Dental Caries Thresholds among Adolescents in England, Wales and Northern Ireland, 2013 at 12, and 15 years: Implications for Epidemiology and Clinical Care

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Abstract

Background

Dental caries is the most prevalent condition globally. Despite improvements over the past few decades, there remains a significant disease burden in childhood. Epidemiological surveys provide insight to disease patterns and trends, have traditionally focused on obvious decay which are inconsistent with contemporary clinical criteria. This study examined the distribution of dental caries in 12- and 15-year-olds in England, Wales and Northern Ireland, by severity threshold, at surface, tooth and child level and explored its association with socioeconomic, psychological and behavioural factors.

Methods

Data from 12- and 15-year-olds in the 2013 Children’s Dental Health Survey (CDHS 2013) were analysed at three levels, taking account of dental caries thresholds which involved recording both clinical decay (visual enamel caries (AV) and above) and obvious decay (non-cavitated dentine lesions (2V) and above). Negative binomial regression was used to identify factors associated with dental caries experience at both thresholds.

Results

The prevalence and severity of dental caries experience was higher among 15-year-olds at all levels. Lesions in AV were by far the most common stage of caries recorded in both ages. The average number of surfaces with obvious decay experience, which has been the traditional epidemiological threshold, in 12- and 15-year-olds was 2.3 and 3.9 respectively. The corresponding values under the clinical decay threshold were higher, at 3.9 and 5.9 respectively. Visualisation of the distribution of dental caries at surface/tooth-level exhibited left:right symmetry and to a lesser extent upper:lower. In the adjusted models for both ages, country/region, school type, area deprivation, high frequency sugar consumption and irregular dental attendance were associated with greater caries experience in both groups. Dental anxiety was inversely associated with caries experience among 15-year-olds.

Conclusion

This research highlights the importance of recognising dental caries patterns by surface, tooth and child-level amongst adolescents and the value of reporting dental caries distribution by threshold in epidemiological surveys and its relevance for clinical care. Inclusion of enamel caries reveals the extent of caries management required at a point when non-invasive care is possible, emphasising the importance of prevention in primary care.

Background

Dental caries is the most common disease in the oral cavity globally [1]. A decline in caries experience measured by the decayed, missing and filled (DMFT/S) index has occurred in high-income countries over the past five decades [2-5]. Remarkably, neither the prevalence nor incidence of untreated caries in permanent teeth has changed between 1990 and 2015 in all ages globally [1, 6, 7].

The 2013 Children’s Dental Health Survey (CDHS 2013), commissioned by the Health and Social Care Information Centre, is the fifth in a series of national surveys of children’s oral health within the United Kingdom (UK). Recognising the process of dental caries development and progression, clinical indices such as International Caries Detection and Assessment System (ICDAS) [8-11], helpfully map the profile of disease at the individual level, recognising the importance of shifting from a restorative-approach towards early management of disease [12, 13]. Informed by ICDAS, enamel caries was recorded both at visual (non-cavitated) and cavitated level for the first time in this series of national surveys in 2013. This revealed that whilst just 34% of 12-year-olds and 46% 15-year-olds had obvious decay experience (non-cavitation lesions into dentine and above), 57% and 63% of them respectively had clinical decay experience when early caries (non-cavitated enamel caries and above) was included [14, 15]. Understanding the pattern of disease is fundamental to good contemporary dental caries management which involves early identification and managing the risk of further disease [1, 16].

The aims of this study were to examine the distribution of dental caries across a range of lesion-severity thresholds in 12- and 15-year-old children in England, Wales and Northern Ireland, at surface, tooth and individual levels and its associated socioeconomic, psychological and behavioural factors.

Methods

Study population and Data collection

This study involved secondary analysis of cross-sectional data from the CDHS 2013, collected in line with the published methodology [17, 18]. Three of the four nations of the UK, England, Wales, and Northern Ireland participated in this survey. A representative sample of eligible 12- (n=2,532) and 15-year-olds (n=2,418) from secondary schools in England, Wales and Northern Ireland was examined [14]. Pupils in two countries (Wales, Northern Ireland) and in more deprived schools were oversampled to facilitate reporting by country and relative deprivation [17]. Pupils were invited to complete a questionnaire survey at the same appointment exploring a range of issues including their self-rated health, oral symptoms and problems, impact of dental health on the quality of life, behavioural habits and psychological status [17], and a high response of 99.6% was achieved [14]. All methods were carried out in accordance with relevant guidelines and regulations for the primary data collection.

Dental examinations were undertaken in school settings by 75 trained and calibrated dentists [17]. Consent for the dental survey involved a decision to ‘opt-in’ by children on the day, with the possibility for parental ‘opt-out’ in advance. Visual examination was carried out using a plane mouth mirror and ball ended CPITN probe (WHO ball-ended probes) after drying with cotton wool/gauze; no radiographs were used [17]. Dental caries is a progressive and conceptually staged disease. In support of early detection of carious lesions, visual change in enamel was recorded as caries for the first time in the 2013 CDHS survey. The criteria used were consistent with the ICDAS [10, 11, 14]. Caries assessment was undertaken by surface and coded as follows: sound (including any sub-
clinical decay); visual change in enamel (CDHS AV): ICDAS 1&2; visual enamel change with cavitation (CDHS AC): ICDAS 3; visual dentine caries (non-cavitated, CDHS 2V): ICDAS 4; cavitated dentine caries (CDHS 2C); and, decay with pulpal involvement (CDHS 3): ICDAS 5&6. In addition, filled with recurrent decay (with/without cavitation), filling needs replacement, sound fillings (F), and extracted due to caries (M) were also recorded (14, 17). Two visual detection thresholds were used to assess caries status in this research, which were presented as clinical decay (CDHS AV and above), and obvious decay (CDHS 2V and above). Decay experience in terms of these criteria includes currently and previously decayed teeth/surfaces, and were reported as $D_{AV,MFT/S}$, $D_{2V,MFT/S}$ respectively.

