sullivan et al., 2011). However, this study collects limited data with regards to tooth wear, DH and GR. In the most recent ADHS (2009), a shortened index was used to record tooth wear focusing purely on anterior teeth, the periodontal indices did not include the measurement of GR and DH was not assessed at all (White et al., 2012). Furthermore, several of the associated risk factors were not investigated.

In a previous 2011 European study (Bartlett et al., 2013; West et al., 2013a), the highest levels of tooth wear in the 7 countries examined were seen in the UK where 54.4% of participants scored BEWE 2 or 3 on at least one tooth surface. However, this study only included young adults aged 18-35 years. Given the high levels of tooth wear discovered, it is the intention of the study presented in this chapter to investigate tooth wear prevalence further, including looking to see if tooth wear is affecting the older population as significantly as the younger population, and to gain a better understanding of associated risk factors.

As anticipated, in the 2011 European study DH was positively associated with tooth wear and both were also significantly associated with exposure of teeth to extrinsic and intrinsic acids, in particular sports drinks and fruit (Bartlett et al., 2013; West et al., 2013a). Several unexpected results also arose including DH positively correlating with snoring. The use of a powered toothbrush was significantly associated with tooth wear, although a similar correlation was not detected with DH. The strength of the data collected in the 2011 European study and the presence of several significant but unexpected correlations confirm the value of such large prevalence studies. It is clear, however, that further data relating to the risk factors and prevalence of DH, GR and tooth wear are still required to fully understand their relationship.

The design of this study is similar to that undertaken in 2011 but this time recruiting healthy participants from all age ranges rather than 18-35 years of age as the prevalence of both DH and tooth wear was higher in the 26-35 than the 18-25 age group in the 2011 study, and both may increase further with age as tooth wear is irreversible. The inclusion of older individuals aims to increase understanding of the extent of the conditions and improve awareness of the age groups most commonly affected. The clinical data collected has also been increased to record palatal sensitivity scores and utilises the newly developed index: the Cervical Localisation Code, with the aim of providing a more comprehensive picture of GR, DH and tooth wear.

3.2 Aim and Objectives

The aim of this study was to determine the prevalence of GR, DH, tooth wear and associated risk factors, in UK adults aged 18 and over in the general population.

Specific Objectives

In this study population:

1. To determine clinically, the prevalence of GR, DH and tooth wear and their distribution in the dental arch.
2. To determine the relationship between tooth wear, DH and GR as identified clinically.
3. To analyse the relationship between risk factors identified via the self-reported questionnaire and the prevalence of severe tooth wear.

3.3 Method

3.3.1 Overview of study design

This was an observational, cross-sectional epidemiological study in healthy adult participants who were enrolled onto the study after providing informed consent to participate and fulfilling the study inclusion and exclusion criteria. Each eligible participant then completed a questionnaire relating to tooth sensitivity, tooth wear and periodontal health before undergoing a standardised clinical examination with a trained and calibrated research dentist.

Ethical approval was gained from London-Surrey NHS Research Ethics Committee (REC Reference: 18/LO/0664; IRAS ID: 244298) and the study was carried out in accordance with good clinical practice guidance.

3.3.2 Training and calibration of examiners

The majority of data collection was completed by a single examiner (LG) aided by 3 further research dentists, a general dental practitioner and 2 specialists in periodontics, from the University of Bristol Clinical Trials Unit. Training resources were developed for use both within the UK and across Europe. This included the shooting of 4 instructional videos to describe how to score each condition and correctly complete the study paperwork (Appendix 5). Clinical assessments undertaken are described in section 3.3.7. The day of training was delivered by an expert in the field and at the end of training each research dentist completed a calibration exercise which involved scoring study models, photos of clinical cases and video footage of reactions used to score DH (Schiff et al., 1994).

3.3.3 Participant recruitment and stratification

Healthy participants were recruited in a number of ways. Volunteers who were registered on the Clinical Trials Unit database having previously expressed an interest in taking part in clinical research, were approached by clinical trials staff. Patients at a private general dental practice who were due to attend a regular appointment with their general dental practitioner were approached by the practice. Recruitment of participants from the University of Bristol and local National Health Service (NHS) trust was facilitated via faculty emails and advertisements in staff/student news bulletins. Finally, study posters were put up locally to attract members of the public. Emphasis was placed on recruiting both regular and irregular dental attenders and not those attending specialist practice.

Recruitment was guided by age and gender stratifications. Recruited participants were divided into the following age ranges: 18-27, 28-37, 38-47, 48-57, 58+ with approximately 70 males and 70 females recruited per age stratification.

3.3.4 Eligibility and consent

Each potential participant was supplied with a participant information sheet (Appendix 6) before informed consent (Appendix 7) was gained by a trained member of the research team. Eligibility to take part in the study was then confirmed by the study dentist according to the inclusion and exclusion criteria (Tables 3.1 and 3.2). Medical history was assessed verbally to confirm the health of the participant and participants who were eligible to take part were enrolled onto the study.

Table 3.1 Inclusion criteria.

Inclusion criteria for participants
1. Healthy participants of either gender who are able to attend an appointment with a research dentist.
2. Aged 18 or over.
3. Understand and are willing, able and likely to comply with all study procedures and restrictions.
4. Accept the form of the study and signs a declaration of informed consent.
5. Are in good health (see exclusion criteria below).
6. Have a minimum of 10 teeth not including implants or teeth with crowns or bridges.

Table 3.2 Exclusion criteria.

Exclusion criteria for participants
1. Persons incapable of responding to the questions.
2. An immediate employee of the sponsor or the research team conducting the study. Employees of the sponsor or research site not associated with the research team are eligible to participate.
3. Women known to be pregnant.
4. Persons currently using maxillary and/or mandibular orthodontic appliances.
5. Persons who have used analgesic (pain relieving) drugs or had used a topical analgesic in the preceding 24 hours.
6. Persons who required antibiotic cover (following infective endocarditis, using prosthetic cardiac valves).
7. Persons having pathology – haemophilia, using anti-coagulants (including plaque anti-aggregants).
8. Anyone who in the investigator's opinion is not suitable to take part in the study.

3.3.5 Study visit and data collection

Once enrolled on the study, the Case Report Form (Appendix 8) was completed by the research dentist which recorded data regarding the participants demographics, socioeconomic status, residential location and dental attendance within the previous 12-month period. The participant then completed the study questionnaire (Appendix 9) with assistance from a member of the study team if required. After completion of the questionnaire, the clinical examination was carried out by a designated research dentist and data entered in the clinical form (Appendix 10). All data remained anonymous and the participant was only identifiable by a screening ID number.

3.3.6 Questionnaire development

The questionnaire was developed based on that used in the previous European study (Bartlett et al., 2013; West et al., 2013a; Seong et al., 2018a). Questions investigated oral hygiene, diet and lifestyle habits as in the previous European study, however more were added focusing on the participant's perception of their oral health and any experienced sensitivity, utilising questions from the DHEQ (Boiko et al., 2010). Further and more detailed questions regarding diet and timing of acid consumptions were added following the findings of O'Toole et al. (2017). The finalised questionnaire (Appendix 9) had 33 questions and was piloted on a selected group of lay persons who manually self-completed the questionnaire with assistance from a member of the clinical trials team if required. The reported time taken to complete the questionnaire ranged between 10 and 20 minutes. The data was then transferred to the study statistician for approval.

3.3.7 Clinical assessments

Tooth wear, DH and periodontal health were scored for all eligible teeth present, both buccally and palatally/lingually in both arches, see Table 3.3 for eligibility criteria. Clinical examination was completed without magnification, teeth were dried and assessed under good lighting using a dental mirror, triple air syringe and periodontal probes, as described below.

Table 3.3 Tooth exclusions in clinical assessments.

Exclusions	Detail
For all conditions	Missing teeth Any teeth undergoing orthodontic treatment Wisdom teeth
For DH	Teeth with caries
	Teeth with restorations in the proximity of CEJ
	Teeth which had been endodontically treated
	Any tooth surface with crown or bridgework
For Tooth wear (BEWE/Cervical index)	Teeth with large restorations/restorations in the proximity of the CEJ, on the surface to be scored
	Teeth with gross caries
	Any tooth surface with crown or bridgework

General tooth wear (erosion, abrasion, attrition) was recorded using the BEWE index (Table 3.4) and specific detail of tooth wear in the cervical region was also captured as part of the Cervical

Localisation Code (Table 2.1). Teeth were dried with a triple air syringe or cotton wool and examined with a dental mirror, without the use of magnification.

Table 3.4 BEWE score (Bartlett et al., 2008).

Score	Description
0	No erosive wear
1	Initial loss of surface texture
2	Distinct defect, hard tissue loss on less than 50% surface area of clinical crown
3	Hard tissue loss greater or equal to 50% surface area of clinical crown

The Cervical Localisation Code (Table 2.1) was used as a measure of both tooth wear and GR in the cervical region.

For DH, teeth with clinically detectable caries were excluded, as were those which had a clear access cavity from previous endodontic treatment. These exclusion criteria were assessed purely by visual examination without the use of further diagnostic tests, such as radiographs. DH was assessed on both the buccal and palatal/lingual aspects of all eligible teeth using an evaporative air stimulus from a triple air syringe set to 60psi and an operating temperature of 19°C. Air was directed to the cervical region of the tooth from a distance of approximately 1cm for 1 second, ensuring that the adjacent teeth were covered. The participant's response to the stimulus was scored from the clinician's perspective, using the Schiff Sensitivity score (Table 3.5) and the participant was then asked to confirm if they found the stimulus painful which was simply coded as a binary Yes/No answer (0= no, 1= yes).

Table 3.5 Schiff sensitivity score (Schiff et al., 1994).

Score	Criteria
0	Subject does not respond to stimulus
1	Subject responds to stimulus, but does not request discontinuation of stimulus
2	Subject responds to stimulus and requests discontinuation or moves from stimulus
3	Subject responds to stimulus, considers stimulus to be painful and requests discontinuation of the stimulus.

Clinical data about the periodontium was recorded using the standardised UNC 15mm periodontal probe. GR was measured on both buccal and palatal/lingual aspects of all scorable teeth by measuring the distance from the CEJ to the gingival margin. The largest recession defect was recorded for both the buccal and palatal/lingual surface of the tooth, recording the value to the nearest millimetre. Pocket probing depth was measured from the gingival margin to the apical base of the pocket, measuring to the nearest millimetre. This was recorded at the site of the recession defect, or if no recession was recorded at the mid-buccal or mid-palatal aspect of the tooth.

Gingival phenotype was recorded as thick or thin (Thick = 1, Thin = 2) on the buccal and palatal/lingual surfaces of all eligible teeth by assessing if the periodontal probe was detectable through the sulcal tissues (Jepsen et al., 2018). If the probe could be seen under the gingival margin the gingival phenotype was classified as thin, if the probe could not be seen then it was classified as thick. Gingival bleeding was recorded as present or absent on the buccal and palatal/lingual surfaces (0= no bleeding, 1= bleeding). Bleeding was assessed at three points per surface of the tooth- distal, mid-buccal or mid-palatal and mesial and bleeding at any one of these sites for the surface of the tooth, scored positively.

The Basic Periodontal Examination (BPE) was then completed using the World Health Organisation probe according to guidance set out by the British Society of Periodontology (BSP, 2019). Finally, the periodontal status was scored from the perspective of the clinician as healthy, gingivitis, periodontitis or treated periodontitis. The diagnosis of current or treated periodontitis was made using a combination of the periodontal pocket depths recorded, the clinical presence of bleeding on probing and the presence or absence of interproximal GR.

3.3.8 Statistical analysis

Statistical analysis was performed by the study statistician (RN). The study sample size was calculated based on the data obtained in the previous 2011 European study in which the overall proportion of participants with DH at one or more sites was 42%. For a risk factor with prevalence of approximately 25% (such as use of a powered toothbrush, as determined in that study), a sample size of 700 participants will detect an odds ratio of 1.63, with a power of 80% using a test at the conventional two-sided alpha level. Recruitment was guided by age and gender stratifications. Recruited participants were divided into the following age ranges: 18-27, 28-37, 38-47, 48-57, 58+. The aim was to recruit approximately 70 males and 70 females per age stratification.

For the analysis of study data, clinical and questionnaire data were keyed into Microsoft Excel spreadsheets and then transferred to IBM SPSS Statistics version 24 for analysis. Preliminary, descriptive level analyses were performed for the questionnaire variables. For each clinical scoring variable, in addition to overall prevalence per participant, frequency distributions by tooth site were produced and summarised with bar charts showing the variation between different areas of the mouth.

The main analyses were at patient level, the relationship between the clinical conditions was examined by crosstabulations and Spearman's rank correlation. Causal relationships between questionnaire variables and severe tooth wear were examined by Chi-square or Mann-Whitney U/mn statistic. All analyses were characterised by suitable summary statistics with effect size measures (linear regression coefficient or odds ratio for logistic regression) with confidence intervals, as well as p-values. Severe (BEWE 3), rather than clinically relevant (BEWE 2 or 3), tooth wear was selected following a review of the data on the advice of the study statistician as in this patient population clinically relevant tooth wear was present in the majority of participants. It was considered that looking for associations between risk factors and severe tooth wear might be more informative.

3.4 Results

Data collection took place between January 2018 and February 2020. A total of 791 participants were recruited and assessed by 4 different examiners, of which the author of this work undertook more than two thirds of the assessments (540 participants).

3.4.1 Characteristics of the study population

3.4.1.1 General characteristics

Recruitment was stratified by age and gender, with at least 70 females and males recruited per age group. Participant ages ranged from 18 to 86 years. Younger females predominated and in total 51.5% of participants were female and 48.5% were male (Table 3.6).

Table 3.6 Number of participants recruited as guided by gender and age group.

	Age 18-27	Age 28-37	Age 38-47	Age 48-57	Age 58 +	Total
Male	97	76	70	70	71	**384**
Female	111	82	73	71	70	**407**
Total	**208**	**158**	**143**	**141**	**141**	**791**

The majority of participants described their residence as urban (76.6%) and were employed in non-manual work (Figure 3.1). The number of dental visits during the preceding 12 months ranged from 0 to 12 with most participants visiting a dentist once in the last 12 months, although 28.6% had not visited the dentist at all in this time (Table 3.7). Over a third of participants (35.6%) had a history of orthodontic treatment.

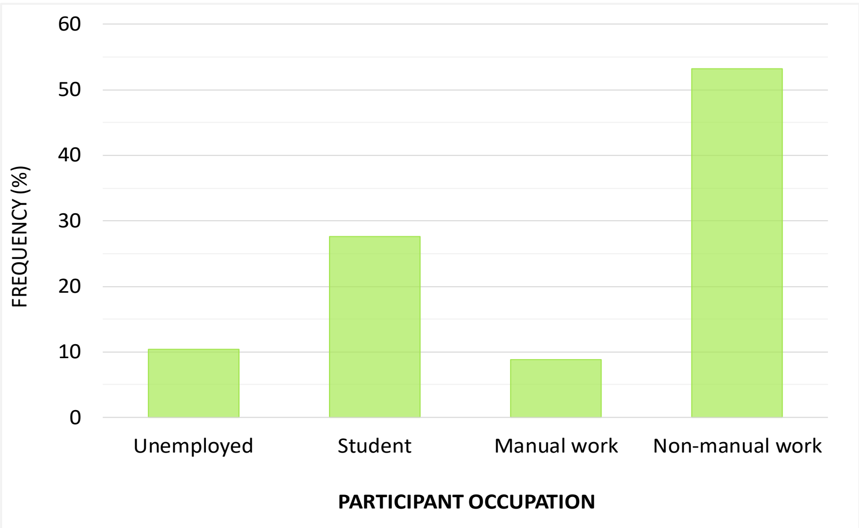

Figure 3.1 Employment status of the study population.

Table 3.7 Number of dental visits in last 12 months.

Number of dental visits in last 12 months	Frequency	Percent
0	226	28.6
1	250	31.6
2	181	22.9
3	69	8.7
4 or more	65	8.2

The majority of participants (79.6%) brushed their teeth twice a day, 8.6% brushed more than this while 11.8% brushed once daily or less. Powered toothbrushes were used more frequently (55.3%) than manual ones with most participants brushing for 2 minutes or less (58.9%) and 36.6% exceeding 2 minutes. The majority brushed using their right hand (87.9%), 7.8% used their left hand and 4.3% swapped between hands. A desensitising toothpaste was used by almost a third of the study population (32.4%).

3.4.1.2 Dietary habits

Figure 3.2 shows the daily frequency of eating and drinking as reported by participants. The most commonly reported daily dietary intakes were between 4 and 6 times daily (54.3%), with only 13.2% reporting 3 or less intakes and 12.5% consuming 10 or more dietary intakes a day.

