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Exponential tooth decay curve

N P Monaghan

Public Health Wales, Capital Quarter 2, Cardiff CF10 4BZ

Objective: A review of the distribution of $d_3$mft scores for Wales was undertaken to inform decisions on future reporting of decay experience. Visual examination of data from one survey suggested that caries in Wales is distributed along an exponential decay curve. ***Basic Research Design:*** Weighted $d_3$mft data from 2007/8, 2011/12 and 2014/15 was utilised. The data was compared with a pragmatically chosen exponential decay model. Distribution curves for $d_3$mft were plotted for each data set, correlation coefficients calculated and residuals plotted. ***Results:*** The three surveys demonstrate similar exponential decay distributions across the range of $d_3$mft scores. Plots of each curve against the exponential decay model demonstrated close correlation (0.9826 – 0.9871). The progressive shift of these similarly shaped curves suggest similar levels of caries reduction across the spectrum of caries experience and thus improved oral health without widening of health inequality. The close fit with this simple mathematical model suggests that caries prevalence could be used to generate a theoretical distribution and thereby and estimate of mean $d_3$mft score. Such an approach could facilitate simplified oral health surveillance in areas where caries distributions are known from previous surveys. ***Conclusions:*** Within Wales caries does seem to be distributed in line with an exponential decay curve. As a result decay prevalence and mean $d_3$mft are mathematically related. This finding may have potential to support simplified local oral health surveillance. The data provides evidence suggesting improvements in caries experience in Wales are not at the expense of increased inequality.

Key words: *Dental caries/epidemiology; DMF Index; Models, statistical*

Introduction

George Box, a statistician, stated "All models are wrong, but some are useful" (Box, 1976). A visual examination of 5 year old caries data from the 2014/15 NHS dental survey in Wales suggested that the caries experience of children is distributed along an exponential decay curve. This paper explores this finding and proposes an exponential decay model for the distribution of caries. The relationship between caries prevalence and severity provides potential opportunities for simplified oral health surveillance where caries is distributed in this manner.

Method

Weighted data on $d_3$mft scores by child from 3 dental surveys of school year 1 children (aged 5 to 6) in Wales were collated. The number of children examined was 7,100 in 2007/08 (Davies *et al*., 2011); 7,734 in 2012/13 (Monaghan *et al*., 2014) and 7,716 in 2014/15 (Jones *et al*., 2017). Data from these three surveys were used because they all used the same approach for data collection in terms of diagnostic criteria and consent arrangements.

For each survey the data distribution by number of carious teeth per child was tabulated (i.e. the percentage of children with no caries experience, with 1 carious tooth, with 2 carious teeth, etc.). The resulting caries experience for each survey (for children with at least 1 caries affected tooth) was then plotted as a curve. There were differences in caries prevalence across the three surveys reflecting improvements in oral health over time. However the data from each survey also showed that approximately one in four of the children with visually obvious caries had a $d_3$mft = 1. Visually the caries distribution appeared to follow an exponential decay distribution.

As a simple model of the caries distribution, theoretical exponential decay curves based upon the reported caries prevalence and $d_3\text{mft}n = 0.25 \times 0.75^{(n-1)}$ for n = 1 to n = 20 (reflecting up to 20 deciduous teeth) were calculated for each of the three surveys and compared with the actual distribution from each survey. Correlation coefficients were calculated to measure the relationship between the actual caries distribution and this simple model. Following this further analysis was undertaken to see how accurately $d_3$mft scores could be predicted from caries prevalence data for Wales, Scotland and England for these surveys.

Results

The fall in caries prevalence in Wales between 2007/08 and 2014/15 is demonstrated by the data distribution curves in Figure 1. The figure visually demonstrates falls in the proportion of examined children with caries across the spectrum of $d_3$mft scores over this period. Figures 2, 3 and 4 compare the findings from the distribution of $d_3$mft scores of the 2007/08, 2011/12 and 2014/5 surveys with the curves generated from the formula $d_3\text{mft}n = 0.25 \times 0.75^{(n-1)}$ for the $d_3$mft prevalence reported in each of the three surveys.