Data management

Key sociodemographic factors were included in this analysis as potential confounders [7, 19]. Sex (male/female) and ethnicity (white/non-white) were treated as dichotomous variables. Government Office Region was a 11-category variable, constituted by nine regions in England, plus Wales, and North Ireland. School type was grouped into three categories: independent, secondary and academy or free school. Free school meal eligibility and the index of multiple deprivation quintile [20-22], two indicators for family and contextual socioeconomic status, were used within the analysis. Toothbrushing frequency was reported as a binary categorical variable as twice a day or more versus once a day or less. Frequency of sugar intake—aggregating daily consumption of several common sugary foods and drinks (sweets, biscuits, cakes, fruits, soft drinks that contain sugar, energy/sports drinks, and fruit juice or smoothies) into a total score, then categorized into two groups: less than four times a day and four or more times a day. Because only 2.41% of participants reported having “never been to the dentist”, reason for usual dental attendance was dichotomized into regular (for a check-up) versus all the rest which is irregular (only when have trouble)/none. The Modified Dental Anxiety Scale (MDAS) was first introduced to CDHS in 2013. It consists of 5 questions each with a 5-category rating scale, ranging from ‘not anxious’ to ‘extremely anxious’. A 3-group variable derived from total MDAS score is established as self-rated dental anxiety score MDAS grouping: score 5-9 indicating low/no anxiety, 10-18 representing moderate anxiety, and 19-25 showing extreme anxiety.

Statistical Analysis

First, we calculated the distribution and composition of different stages or thresholds of dental caries (clinical and obvious decay) across the permanent dentition at surface, tooth, and child level for 12- and 15-years-olds. Second, the characteristics of participants according to relevant socio-demographic factors, behavioural and psychological factors were examined. The distribution of excluded pupils was compared with research samples in relevant variables by using Chi-square test to evaluate the impact of missing data. Complex survey design (stratification and clustering) was taken into consideration by using Negative binomial regression [17]. Third, to test the association between dental behavioural, psychological factors and caries experience (DMFS$_{AV}$ index), an unadjusted model and an adjusted model were successively built using negative binomial regression. The association of toothbrushing frequency, frequency of sugar intake, usual dental attendance, and dental anxiety with dental caries experience ($D_{AV/MFS}$) were estimated. Potential confounders including demographic status were introduced into the model to make an adjusted estimation. Rate ratios (RRs), 95% confidence intervals (95% CI) and level of significance were reported and compared in all models. All analyses were conducted using Stata/SE 15 (StataCorp LLC, College Station, TX). $P < 0.05$ was considered as statistically significant.

Results

The distribution of dental caries in the permanent dentition was presented at surface, tooth, and child level, by caries stage/threshold, for both ages examined in the national survey (Tables 1 & 2). At all three levels, the prevalence and average number of surfaces or teeth with dental caries experience was higher in 15-year-olds compared with 12-year-old children.

When considering obvious decay, the average number of decayed surfaces in 12- and 15-year-olds was only 0.99 and 1.16, respectively. The volume of recorded disease was higher when using the clinical decay threshold (which incorporated enamel caries) up to 2.74 times higher in 12- and 15-year-olds at 2.60 and 3.18, respectively.

The findings revealed that 3.32% of surfaces and 9.62% teeth in 12-year-olds, and 4.94% surfaces and 13.56% teeth in 15-year-olds had clinical decay experience ($D_{AV,MFS/T}$). 41% of the surfaces and 50% of teeth with decay-experience were enamel caries in 12-year-olds, while these proportions were lower in 15-year-olds at 32% and 41% respectively. Past decay experience, managed through extractions and fillings (missing or filled teeth), occupied a larger portion of decay experience in both age groups. It is important, therefore, to recognise the dramatic finding that by far the most frequent “stage” of lesions encountered in 12- and 15-year-olds was visual enamel caries (AV).

Dental decay prevalence by stage is presented visually by at tooth and surface in Figure 1 and Appendix 1 respectively. Occlusal surfaces of all molars, buccal surfaces of lower first molars, and then smooth surfaces of upper first molars and buccal surfaces of lower second molars were most likely to be attacked by dental caries. The level of dental caries experience was higher in 15-year-olds, most notably in first and second molars. Caries prevalence amongst lower anterior and upper canine teeth remained low.

Overall, there was generally horizontal (right/left) symmetry, and to a lesser extent, vertical symmetry. First molar teeth, which had been longest in the oral cavity exhibited comparable clinical decay prevalence of 35-39% across the four quadrants in 12-year-olds, rising to between 42 and 46% in 15-year-olds. There was little difference observed between upper/lower or left/right dentitions, merely more teeth extracted due to decay in 15-year-olds. Second molars in same dentition on both sides of the dental arch shared similar decay status with the prevalence of clinical decay experience whilst maxillary decay was lower and milder than mandibular in both age groups. Amongst pupils aged 12 years who had decayed lower second molars, only 47% of them had decayed upper second molars, this proportion increasing to 68% in 15-year-olds (Figure 1).
The distribution of clinical and obvious decay exhibited marked differences amongst the 12- and 15-year-old populations as shown in Figure 2. The average number of surfaces suffered from obvious decay experience was 2.3 in 12-year-olds and 3.9 in 15-year-olds, then this rose to 3.9 in 12-year-olds and 5.9 in 15-year-olds, when the clinical decay threshold including enamel caries was considered.

The multivariate analysis involved 1,964 12-year-old and 1,963 15-year-old pupils with complete data for all relevant variables to further explore associated factors with clinical and obvious decay experience. The characteristics of children at both ages are presented in Table 3. Behavioural and psychological factors involved in this analysis, including toothbrushing frequency, sugar intake frequency, dental attendance and dental anxiety were significantly associated with clinical and obvious decay experience in the unadjusted models at one or both ages (Tables 4&5).

After adjusting for sociodemographic factors in 12-year-olds, geographic factors relating to the country/region of England, area deprivation, free school meals, white ethnicity, remained significant, together with behavioural factors notably higher frequency sugar consumption (four or more times per day), and irregular/no dental attendance emerged as the leading risk factors for clinical decay at tooth surface level. In relation to obvious decay amongst 12-year-olds, similar patterns were present, the only differences being that school type was also significant whilst high frequency sugar consumption was not (Table 4).