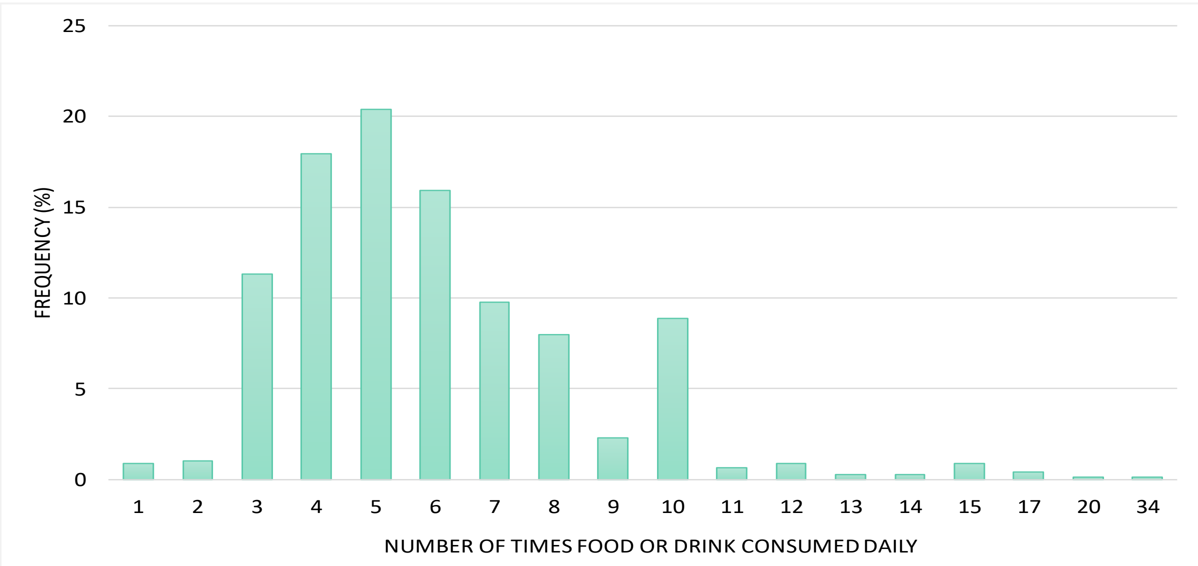

Figure 3.2 Frequency of daily food and drink intake by participants.
Food and drink intakes were defined as consumption of any snacks, main meals and drinks throughout the day, excluding water.

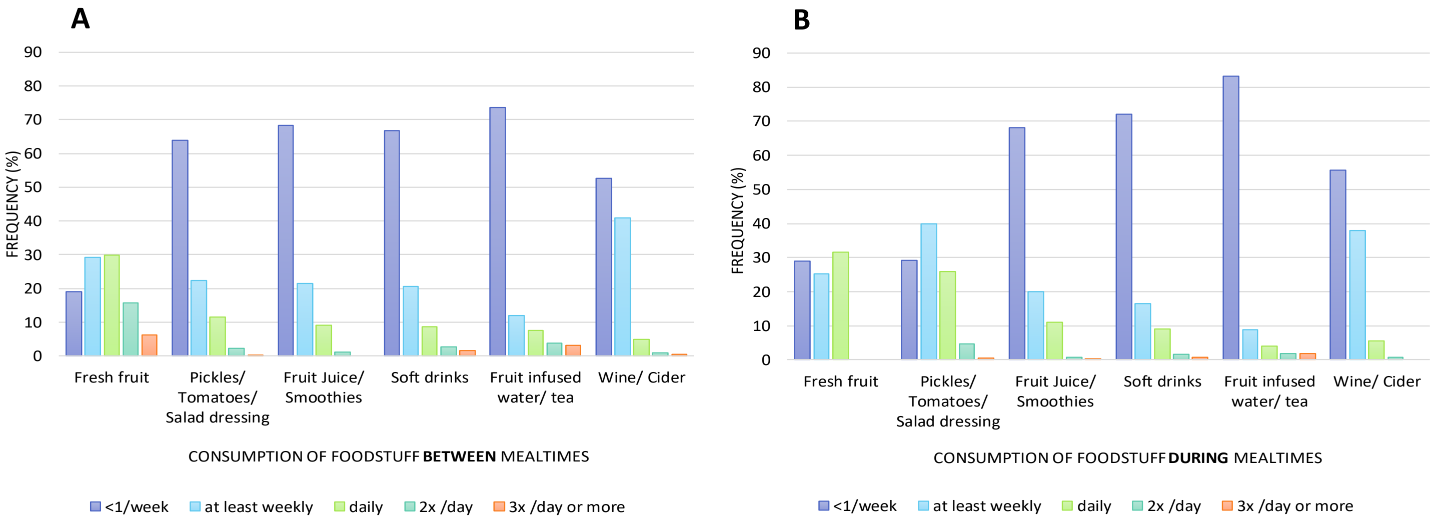

Figure 3.3 Frequency of consumption of food and drink between meals (A) and during meals (B) as reported by participants.

Figure 3.3 shows the frequency of consumption of certain acidic foods and drinks in relation to mealtimes. For most dietary acids there was only small variation in frequency of their consumption between or during mealtimes. Fresh fruit, however, was more commonly eaten as a snack between meals and tomatoes, pickles and salad dressings were more commonly consumed during a meal. The frequency of consumption of a single acidic food source ≥2 times a day was generally low.

Regarding the consumption of acidic foods, only 5% held or swished acidic drinks in their mouth prior to swallowing, 13% regularly used a straw for acidic drinks and 14% normally had citrus fruit or fruit juice with their breakfast.

3.4.1.3 Lifestyle factors

Oral health related risk factors are detailed in Figure 3.4. The most commonly reported on at least an occasional basis were alcohol consumption (over 85%), feeling stressed (65.9%), snoring (60.9%) and chewing gum (60.7%). Frequency of exercise was also recorded with almost a quarter of participants exercising less than once a week (23.9%), the majority exercising once or twice a week (31.1%) and 17% exercising 5 or more times a week. The mean Body Mass Index (BMI) of participants was 24.9, representing the upper limit of a 'healthy' score (18.5-24.9).

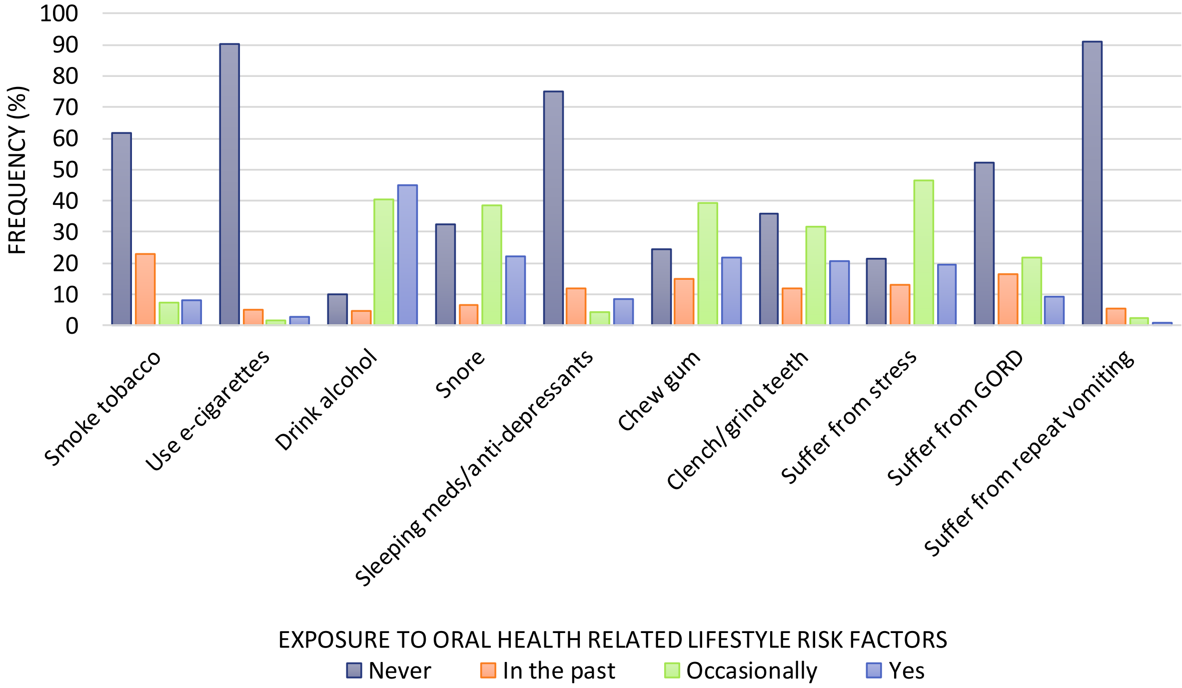

Figure 3.4 Frequency of oral health related lifestyle risk factors.
Participants selected out whether they currently were exposed to these risk factors, had previously been or never at all.

3.4.2 Clinical characteristics

3.4.2.1 Prevalence of clinical conditions in the participant population

The periodontal status of the study population is shown in Figure 3.5. The majority of patients had evidence of periodontal disease, most commonly gingivitis, while 28% were deemed to be periodontally healthy.

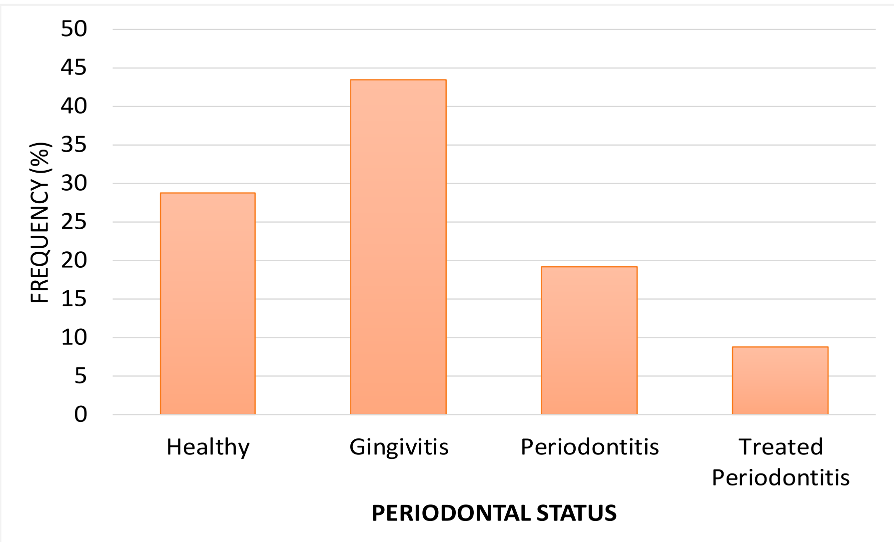

Figure 3.5 Periodontal status of the study population.

The frequency of the scored Cervical Localisation Codes are shown in Figure 3.6. Codes 0 and 2 were the most common both buccally and palatal/lingually. Buccal sites were more likely to score a code 2 or 3 (indicating GR with or without distinct coronal tooth wear, respectively) whereas a code 1 (coronal tooth wear without associated GR) was most commonly scored for palatal/lingual surfaces.

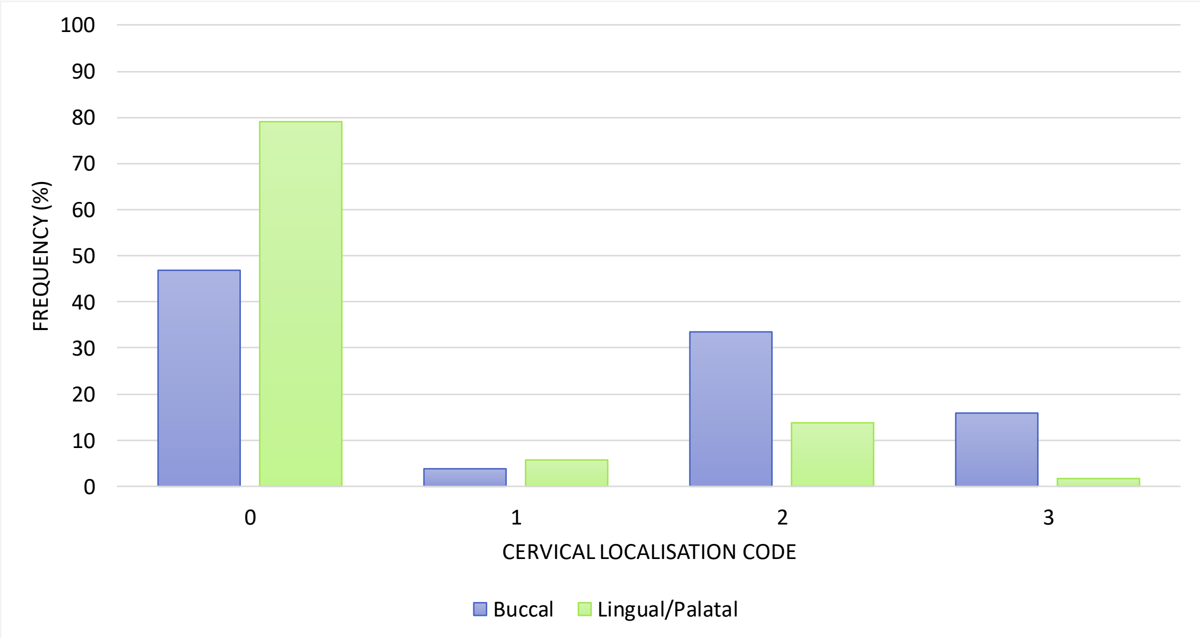

Figure 3.6 Frequency of Cervical Localisation Code scores.
The frequency is expressed as a percentage of the total number of surfaces scored

Figure 3.7 shows the maximum BEWE scores recorded on buccal and palatal/lingual surfaces per mouth. Nearly all participants had some tooth wear recorded on at least one tooth per mouth. A maximum BEWE score of 2 or 3, representing clinically relevant tooth wear, was seen in three quarters of participants buccally and just under half the participants for lingual/palatal sites (47.6%) which equated to 78% of participants with a maximum BEWE 2 or 3 on any tooth surface. Severe tooth wear (BEWE score of 3) was more prevalent on palatal/lingual surfaces (11.8%) than buccal (8%).

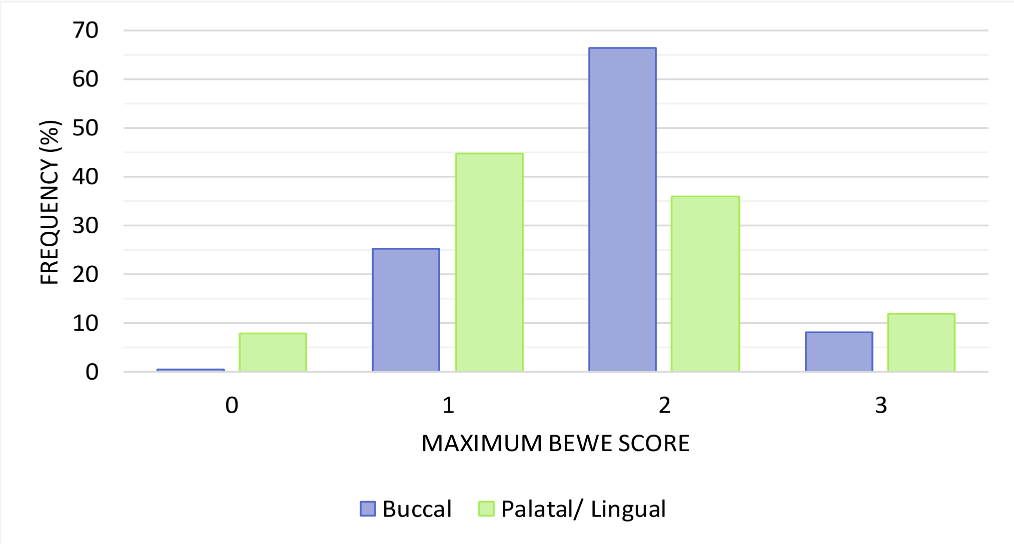

Figure 3.7 Maximum BEWE score on buccal, palatal/ lingual surfaces per mouth.
The frequency is expressed as a percentage of participants with each maximum score.

Maximum GR scores ranged from 0-9mm, as shown in Figure 3.8, with GR more severe on buccal surfaces than palatal/lingual. Clinically relevant GR ≥4mm was detected in 31% of participants buccally and 10% palatal/lingually. On the palatal/lingual surfaces, a score of 0mm (no GR) was the most frequent score (48%). Overall, GR ≥1mm was detected on at least one tooth surface for 94.7% of participants, with 33.6% displaying GR ≥4mm

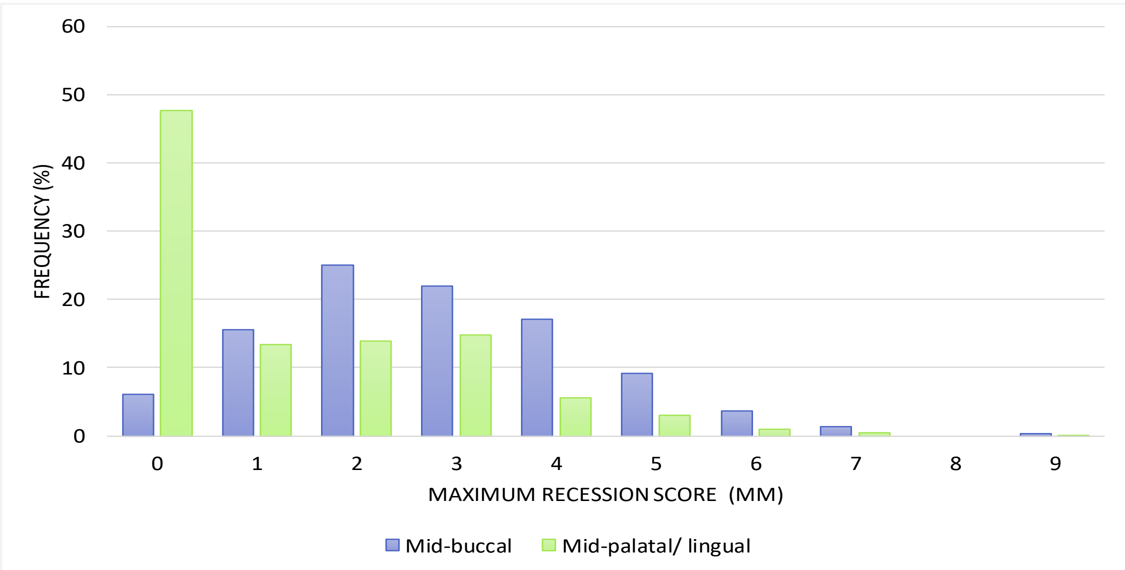

Figure 3.8 Maximum GR scores recorded buccal and palatal/ lingual per mouth.
The frequency is expressed as a percentage of participants with each maximum score.