Comparing the exponential decay curve with the survey data, all three surveys demonstrated a visually close fit. Exponential regression analysis using Microsoft Excel demonstrated that the curves are similar but not identical:

Correspondence to: nigel.monaghan@wales.nhs.uk

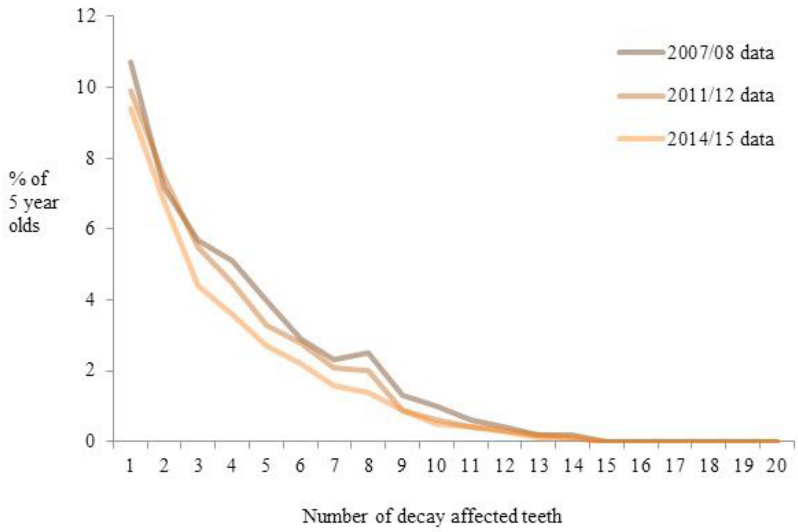

Figure 1. Distribution of caries experience for three surveys of five-year-olds in Wales

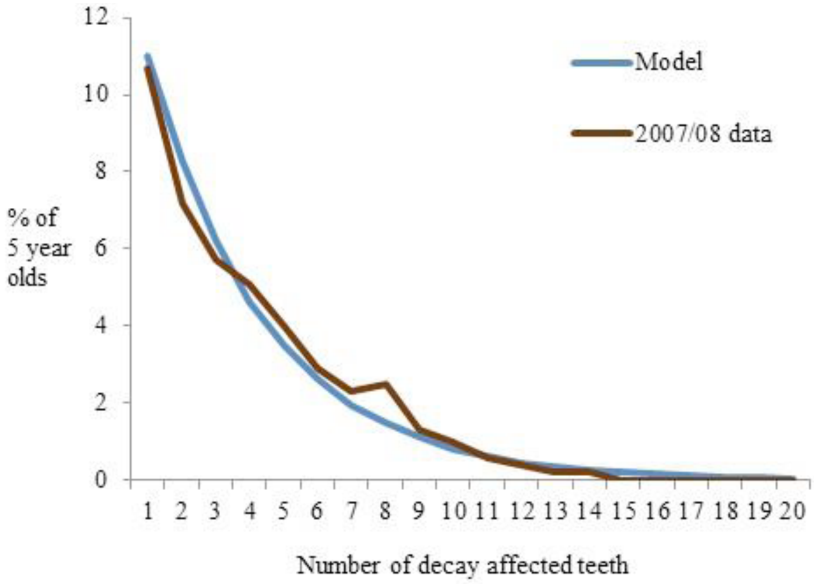

*Figure 2. Comparing decay experience in 2007/08 with simple exponential decay model**