After adjusting for personal and socio-economic factors in 15-year-olds, social factors relating to the country/region of England, gender, school type, behavioural factors including higher frequency sugar consumption, less frequent toothbrushing and irregular/no dental attendance emerged as risk factors for clinical decay at tooth surface level, whereas reporting moderate anxiety to be a protective factor. In relation to obvious decay, similar patterns were present, the only differences being that area deprivation was statistically significant and toothbrushing was not (Table 5).

Discussion

Summary of findings:

This study provides important insights into the pattern of dental caries at tooth surface, tooth and individual level in a high-income country where dental caries, despite a recent decline, remains the most prevalent condition in childhood. Visualisation of the distribution of dental caries at different stages of carious process across every surface of permanent dentition in 12- and 15-year-old children from England, Wales, and Northern Ireland shows the burden of disease carried by each tooth, most notably first permanent molars. Examination of two diagnostic thresholds: clinical decay which includes enamel caries and represents the criteria used by clinicians examining and providing care; and obvious decay which relates to previous epidemiological survey thresholds and is consistent with the WHO oral health surveys basic methods [23], highlights the volume of initial caries lesions (enamel caries) in these children, particularly 12-year-olds. The relative merits of using both of these thresholds have been debated in Europe and interested organisations have produced a recent “Brussels Statement” setting out the needs of modern caries epidemiology in Europe and beyond [24]. It is clear from these data that using the clinical decay threshold provides a more complete and higher representation of disease at population level, with implications for both clinical care and health policy. The findings also highlight the importance of social and behavioural factors in particular.

Epidemiology implications:

It is very clear from these findings that the threshold of reporting dental caries level is important to consider in epidemiological studies, suggesting that surveys which just focus on obvious decay seriously under-report the prevalence of disease, which increases with age cohort. If epidemiological surveys focus on code CDHS 2V (which equals to ICDAS 4) and above as the diagnostic threshold for decay [14], they will miss at least 40% of the dental caries. Enamel lesions are reversible [10]. Data on the volume of enamel caries provide an indication of great preventive opportunity [25] and should be taken into account by clinicians.

Clinical implications:

If readers consider that the majority of lesions in 12-year-olds were in enamel, this suggests that progression of much future disease could be prevented by supporting young people to increase toothbrushing, fluoride application and lower sugar consumption to recommended levels. This presents a large opportunity for prevention early in adolescence. If we do not do this, we fail the children themselves, and the healthcare system, leading to higher disease treatment and retreatment, with its associated costs for individuals and government. Implementing national guidance such as Delivering Better Oral Health [26], can support these children effectively through managing risk. Examples include behavioural changes in swapping sugar sweetened beverages and snacks for healthy snacks, as outlined in the Change 4 Life programme, particularly between meals, is important [27].

Children: patterns within the oral cavity

The number of standing teeth, particularly sound untreated teeth in childhood is the foundation of maintaining a ‘functional dentition’ through adulthood [28]. The proportions of dental caries experience that involved enamel decay in all surfaces in 15-year-olds was around 10% lower than in 12-year-olds, whilst more lesions were treated or had obvious decay. Furthermore, the prevalence, level and intensity of decay increased by age with more surfaces, teeth and children affected in this cross-sectional survey. As expected, occlusal and buccal surfaces of first molars as well as lower second molars were most effected by dental caries and either restored or in need of dental intervention. This suggests that the surface/tooth-level of caries prevalence exhibited overall symmetry. Left: right symmetry, which indicated similar propensity of decay affected for both sides of the same dentition can be observed in most tooth sites. While a sort of symmetry between upper and lower posterior sextants could be pointed out at the same time. The traditional view holds that mandibular molars are more vulnerable to dental caries comparing with their maxillary counterparts as indicated by Luan et al. [29] who conducted a ten year follow-up study among the Chinese population. Our results confirmed the same decay affected characteristic of second molars in both age populations which was in agreement with Macek’s finding [30]. Nevertheless, first molars which have been present in the oral cavity for over 6 years show little difference in临床 decay experience vertically or horizontally. Similar to our findings, Macek et al. reported that maxillary and mandibular first molars had the same post eruptive tooth age among
19.5-year-olds in U.S., thus sharing similar relative susceptibility to dental caries [30]. Batchelor and Sheiham also suggested that occlusal fissured surfaces of the first molar teeth, and buccal pits sites on lower first molars could be grouped together according to their similar caries susceptibility [31].

Interestingly, symmetry of caries prevalence does not illustrate these teeth/tooth surfaces necessarily suffered from same stages of caries simultaneously in a certain child, which hasn't been emphasized before. The proportion of pupils with decayed lower second molars who's upper second molars suffered from caries at the same time, increased from 47% in 12-years to 68% in 15-years with age cohort. It is quite possible that a tooth/surface is in a very early (subclinical) stage of caries which cannot be detected by clinical visual examination, meanwhile, its asymmetrical surface already progressed to more advanced signs (white spot or cavitation). The fact that caries occurs horizontally and certain vertically in the same type of teeth suggests that when an effect that reduces/increases the cariogenic process of one of the teeth in children, is likely to affect all the other 1 to 3 teeth as they grow older. This was supported by Batchelor and Sheiham's findings that occlusal surfaces of second molars and buccal sites on mandibular second molars were in the same group in order of caries susceptibility when 5- to 16-year-olds were involved [31]. Similar risk horizontally and differences vertically seem to reduce with increasing length of time in the oral cavity.