Clinician scored and participant reported DH scores in response to a cold-air stimulus are shown in Figure 3.9. For both scoring methods, sensitivity was more commonly observed buccally than palatal/ lingually with 58% of participants reporting DH in response to an air-blast on at least one buccal site, whereas only 34.4% were affected palatal/lingually. This translated to 60.4% of participants having at least one site of DH in the mouth. Clinically relevant DH scores, where the participant requested the clinician stopped the stimulus and/or reported pain (Schiff 2 or 3) were seen in 36.2% of participants buccally and 13.4% palatal/lingually, equating to a total of 37.9% of participants scoring Schiff 2 or 3 on at least one tooth surface. DH was also captured in the questionnaire, with 50% of participants reporting experience of DH symptoms.

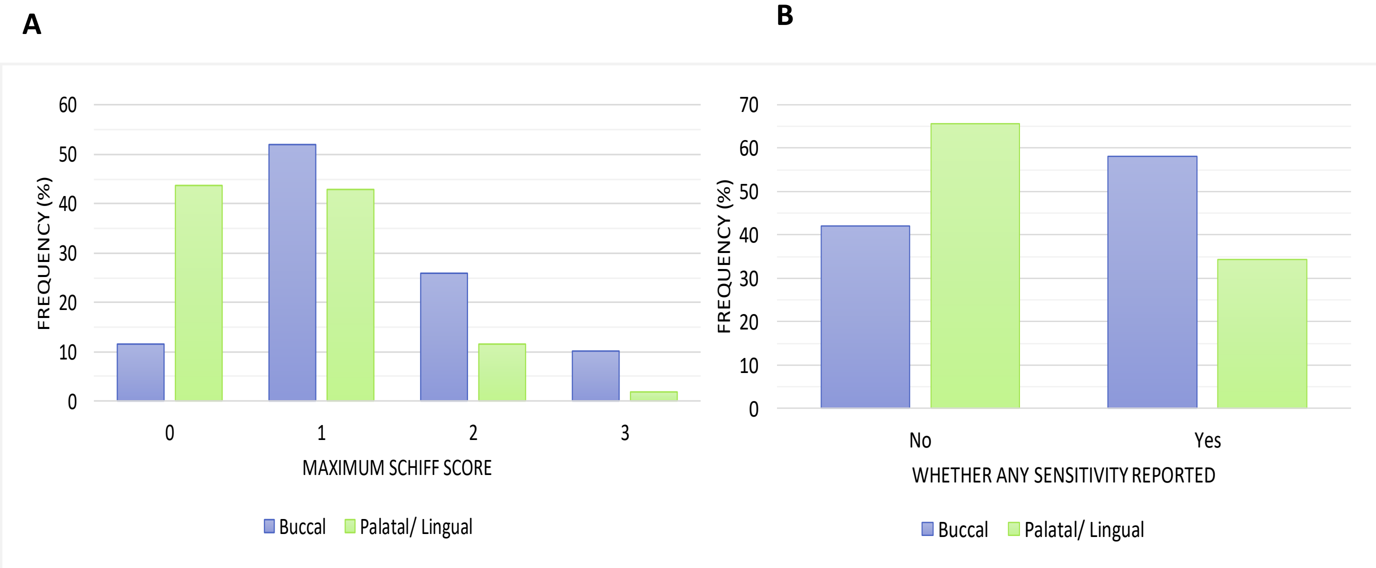

Figure 3.9 Maximum DH scores for buccal and palatal/ lingual surfaces per mouth.
Reported as Schiff scores (A) from the clinician's perspective and a Yes/No answer (B) as reported by the participant in response to the question 'Was that painful?'. The frequency is expressed as a percentage of participants with each maximum score ('Yes' corresponds to a maximum).

3.4.2.2 Distribution of clinical conditions across the dental arches

The distribution of clinical scores for all conditions under study, both buccally and palatal/lingually, across the dental arch are shown in Figure 3.10

Buccal BEWE scores of 2 or 3, representing distinct tooth wear defects were observed most frequently for first premolars and first molars in the upper arch, and the first and second premolars in the lower arch. Generally, the buccal surfaces were more affected by distinct tooth wear than the palatal/lingual surfaces, however the highest frequency of BEWE 3 scores were seen for the palatal surfaces of the upper anterior teeth. The surfaces most frequently unaffected by tooth wear (BEWE score 0) were the palatal surfaces of posterior teeth.

The Cervical Localisation Code data indicated that for palatal/lingual surfaces the vast majority of teeth had no clinically relevant tooth wear cervically or GR (Code 0). Distinct coronal tooth wear at the gingival margin without accompanying GR (Code 1) was the least common presentation buccally but was the second most frequent score, after 0, on the palatal surfaces of the upper anterior teeth. The general pattern of buccal cervical sites scoring code 3 (GR and coronal tooth wear) was similar to that of BEWE scores 2 or 3, although the frequencies were slightly lower.

The frequency of clinician assessed Schiff scores showed little variation across the dental arch with minimal differences in the distribution of scores across palatal surfaces and a similar trend seen for the buccal aspects, although the distribution of scores on the buccal surfaces displayed somewhat less uniformity. Clinically relevant DH, as measured by Schiff score 2 or 3, was most frequently observed on buccal surfaces, although these scores were still relatively uncommon. The tooth surfaces where participants reported sensitivity followed a similar general pattern to Schiff scores 2 and 3; but the frequency of positive responses was higher when reported by the participant than the clinician. The most common surfaces to elicit sensitivity palatal/lingually were the lower anteriors. A similar distribution of sensitive sites was seen buccally on the left and right sides although the UL4 had a higher number of positive responses than the contralateral side.

Buccally the frequency of GR (≥1mm) tended to increase from anterior to posterior. This was more pronounced for the buccal aspects of upper teeth, whereas for the lower dentition the first and second premolars experienced more GR than the molars. The sites most frequently exhibiting buccal GR ≥4mm in the maxillary dentition were the first molars, first premolars and canines and in the mandibular dentition the first and second premolars. Fewer palatal/lingual sites of GR were observed, with GR defects ≥1mm most frequently recorded for the lingual aspects of lower incisors and defects ≥4mm most commonly scored for upper first molars. As expected, the pattern of distribution for GR correlates closely with that of the Cervical Localisation Code.

Comparing the graphs for general trends across the conditions, it is noticeable that the buccal of the upper first premolars, upper first molars, lower first premolars, lower second premolars and lower first molars are sites where BEWE scores tend to be the highest, Cervical Localisation Code scores of 3 are most frequent and where the most GR tends to be experienced. The palatal of the upper incisors are the sites most frequently affected by severe tooth wear (BEWE 3) and are also the major site where coronal tooth wear occurs at the cervical margin unaccompanied by GR (Cervical Localisation Code 1) but despite this these sites appear to experience limited DH.

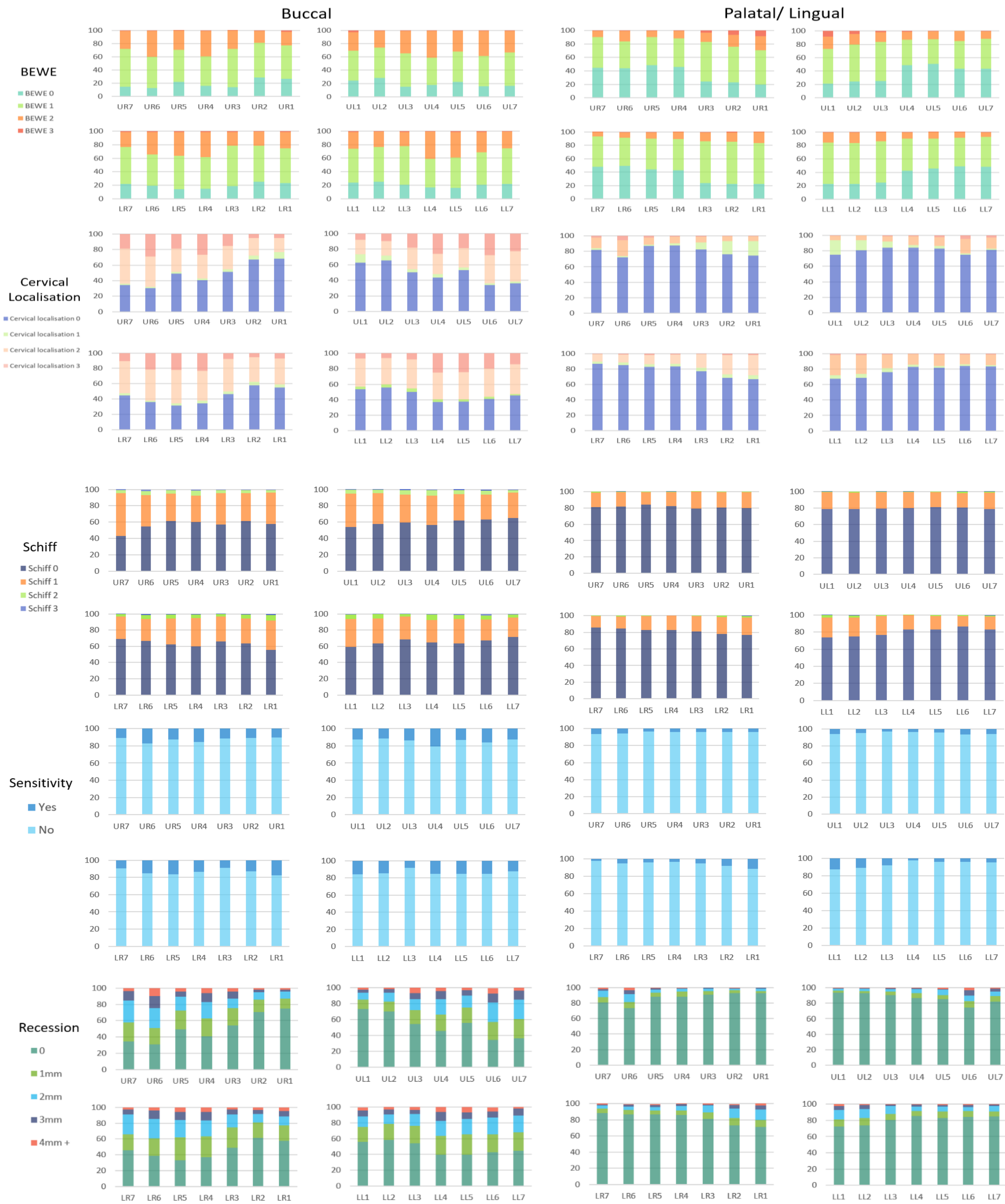

Figure 3.10 The distribution of clinical scores across both buccal and palatal/lingual surfaces of teeth in both dental arches. The y axis represents the percentage of participants with each score once missing values had been removed from the data set and the x axis shows the tooth in question. The graphs for each score are laid out as a clinical mouth map.

3.4.4 Associations between clinical conditions

Associations between the clinical conditions were determined and the strongest associations for the conditions of interest are shown in Table 3.8. The strongest positive correlation was detected for the sensitivity scores reported by the participant (any sensitivity) and those scored by the clinician (Schiff), as expected.

The maximum BEWE score was significantly positively associated with maximum GR and maximum probing depth. There was a less statistically significant correlation between the maximum BEWE severity and elicited sensitivity.

Table 3.8 Strong positive correlations detected for the oral conditions of interest.

		Spearman's Rank correlation (Rho)	p value
Any sensitivity	Max Schiff score	0.625	<0.001
Maximum BEWE severity	Maximum gingival recession	0.432	<0.001
Maximum gingival recession	Maximum Probing Depth	0.401	<0.001
Maximum BEWE severity	Maximum Probing Depth	0.259	<0.001
Maximum BEWE severity	Any sensitivity	0.193	<0.001

There was no significant association between maximum GR and any maximum measure of DH and the maximum Schiff score did not have any significant correlations with other clinical conditions. The correlations for periodontal conditions are not included as they are beyond the scope of this thesis.

3.4.5 Association between severe tooth wear and possible risk factors

The association between severe tooth wear and possible risk factors, identified in the questionnaire/ case report form, was determined using the criteria of a maximum BEWE severity score 3. All variables and their associations are shown in Table 3.9. Values shaded green show statistical significance, whereas variables approaching significance are shaded orange.

Table 3.9 Association of maximum severity BEWE 3 with investigated variables.

Variable	Test	Test statistic	95% CI	p value
Age	Pearson Chi-square	Chi^2 = 37.355		<0.001
	Linear-by linear association (Mantel-Haenszel test)	Chi^2= 34.724		<0.001
	Generalised Mann-Whitney measure	U/mn = 0.674	0.619-0.724	<0.001
Gender	Pearson Chi-square	Chi^2 = 3.795		0.051
Oral variables				
Frequency of Brushing	Pearson Chi-square	Chi^2 = 3.481		0.175
	Linear-by linear association	Chi^2= 3.445		0.063
Previous orthodontic treatment	Pearson Chi-square	Chi^2= 2.582		0.108
Dry mouth	Pearson Chi-square	Chi^2= 1.326		0.249
Right vs left-handed toothbrushing	Pearson Chi-square	Chi^2= 2.234		0.327
Brushing time (2 min or less vs more than 2min)	Pearson Chi-square	Chi^2= 0.814		0.367
Hardness of toothbrush bristle (soft, medium, hard)	Pearson Chi-square	Chi^2= 0.550		0.760
	Linear-by linear association	Chi^2= 0.527		0.468
Toothbrushing time in relation to breakfast	Pearson Chi-square	Chi^2= 6.111		0.527
Type of toothbrush (powered vs manual)	Pearson Chi-square	Chi^2= 0.256		0.613
Dietary Variables				
Weekly consumption of fruit juice at meals	Generalised Mann-Whitney measure	U/mn = 0.448	0.391-0.506	0.08
Time to consume fruit (<5, 5-10, >10 min)	Generalised Mann-Whitney measure	U/mn = 0.539	0.481-0.595	0.182
Weekly consumption: fruit between meals	Generalised Mann-Whitney measure	U/mn = 0.462	0.405-0.520	0.201
Weekly consumption of fruit flavoured water at meals	Generalised Mann-Whitney measure	U/mn = 0.472	0.415-0.530	0.343
Weekly consumption of fruit juice between meals	Generalised Mann-Whitney measure	U/mn = 0.474	0.416-0.533	0.394
Consumption of fruit juice at breakfast (Y/N)	Pearson Chi-square	Chi^2= 0.665		0.415
Time to consume fruit juice (<5, 5-10, >10 min)	Generalised Mann-Whitney measure	U/mn = 0.472	0.404-0.541	0.432
Weekly consumption of wine or cider at meals	Generalised Mann-Whitney measure	U/mn = 0.523	0.464-0.581	0.44
Weekly consumption: acid foods at meals	Generalised Mann-Whitney measure	U/mn = 0.485	0.428-0.542	0.603
Weekly consumption of wine or cider between meals	Generalised Mann-Whitney measure	U/mn = 0.485	0.427-0.543	0.623
Time to consume fruit flavoured water (<5, 5-10, >10 min)	Generalised Mann-Whitney measure	U/mn = 0.521	0.437-0.604	0.627
Weekly consumption: acid foods between meals	Generalised Mann-Whitney measure	U/mn = 0.490	0.433-0.548	0.745

Swish drinks around mouth (Y/N)	Pearson Chi-square	Chi^2= 0.104		0.748
Weekly consumption of fruit flavoured water between meals	Generalised Mann-Whitney measure	U/mn = 0.507	0.449-0.565	0.824
Time to consume soft drink (<5, 5-10, >10 min)	Generalised Mann-Whitney measure	U/mn = 0.507	0.431-0.583	0.862
Weekly consumption of soft drinks between meals	Generalised Mann-Whitney measure	U/mn = 0.498	0.440-0.556	0.938
Weekly consumption: fruit at meals	Generalised Mann-Whitney measure	U/mn = 0.499	0.442-0.556	0.966
Weekly consumption of soft drinks at meals	Generalised Mann-Whitney measure	U/mn = 0.501	0.442-0.559	0.967
Frequency of eating or drinking episodes	Generalised Mann-Whitney measure	U/mn = 0.503	0.445-0.561	0.992
Lifestyle variables				
Use of straw (Y/N)	Pearson Chi-square	Chi^2= 7.175		0.007
Chew gum (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2 = 5.334		0.149
	Linear-by linear association	Chi^2 = 5.303		0.021
Exercise frequency (< weekly, 1-2 weekly, 3-4 weekly, 5+ weekly)	Pearson Chi-square	Chi^2 = 7.391		0.060
	Linear-by linear association	Chi^2 = 1.873		0.171
Take medicines for sleeping/depression (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2 = 6.910		0.075
	Linear-by linear association	Chi^2 = 0.556		0.456
Drink Alcohol (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2= 3.488		0.322
	Linear-by linear association	Chi^2= 2.880		0.090
Snore (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2= 5.625		0.131
	Linear-by linear association	Chi^2= 0.600		0.439
Use e-cigarettes (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2= 5.356		0.148
	Linear-by linear association	Chi^2= 0.496		0.481
Clench or grind teeth (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2 = 5.216		0.157
	Linear-by linear association	Chi^2 = 0.648		0.421
Suffer from stress (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2 = 3.145		0.370
	Linear-by linear association	Chi^2 = 1.675		0.196
Suffer from repeat vomiting (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2 = 0.469		0.926
	Linear-by linear association	Chi^2 = 0.303		0.582
Smoke tobacco (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2= 1.751		0.626
	Linear-by linear association	Chi^2= 0.152		0.696
Suffer from GORD (Yes/occasionally/in the past/never)	Pearson Chi-square	Chi^2 = 1.213		0.750
	Linear-by linear association	Chi^2 = 0.065		0.799

The most highly significant association for severe tooth wear was age, which was strongly positively associated. The only other variables which show statistical significance ($p \leq 0.05$) are the use of chewing gum and use of a straw, both of which appear to have a protective effect as severe tooth wear was less frequently reported in participants with either of these habits. Gender nearly approached significance ($p=0.051$) with males more frequently affected by severe tooth wear than females.