**model assumes that ¼ of those with decay have 1 decayed tooth and subsequent decay scores are ¾ of the previous score*

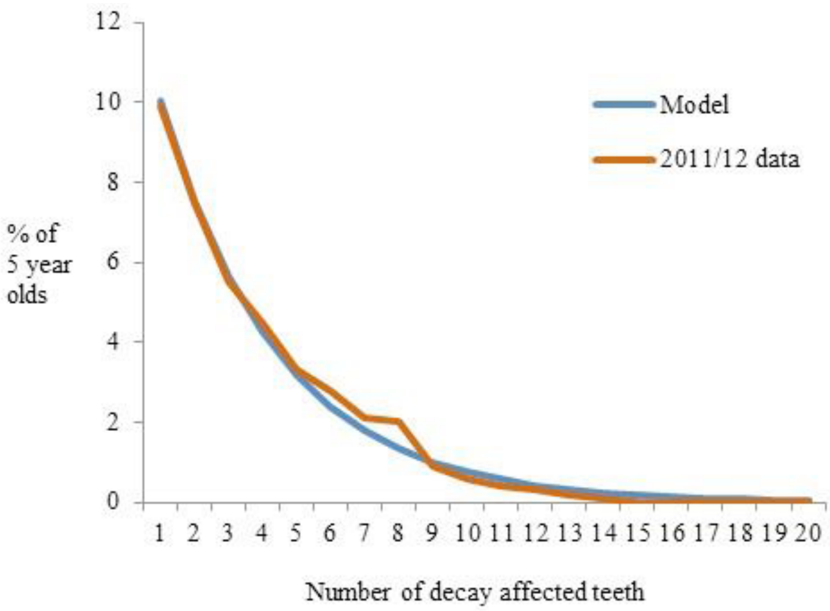

*Figure 3. Comparing decay experience in 2011/12 with simple exponential decay model**

**model assumes that ¼ of those with decay have 1 decayed tooth and subsequent decay scores are ¾ of the previous score*

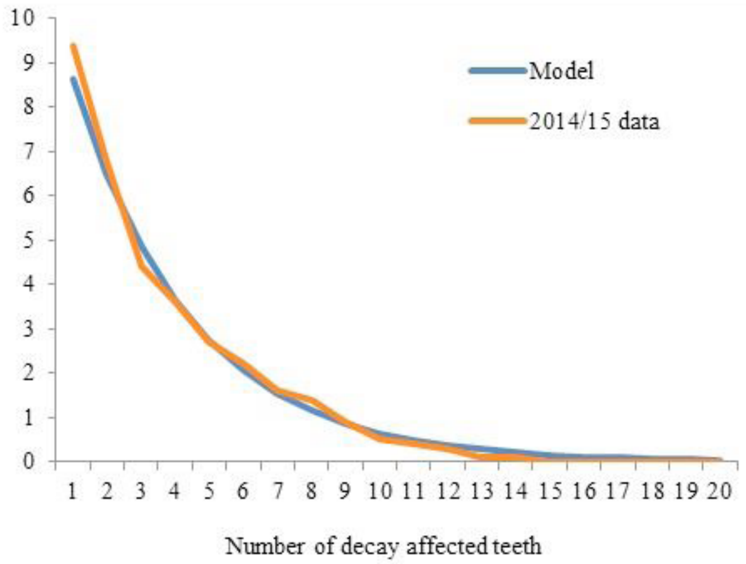

*Figure 4. Comparing decay experience in 2014/15 with simple exponential decay model**

**model assumes that ¼ of those with decay have 1 decayed tooth and subsequent decay scores are ¾ of the previous score*

- 2007/08 $\log_{10} y = 1.2346 - 0.1304x$
- 2011/12 $\log_{10} y = 1.2489 - 0.1468x$
- 2014/15 $\log_{10} y = 1.2548 - 0.1628x$

Closeness of fit of the model with the three surveys was then explored statistically. The Pearson correlation coefficient for the three curves gave the following results:

- 2007/08, $r = 0.9826$
- 2011/12, $r = 0.9871$
- 2014/15, $r = 0.9865$

These findings suggest that the model is a close fit with the actual distribution of caries amongst 5 year olds in these three surveys. Plots of the residuals had just 14 data points on each plot, and there were no clear patterns emerging on these plots.