What do the models tell us that will support clinical care and community action. Modelling these data suggests that dental caries prevalence at surface level for clinical/obvious decay thresholds was associated with similar but not identical dental behavioural and psychological factors in two age groups, albeit that not always significant. Sugar intake frequency, one of the most recognised dental caries risk factors were proved to be related with clinical/obvious decay experience ($D_{AV/2V}$,MFS) in this research, which is consistent with the finding of 4th National Oral Health Survey in China [2], and the body of evidence reported by Moynihan and colleagues in their important systematic review [32]. The WHO strongly recommends a reduced intake of free sugars (include monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates) to less than 10% of total energy intake throughout the life-course [6], affirmed within the UK [33-35]. Toothbrushing plays an important role in delivering fluoride toothpaste and should be advised in line with current evidence [26]. Whilst attending a dentist does not necessarily prevent disease it increasingly can assist with disease prevention in young people through delivery of fluoride varnish and fissure sealants, together with advice on fluoride and diet. There remains a lack of consensus on the relationship between dental anxiety and dental caries [36-38]. Dental anxiety was reported to predict caries incidence in 15- to 18-year olds [37], but not significantly associated with dental caries experience at age 12 to 15 [36]. Interestingly, between the different age-groups examined (12- and 15-year-olds), moderate dental anxiety was verified as a strongly protective factor in this study for the first time. This may possibly be explained by the fact that these children have had a heightened awareness of dentistry and other input such as orthodontic treatment (with possible extractions due to crowding) and greater preventive input: however, this should be investigated further. Overall, these findings suggest the importance of evidence-based preventive care supported by regular dental attendance, particular if dentists are practicing preventive and minimally invasive dentistry.

Variation in the significance of the findings of the analysis could relate to the year cohort, sampling or the instruments utilized for data collection. What is clear is that the same patterns are present across both ages. Importantly the patterns and trends were similar in relation to significant or tending towards significance in both adjusted models.

The limitations of the study include the fact that it used cross-sectional data and differences between study samples and excluded samples could be found which have implications for its representativeness. None-the-less the uptake of the self-complete questionnaire survey was high and the survey was innovative in providing the opportunity to compare the data retrospectively with past surveys to document a further decline in caries [25], as well as being epidemiologically innovative. Ideally, it would be good to have longitudinal data to provide a better representation of caries trajectories, as with the Dunedin study [39].

The present findings have very important implications for public health policy, starting with epidemiology. First, initial stage of dental caries occupied almost half of decay-experienced surfaces/teeth in children according to information of CDHS 2013. Thus, if epidemiological surveys just focus on obvious decay to achieve comparability with past surveys, the findings will seriously underestimate the prevalence of disease, and provide limited insight to the planning of health interventions. Reporting dental caries levels at the clinical decay threshold is increasingly important and possible, and the methodology used by the CDHS 2013 survey can be useful to other countries and should be replicated in the UK in future surveys. Second, The volume of enamel caries in both age-groups, highlight the really important opportunity to recognise and arrest progression of these non-cavitation lesions – if they are controlled many restorations and repeated restorations will be prevented with cost savings [24, 25]. Action is required to alter children's risk of oral disease. Third, caries susceptibility follows a clear pattern with left: right symmetry, and certain upper: lower symmetry with these modest differences reducing with age. This tendency indicates high requirements of early dental interventions, i.e. pit and fissure sealing and preventive resin restoration, particularly in first molars and second molars whose asymmetrical teeth already infected by dental decay. Fourth, and finally, given the pattern of disease in society and multiple risk factors, further research needs to be addressed to explore a way of categorizing individuals into different dental caries affected patterns.

**Conclusion**

In conclusion this research highlights the importance of recognising the dental caries patterns in epidemiological surveys, and the importance of appreciating the caries process and being clear about the dental caries threshold in the population. Secondary analysis illustrates that working with and examining different caries thresholds including initial stage lesions can give better insights into the dental caries process and prevalence and can inform both clinical and preventive care.

**Abbreviations**

CDHS 2013 - 2013 Children's Dental Health Survey
ICDAS - International Caries Detection and Assessment System

UK - United Kingdom

RRs - Rate ratios

CI - Confidence intervals

Declaration

Ethics approval and consent to participate: The original survey was subject to ethical review by the University ethics committee at University College London (Project ID 2000/003). Informed Consent was obtained from parents and/or legal guardians of the minors for the primary data collection. Further ethical clearance was not required since the present study was based on a secondary analysis of data provided by the public UK data service website.

Consent for publication: Not applicable.

Availability of data and materials: The dataset supporting the conclusions of this article is available in the public UK data service website, available from: http://doi.org/10.5255/UKDA-SN-7774-1.

Competing interests: Professor Pitts was a member of the Child Dental Health Survey Consortium which undertook the Survey and is also Chair of the International Caries Detection and Assessment System (ICDAS) charity which helps to harmonise International caries criteria. Xiaozhe Wang is a reviewer of BMC Oral Health. Other authors have no competing interest to declare.

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Authors’ contributions: JEG devised the project, contributed to the research design, interpretation and writing of the paper. XZW conceptualized and designed the research, conducted the data analysis, drafted the initial manuscript, and revised the manuscript. EB contributed to the research design, conducted the data analysis and interpretation, revised the manuscript. NP and SGZ contributed to interpretation of data, and critically reviewed and revised the manuscript for content. All authors reviewed and approved the final paper.

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**Tables**

**Table 1** Dental caries distribution at surface, tooth and child levels amongst 12-year-olds a,b
Table 2 Dental caries distribution at surface, tooth and child levels amongst 15-year-olds a,b