Given the dominant association between age and severity of tooth wear in our data set, further logistic regression modelling was completed for the strong associations to consider the confounding impact of age (Table 3.10). For both variables, the strength of the association decreased below statistical significance once age had been accounted for.

Table 3.10 Strong associating factors with age accounted for as confounder.

Variable	**Prior to accounting for age**		**After accounting for age**	
	Odds ratio (95% CI)	**p-value**	**Odds ratio (95% CI)**	**p-value**
Use of straw (Y/N)	0.330 (0.141-0.772)	0.011	0.488 (0.202-1.180)	0.11
Chew gum	0.513 (0.279-0.944)	0.032	0.835 (0.441-1.580)	0.58

Other variables which approached significance included the frequency of toothbrushing, which unexpectedly suggested that tooth wear was related to less frequent brushing. Frequency of exercise was also close to being significantly associated, with the frequency of severe tooth wear increasing with the number of times exercise was performed weekly, with the exception that the highest levels of wear was scored for those exercising less than weekly.

There were no statistically significant associations between the timing of consumption of different dietary acids and severe tooth wear.

3.5 Discussion

This study investigated the prevalence of GR, DH, tooth wear and associated risk factors in an adult population, forming the UK data for these clinical conditions as part of a larger European epidemiology study. The aim was to recruit approximately 700 participants, with at least 70 males and 70 females in each designated age group. Data was analysed to establish the prevalence of the clinical conditions and relationships between them. Specific statistical consideration was given to relationships between severe tooth wear (BEWE 3) and associated risk factors.

3.5.1 Participant characteristics

This study recruited 791 adults from across the South West of the UK and enrolled participants from all walks of life. The sample size is comparable to the number of participants recruited for a dental examination across a similar region during the most recent ADHS in 2009 (663) and to a more recent epidemiological study examining 814 patients in NHS general dental practices in the South West (Midwood et al., 2019; O'Sullivan et al., 2011), highlighting the impact of the results presented in this thesis.

Recruitment was stratified according to age to ensure adequate data from all age groups was collected, and also gender. The resulting gender-split recorded in this study (48.5% male, 51.5% female) was very similar to that reported for the whole UK population in 2018, 49.4% male and 50.6% female (Office for National Statistics, 2019a). Over half the study participants were employed in non-manual work with a further 28% still in higher education, which could suggest a generally well-educated study population, although data about the level to which participants had been educated was not collected. Approximately 10% of the study population identified themselves as unemployed which is higher than the 3.4% recorded unemployment rate for the UK in 2019 (Office for National Statistics, 2019b). The international definition of unemployment defines unemployed people as being without a job, actively seeking work in the past four weeks and available/waiting to start work in the next two weeks. However, it was clear when analysing the data and reviewing participant ages that the majority of those who identified themselves as unemployed were actually retired and ticked this box as it was the closest to their current status, highlighting that the option of retirement should have been given.

Dental attendance closely mirrored the findings of the ADHS 2009, with the number of participants who had visited the dentist at least once within the last 12 months reported as 72% compared to 73% for the ADHS (Fuller et al., 2011). Despite the fact that nearly a third of participants had not visited the dentist/hygienist recently, the periodontal health of the study population was generally good with only just over a quarter of the population showing signs of active or historic periodontitis, which is lower than the 45% reported in the last ADHS 2009 (Steele and O'Sullivan, 2011). This low level of periodontal disease is comparable to a recent study of regular dental attenders in the South West (25%) (Midwood et al., 2019) and might be explained by the good oral hygiene regime reported by the majority of participants.

Most participants (88.2%) brushed the recommended frequency of twice or more daily (Public Health England, 2017; European Federation of Periodontology, 2020). This is a higher proportion than was reported in the most recent ADHS 2009 (75% total population, 73% South West) (Chadwick et al., 2011) which could reflect improvements in oral hygiene practices in the UK over the last decade. With each of the most recent ADHS, the number of individuals reporting they brushed twice daily or more has steadily increased from 67% in 1988 and 74% in 1998 to 75% in 2009 (Hill et al., 2013), although the rise to 88.2% since 2009 is larger than seen previously. In a more recent study looking at patients in NHS general practice in the South West, 82% of subjects reported brushing twice daily or more which is closer, but still below, the findings of the present study, even though the participants were all regular attenders at dental practice (Midwood et al., 2019). In addition, over a third of participants in the present study reported brushing for more than 2 minutes at a time, suggesting they were motivated with regards to oral hygiene practice. 2 minutes has been recommended as sufficient brushing time for periodontally low risk patients, but it is accepted that high risk patients require significantly longer than this to achieve optimal oral hygiene (European Federation of Periodontology, 2014). In the current study, 87.9% brushed with their right-hand, correlating closely with the results of a recent study looking at the hand preference of 501,730 UK participants which reported 89% right hand dominance (de Kovel et al., 2019).

Perhaps the general high levels of oral hygiene in the current study can be explained in part by the recruitment avenues utilised, which included study flyers in newsletters routinely sent to staff in both the local University and NHS trusts. The resulting population may have had a higher education level or better general health awareness than those recruited by mailshot of addresses selected at random in the ADHS or via attendance at the NHS practices examined by Midwood et al. (2019), even though nearly 30% of participants had not visited a dentist in the past year. Response bias could also have played a role, with the participants falsely reporting a superior oral hygiene regime in order to appear more responsible.

The finding that more than half of the study participants reported using a powered toothbrush also suggests that the population were motivated to achieve optimum oral health. This proportion is similar to the findings of Midwood (2018) who showed 54% of participants used a powered toothbrush in a population with similarly low levels of periodontal disease and good oral hygiene. By contrast, reported use of a powered toothbrush was much lower in both the most recent ADHS (26%) (Chadwick et al., 2011) and the previous European study (23%) (Bartlett et al., 2013). Perhaps this could be explained by an increased availability of powered toothbrushes over the last decade (Statista Research Department, 2019) and increasing evidence of their superiority to manual brushes, in certain situations (Yaacob et al., 2014), which may have resulted in more dentists recommending them. The higher proportion using a powered toothbrush is unlikely to reflect the socioeconomic status of the current population as this is similar to the previous ADHS with 53% in non-manual work in the current study and 54% in managerial or professional roles in the latter (Fuller et al., 2011).

The frequency that participants in this study engaged in exercise varied, however the majority exercised once or twice a week and 17% reported exercising 5 or more times a week, which again is suggestive of a health-conscious population. However inactivity levels were comparable with data for the general population, with 23.9% exercising less than once a week in the current study and an average of 27% of adults reporting less than 30 minutes of moderate or vigorous physical exercise per week in the general population (NHS Digital, 2019a). The current government recommendation is that adults should aim to be active daily and that weekly activity should add up to at least 150 minutes of moderate intensity activity or 75 minutes of vigorous intensity (Department of Health and Social Care, 2019). As the current study did not measure exercise in such detail, it is difficult to assess how many participants achieved this recommended level. Despite this, the average BMI of participants was within the optimal healthy range and below the UK average of 27.5 recorded for 2018 (NHS digital, 2019a).

Taken together, the data suggests that the study participants were a relatively well-educated, health-conscious population with good oral hygiene and a low experience of periodontal disease despite nearly 30% not having not visited the dentist within the last year.

3.5.2 Dietary and lifestyle habits

In order to establish the number of times a day teeth were exposed to dietary challenges, the frequency of eating and drinking episodes were recorded. Participants most frequently recorded 4-6 intakes daily, with a maximum of 34 daily intakes reported by an individual. Although this provides some insight into the frequency of dietary attacks on the dentition, recording the frequency and timing of acidic foods and drinks in particular is more pertinent when considering the aetiology of tooth wear.

Of all the acidic foods and drinks investigated in this study, fresh fruit was the most frequently consumed either with or between meals, followed by acidic foods during meals. Fruit juice and smoothies were consumed infrequently with only around 10% of participants reporting their regular consumption at or between mealtimes and only 14% usually consuming citrus fruit or fruit juice with their breakfast. While it is not possible to determine if participants who ate fruit at meals also ate it between meals or if a participant’s diet was rich in vegetables, the finding that many participants didn’t eat fruit regularly could suggest that they are not reaching the intake levels recommended by the World Health Organisation in consuming 400g (approximately 5 pieces) of fruit and vegetables a day (WHO, 2005). This finding is at odds with the indication that participants were a health conscious group, but is in line with general data for England which found that only 29% of adults get their recommended 5 a day (NHS Digital, 2019b).

In contrast to the present study, in a large European epidemiological study including the UK and six other countries, approximately a third of participants reported that they consumed fruit (35.6%) and fruit juice (31%) 'often' (Bartlett et al., 2013). The lack of quantification and differing measurables for recording the frequency of intake make for difficult comparison between this and the present study and, as mentioned above, there may have been those in the present study who consumed fruit frequently both at and between meals which has not been captured in the data. However, taken as a whole, it appears that the fruit and fruit juice intake in this current population was less frequent than in the European population (Bartlett et al., 2013) which might be explained by the tendency of the other countries to have more fruit and vegetables as part of a Mediterranean diet (D'Alessandro et al., 2018).

O'Toole et al. (2017) investigated dietary intake using the same variables as the present study, facilitating easier comparison. They reported a much higher fruit intake for the study population of 600 adults with consumption of fresh fruit ≥2 times per day between and with a meal as 51% and 12%, respectively. In the current study only 20% consumed fresh fruit ≥2 times per day between meals and nobody reported consumption of fresh fruit this frequently with a meal. This comparatively high intake of fruit likely reflects the method of recruitment as in the study by O'Toole et al. (2017) half of the participants were individuals recruited from a specialist referral clinic who had been identified as having severe tooth wear, the remainder being age matched controls. Thus, it might be expected that half the participants would report a high frequency of acid intake.

In the current study the frequency of consumption of other acidic drinks as well as fruit juice appeared similarly low with only around 10% of participants reporting once or more daily consumption of a soft drink or fruit water/fruit tea either between or at meals. Studies reporting acidic soft drink consumption in adults are limited and the author is unaware of any to date that report similar low intake, however a low consumption of acidic soft drinks was also reported for school children in Mexico (González-Aragón Pineda et al., 2019). By contrast, O'Toole et al. (2017) reported that 47% of study participants consumed acidic drinks between mealtimes at least twice a day, however this data was gathered from a specialist referral clinic for tooth wear. In young adults frequent consumption of acidic soft drinks was reported by 20% of participants in a European population (Bartlett et al., 2013) and an average of 3 times or more daily in an Icelandic study

(Jensdottir et al., 2004). These findings are in line with the majority of studies which report a higher intake of acidic drinks than identified in the current study (Hasheminejad et al., 2020; Schienkiewitz et al., 2020) and with increases in acidic soft drink consumption reported nationally (British Soft Drink Association, 2019). Perhaps the low acidic drink intake in the present study reflects the age of the population which included older generations, whereas participants in the above studies are generally adolescents or younger adults which are the age groups where the highest increase in acidic soft drink consumption has been reported (Tahmassebi and BaniHani, 2020). There is little literature to date investigating the consumption of acidic drinks and foods in older adults, highlighting the importance of the current study.

Data obtained about the other lifestyle habits of participants in the present study demonstrated that the majority of participants (61%) chewed gum at least occasionally, closely mirroring the findings of two larger scale European studies, both which reported at least occasional chewing gum use by two thirds of participants (Hearty et al., 2014; West et al., 2013a). The regular use of a straw for the consumption of acidic drinks by participants in this study (13%) was also similar to published data, in a recent epidemiological study of 600 Colombian students recording straw use in 15% of participants (Martignon et al., 2019). Further, levels of smoking and alcohol consumption in study participants were comparable to the figures of 17% (adults who smoke) and 82% (adults who had consumed alcohol within the last 12 months) obtained in the most recent Health Survey for England (NHS Digital, 2019a). E-cigarettes were used by 7.1% of UK adults in 2019 (ASH, 2019), which was marginally higher than reported in the present study (4.6%). Similarly, the prevalence of regular gastroesophageal reflux symptoms in Northern Europe (15%; Eusebi et al., 2018) and prescription of antidepressants or sleeping medications in the UK (16.3%; NHSBSA, 2017) were similar, but slightly higher than reported in the current study (9.4% and 12.8%, respectively). By contrast, more than half of participants in the present study reported clenching or grinding their teeth on at least an occasional basis (52.3%), which is higher than previous reported prevalence (8-31.4%; Wetselaar et al 2019), and snoring was reported more than twice as frequently (61%) as compared to a previous pan European study (26%; West et al., 2013a).

Overall, the prevalence of lifestyle factors for the current study tended to match closely to other datasets available for similar populations, albeit with a higher prevalence of snoring and bruxism compared to recent studies. Perhaps the latter could reflect the high stress levels which participants of the current study reported (65.9%) as stress and bruxism have been linked previously (Przystańska et al., 2019). However, it appears that the dietary acid intake in the population was low compared to previous studies. The low intake of acidic beverages could reflect a high level of education regarding the link between erosive drinks and tooth wear, or perhaps it is more likely that the knowledge of the cariogenic, rather than erosive, damage caused by several of these drinks resulted in a decrease in their consumption. It could also have resulted from response bias if participants answered the questions in the way to make their diet appear more favourable, knowing that oral health and tooth wear were under study. As dietary acids are a recognised risk factor for tooth wear (Lussi et al., 2011; West et al., 2013b) it might be expected that the levels of tooth wear in this population would also be low, however this was not the case, as discussed in section 3.5.3.

3.5.3 Prevalence and relationship of conditions

A high prevalence of tooth wear was recorded in the present study, with 78% of participants scoring BEWE 2 or 3 on at least one tooth surface in the mouth (buccal or palatal/lingual). This figure is similar to that reported by the 2009 ADHS in which 77% of participants had tooth wear extending into dentine (White et al., 2011) however, the ADHS also included incisal surfaces but with assessment limited to the 12 anterior teeth. It is interesting that the two studies had such similar results despite the difference in tooth sites scored as the tooth wear recorded for the current study was mainly localised buccally on the premolars and molars, which were not scored in the ADHS, and incisal tooth wear was not assessed. Incisal tooth wear was also included in a more recent study with a comparable sized population in which whole mouth maximum BEWE scores of 2 or 3 were recorded for 73% of participants (Midwood et al., 2019). Use of the BEWE on incisal surfaces can result in an overestimate of severe tooth wear (BEWE 3) since mild tooth wear affecting more than 50% of the incisal surface area would warrant this score even in the absence of loss of occlusal height. Therefore, a higher prevalence of BEWE 2 or 3 in the study of Midwood et al. (2019) as compared to the present study might have been expected. The slightly lower prevalence figure observed despite the inclusion of incisal scores may reflect differences in the study populations. In the study of Midwood et al. (2019) all participants were regular attenders at NHS general practice, 54% who recognised they had some extent of tooth wear and a further 43% of those having previously discussed this with their dentist who may have given them preventative advice to halt its progression.

By contrast, only 29% of participants had a maximum BEWE score of 2 or 3 on at least one tooth in a previous pan European study (Bartlett et al., 2013). However, the UK had the highest levels of tooth wear of all countries investigated (55% maximum BEWE 2 or 3) although this figure is still lower than the current study. This could be explained by the age of the participants, which ranged from 18-35 years, whereas in the current study recruitment also included those of older generations. As tooth wear accumulates with age (Lussi and Schaffner, 2000), it would be expected to be more prevalent in the current study population. In common with the present study, the pan European study found higher levels of tooth wear on the premolar and molar teeth for the UK population, although participants in the other European countries studied by Bartlett et al. (2013) tended to have more tooth wear on the anterior teeth. The same pattern of tooth wear, affecting premolars and molars preferentially, was also reported more recently by Teixeira et al. (2018). The localisation of the tooth wear on the buccal of premolars and molars may suggest that toothbrushing played a dominant role. The tendency for the highest levels of tooth wear (BEWE 3) to be located on the palatal surfaces of the upper anterior teeth is suggestive of erosive tooth wear, with the tongue abrading the softened enamel and dentine of the upper incisor and canine teeth (Seong et al., 2017).