Ideally the next step would have been to plot actual caries distributions elsewhere. Without access to the datasets from Scotland and England the pragmatic approach was to plug the reported prevalence of caries for the last 3 surveys in Wales, Scotland, England and the North West of England into the $d_3mft n = 0.25 \times 0.75^{(n-1)}$ model. The North West Region of England has been the benchmark for measurement of dental caries in Wales because of similar levels of decay in the past. The estimated proportion of children with 1, 2, 3,... teeth permits calculation of an estimated $d_3$mft score. The resulting estimates were within:

- 0.09 of the reported d3mft score in Wales (range -0.05 to +0.09)
- 0.09 of the reported d3mft score in Scotland (range -0.09 to 0.00)
- 0.09 of the reported d3mft score in the region of North West England (range -0.01 to 0.09)
- 0.17 of the reported d3mft score for England as a whole (range 0.13 to 0.17)

Discussion

There does seem to be a close relationship between caries prevalence and the distribution of caries for data from Wales. Dental caries among 5 year olds in Wales appears to be distributed according to an exponential decay pattern, and can be modelled using $d_3mft n = 0.25 \times 0.75^{(n-1)}$. The seeming ability of this model to estimate mean $d_3$mft score in Scotland and the North West of England suggests that there is an exponential decay distribution curve present in these data sets. This is despite the limitations of the survey data and different consent approaches (Davies *et al*., 2011; Monaghan *et al*., 2011). Plotting the actual caries distributions in Scotland and North West England could test this hypothesis. Conversely the lack of ability to predict mean levels of caries in England using caries prevalence indicates the limitations of an approach using the model from Wales.

Most analyses of oral health inequalities use population socio-economic deprivation scores to assess inequality by social deprivation of the home neighbourhood (Riley *et al*., 1999; Steele *et al*., 2014). This is appropriate to underpin arguments about addressing social inequality as a means of tacking oral health inequality. The caries distribution curves in this paper are directly demonstrating inequality in caries experience. The three curves in figures 2 to 4 are associated with progressively decreasing $d_3$mft scores and are all similar to the same mathematical curve. The caries distribution curve is being progressively shifted to the left, demonstrating improvements in caries in Wales are being seen equally across the $d_3$mft score spectrum. The improvement in caries experience in Wales is not associated with increased caries experience inequality. This finding is in line with previous analysis findings that used the Welsh Index of Multiple Deprivation as a measure of social inequality (Farnell *et al*., 2017).

Caries data in Wales inform the child poverty targets (Welsh Government 2010), and the public health outcomes framework (Welsh Government and Public Health Wales 2016). Given the relationship between the caries prevalence and mean $d_3$mft scores in Wales, and non-normal distribution of $d_3$mft data, there is now a shared opinion in Wales that caries prevalence should be the preferred measure of dental caries. It may take some time to implement this change.

The World Health Organisation define public health surveillance as "... the continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public health practice. Such surveillance can serve as an early warning system for impending public health emergencies; document the impact of an intervention, or track progress towards specified goals; and monitor and clarify the epidemiology of health problems, to allow priorities to be set and to inform public health policy and strategies" (WHO 2017).

Surveillance programmes can and should escalate and de-escalate the data collected according to circumstances (Briand *et al*., 2011). More detail is collected when needed, for example when new disease emerges and comprehensive assessment is needed to clarify the problem. A smaller data set is typically collected for both early warning and monitoring a pandemic. The analyses in this paper present an opportunity for simplified oral health surveillance in Wales. If the caries distribution can be predicted reasonably accurately from known caries prevalence, then caries surveillance data could be limited to identification of whether a child has visually obvious decay or not. This could shorten the time needed to collect epidemiology in the field and in data cleaning, analysis and reporting. This would only apply so long as the caries distribution model applies. This could be piloted for alternate surveys in Wales, allowing some simplified surveillance but allowing ongoing checks to be undertaken to ensure that the model remains appropriate.

Conclusions

Within Wales caries does seem to be distributed in line with an exponential decay curve which demonstrates a degree of stability over time. This provides evidence suggesting improvements in caries experience in Wales are not at the expense of increased inequality. This finding also has potential to support simplified local oral health surveillance in areas where this type of relationship can be demonstrated.

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