| Distribution according to CDHS 2013 code | Surface Level | Tooth Level c | Child Level c |
|------------------------------------------|--------------|--------------|--------------|
|                                          | Sum | %   | Mean/child | S.D. | Sum | %   | Mean/child | S.D. | Sum | %   |
| Sound d                                 | 288,502 | 96.68 | 113.94 | 16.15 | 59,285 | 90.38 | 23.41 | 4.20 | 890 | 35.15 |
| Code AV-Visual change in enamel          | 3,718 | 1.25 | 1.47 | 2.79 | 2,841 | 4.33 | 1.12 | 2.02 | 431 | 17.02 |
| Code AC-Enamel change with cavitation    | 359 | 0.12 | 0.14 | 0.58 | 314 | 0.48 | 0.12 | 0.50 | 75 | 2.96 |
| Code 2V-Visual dentine caries           | 1,157 | 0.39 | 0.46 | 1.42 | 819 | 1.25 | 0.32 | 0.90 | 174 | 6.87 |
| Code 2C-Cavitated dentin caries         | 743 | 0.25 | 0.29 | 1.14 | 515 | 0.79 | 0.20 | 0.70 | 221 | 8.73 |
| Code 3-Decay with pulpal involvement    | 414 | 0.14 | 0.16 | 1.32 | 108 | 0.16 | 0.04 | 0.31 | 57 | 2.25 |
| Filled with recurrent decay             | 191 | 0.06 | 0.08 | 0.46 | 144 | 0.22 | 0.06 | 0.33 | 80 | 3.16 |
| Filling needs replacement, no decay     | 25 | 0.01 | 0.01 | 0.17 | 14 | 0.02 | 0.01 | 0.08 | 5 | 0.20 |
| Sound filling                           | 2,001 | 0.67 | 0.79 | 1.83 | 1,290 | 1.97 | 0.51 | 1.06 | 470 | 18.56 |
| Missing due to decay                    | 1,310 | 0.44 | 0.52 | 2.60 | 262 | 0.40 | 0.10 | 0.52 | 129 | 5.09 |
| Total                                   | 298,420 | 100.00 | 65,592 | 100.00 | 2,532 | 100.00 |

\[a\] Counts and proportions are unweighted.

\[b\] 2013 Children's Dental Health Survey included England, Wales, and Northern Ireland

\[c\] Codes at tooth and child level represent the worst code in each tooth and child.

\[d\] Including sub-clinical decay and lesions seen only on radiographs.
Table 3 Characteristics of 12- and 15-year-olds according to *Clinical* and *Obvious Decay* thresholds \(^a\)
| Variables                        | 12-year-olds | 15-year-olds |
|---------------------------------|--------------|--------------|
|                                 | N | Weighted % [95% CI] | Mean D$_{A_2}$MFS [95% CI] | Mean D$_{A_2}$MFS [95% CI] | N | Weighted % [95% CI] |
| Sex                             |   |                  |                             |                             |   |                  |
| Male                            | 955 | 50.97 [44.78, 57.12] | 2.74 [2.13, 3.36] | 1.32 [0.96, 1.67] | 936 | 47.94 [41.25, 54.7] |
| Female                          | 1009 | 49.03 [42.88, 55.22] | 2.99 [2.23, 3.76] | 1.66 [1.10, 2.21] | 1027 | 52.06 [45.29, 58.7] |
| Free school meal eligibility    |   |                  |                             |                             |   |                  |
| Not eligible for free school meals | 1432 | 79.02 [74.93, 82.61] | 2.41 [1.95, 2.86] | 1.11 [0.89, 1.32] | 1518 | 83.75 [79.01, 87.6] |
| Eligible for free school meals  | 532 | 20.98 [17.39, 25.07] | 4.60 [3.40, 5.80] | 2.90 [1.95, 3.85] | 445 | 16.25 [12.40, 20.9] |
| Region                          |   |                  |                             |                             |   |                  |
| London                          | 138 | 10.84 [7.03, 16.35] | 2.00 [1.12, 2.87] | 1.31 [0.48, 2.15] | 121 | 9.41 [6.79, 12.9] |
| South East                      | 122 | 16.55 [8.77, 29.04] | 1.33 [0.33, 2.33] | 0.55 [0.25, 0.85] | 108 | 16.68 [7.69, 32.4] |
| East of England                 | 123 | 11.47 [6.31, 19.97] | 2.97 [1.76, 4.18] | 1.64 [0.73, 2.55] | 105 | 11.90 [5.63, 23.4] |
| West Midlands                   | 118 | 11.45 [7.03, 18.09] | 1.71 [1.32, 2.11] | 0.98 [0.69, 1.27] | 125 | 11.97 [9.00, 15.7] |
| East Midlands                   | 79  | 8.24 [1.74, 31.34] | 3.72 [3.41, 4.03] | 1.47 [0.94, 1.99] | 82  | 7.39 [1.77, 26.1] |
| Yorkshire and the Humber        | 125 | 9.36 [5.06, 16.69] | 2.69 [2.01, 3.37] | 0.91 [0.35, 1.46] | 115 | 10.44 [5.43, 19.1] |
| North East                      | 138 | 4.65 [2.13, 9.87] | 3.42 [2.27, 4.58] | 2.15 [1.47, 2.82] | 158 | 5.10 [2.40, 10.5] |
| South West                      | 96  | 7.22 [3.80, 13.3] | 1.79 [0.31, 3.27] | 0.97 [0.34, 1.61] | 83  | 7.48 [4.19, 13.0] |
| Wales                           | 482 | 5.23 [3.37, 8.33] | 4.35 [3.74, 4.97] | 2.34 [1.73, 2.96] | 439 | 5.75 [3.58, 9.12] |
| Northern Ireland                | 170 | 11.42 [4.64, 25.47] | 5.82 [4.58, 7.05] | 3.04 [1.66, 4.43] | 188 | 10.19 [4.87, 20.1] |
| School type                     |   |                  |                             |                             |   |                  |
| Independent school              | 101 | 6.52 [2.40, 16.49] | 1.16 [0.24, 2.08] | 0.37 [0.16, 0.58] | 81  | 8.22 [2.29, 25.4] |
| Academy or free school          | 429 | 37.74 [24.75, 52.77] | 2.70 [1.97, 3.43] | 1.32 [0.93, 1.71] | 410 | 37.33 [24.85, 51.7] |
| Secondary school                | 1434 | 55.74 [39.82, 70.56] | 3.18 [2.52, 3.84] | 1.73 [1.26, 2.19] | 1472 | 54.46 [37.82, 70.1] |
| Ethnicity                       |   |                  |                             |                             |   |                  |
| White                           | 1647 | 80.83 [74.30, 86.01] | 3.08 [2.52, 3.64] | 1.62 [1.23, 2.00] | 1639 | 81.17 [75.46, 85.8] |
| Non-white                       | 317  | 19.17 [13.99, 25.7] | 1.97 [1.40, 2.53] | 0.93 [0.56, 1.30] | 324 | 18.83 [14.20, 24.5] |
| Frequency of brushing teeth     |   |                  |                             |                             |   |                  |
| Twice a day or more             | 1499 | 77.61 [73.59, 81.17] | 2.57 [2.07, 3.08] | 1.38 [1.03, 1.73] | 1545 | 80.81 [77.95, 83.3] |
| Once a day or less              | 465  | 22.39 [18.83, 26.41] | 3.88 [2.66, 5.11] | 1.86 [1.20, 2.51] | 418 | 19.19 [16.63, 22.0] |
| Frequency of sugar intake       |   |                  |                             |                             |   |                  |
| Less than four times a day      | 650  | 35.02 [30.97, 39.39] | 2.04 [1.56, 2.53] | 1.03 [0.66, 1.41] | 683 | 38.42 [34.64, 42.3] |
| Four or more times a day        | 1314 | 64.98 [60.71, 69.03] | 3.31 [2.72, 3.90] | 1.73 [1.31, 2.14] | 1280 | 61.58 [57.65, 65.3] |
Usual dental attendance \textsuperscript{b}