The prevalence of GR in the present study was similar to that reported in the literature for other UK based studies. Nearly all participants (94.7%) had at least one tooth with GR ≥1mm and a third had at least one site of GR ≥4mm which are similar to the figures reported by Midwood et al. (2019) who found almost 90% had at least one site of GR ≥1mm and 27% GR ≥4mm, in a population of adults with similarly low levels of periodontal disease. High levels of GR are also reported in studies on young European adult populations with figures of 85% ≥1mm GR and 64% >3mm GR in Spain and Greece, respectively (Matas et al., 2011; Chrysanthakopoulos, 2014). Seong et al. (2018a) recorded the prevalence of GR in a UK population of 18-35 year olds and reported higher experience of GR with all participants displaying some extent of GR (≥1mm) and 42% with a maximum GR site of 4-8mm. The figures and the distribution of GR reported by Seong et al. (2018a) are similar to the present study with GR predominantly affecting buccal surfaces and a tendency to increase in prevalence from anterior to posterior of buccal surfaces in the dental arch. However, Seong et al. (2018a) also reported this trend palatal/lingually whereas in the present study lingual GR defects ≥1mm were most frequently recorded on the lower incisors, which could be explained by the tendency for calculus accumulation in this region leading to persistent inflammation and subsequent GR (Abhyankar et al., 2018; Cortellini and Bissada, 2018).

As over a quarter of the participants in the present study were periodontally healthy with less than 30% displaying signs of active or historic periodontitis, it is unlikely that periodontal loss of attachment was the main cause of GR. This is further evidenced by the fact GR predominated buccally, whereas in periodontal patients GR may occur on all surfaces due to loss of circumferential alveolar bone (Tugnait and Clerehugh, 2001). The distribution of sites with higher GR also closely matched that of sites with more severe tooth wear (BEWE 2 or 3). It is therefore likely that the dominant factor in the high prevalence of GR was traumatic toothbrushing although the posterior GR recorded may have been associated with poorer oral hygiene as individuals have been shown to have poorer oral hygiene posteriorly as these teeth are more easily missed during the brushing cycle (Prasad et al., 2011; Heasman et al., 2015; Seong et al., 2018a). It is also probable that orthodontics played a role as over a third of participants had a history of orthodontic treatment, which may have resulted in the teeth being unfavourably positioned with minimal buccal bony support (Cortellini and Bissada, 2018).

This was the first study to utilise the Cervical Localisation Code to determine the prevalence of hard and soft tissue defects in the cervical region and the first time the frequency and distribution of these codes had been established using a large population. As expected, the distribution of the codes across the dental arch closely matched that of GR and tooth wear. Code 0 was the most commonly scored, meaning approximately two thirds of sites were 'healthy' (no GR and no distinct tooth wear). This is in line with findings from the 2013 European study in which the combined prevalence of BEWE 0 and 1 was 70.6% (Bartlett et al., 2013), although this was measured as whole mouth maximum scores, which were not calculated for the Cervical Localisation Code as it is not an ordered ordinal scale. The slightly lower figure indicating 'health' in the present study could be due in part to the fact that Code 2 also captures this degree of tooth wear. When the frequency of BEWE scores for the current study were calculated as a percentage of the total surfaces scored (rather than a maximum score), to allow comparison to the Cervical Localisation Code data, the prevalence of BEWE 0 and 1 was 78% which was similar to although a little lower than the combined scores of Cervical Localisation Code 0 and 2 which represent no distinct coronal tooth wear (87%). The difference observed was probably due to the fact that Code 2 of the Cervical Localisation Code also encompasses radicular tooth wear, or that distinct tooth wear in a different location to the cervical region was also captured in the BEWE scores.

Cervical Localisation Code 1 (no GR but distinct coronal tooth wear) was the least common code and was scored most frequently on the palatal/lingual surfaces perhaps because these surfaces are less likely to be subjected to toothbrush abrasion (Macgregor and Rugg-Gunn, 1979) and therefore tooth wear at these sites is less likely to be accompanied by GR (Seong et al., 2018a). When palatal erosive tooth wear is found it is usually in association with the upper incisor and canine teeth, where the tongue is thought to abrade the softened enamel and dentine (Seong et al., 2017). GR was a prerequisite for Codes 2 and 3 to be scored, and these were most commonly reported buccally, in consistence with other studies in the literature which also report a heavier concentration of GR on buccal aspects of the teeth (Löe et al., 1992; Matas et al., 2011; Seong et al., 2018). Sites with high levels of GR and the highest BEWE scores also correlated with those scoring Code 3, namely the buccal surfaces of upper and lower premolars and first molars. A possible explanation is that these sites were often the first brushed tooth in the mouth, thus receiving the largest dose of toothpaste.

Toothpaste is recognised as the main factor in abrasive tooth wear from toothbrushing, rather than the toothbrush itself (Addy, 2005) and it has been shown that individuals tend to brush a certain tooth first and then will return to this tooth more than once in the brushing cycle (Macgregor and Rugg-Gunn, 1979), thus sites which are brushed first might be expected to exhibit the most tooth wear and GR. To date, there is little in the literature investigating the relationship between the first brushed tooth and presence of tooth wear or GR (Heasman et al., 2015). Although this data was recorded in the current study, it is not due to be processed until the rest of the European data has been collected, and so no conclusions can be drawn yet.

DH in response to an evaporative air stimulus was common in the present study by both measures, with over half of participants (60.4%) reporting pain and a clinician reported Schiff score 2 or higher recorded for 37.9% of participants on at least one tooth surface. This is a higher prevalence than other similar studies in the literature, although 2 questionnaire-based studies have also reported a high prevalence of 68% (Bamise et al., 2010) and 57.7% (Irwin and McCusker, 1997). Similarly, the figures are higher than those reported by West et al. (2013a) in young adults where UK prevalence figures for DH on at least one tooth were 45% for patient reported sensitivity and 16.6% for clinician recorded Schiff score 2 or 3. Studies have suggested the highest prevalence of DH occurs in those aged 30-49 years (Gillam et al., 1999; Amarasena et al., 2011), as participants in this age bracket were included in the present study but excluded in the study of West et al. (2013a) this may explain the differences in prevalence observed. A lower prevalence for DH compared to the present study was also observed in a UK adult population of regular dental attenders in which only 24% had a maximum Schiff score of 2 or 3 despite participants having a similarly high level of GR and tooth wear (Midwood et al., 2019). This could be attributed to successful preventative advice being given by their regular dentist, enabling them to effectively manage the condition. Despite the lower frequency of clinically relevant DH reported, in common with the current study the distribution of DH in the dental arch was similar to the present study with Schiff 3 most frequently seen in the premolar and first molar regions in both arches and on the lower incisors (Midwood et al., 2019).

In the current study, the prevalence of DH recorded from the participant elicited response (60.4%) was higher than that they reported in the questionnaire (50%) which is turn was higher than the clinically relevant DH scored by the clinician (37.9%). That higher DH levels were reported clinically by the participant compared to in the questionnaire is not an uncommon phenomenon (West et al., 2013a; Barroso et al., 2019), and this under-reporting may be explained by the subjective nature of perceived pain and the episodic presentation of DH symptoms, or coping mechanisms which decrease the impact of DH on everyday life (Chabanski and Gillam, 1997; West et al., 2014). Further, the clinically applied air stimulus is not an exact reproduction of a normal daily stimulus and therefore responses may have been evoked in those who do not normally suffer from DH (Fischer et al., 1992). The lower prevalence scored by the clinician may reflect the interpretation of Schiff scores, which are mainly based on the participant's physical reaction to the stimulus (Schiff et al., 1994). This meant it was possible that a participant received a low Schiff score if they did not respond physically to the stimulus but then scored positively when asked if the stimulus was painful, highlighting the subjective nature of pain and the importance of recording DH via more than one method. Overall, a high prevalence of DH was seen in this study compared to recent studies in European populations. This might be expected given the high levels of tooth wear and GR reported above, as both are aetiological factors in localising DH (West et al., 2013b).

The relationships between whole mouth maximum scores for each clinical condition were also investigated in the current study, with the highest correlation between all conditions being that of maximum Schiff score with the presence of participant identified DH. This was anticipated as they are different measures of the same variable and considering this, the relationship between the two was not as strong as expected. As discussed above this could reflect the subjective nature of the pain elicited and the differences in patient's physical responses to the stimulus (Mantzourani and Sharma, 2013). Another strong positive correlation was observed between clinically relevant tooth wear and the extent of GR experienced, in agreement with the literature (Seong et al., 2018a; Teixeira et al., 2018). This can be explained as once GR occurs, cementum is rapidly lost and exposed radicular dentine is susceptible to tooth wear (Bevenius et al., 1994; West et al., 2013b). Dentine when exposed to an erosive challenge and aggressive toothbrushing technique, is rapidly removed (Addy, 2005; Shellis and Addy, 2014).

Whole mouth maximum BEWE also positively correlated with participant reported DH, although the correlation was not as strong as anticipated (Rho= 0.193) and the association when DH was measured by Schiff was slightly weaker. Although both correlations gave highly significant p-values a Rho of 0.2 only suggests a weak association between the 2 variables tested, indicating that one variable accounts for only 4% of the variation of another. Erosive tooth wear is accepted to both localise and initiate DH (West et al., 2013b) with many studies therefore reporting significant association between these two conditions (Bartlett et al., 2013; West et al., 2013a; O'Toole and Bartlett, 2017; Teixeira et al., 2018). Indeed, in the present study the tooth sites where the highest DH, BEWE and GR scores were mostly commonly recorded were buccal premolars and first molars. However, there was no significant correlation between maximum whole mouth GR score and either whole mouth maximum measure of DH although as GR is also known to play a key role in localising DH (West et al., 2013b), a relationship between the two variables was expected (Addy et al., 1987; West et al., 2013a; Teixeira et al., 2018). Perhaps the relationships between maximum DH and tooth wear/GR seen in this study were weaker/not detected as a result of the inclusion of older participants. Tooth wear and GR accumulate with age (Serino et al., 1994; Albandar and Kingman, 1999; Litonjua et al., 2003; Van't Spijker et al., 2009). However, those participants who displayed the most tooth wear and GR were also more likely to have occluded dentine tubules due to age related deposition of secondary dentine (West et al., 2014; Lamster et al., 2016). Alternatively, in the case of tooth wear, the low level of association could reflect the relatively infrequent consumption of acidic drinks which have been shown to increase the likelihood of DH if consumed 1 hour prior to testing for DH symptoms (Olley et al., 2015). For GR, it is likely that the use of a maximum GR score resulted in a decreased association, as these sites were more likely to have had deposition of reparative dentine. Maybe if the statistical analyses were done using the early presentation of GR (1-2mm) instead, there would have been a more significant correlation.

In summary, the prevalence of tooth wear, GR and DH in the present study were relatively high. A strong positive relationship was identified between the different measures of DH and also between GR and tooth wear. Not all expected relationships between tooth wear, GR and DH were identified in the study population, perhaps reflecting age-related changes in the dentition of older participants.

3.5.4 Relationship of risk factors with severe tooth wear

A strong positive correlation was found between severe tooth wear and age, which was expected as the damage of tooth wear is irreversible and thus accumulates over time. This is in agreement with the literature (Lussi and Schaffner, 2000; Van't Spijker et al., 2009) and was also reported as a significant positive association in the previous European study, despite a smaller participant age range (Bartlett et al., 2013).

The use of a straw appeared to provide protection against severe tooth wear although the statistical significance of this relationship was lost once age was accounted for suggesting that, as might be expected, straws were used more frequently by the younger population who had less tooth wear. Laboratory based studies have previously supported straws as a protective method of consuming beverages with their use resulting in a decreased plaque pH drop (Tahmassebi and Duggal, 1997) and a reduction in the contact time of drinks with the molar and incisor teeth imaged using videofluoroscopy (Edwards et al., 1998). However, there is also evidence that the use of a straw has the potential to cause increased localised tooth wear if directed at a tooth surface rather than the posterior of the oral cavity (Shellis et al., 2005). Similar to the age adjusted findings of the present study, in a recent epidemiological study conducted on 600 Colombian students with an average age of 20, use of a straw offered no protective effect against tooth wear (Martignon et al., 2019).

In the current study the use of chewing gum was the other lifestyle factor which had a significant negative association with severe tooth wear prior to adjusting for age. The anti-erosive effect of non-fruity chewing gum is due to its ability to increase salivary flow rate, promoting clearance of gastric acids in the oesophagus and providing pH buffering (Moazzez et al., 2005; Buzalaf et al., 2018). It has been demonstrated that chewing sugar-free gum for half an hour after a meal reduces postprandial oesophageal reflux (Moazzez et al., 2005), which in turn would decrease the likelihood of erosive tooth wear from internal acids. A protective effect has also been demonstrated in-situ in a study investigating the effect of sugar-free chewing gum on enamel that was subjected to short-term acidic exposure (de Alencar et al., 2014). Subjects chewed sugar-free gum for 30 minutes after the acidic insult and the enamel surface hardness significantly increased for those who chewed standard sugar-free chewing gum compared to the control group who did not chew gum. This protective hardening effect significantly increased again when a casein phosphopeptide – amorphous calcium phosphate (CPP-ACP) containing chewing gum was used (de Alencar et al., 2014). By contrast, a damaging effect of chewing gum on dental erosion was reported in a Brazilian population of 12-30 year olds (Luciano et al., 2017). However, the authors speculated that this could be explained by the type of gum frequently chewed by this population, which had an acidic liquid filling in the centre and has previously been shown to be erosive in vitro (Bolan et al., 2008). Paice et al. (2011) have also demonstrated the significant erosive effect of chewing acidic fruity gum in comparison to a non-acidic peppermint flavoured gum. In a European population of young adults, however, no significant relationship was found between tooth wear and the use of chewing gum (Bartlett et al., 2013). This finding is similar to the present study in which statistical evidence for a protective effect of chewing gum was lost when the data was age adjusted suggesting that, like the use of a straw, chewing gum use is more common in younger adults who have less tooth wear.

A number of other correlations between severe tooth wear and risk factors that approached significance were also found in the present study, the strongest of which was a positive association with being male, although this did not quite reach significance (p=0.051). This finding is in accordance with reports for both Swedish and Norwegian populations (Hugoson et al., 1988; Mulic et al., 2012a; Skalsky et al., 2018) and a similar finding in Turkey (Akgül et al., 2003). However, in a European study investigating 3187 patients, no significant relationship between tooth wear and gender was reported (Bartlett et al., 2013). The reported tendency for males to have more severe tooth wear could possibly reflect behavioural habits as males have previously been reported to have a higher consumption of soft drinks (Pollard et al., 2016) and have higher experience of reflux

(Royston and Bardhan, 2017), however this has not been assessed for population of the current study.

The association between frequency of toothbrushing and severe tooth wear also approached significance, unexpectedly showing that tooth wear was related to less frequent brushing. A similar finding was reported for young Norwegian adults (Mulic et al., 2012a) and Chinese adolescents (Zhang et al., 2015) with those brushing once daily or less often displaying a significantly higher prevalence of erosive lesions. This may be due to the anti-erosive action of some fluoride toothpastes (Lussi and Carvalho, 2015), with those brushing more frequently benefitting from its protection (Bardsley et al., 2004). By contrast, increased frequency of toothbrushing resulted in increased tooth wear in a 6 year longitudinal study (Lussi and Schaffner, 2000) and this association has also been reported in both adult and adolescent populations (Bergström and Lavstedt, 1979; Akgül et al., 2003; Bardolia et al., 2010). Other epidemiological studies have found no significant relationship between frequency of toothbrushing and tooth wear (Bartlett et al., 2013; Søvik et al., 2015).

The lack of positive association between tooth wear and toothbrushing frequency in the current study could be due to the multifactorial nature of tooth wear in the cervical region (Bader et al., 1996; Bartlett et al., 2006) with erosion being the dominant factor. Addy and Hunter (2003) concluded that toothbrushing with normal habits and a toothpaste which meets ISO guidance for abrasivity causes clinically insignificant wear to dentine and enamel. It is possible that the low intake of dietary acid observed in the present study resulted in limited severe tooth wear from this synergistic action. A further explanation is that some participants with severe tooth wear had previously brushed more frequently but reduced the number of times they brushed daily after receiving preventive advice from a dentist, thus the tooth wear detected was historic but the reported brushing habit was their current less damaging routine.

Frequency of exercise also had an association with severe tooth wear which almost reached significance, with the frequency of severe tooth wear increasing with the number of times exercise was performed weekly. The exception to this trend was that the highest levels of wear were scored for those exercising less than weekly, which is likely to be accounted for by age. A high frequency of exercise has previously been highlighted as a risk factor for tooth wear which has been attributed to a decreased salivary flow rate, the consumption of isotonic sports drinks and, in the case of swimmers, poorly regulated swimming pools (Dawes and Boroditsky, 2008; Mulic et al., 2012b; Bartlett et al., 2013; Antunes et al., 2017).