|                  | Attendance | Clinical decay threshold (D\textsubscript{AV}MFS) | Obvious decay threshold (D\textsubscript{2V}MFS) |
|------------------|------------|-----------------------------------------------|-----------------------------------------------|
| Regular          | 1677       | 84.55 \([81.14, 87.44]\)                      | 2.61 \([2.17, 3.05]\)                       |
|                  |            |                                               |                                               |
| Irregular/none   | 287        | 15.45 \([12.56, 18.86]\)                      | 4.27 \([2.71, 5.83]\)                       |

Self-Rated Dental anxiety score MDAS grouping

|                   | Low/no anxiety (score 5-9) | Moderate anxiety (score 10-18) | Extreme anxiety (score 19-25) |
|-------------------|----------------------------|--------------------------------|-------------------------------|
| Regular           | 551                        | 1163                           | 250                           |
|                   | 24.78 \([21.8, 28.02]\)    | 62.19 \([58.74, 65.51]\)      | 13.04 \([11.02, 15.36]\)     |
|                   | 3.52 \([2.69, 4.36]\)      | 2.52 \([1.99, 3.05]\)         | 3.26 \([2.11, 4.41]\)        |

Total

|                  | 1964 |
|------------------|------|
| Attendance       | 100  |
| Clinical decay   | 2.87 \([2.39, 3.34]\) |
| Obvious decay    | 1.48 \([1.18, 1.78]\)  |

\textsuperscript{a} Clinical decay threshold (D\textsubscript{AV}MFS) represents CDHS AV and above. Obvious decay threshold (D\textsubscript{2V}MFS) represents CDHS 2V and above.

\textsuperscript{b} Regular represents “for a check-up”, irregular/none combines “only when have trouble with teeth” and “never been to the dentist”.