The questionnaire used in the present study asked specific questions regarding the timing of acidic intakes in relationship to meals after O'Toole et al. (2017) reported that intake of fruit between meals but not with meals was associated with tooth wear, in a group of patients referred into specialist consultant clinics. In the current study, the only dietary variable to approach a statistically significant positive association with severe tooth wear was the consumption of fruit juice at meals, however there was no obvious trend with regards to the frequency of consumption. Bartlett et al. (2013) reported that tooth wear was associated with all dietary acid intakes, in particular fresh fruit and isotonic energy drinks, however, similar significant positive associations with severe tooth wear were not observed in this study. This finding is most likely due to the small sample under investigation, as only 116 participants (15%) had a maximum BEWE score 3 and of those the number consuming dietary acids more than once a day was very small. This meant that statistical power to detect a meaningful relationship was low in this sample.

Gastroesophageal reflux is an accepted risk factor for tooth wear, with a recent meta-analysis concluding that individuals with reflux disease or symptoms had double to quadruple the odds of displaying erosive tooth wear when compared to those without (Jordão et al., 2020). However, in the current study there was no significant correlation between reflux and severe tooth wear which again may be explained by the low numbers on which analysis was conducted. It is also possible that some participants had undiagnosed asymptomatic reflux, which has previously been linked to erosive tooth wear (Taylor et al., 1992).

In the previous 2011 European study (Bartlett et al., 2013), more dietary and lifestyle variables were significantly associated with tooth wear than the current study. However, this it to be expected given the larger sample size (3187) and because significant tooth wear (BEWE 2 or 3) was analysed, rather than in the current study where only the severest tooth wear (BEWE 3) has been assessed to date. Age was also not accounted for by Bartlett et al. (2013), perhaps due to the smaller age range (18-35 years), however it may be the case that some of the associations would also have lost significance if these statistical tests had been run. The high prevalence of tooth wear seen in the present study despite a low dietary acid intake and lower than average experience of gastroesophageal reflux is surprising as erosion is accepted to be the dominant factor in tooth wear (Shellis and Addy, 2014). One explanation could be that the questionnaire only captured current dietary habits and so it is possible that some participants had a higher acid diet in the past which had caused irreversible tooth wear, but then decreased their acid intake on receiving preventative advice.

In summary, the only risk factor which had a statistically robust association with severe tooth wear in the current population was increasing age, which was anticipated due to the irreversible nature of tooth wear. Drinking through a straw and chewing gum were protective against severe tooth wear but these relationships were confounded by age, losing significance once age was taken into consideration. Although several anticipated relationships were not detectable in the current study, this is likely due to the relatively small sample with severe tooth wear on which analyses were conducted. It is the hope that when the same statistical analyses are completed for the full data set from all 7 European countries, further associations will be identified.

3.5.5 Study design and limitations

The UK epidemiological data presented in this thesis forms part of the Meribel project, a multi-centre study to determine the prevalence of GR, tooth wear, DH and the risk factors associated with these conditions, in adults from 7 European countries. When complete it will be the largest study of this type to date recruiting ~5000 individuals. The development of the Cervical Localisation Code presented here was part of the extensive planning phase which also included shooting instructional videos, compiling calibration resources and the creation of study documents. Training of investigator dentists and a calibration exercise was undertaken in each country to ensure they were equipped with the knowledge to carry out all aspects of the study and that scoring of clinical conditions was consistent. For a comprehensive assessment of the clinical conditions, data collection utilised a full mouth approach scoring multiple indices on both the buccal and palatal/lingual surfaces. This coupled with the detailed questionnaire provided a detailed picture of the study population. To check for potential differences or drift in examiner scoring, data was input at regular intervals and a preliminary statistical analysis was conducted by the statistician after the first 300 UK participants.

The large volume of data collected from each participant meant that a study visit lasted between 30-45 minutes and recruitment of sufficient participants to attend an appointment of this length in the absence of any financial incentive, proved a significant challenge. As the study aimed to capture individuals from all walks of life, recruitment avenues to try to capture a representative mix of people were opened including general dental practices, advertising to members of the public and approaching those who had previously taken part in clinical trials. However, the most successful routes of recruitment were by advertising in the local NHS trust and University weekly newsletters. Although participants from many departments and different hierarchical levels of these organisations were enrolled on the study, it is likely that there were a higher proportion of well-educated or health-conscious individuals in this group than in the general population. Nevertheless, a significant proportion of those who chose to participate via this route were using the opportunity to have a dentist look over their teeth, having not been to the dentist for several years. It is also probable that, no matter the route of recruitment, individuals who decided to partake in the study were generally more health conscious to be interested in participating (Reynolds, 2011), especially with no financial incentive available, thus this selection bias was difficult to avoid. Overall, multiple methods of recruitment were required in order to reach the necessary number of participants within a 2-year time frame, however, it is unlikely that the resulting sample reflects the general population to quite the same extent that the ADHS does by mailshotting random postcodes.

In hindsight, it would also have been beneficial to record the number of participants who were approached but declined to participate via each of the recruitment avenues as this data would have been useful to inform future research studies. However, practically achieving this would have been challenging due to the methods of recruitment used, for example it is not possible to know how many of those who were emailed a newsletter actually opened it, read the section about research studies and made an active decision about whether to participate or not. A detailed written medical history could have been taken from the participants, however, as there was already a large amount of paperwork to complete during the study appointment it was decided that this could be deduced verbally instead. On reflection, perhaps stricter guidance on what counted as ‘health’ for the inclusion criteria could have been detailed to ensure a standardised approach.

The participant questionnaire was completed prior to clinical examination. Previous research has shown that response rates for questionnaires improve the shorter the questionnaire is (Edwards et al., 2009) and it soon became evident that the questionnaire in the current study was considered lengthy. Several participants commented on how many pages of questions there were with many rushing through the answers to complete it as quickly as possible. To address this, the questionnaire was checked for completeness by the study team while the participant was still in the dental chair, allowing missed questions to be highlighted and corrected during the appointment. However, on reflection, this may have contributed to response bias. The questionnaire needed to encompass more variables than discussed in the current thesis yet, in retrospect, maybe a better balance could have been struck between the gain in extra data collected and the added time for paperwork completion by the participant.

The questions to investigate the frequency of dietary acid in the questionnaire were chosen to capture any associations between dietary intakes in relation to mealtimes as acidic intakes between meals have previously been reported to be more damaging than those during meals (O’Toole et al., 2017). However, splitting the frequency to between and during meals made it impossible to determine overall dietary acid intake per participant, which in turn resulted in difficulties comparing the current study findings with the literature. Further, few relationships were found between tooth wear and dietary acid as many participants recorded the same level of intake. Perhaps if the frequency of consumption had been assessed using different descriptors the results would have been easier to compare with the literature and participant consumption would have been spread over a broader range which may have resulted in more relationships being identified.

The exclusion criteria for the assessment of DH included caries and endodontically treated teeth which were diagnosed visually, as the use of radiographs would have resulted an unnecessary dose of radiation to the participant. It is possible, however, that endodontically treated teeth without an obvious access cavity or early interproximal caries may have been included, falsely contributing the overall DH scored. Additionally, the population studied had generally low levels of periodontitis compared to other population-based measures of the disease. Although this could reflect the participants' good oral hygiene, these low levels may also be due to how periodontal status was measured. For this study, the criteria for the assessment of periodontal status were not defined but depended on the clinical judgement of the examiner after completion of the BPE and probing depths which were recorded at the site of a GR defect or mid-buccal/ mid-lingual. Although guidance was given during training, the absence of written clinical parameters may have resulted in a lack of consistency diagnosing the periodontal status. In the future, stricter restraints of diagnostic measures for periodontitis based on the recently updated periodontal classification (Caton et al., 2018) should be implemented to maintain consistency and facilitate ease of comparison with the literature.

The results suggest that the Schiff score did not provide as useful a measure of insight into the participant experienced DH in the present study as other studies have shown (West et al., 2013a). The correlation between Schiff score and participant elicited DH was not as strong as anticipated possibly due to the difficulties in measuring a subjective symptom such as pain. The Schiff score is based on the clinician's subjective interpretation of the participant's response. In the current study, a number of participants did not respond at all to the stimulus but, when asked, said that they had considered it to be painful (participant elicited DH). This suggested that the population were good at coping with their pain symptoms and perhaps the use of the Schiff on such a group of individuals does not provide as accurate a representation of their DH experience. Many individuals also questioned what was meant by 'painful' as they had felt some sensation in the tooth but it was what they considered to be 'a bit of sensitivity' rather than pain. To ensure standardisation and minimise interviewer bias, the participant was not given any extra guidance but had to arrive at their own interpretation of what to classify as pain. As pain is a subjective measure, the difficulties in assessing

DH were taken into consideration from the outset and 3 different measures of DH were recorded, enabling good overall appreciation of the condition. This needs to be considered in design of future studies and perhaps other stimuli utilised, such as a tactile together with an air stimulus, as in randomised controlled studies aiming to demonstrate treatment efficacy.

Overall, the study design was successful and appropriate to achieve all outcomes. The high prevalence of tooth wear, GR and DH was captured and possible risk factors for severe tooth wear explored, with appropriate measures taken to maximise the validity of results.

4 Discussion

This thesis set out to devise and validate a novel index to assess tooth wear and GR in the cervical region that could be used as a tool in research studies and in general dental practice, to guide the management of patients presenting with hard or soft tissue loss cervically. As part of a larger European study, the prevalence of cervical lesions as described by the Cervical Localisation Code, tooth wear, GR and DH, were determined and the association of severe tooth wear with risk factors which could be causal examined.

The Cervical Localisation Code developed and validated in this thesis assesses GR and tooth wear in their relationship to DH, their common symptom and was successfully used in the subsequent epidemiological study in which it was clear that it correlates well with both GR and tooth wear. However, these initial studies highlighted that the numerical codes 0,1,2,3 imply ordinal progression, similar to BEWE scores, despite each code representing a distinct clinical entity. It is therefore proposed that the code names are altered to A,B,C,D as these do not imply progression in the same manner.

While the BEWE provides a good overview of general tooth wear, it does not indicate if it is located in the cervical region, and current indices to assess GR are generally focused on periodontal disease rather than the aetiological role of GR in DH. The Cervical Localisation Code is therefore particularly useful in diagnosing the aetiology of DH as it captures both tooth wear and GR at the cervical margin, where DH is most commonly identified (Addy, 2005). It is the suggestion of the author that the BEWE and Cervical Localisation Code complement one another for use in general dental practice. The joint use of these indices would give a better appreciation of where tooth wear is located and improve patient outcomes, with the BEWE giving an indication of general severity of wear across the whole mouth and suggesting tooth wear interventions, and the Cervical Localisation Code detailing management of any GR and DH with associated lesions. However, the specific use of the Cervical Localisation Code in DH studies gives the advantage over the BEWE in that it allows analysis of whether hard or soft tissue loss (or both) is most commonly associated with DH symptoms in the cervical region. Introducing the Cervical Localisation Code as a gold standard to record the clinical presentation of teeth with DH symptoms will allow the potential aetiology of the symptoms to be assessed as well as encouraging standardisation of how GR and tooth wear are detailed in these studies, allowing easier comparison.

The epidemiological study recruited participants of a broad age range (18-86 years) who were healthy, well-educated about oral hygiene and had a low dietary acid intake. In this study, the association between BEWE score and GR captured in the Cervical Localisation Code was shown to be strong when the whole mouth maximum scores were analysed. A weaker association was detected between DH and BEWE, and no association between GR and DH was found but this may have been due to the age of participants showing the greatest tooth wear and GR, who were also more likely to have sclerosed dentinal tubules.

When examining risk factors for severe tooth wear, a strongly significant association was only identified for age which was positively correlated with it, in line with published literature (Lussi and Schaffner, 2000; Van't Spijker et al., 2009). Drinking through a straw and chewing gum were protective against severe tooth wear but these relationships became insignificant once age had been accounted for, however it is possible that in a larger sample these relationships would retain significance as evidence for both as protective factors for tooth wear has previously been reported (de Alencar et al., 2014; Tahmassebi and Duggal, 1997). It was surprising that none of the acidic dietary foods or drinks correlated with severe tooth wear as dietary acid erosion is indicated as causal in other studies (Bartlett et al., 2013; O'Toole et al., 2017; Yoshizaki et al., 2017), but the lack of statistical significance was likely down to the relatively low reported levels of consumption of these dietary foodstuffs, with the majority of participants recording the same level of intake. Perhaps if the frequency of consumption of these agents had been assessed using different descriptors for frequency, participant consumption would have been over a broader range and some associations would have been seen. It is probable that the majority of tooth wear recorded in this population was historic. Considering tooth wear is multifactorial, the evidence suggests that the tooth wear observed in this population was a combination of erosion, abrasion and attrition, unlike in younger populations where erosive factors predominate.

5 Conclusions

In summary, this thesis devised a novel index to assess tooth wear and GR in the cervical region, addressing the lack of previous indices to capture both parameters, despite their joint role in the aetiology of DH and is designed for use both in clinical practice and in research studies investigating tooth wear, DH and GR. The Cervical Localisation Code was validated in a preliminary study with three examiners showing good intra-examiner and inter-examiner reliability for all scores and was successfully implemented in a subsequent large-scale UK epidemiological study.

The participants in the epidemiological study were a relatively health-conscious group of individuals with good oral hygiene and a low experience of periodontitis. Prevalence figures for DH, GR and tooth wear were high with a strong positive correlation between the latter. Age was identified as the major risk factor for tooth wear, with the use of chewing gum and drinking through a straw both losing their significance once age had been accounted for.

The findings of this epidemiological study support the notion that tooth wear and DH are on the rise, with a high prevalence of both reported in comparison to earlier studies, although this must be interpreted with caution due to differing methodologies. The Cervical Localisation Code will aid general dental practitioners in recording these increasingly common conditions, helping to improve diagnosis and patient management.

6 Future Work

While the prevalence of tooth wear, GR and DH were shown to be high in this UK population, to better understand the overall scale of these conditions in Europe further work is already underway to collect the same data in Germany, Italy, Portugal, Republic of Ireland, Spain and Switzerland. This larger data set will reveal clearer trends regarding the relationships both between these conditions and with possible risk factors associated. Of particular interest will be any correlations between clinical conditions and the first brushed tooth, as this is the first study to investigate this relationship and a positive association has the potential to inform future oral hygiene guidance.

Future analysis of the current data set would also provide further insight. Investigating the relationship between the Cervical Localisation Code and DH symptoms would inform whether GR or tooth wear is more frequently associated with this pain condition. In addition, it is suggested that DH is more likely to be associated with early GR therefore an analysis of the relationship between GR 1-2mm and DH would be beneficial to confirm this hypothesis.

It is the intention that the Cervical Localisation Code is implemented nationally in the primary care setting to help focus management of the cervical region, an area where guidance is currently lacking. The challenges of introducing a new index into busy primary care practice are recognised as practitioners are have great time restraints and therefore it is the hope that Dental Foundation Trainees could be used to confirm the suitability of the index and its management section in primary care by inviting them to complete a research project as part of their foundation training. This opportunity would provide the trainees with invaluable research experience while also capturing the prevalence of these conditions in NHS general practice and piloting the use of the index in primary care.

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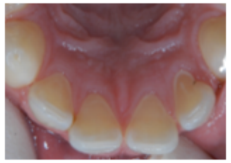
Appendices

1. Cervical Localisation Code

Code	Description	Interpretation	Example	Management
0	No gingival recession, **and** No distinct tooth wear on crown in cervical region	Health No recession and no distinct cervical tooth wear		• Reinforce continuation of good oral hygiene • Routine maintenance and observation • Prevention – ensure patient awareness of aetiology of tooth wear
1	No gingival recession, **and** Distinct tooth wear on crown in cervical region	Enamel loss in cervical area- Erosion/abrasion		Identify main aetiological factor and implement strategies to eliminate: • Diet diary and analysis with individually focused advice: highlight dietary acids and recommend decrease frequency of consumption and keep to mealtimes • Explore intrinsic acid sources- vomiting, reflux, eating disorders: refer to GMP if required • Recommend fluoridation measures to increase resistance of tooth surface to erosion: use of fluoride mouthrinse during day, stannous fluoride toothpaste reinforcing spit don't rinse. • Address any traumatic toothbrushing habits, ensure brushing is not straight after acidic insult. Consider brushing before breakfast • Treat dentine hypersensitivity using twice daily desensitising toothpaste advising spit don't rinse • Ideally avoid restorations if possible. If required for aesthetics/ function/ pain, stabilise causative factors prior to restorative rehabilitation, consider referral
2	Gingival recession with or without distinct tooth wear on root in cervical region, **and** No distinct tooth wear on crown in cervical region	Recession (main causes)- Traumatic brushing Periodontal disease Treated periodontitis No distinct tooth wear cervically on crown		Identify main aetiological factor: • Traumatic brushing – tailored toothbrush instruction, ensure brushing no more than twice daily and no scrubbing action, consider use of electric toothbrush . • Periodontitis – periodontal treatment, warning that recession is likely to increase once inflammation has subsided • Treated periodontitis – ensure brushing is atraumatic on exposed root surface whilst maintaining excellent oral hygiene. • Treat dentine hypersensitivity using twice daily desensitising toothpaste – advising spit don't rinse • Consider referral to specialist for mucogingival surgery if sufficient interdental bone • Ideally do not restore root surface as likely to exacerbate condition due to plaque retention
3	Gingival recession with distinct tooth wear on root in cervical region, **and** Distinct tooth wear on crown in cervical region	Recession (main causes) Traumatic brushing Periodontitis Treated periodontitis **and** tooth wear- Erosion/abrasion		Identify main aetiological factors and implement strategies to eliminate: • Diet diary and analysis with individually focused advice: highlight dietary acids and recommend decrease frequency of consumption and keep to mealtimes • Explore intrinsic acid sources- vomiting, reflux, eating disorders – refer to GMP if required • Recommend fluoridation measures to increase resistance of tooth surface to erosion: use of fluoride mouthrinse during day, stannous fluoride toothpaste reinforcing spit don't rinse. • Reinforce oral hygiene instruction, address any traumatic toothbrushing habits, ensure brushing no more than twice daily, consider use of electric toothbrush , ensure brushing is not straight after acidic insult. Consider brushing before breakfast • Treat dentine hypersensitivity using twice daily desensitising dentifrice – advising spit don't rinse • Ideally avoid restorations if possible. If required for aesthetics/ function/ pain, stabilise causative factors prior to restorative rehabilitation, consider referral
Key Notes: Distinct tooth wear=a 'step' or 'scooped-out' defect, visible to the eye and detectable when running a probe over the tooth surface. **Crown**=anatomical crown **Root**=anatomical root				

2. Participant Information Sheet

University of BRISTOL

Bristol Dental School
Clinical Trials Unit
University of Bristol
Lower Maudlin Street, BRISTOL BS1 2LY,
Telephone: (0117) 342 9638
Fax: (0117) 342 4100; International: +44 117

Professor N West BDS FDS RCS PhD FDS (Rest Dent) FHEA
Professor/Honorary Consultant in Restorative Dentistry
E-mail: N.X.West@bristol.ac.uk

RESEARCH PARTICIPANT INFORMATION SHEET

Cervical localisation code – validation of a new index

You are being invited to take part in this research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully and discuss it with others, such as family, friends or your dentist, if you wish. Your dentist will go through the information sheet with you and answer any questions you may have. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part and thank you for your interest in this research study.

What is the purpose of the study? Why is this study being carried out?

This research study has been designed to validate a new clinical scoring system (index) for dentists, which is focused at the junction where your gums meets your teeth. The index has been designed to look specifically for worn surfaces of the teeth and receding gums in this area as this is an increasing problem in the population and can often cause problems, such as sensitive teeth. We are developing the index to act as a guide for dentists on how to manage problems in this area, such as receding gums from toothbrushing too vigorously and sensitivity from exposed dentine near the gum. You have been approached as part of the initial development of the index, to ensure that our research dentists agree on the scoring system which is to be used. We hope that once this index has been developed, the information can be given to dentists equipping them with better knowledge to advise and treat their patients.

This study is being sponsored by the University of Bristol. The University has Public Liability insurance to cover the liability of the University to research participants.

Why have I been invited to take part?

You have been invited because you are attending the University Dental Hospital for an appointment. We are also approaching University Dental School/Hospital staff and students and members of the general public who have expressed an interest in participating in new studies with the Clinical Trials Unit. We are hoping to recruit 39 participants to take part in this study.

Do I have to take part in this study?
No, you are entirely free to choose whether to take part or not, and you may stop taking part in the study at any time without giving a reason. It will not affect your dental care in any way if you choose not to take part.

What will happen to me if I take part in this study / what will I have to do?
If you agree to participate in this study, you must read this Research Participant Information Sheet and sign the Consent Form before any study procedures begin. You will be provided with a copy of the signed Consent Form and Research Participant Information Sheet to keep.

Once you have provided informed consent, a study dentist will then confirm that you are fully eligible for the study by asking you a few short questions. To complete the study, you will attend for 1 appointment which will last approximately 30 minutes. The study visit will consist of a short oral examination, which will be repeated by 3 different research dentists to ensure that they are scoring consistently with each other.

The oral examination involves the dentists counting your teeth and looking for any tooth wear or areas where your gums have receded. This will be done using the dental light, a mirror and a probe. If the dentist wishes to dry the tooth to be able to see the area more clearly, this will be done using a gentle puff of air. These are all routine instruments used by dentists during a check-up. A score will be written down for two surfaces per tooth – the outer surface near the cheek, and the inside surface near the tongue/roof of the mouth.

In addition, your study dentist may take a picture of your teeth using a camera. The pictures will be used to monitor ongoing calibration in the clinical assessments performed by your dentist throughout the study. Your consent to take pictures will be requested prior to any assessments taking place. The pictures will be anonymous and will only be identified by your individual study number.

Expenses and payment
There are no expenses or payments for taking part in this study.

Is there anything I should or should not do?
No lifestyle changes are required in association with this study so please carry out everything as normal. This research will not interfere with the treatment you will receive from your dentist. Your dentist remains free to choose the treatment of their choice and follow up.

What are the possible risks of taking part?
There are no anticipated risks or side effects. Participation in this study will not interfere with either medical or dental treatment. All procedures and assessments will be carried out by experienced and appropriately qualified dentists. Standard examining procedures and sterile oral examination instruments will be used.

Are there any benefits in taking part?

There is no direct, immediate benefit to you from taking part in this research study. However, you will have helped the dental profession gain a better understanding of factors that might influence dental health in the adult UK population.

What will happen if I don't want to carry on with the study?
You are free to withdraw from the study at any time without giving a reason. This will have no effect on your dental treatment.

What happens when the research study ends?
Your anonymised data will be held within the Clinical Trials Unit at Bristol Dental Hospital and with your permission may be released in anonymised form to support other researchers in the future.

What will happen to the results of the research study?
It is possible that the results of the study will be published in an internationally refereed scientific journal. Should this be the case any information about you will be anonymised as detailed below. The protocol summary may be posted on a publicly available protocol register. We will provide you with the result of the study if you request them.

Will my taking part in the study be kept confidential?
Yes. All information about you will be handled in confidence.

Bristol University is the sponsor for this study. This means that they will oversee the initiation, management and funding of this research. Bristol University are also the data controller for this study and are responsible for looking after your information and using it properly. The Clinical Trials Unit, at the Bristol Dental School, will collect information from you for this study in accordance with our instructions and approvals.

The Clinical Trials Unit will keep your name and date of birth confidential and will not pass this information to Bristol University. The Clinical Trials Unit will use this information as needed, to make sure that relevant information about the study is recorded and to oversee the quality of the study. Certain individuals from Bristol University and regulatory organisations may look at the research records to check the accuracy of the research study. Bristol University will only receive information without any identifying information. The people who analyse the information will not be able to identify you and will not be able to find out your name. The Clinical Trials Unit will keep identifiable information about you from this study for 15 years after the study has finished.

Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. If you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally-identifiable information possible. You can find out more about how we use your information at https://www.hra.nhs.uk/information-about-patients.

What happens if something goes wrong?
If you are harmed due to someone's negligence, then you may have grounds for legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor

Nicola West on 0117 342 9638 or the Patient Support and Complaints Team (at UHBristol) on 0117 3423604. For complaints, please email research-governance@bris.ac.uk.

Who has reviewed the study?
This study has been reviewed and given favourable ethical opinion by the HRA and the NRES REC London Queen Square committee.

Contact details
If you have any further questions concerning the study, or in case of any difficulty during the study please contact:

Primary Contact	**Secondary Contact**
Prof. Nicola West - Principal Investigator Bristol Dental School Clinical Trials Unit University of Bristol Lower Maudlin Street Bristol BS1 2LY Tel: 0117 342 9638	Nikki Hellin – Study Co-ordinator Bristol Dental School Clinical Trials Unit University of Bristol Lower Maudlin Street Bristol BS1 2LY Tel: 0117 342 9638
Emergency 24 hour contact number: 07773 579130 **e-mail: dental-clinical-trials@bristol.ac.uk**	

Thank you for reading this document.
If you have any further questions, please do not hesitate to ask.

3. Consent Form

Research Participant Consent Form - Version 3.0, 14th November 2018
IRAS ID: 225373

University of BRISTOL

Bristol Dental School
Clinical Trials Unit
University of Bristol
Lower Maudlin Street, BRISTOL BS1 2LY
Telephone: (0117) 342 9638
Fax: (0117) 342 4100; International: +44 117
Professor N West BDS FDS RCS PhD FDS (Rest Dent) FHEA
Professor/Honorary Consultant in Restorative Dentistry
E-mail: N.X.West@bristol.ac.uk

RESEARCH PARTICIPANT CONSENT FORM

Cervical localisation code – validation of a new index

		Please initial boxes
1	I confirm that I have read and understood the Research Participant Information Sheet dated 14th Nov 2018, version 3.0 for the above study and have had the opportunity to ask questions which have been answered to my satisfaction.	
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical/dental care or legal rights being affected.	
3	I understand that data collected during the study may be looked at by individuals from the Sponsor or from regulatory authorities, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my study data.	
4	I understand that the information collected about me will be used to support other research in the future and may be shared anonymously with other researchers.	
5	I agree to pictures of my mouth being taken to monitor ongoing calibration in the clinical assessments performed by my research dentist throughout the study.	
6	I agree to take part in the above study.	

Participant Screening Number

____

Signature of Participant	**Full name of Participant (print)**	**Date**
_____________________________	__________________________________	________________
Signature of Person Taking Consent	**Name of Person taking Consent (print)**	**Date**
_____________________________	__________________________________	__________________

4. Clinical Form

Examiner ID:								
Participant ID:								
Date of examination	D	D	M	M	Y	Y	Y	Y

Cervical Localisation Code	Buccal														
	Palatal														
		17	16	15	14	13	12	11	21	22	23	24	25	26	27
		47	46	45	44	43	42	41	31	32	33	34	35	36	37
Cervical Localisation Code	Buccal														
	Lingual														

Cervical Localisation codes

0 No gingival recession, and
No distinct tooth wear on crown in cervical region

1 No gingival recession, and
Distinct tooth wear on crown in cervical region

2 Gingival recession with or without distinct tooth wear on root in cervical region, and
No distinct tooth wear on crown in cervical region

3 Gingival recession and distinct tooth wear on root in cervical region, and
Distinct tooth wear on crown in cervical region

N.B

Distinct tooth wear**=**
a 'step' or 'scooped-out' defect, visible to the eye and detectable when running a probe over the tooth surface

Crown = anatomical crown

Root = anatomical root

PLEASE ENSURE THAT EVERY BOX HAS A VALUE IN IT. DO NOT LEAVE ANY BOXES BLANK.
For all conditions: X = Excluded or Missing Teeth/ Cannot determine/ Not applicable

5. Links to instructional videos

Video 1 – Introduction

Video 2 – Tooth wear

Video 3 – Dentine hypersensitivity

Video 4 – Periodontal health

REDACTED - Video links removed due to permissions issue.

6. Participant Information Sheet

University of BRISTOL

School of Oral and Dental Sciences
Clinical Trials Unit (Periodontology)
Bristol Dental School & Hospital
Lower Maudlin Street, BRISTOL BS1 2LY,
Telephone: (0117) 342 9638
Fax: (0117) 342 4100; International: +44 117

Professor N West BDS FDS RCS PhD FDS (Rest Dent) FHEA
Professor/Honorary Consultant in Restorative Dentistry
E-mail : N.X.West@bristol.ac.uk

RESEARCH PARTICIPANT INFORMATION SHEET

Recession, dentine hypersensitivity, tooth wear and associated risk factors:
An observational, cross-sectional multi-centre epidemiological study

You are being invited to take part in this research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully and discuss it with others, such as family, friends or your dentist, if you wish. Your dentist will go through the information sheet with you and answer any questions you may have. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for your interest in this research study.

What is the purpose of the study? Why is this study being carried out?
This research study has been designed to look into the number of people who suffer with sensitive teeth (dentine hypersensitivity), worn teeth (tooth wear) and gum health (recession) across seven European countries. You have been approached as part of the UK data collection towards this. The study also looks at how these conditions are related and aims to identify any risk factors which increase the likelihood that a person will be affected. These conditions are relatively common and can be a real problem for those affected. If we can learn more about how often and why these conditions occur and any links between them, this information can be given to dentists equipping them with better knowledge to advise and treat their patients.

This study is being sponsored by the University of Bristol and is being funded by a grant from GlaxoSmithKline Consumer Healthcare. The study has been approved by London - Surrey Research Ethics Committee.

Why have I been invited to take part?
You have been invited because you are a private patient of this dental practice or patient of the University dental hospital and are attending for a routine appointment. We are approaching all patients attending the practice for review/check-up appointments to see if they would be willing to

participate in the study. We are also recruiting healthy participants from staff and students and associated personnel across the University of Bristol and affiliated institutions and members of the public outside of our database who have expressed an interest in taking part in research studies. We will also approach potential participants who are part of the Clinical Trials database of previous participants who have expressed an interest in taking part in future dental related research studies.

Do I have to take part in this study?

NO, you are entirely free to choose whether to take part or not, and you may stop taking part in the study at any time without giving a reason. It will not affect your dental care in any way if you choose not to take part. If you do decide to take part, you will be asked to sign a consent form. You will be given a copy of this participant information sheet and consent form to keep.

What will happen to me if I take part in this study / what will I have to do?

If you agree to participate in this study, you must read this Research Participant Information Sheet and sign the Consent Form before any study procedures begin. You will be provided with a copy of the signed Consent Form and Research Participant Information Sheet.

Once you have provided informed consent, a study dentist will then confirm that you are fully eligible for the study by asking you a few short questions. To complete the study, you will attend for 1 appointment which will last approximately 30 minutes. The study visit will consist of a questionnaire and an oral examination.

If you are eligible for the study you will firstly be asked to complete a questionnaire relating to questions about your teeth, diet and lifestyle. A member of the study team will help in case of any queries when completing the questionnaire.

After completing the questionnaire, the research dentist will look inside your mouth and examine your teeth. The tooth wear around your teeth will be examined by looking at the teeth and writing down a score or code for each tooth recorded. This involves counting your teeth, recording the severity of wear and using instruments to take measurements from the gums. You will also have cold air sprayed onto your teeth to see if any of them cause you sensitivity. This cold spray is the same instrument your dentist uses in your routine check-up to dry your teeth. The sensation is similar to that which someone might experience if they get sensitivity with ice cream or cold drinks. It lasts momentarily and causes no damage to the teeth. The dentist will finally check the health of your gums by placing a dental instrument used by all dentists around the gum. These tests are routinely carried out by dentists during a check-up, we will just be recording the measurements in more detail than usual.

Your study dentist may in addition take a picture of your teeth using a camera. The pictures will be used to monitor ongoing calibration in the clinical assessments performed by your dentist throughout the study. Your consent to take pictures will be requested prior to any assessments taking place. The pictures will only be identified by your individual study number and site/country code.

Expenses and payment

There are no expenses or payments for taking part in this study.

Is there anything I should or should not do?

No lifestyle changes are required in association with this study so please carry out everything as normal.

This research will not interfere with the current or any future treatment you will receive from your dentist. Your dentist remains free to choose the treatment of their choice and follow up.

What are the possible risks of taking part?

There are no anticipated risks or side effects. Participation in this study will not interfere with either medical or dental treatment. During the oral examination, in the unlikely event that any abnormalities on the oral hard or soft tissues are detected, your dentist here at the practice will be able to discuss this with you.

The tooth sensitivity assessment techniques may cause you some discomfort, but this will not be any more than what you would experience during a routine dental examination or scale and polish. Any discomfort felt will be short in duration.

All procedures and assessments will be carried out by experienced and appropriately qualified dentists. Standard examining procedures and sterile oral examination instruments will be used.

Are there any benefits in taking part?

There is no direct, immediate benefit to you from taking part in this research study. However, you will have helped the dental profession gain a better understanding of factors that might influence dental health in the adult UK population.

What will happen if I don't want to carry on with the study?

You are free to withdraw from the study at any time without giving a reason. This will have no effect on your dental treatment.

What happens when the research study ends? What will happen to the results of the research study?

It is possible that the results of the study will be published in an international scientific journal. Where results of the study are published, any information about you will be anonymised as detailed in 'Confidentiality' below.

A summary of the anonymised study findings will be made available to you following the end of the whole study once the data has been analysed. This will be available to you through the Clinical Trials Unit at Bristol Dental School, please contact the study team using the contact details at the end of this information sheet for the study results.

Your anonymised data will be held within the Clinical Trials Unit at Bristol Dental Hospital and may be released in anonymised form to support other researchers in the future. Your permission to permit this will be requested if you decide to take part in the study.

Will my taking part in the study be kept confidential?

YES. All information about you will be handled in confidence.

For the purposes of the Data Protection Act the Investigator fulfils the prescribed role of data controller. Your data will be made available to the investigators, members of the ethics committee and/or employees of the competent supervisory authorities exclusively in anonymised form for the purposes of examining data. Your participation in the study will be treated as confidential, that is, any personally identifiable information recorded, for example the signed consent form, will be held and processed under secure conditions only at The Clinical Trials Department at the Bristol Dental School and Hospital. Data will be kept on file for 15 years. You will not be referred to by name in any report or publication (in a scientific journal) of the study. Your identity will not be disclosed to any person, except in the event of a medical emergency or if required by law. You may be entitled under law to access your personal data and to have any justifiable corrections made. If you wish to do so, you should request this from the investigator conducting the study.

Your anonymised data will be processed electronically to determine the outcome of this study. The data will be transferred within the UK for data processing and analysis. With your permission your anonymised data may also be released to support other researchers in the future.

What happens if something goes wrong?