\textbf{Table 4 Association of dental behaviours, diet and dental anxiety with D\textsubscript{AV}MFS and D\textsubscript{2V}MFS in 12-year-olds} \textsuperscript{a}
| Variables                                      | Clinical Decay Threshold | Obvious Decay Threshold |
|-----------------------------------------------|--------------------------|-------------------------|
|                                               | Unadjusted Model<sup>b</sup> | Adjusted Model<sup>b</sup> | Unadjusted Model<sup>b</sup> | Adjusted Model<sup>b</sup> |
|                                               | RR [95% CI]               | RR [95% CI]              | RR [95% CI]                 | RR [95% CI]                 |
| **Sex**                                        |                          |                         |                            |                            |
| Male                                          | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| Female                                        | 1.17 [1.02, 1.34]        | 1.13 [0.90, 1.42]       | 1.30 [1.08, 1.56]          | 1.16 [0.83, 1.62]          |
| **Free school meal eligibility**              |                          |                         |                            |                            |
| Not eligible for free school meals            | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| Eligible for free school meals                | 1.73 [1.49, 2.00]<sup>***</sup> | 1.55 [1.38, 2.10]<sup>**</sup> | 2.09 [1.72, 2.55]<sup>***</sup> | 2.13 [1.52, 2.99]<sup>***</sup> |
| **Region**                                    |                          |                         |                            |                            |
| London                                        | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| South East                                    | 1.01 [0.70, 1.46]        | 1.12 [0.51, 2.49]       | 0.61 [0.36, 1.02]<sup>*</sup> | 1.17 [0.54, 2.56]          |
| East of England                               | 1.46 [1.02, 2.09]        | 2.04 [1.16, 3.55]<sup>**</sup> | 1.22 [0.74, 1.99]          | 2.55 [1.16, 5.61]<sup>*</sup> |
| West Midlands                                 | 0.87 [0.60, 1.27]        | 1.26 [0.77, 2.07]       | 0.74 [0.44, 1.23]          | 1.32 [0.67, 2.62]          |
| East Midlands                                 | 2.10 [1.41, 3.15]        | 1.65 [0.97, 2.79]       | 1.95 [1.13, 3.38]          | 1.05 [0.45, 2.49]          |
| Yorkshire and the Humber                      | 1.30 [0.91, 1.87]        | 2.37 [1.44, 3.90]<sup>***</sup> | 1.02 [0.63, 1.68]          | 1.98 [0.75, 5.25]          |
| North East                                    | 1.56 [1.10, 2.22]<sup>**</sup> | 2.25 [1.32, 3.82]<sup>**</sup> | 1.49 [0.93, 2.40]          | 2.73 [1.22, 6.08]<sup>*</sup> |
| South West                                    | 0.83 [0.56, 1.24]<sup>***</sup> | 1.44 [0.63, 3.26]       | 0.74 [0.43, 1.28]          | 1.95 [0.84, 4.50]          |
| Wales                                         | 1.98 [1.49, 2.63]<sup>***</sup> | 2.85 [1.77, 4.57]<sup>***</sup> | 1.81 [1.23, 2.65]          | 3.14 [1.59, 6.20]<sup>***</sup> |
| North West                                    | 3.11 [2.24, 4.32]<sup>**</sup> | 3.09 [1.99, 4.80]<sup>***</sup> | 2.51 [1.60, 3.92]<sup>*</sup> | 3.02 [1.65, 5.51]<sup>***</sup> |
| Northern Ireland                              | 2.59 [1.94, 3.46]        | 3.11 [1.78, 5.43]<sup>***</sup> | 2.94 [1.99, 4.35]<sup>*</sup> | 4.72 [2.25, 9.89]<sup>***</sup> |
| **School type**                                |                          |                         |                            |                            |
| Independent school                            | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| Academy or free school                        | 1.51 [1.07, 2.11]<sup>*</sup> | 1.42 [0.73, 2.76]       | 2.87 [1.75, 4.72]<sup>***</sup> | 1.87 [1.23, 2.85]<sup>**</sup> |
| Secondary school                              | 2.11 [1.54, 2.90]<sup>*</sup> | 1.39 [0.63, 3.07]       | 4.86 [3.04, 7.77]<sup>***</sup> | 1.93 [1.21, 3.09]<sup>**</sup> |
| **Index of multiple deprivation quintile**    |                          |                         |                            |                            |
| 80%-100% Least deprived                       | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| 60%-80%                                       | 1.30 [0.99, 1.70]        | 1.21 [0.78, 1.87]       | 1.27 [0.88, 1.85]          | 1.22 [0.79, 1.90]          |
| 40%-60%                                       | 1.46 [1.12, 1.90]<sup>***</sup> | 2.00 [1.35, 2.98]<sup>***</sup> | 1.93 [1.34, 2.77]<sup>***</sup> | 3.05 [1.87, 4.98]<sup>***</sup> |
| 20%-40%                                       | 1.82 [1.41, 2.34]<sup>**</sup> | 1.47 [0.97, 2.24]       | 2.28 [1.61, 3.22]<sup>***</sup> | 2.28 [1.28, 4.06]<sup>**</sup> |
| 0-20% Most deprived                           | 2.26 [1.79, 2.86]<sup>***</sup> | 2.29 [1.57, 3.33]<sup>***</sup> | 2.96 [2.15, 4.09]<sup>***</sup> | 3.83 [2.39, 6.12]<sup>***</sup> |
| **Ethnicity**                                  |                          |                         |                            |                            |
| White                                         | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| Non-white                                     | 0.75 [0.62, 0.90]<sup>*</sup> | 0.66 [0.50, 0.88]<sup>**</sup> | 0.56 [0.43, 0.72]<sup>*</sup> | 0.50 [0.33, 0.77]<sup>**</sup> |
| **Frequency of brushing teeth**               |                          |                         |                            |                            |
| Twice a day or more                           | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| Once a day or less                            | 1.51 [1.03, 2.22]<sup>*</sup> | 1.26 [0.95, 1.66]       | 1.35 [0.86, 2.11]          | 1.19 [0.87, 1.64]          |
| **Frequency of sugar intake**                 |                          |                         |                            |                            |
| Less than four times a day                    | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]           | 1.00 [Reference]           |
| Four or more times a day                      | 1.62 [1.23, 2.13]<sup>***</sup> | 1.38 [1.06, 1.78]<sup>*</sup> | 1.67 [1.07, 2.62]<sup>*</sup> | 1.32 [0.83, 2.09]          |
| **Usual dental attendance**                   |                          |                         |                            |                            |
| Group                  | Regular | Low/no anxiety (score 5-9) | Moderate anxiety (score 10-18) | Extreme anxiety (score 19-25) |
|-----------------------|---------|---------------------------|-------------------------------|-------------------------------|
|                      | 1.00    | 1.00                      | 0.78                          | 1.16                          |
|                      | [Reference] | [Reference] | [0.67, 0.91]* | [0.93, 1.45] |
| Irregular/none        | 1.73    | 1.51                      | 0.81                          | 1.43                          |
|                       | [1.44, 2.08]** | [1.11, 2.05]** | [0.62, 1.05] | [0.61, 1.06] |
|                      | 1.95    | 0.78                      | 0.78                          | 1.43                          |
|                       | [1.52, 2.51]** | [0.64, 0.96]* | [0.64, 1.06] | [1.06, 1.93] |
|                      | 1.95    | 0.81                      | 0.77                          | 0.77                          |
|                       | [1.32, 2.88]*** | [0.56, 1.18] | [0.47, 1.26] | [0.47, 1.26] |

Self-Rated Dental anxiety score MDAS grouping

*a DAVMFS (CDHS AV and above) represents decay experience according to clinical decay threshold. D2VMFS (CDHS 2V and above) represents decay experience obvious decay threshold.

*b Unadjusted and full-adjusted Negative binomial regression models were fitted, rate ratios (RR) were reported.

*c Regular represents “for a check-up”, irregular/none combines “only when have trouble with teeth” and “never been to the dentist”.

*p < 0.05; ** p < 0.01; *** p < 0.001.

Table 5 Association of dental behaviours, diet and dental anxiety with DAVMFS and D2VMFS in 15-year-olds *
| Variables                          | Clinical Decay Threshold | Obvious Decay Threshold |
|-----------------------------------|--------------------------|-------------------------|
|                                   | Unadjusted Model b       | Adjusted Model b        | Unadjusted Model b | Adjusted Model b |
|                                   | RR [95% CI]              | RR [95% CI]             | RR [95% CI]       | RR [95% CI]     |
| **Sex**                           |                          |                         |                   |                 |
| Male                              | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Female                            | 1.19 [1.05, 1.35]        | 1.24 [1.02, 1.50]       | 1.36 [1.17, 1.58] | 1.32 [1.01, 1.72] |
| **Free school meal eligibility**  |                          |                         |                   |                 |
| Not eligible for free school meals| 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Eligible for free school meals    | 1.49 [1.29, 1.73]**      | 1.14 [0.87, 1.48]       | 1.68 [1.40, 2.01]** | 1.22 [0.94, 1.59] |
| **Region**                        |                          |                         |                   |                 |
| London                            | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| South East                        | 1.17 [0.82, 1.68]        | 1.18 [0.73, 1.91]       | 0.90 [0.58, 1.40] | 1.27 [0.63, 2.55] |
| East of England                   | 0.88 [0.61, 1.27]        | 1.62 [0.60, 4.35]       | 0.59 [0.37, 0.93] | 1.32 [0.50, 3.49] |
| West Midlands                     | 0.96 [0.68, 1.37]        | 1.53 [0.79, 2.97]       | 0.96 [0.63, 1.48] | 1.58 [0.87, 2.88] |
| East Midlands                     | 2.04 [1.39, 2.99]        | 2.19 [1.38, 3.47]**     | 1.59 [0.99, 2.54] | 1.57 [0.91, 2.69] |
| Yorkshire and the Humber          | 1.25 [0.87, 1.77]        | 2.43 [1.18, 5.03]*      | 0.83 [0.54, 1.29] | 1.90 [0.95, 3.80] |
| North East                        | 1.66 [1.20, 2.31]        | 2.58 [1.51, 4.42]**     | 1.56 [1.05, 2.33] | 2.97 [1.71, 5.18]** |
| South West                        | 1.31 [0.89, 1.93]        | 2.63 [1.09, 6.32]*      | 1.04 [0.65, 1.68] | 2.28 [1.11, 4.66]* |
| Wales                             | 1.73 [1.31, 2.29]**      | 2.79 [1.79, 4.36]**     | 1.59 [1.13, 2.23]* | 2.74 [1.64, 4.57]** |
| North West                        | 2.44 [1.78, 3.34]**      | 2.91 [1.97, 4.29]**     | 1.81 [1.23, 2.66] | 1.91 [1.16, 3.14]** |
| Northern Ireland                  | 2.48 [1.87, 3.27]**      | 3.63 [2.33, 5.67]**     | 2.76 [1.96, 3.87]** | 4.42 [2.67, 7.31]** |
| **School type**                   |                          |                         |                   |                 |
| Independent school                | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Academy or free school            | 2.19 [1.54, 3.11]*       | 1.84 [0.87, 3.90]       | 3.43 [2.16, 5.44]** | 2.04 [1.21, 3.47]** |
| Secondary school                  | 3.41 [2.45, 4.75]**      | 2.13 [0.99, 4.59]*      | 6.40 [4.13, 9.92]** | 2.38 [1.36, 4.15]** |
| **Index of multiple deprivation quintile** |                  |                         |                   |                 |
| 80%-100% Least deprived quintile  | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| 60%-80%                           | 1.25 [0.98, 1.61]        | 1.41 [0.91, 2.17]       | 1.19 [0.87, 1.62] | 1.58 [1.02, 2.44]* |
| 40%-60%                           | 1.33 [1.04, 1.70]        | 1.43 [0.87, 2.34]       | 1.55 [1.14, 2.09] | 1.71 [1.01, 2.90]* |
| 20%-40%                           | 1.52 [1.21, 1.92]*       | 1.38 [0.96, 1.99]       | 1.69 [1.27, 2.26]* | 1.72 [1.21, 2.44]** |
| 0-20% Most deprived quintile      | 1.93 [1.55, 2.39]*       | 1.55 [0.98, 2.44]       | 2.20 [1.69, 2.88]** | 2.11 [1.30, 3.42]** |
| **Ethnicity**                     |                          |                         |                   |                 |
| White                             | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Non-white                         | 0.79 [0.67, 0.93]        | 1.01 [0.73, 1.38]       | 0.70 [0.57, 0.86] | 0.85 [0.60, 1.21] |
| **Frequency of brushing teeth**   |                          |                         |                   |                 |
| Twice a day or more               | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Once a day or less                | 1.36 [1.07, 1.73]**      | 1.26 [1.01, 1.56]*      | 1.40 [0.99, 1.97]* | 1.20 [0.91, 1.60] |
| **Frequency of sugar intake**     |                          |                         |                   |                 |
| Less than four times a day        | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Four or more times a day          | 1.57 [1.22, 2.03]**      | 1.42 [1.13, 1.78]**     | 1.75 [1.36, 2.24]** | 1.54 [1.20, 1.99]** |
| **Usual dental attendance** c      |                          |                         |                   |                 |
| Regular                           | 1.00 [Reference]         | 1.00 [Reference]        | 1.00 [Reference]  | 1.00 [Reference] |
| Irregular/none                    | 1.82 [1.54, 2.15]**      | 2.18 [1.58, 3.00]**     | 2.05 [1.67, 2.52]** | 2.75 [1.95, 3.87]** |
| **Self-Rated Dental anxiety score MDAS** |          |                         |                   |                 |
| Grouping | RR (95% CI) | P-value |
|----------|------------|---------|
| Low/no anxiety (score 5-9) | 1.00 [Reference] | 1.00 [Reference] | 1.00 [Reference] | 1.00 [Reference] |
| Moderate anxiety (score 10-18) | 0.93 [0.82, 1.07]*** | 0.73 [0.60, 0.89]** | 0.87 [0.74, 1.02]*** | 0.68 [0.53, 0.87]** |
| Extreme anxiety (score 19-25) | 1.28 [1.05, 1.57] | 0.99 [0.76, 1.30] | 1.39 [1.09, 1.79] | 1.06 [0.77, 1.46] |

*a* D₄AV,MFS (CDHS AV and above) represents decay experience *according to clinical decay* threshold. D₂V,MFS (CDHS 2V and above) represents decay experience *obvious decay* threshold.

*Unadjusted and full-adjusted Negative binomial regression models were fitted, rate ratios (RR) were reported.*

*c* Regular represents “for a check-up”, irregular/none combines “only when have trouble with teeth” and “never been to the dentist”.

*p < 0.05; ** p < 0.01; *** p < 0.001.*