If you are harmed due to someone's negligence, then you may have grounds for legal action but you may have to pay for any legal fees incurred. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this training exercise, please contact Professor Nicola West on 0117 342 9638 or the Patient Support and Complaints Team (at UHBristol) on 0117 3423604. For complaints, please email research-governance@bris.ac.uk.

Who has reviewed the study?

This study has been reviewed and given favourable ethical opinion by the London-Surrey NHS Research Ethics Committee.

Contact details

If you have any further questions concerning the study, or in case of any difficulty during the study please contact:

Primary Contact	**Secondary Contact**
Prof. Nicola West - Principal Investigator Clinical Trials Unit School of Oral & Dental Science Bristol Dental School & Hospital Lower Maudlin Street Bristol BS1 2LY Tel: 0117 342 9503	Nikki Hellin – Study Co-ordinator Clinical Trials Unit School of Oral & Dental Science Bristol Dental School & Hospital Lower Maudlin Street Bristol BS1 2LY Tel: 0117 342 9638
Emergency 24 hour contact number: 07773 579130 **e-mail: dental-clinical-trials@bristol.ac.uk**	

Thank you for reading this document.
If you have any further questions, please do not hesitate to ask.

7. Consent Form

University of BRISTOL
School of Oral and Dental Sciences
Clinical Trials Unit (Periodontology)
Bristol Dental School & Hospital
Lower Maudlin Street, BRISTOL BS1 2LY
Telephone: (0117) 342 9638
Fax: (0117) 342 4100; International: +44 117
Professor N West BDS FDS RCS PhD FDS (Rest Dent) FHEA
Professor/Honorary Consultant in Restorative Dentistry
E-mail: N.X.West@bristol.ac.uk

RESEARCH PARTICIPANT CONSENT FORM

Recession, periodontitis, dentine hypersensitivity, tooth wear and associated risk factors: An observational, cross-sectional multi-centre epidemiological study

		Please initial boxes
1	I confirm that I have read and understood the Research Participant Information Sheet dated **28th November 2018, Version 3.0** for the above study and have had the opportunity to ask questions which have been answered to my satisfaction.	
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical/dental care or legal rights being affected.	
3	I understand that data collected during the study may be looked at by individuals from the Sponsor or from regulatory authorities, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my study data.	
4	I understand that the information collected about me will be used to support other research in the future, and may be shared anonymously with other researchers	
5	I agree to pictures of my mouth may be taken to monitor ongoing calibration in the clinical assessments performed by my research dentist throughout the study.	
6	I agree to take part in the above study.	

Participant Screening Number

____

Signature of Participant	**Full name of Participant (print)**	**Date**
______________________________	______________________________	____________
Signature of Person Taking Consent	**Name of Person Taking Consent (print)**	**Date**
______________________________	______________________________	____________

8. Case Report Form

Case Report Form - Final V1a 25th Jan 2018

Case Report Form

Country Code:								
Research Site ID:								
Participant ID:								
Date of examination	D	D	M	M	Y	Y	Y	Y

Gender (please tick) Male ☐ Female ☐ Other ☐

Date of birth ☐☐/☐☐/☐☐☐☐
D D M M Y Y Y Y

Age (one digit per box) ☐☐ years

Weight ☐☐☐ kg **Height** ☐☐☐ cm

Does the participant live in a rural or urban area? *(Please tick)*

Rural ☐ Urban ☐

Tick the box which best describes the participant's current employment status:

Unemployed ☐ Student ☐

Employed manual labour ☐ Employed non- manual labour ☐

How many times has the participant seen a dentist/ hygienist in the last 12 months?

☐ Times

9. Questionnaire

Country Code ☐☐ Site code ☐☐ Participant ID ☐☐☐

Patient Questionnaire

Oral Hygiene

1 **How many times per day do you brush your teeth?** *(Please tick one box only)*

Once a day, or less often ☐ 2 times a day ☐ 3 or more times a day ☐

2 **How long do you normally brush your teeth for?** *(Please tick one box only)*

Approximately 2 minutes, or less ☐ More than 2 minutes ☐ Don't know ☐

3a **Which kind of toothbrush do you use most frequently?** *(Please tick one box only)*

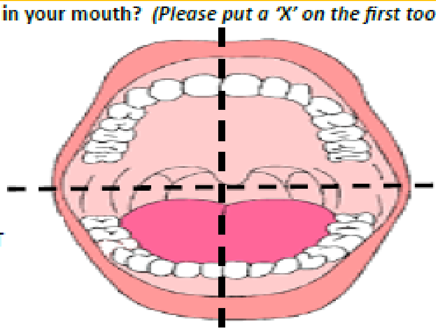
Electric toothbrush ☐ Manual toothbrush ☐

If Electric Go to Q4

3b **If you use a manual brush, which firmness of bristle do you normally use?** *(Please tick one box only)*

Soft ☐ Medium ☐ Hard ☐ Don't know ☐

4 **Where do you brush first in your mouth?** *(Please put a 'X' on the first tooth you place your toothbrush on)*



5 **When do you usually brush your teeth in relation to the following meals?** *(Please tick one box per line)*

	I don't normally brush before or after this meal	I brush before and after this meal	More than 30 min before	10-30 min before	Less than 10 min before	Less than 10 min after	10-30 min after	More than 30 min after
Breakfast								
Lunch								
Dinner								

6 **Which hand do you usually use to hold your toothbrush?** *(Please tick one box only)*

Left hand ☐ Right hand ☐ I swap between hands ☐

7 **Do you use a desensitising toothpaste (a toothpaste that is designed to reduce sensitivity in your teeth)?** *(Please tick one box only)*

Don't know ☐ No ☐ Yes ☐

8 **Do you worry that you have bad breath?** *(Please tick one box only)*

No ☐ Yes ☐

9 **Do you consider yourself to have a persistently dry mouth?** *(Please tick one box only)*

Don't know ☐ No ☐ Yes ☐

10 **Have you had braces/orthodontic treatment in the past?** *(Please tick one box only)*

Don't know ☐ No ☐ Yes ☐

Country Code ☐☐ Site code ☐☐ Participant ID ☐☐☐

Diet and lifestyle

11 On average, how many times a day do you consume <u>food or drink</u>, other than water?
(Please total the number of times you consume snacks, main meals and drinks throughout the day)

☐☐ times

12 How often do you consume the following <u>between</u> meal times? *(Please tick one box per line)*

	Less than once a week	Once a week or more, but not everyday	Once a day	Twice a day	Three or more times a day
Fresh fruit					
Pickles, tomatoes, salad dressing					
Fruit juice or smoothies					
Soft/ fizzy/ sports drinks					
Fruit infused water/ Fruit tea					
Wine/ Cider					

13 How often do you consume the following <u>at a meal time</u>? *(Please tick one box per line)*

	Less than once a week	Once a week or more, but not everyday	One meal per day	Two meals per day	Three or more meals per day
Fresh fruit					
Pickles, tomatoes, salad dressing					
Fruit juice or smoothies					
Soft/ fizzy/ sports drinks					
Fruit infused water/ Fruit tea					
Wine/ Cider					

14 How long would it usually take you to consume the following? *(Please tick one box per line)*

	I never consume it	Less than 5 min	5 – 10 min	More than 10 min
A portion of fresh fruit				
Fruit juice or smoothies				
Soft/ fizzy/ sports drinks				
Fruit infused water/ Fruit tea				

15 Do you normally have citrus fruit or fruit juice with your breakfast? *(Please tick one box only)*

No ☐ Yes ☐

16 Do you tend to swish or hold fruity/fizzy drinks in your mouth? *(Please tick one box only)*

No ☐ Yes ☐

17 Do you regularly use a straw to drink fruity/fizzy drinks? *(Please tick one box only)*

No ☐ Yes ☐

18 **Do you…** *(Please tick one box per line)*

	Yes	Occasionally	I have in the past	Never	Don't know
Smoke tobacco (cigarettes, cigars, pipes)					
Smoke e-cigarettes/vape					
Drink Alcohol					
Snore					
Take sleeping medication/antidepressants					
Chew gum					
Clench or grind your teeth					
Suffer from stress					
Suffer from heartburn/reflux/regurgitation					
Suffer from repeat vomiting					

19 On average, how often do you exercise or play sport? *(Please tick one box only)*

Less than once a week ☐ 1-2 times a week ☐ 3-4 times a week ☐ 5 times a week or more ☐

Country Code ☐☐ Site code ☐☐ Participant ID ☐☐☐

Oral Health

20a Do your gums bleed when you brush your teeth? *(Please tick one box only)*

No ☐ Yes ☐

If No, Go to Q 21a

If Yes:

19b Have you ever used anything to treat your bleeding gums at home? No ☐ Yes ☐

19c Has your dentist given you advice or treatment for your bleeding gums? No ☐ Yes ☐

21a Do you have wobbly teeth? *(Please tick)*

No ☐ Yes ☐

If No, Go to Q 22

If Yes:

21b Do your wobbly teeth affect your eating? No ☐ Yes ☐

22 Do you think your gums have shrunk or receded? (Can you see more of your tooth than you could when you were younger?) *(Please tick one box only)*

Don't know ☐ No ☐ Yes ☐

23a Do you think your teeth are showing signs of tooth wear? (Are your teeth getting shorter or thinner?) *(Please tick)*

Don't know ☐ No ☐ Yes ☐

If Don't know or No, Go to Q 24

If Yes:

23b Have you ever used anything to treat your tooth wear at home? No ☐ Yes ☐

23c Has your dentist given you advice or treatment for your tooth wear? No ☐ Yes ☐

24 Do you suffer from sensitive teeth? *(Please tick one box only)*

No ☐ Yes ☐

Thank you for completing this questionnaire. You do not need to fill out the last questions.

Please continue and fill in the final questions (Q25-33) regarding your sensitive teeth

25 These questions are about any pain or sensation from your teeth. Thinking about yourself over the last month, to what extent would you agree or disagree with the following statements:

(Please tick one answer per question)

	Strongly Disagree	Disagree	Disagree a little	Neither agree or disagree	Agree a little	Agree	Strongly Agree
Having sensations in my teeth takes a lot of the pleasure out of eating and drinking							
There have been times when I have had problems eating ice cream because of these sensations							
I have to change the way I eat or drink certain things							
I have to be careful how I breathe on a cold day							
When eating some foods I have made sure they don't touch certain teeth							
Going to the dentist is hard for me because I know it is going to be painful as a result of sensations in my teeth							
The sensations in my teeth have been annoying							
Having sensations in my teeth makes me feel as though I am unhealthy							

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Sensitivity *(Please **only** answer if you have ticked **yes** to having sensitive teeth in Q23)*

26 **How long have you been suffering with sensitive teeth?** *(Please tick one box only)*

Less than 1 year ☐ 1 to 2 years ☐ More than 2 years ☐ Don't know ☐

27 **Have you ever used anything to try to treat your sensitive teeth at home?** *(Please tick one box only)*

No ☐ Yes ☐

28 **Has your dentist given you advice/treatment for your sensitive teeth?** *(Please tick one box only)*

No ☐ Yes ☐

29 **Please tick any of the following which trigger the pain from your sensitive teeth:** *(Please tick all that apply)*

Hot food/drink ☐ Cold food/drink/ ice ☐ Sweet food/drink ☐

Cold weather (air) ☐ Touch ☐ Toothbrushing ☐

30 **On a scale of 0 - 10, how painful are your sensitive teeth?** *(Please circle one number on the scale below)*

No pain 0 1 2 3 4 5 6 7 8 9 10 Worst pain imaginable

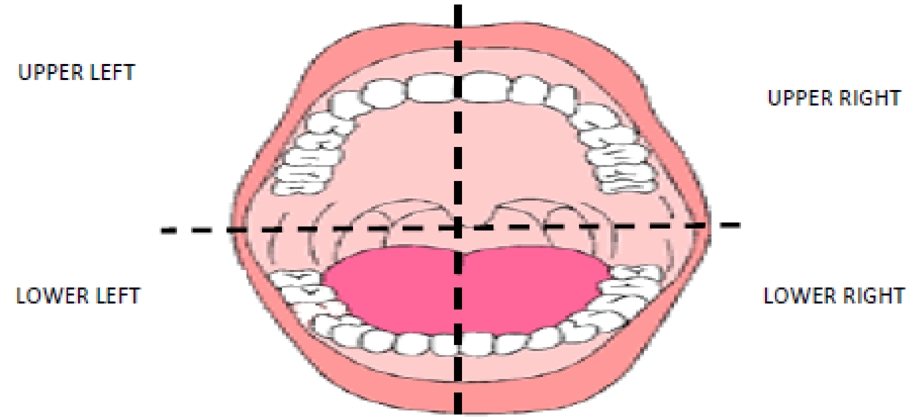
31 **How would you evaluate the intensity of the pain in your sensitive teeth?** *(Please tick one box only)*

Not important ☐ Little importance ☐ Some importance ☐ Very important ☐ Don't know ☐

32 **How much impact does the pain from your sensitive teeth have on your everyday life?**
(Please circle one number on the scale below)

No impact 0 1 2 3 4 5 6 7 8 9 10 It severely affects my quality of life

33 **Please use the diagram below to indicate which of your teeth are sensitive:**
(Put a X on your teeth which are sensitive, a member of the research team can help you fill this in if required)



Thank you for completing this questionnaire

10. Clinical Form

Country Code ☐☐ Site code ☐☐ Participant ID ☐☐☐

Clinical Form – Page 1 of 2 (BEWE, Cervical Localisation and Dentine Hypersensitivity)

Assessment Date

D D / M M / Y Y Y Y

BEWE codes [Bartlett, Ganss, Lussi, 2008] modified per tooth and on the buccal/palatal surfaces

0 No erosive wear
1 Initial loss of surface texture
2 Distinct defect, hard tissue loss < 50% of the surface area (clinical crown)
3 Hard tissue loss ≥50% of the surface area (clinical crown)

Cervical Localisation codes

0 No gingival recession, and No distinct tooth wear on crown in cervical region
1 No gingival recession, and Distinct tooth wear on crown in cervical region
2 Gingival recession with or without distinct tooth wear on root in cervical region, and No distinct tooth wear on crown in cervical region
3 Gingival recession and distinct tooth wear on root in cervical region, and Distinct tooth wear on crown in cervical region

N.B.
Distinct tooth wear= a 'step' or 'scooped-out' defect, visible to the eye and detectable when running a probe over the tooth surface
Crown = anatomical crown
Root = anatomical root

SCHIFF

0 Subject does not respond to air stimulus
1 Subject responds to air stimulus but does not request discontinuation of stimulus
2 Subject responds to air stimulus and requests discontinuation of stimulus
3 Subject responds to air stimulus, considers stimulus to be painful and requests discontinuation of stimulus

Hypersensitivity

1 Yes 0 No

			17	16	15	14	13	12	11	21	22	23	24	25	26	27
BEWE and Cervical Sensitivity Localisation codes	BEWE	Buccal														
		Palatal														
	Cervical Localisation	Buccal														
		Palatal														
Schiff (Clinician Perspective)		Buccal														
		Palatal														
Hypersensitivity (Patient Perspective)		Buccal														
		Palatal														
			47	46	45	44	43	42	41	31	32	33	34	35	36	37
BEWE and Cervical Sensitivity Localisation codes	BEWE	Buccal														
		Lingual														
	Cervical Localisation	Buccal														
		Lingual														
Schiff (Clinician Perspective)		Buccal														
		Lingual														
Hypersensitivity (Patient Perspective)		Buccal														
		Lingual														

PLEASE ENSURE THAT EVERY BOX HAS A VALUE IN IT. DO NOT LEAVE ANY BOXES BLANK.

For all conditions: X = Excluded or Missing Teeth/ Cannot determine/ Not applicable

Country Code ☐☐ Site code ☐☐ Participant ID ☐☐☐

Clinical Form – Page 2 of 2 (Periodontal Tissues)

Assessment Date

D D / M M / Y Y Y Y

Recession
Largest defect, CEJ to gingival crest:
0-9 mm (>9, record as 9+)

Probing depth
Measured at site of recession defect **or** mid-buccal/palatal site (if no recession recorded):
0-9 mm (>9, record as 9+)

Gingival Phenotype
Thick or thin gingival tissue, recorded by transparency on probing
1 Thick = probe not visible
2 Thin = probe visible

Bleeding
0 No
1 Yes

PSR (Periodontal Screening and Recording)/
BPE (Basic Periodontal Examination)

Periodontal Status *(please tick one box)*
Healthy ☐
Gingivitis ☐
Periodontitis ☐
Treated Periodontitis ☐

Periodontal Tissues	Recession	Buccal														
		Palatal														
	Probing Depth	Buccal														
		Palatal														
	Gingival Phenotype	Buccal														
		Palatal														
	Bleeding	Buccal														
		Palatal														
			17	16	15	14	13	12	11	21	22	23	24	25	26	27
			47	46	45	44	43	42	41	31	32	33	34	35	36	37
Periodontal Tissues	Recession	Buccal														
		Lingual														
	Probing Depth	Buccal														
		Lingual														
	Gingival Phenotype	Buccal														
		Lingual														
	Bleeding	Buccal														
		Lingual														

PLEASE ENSURE THAT EVERY BOX HAS A VALUE IN IT. DO NOT LEAVE ANY BOXES BLANK.
For all conditions: X = Excluded or Missing Teeth/ Cannot determine/ Not applicable

Clinical Form - Final V1.0, 9 March 2018, IRAS ID: 244298