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The use of cost-utility analysis for the evaluation of caries prevention: an exploratory case study of two community-based public health interventions in a high-risk population in the UK

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Background: Economic evaluations are important tools for decision makers to determine the best allocation of resources in a healthcare system. This study explored the use of economic evaluation in oral health promotion. ***Methods:*** A literature review identified oral health promotion programmes that measured both the health impact and costs of oral health interventions. A decision analysis model was constructed to examine the cost utility of preventing dental caries in 5 and 12-year-old children via tooth brushing schemes and fluoride varnish programmes. The costs per child that would be justified according to the National Institute for Health and Care Excellence's threshold of £20,000 per QALY were calculated. ***Results:*** The analysis showed that NICE would consider that the expenditure of £55 per child on supervised tooth brushing, or £100 per child on fluoride varnish application would give sufficient health benefits to be justified according to their threshold. ***Conclusions:*** Greater attention needs to be paid to the collection of robust data on costs for oral health promotion. Dental researchers also urgently need to collect outcome data in a form that can be translated into a Quality of Life measure, so that the true cost effectiveness and value for money achieved through the prevention of dental disease can be recognised and compared to other allocations of resource.

Key words: *Caries, dental health attitudes, community based study, prevention, analysis, economics*

Introduction

The NHS spends £3.4 billion a year on primary and secondary dental services treating adults and children in England (NHS England, 2015), yet economic analysis of interventions preventing oral disease are rare. To date, there are few published economic evaluations of the cost-effectiveness of community-based interventions to promote oral health (Coffin *et al*, 2013), and none that utilize the concept of quality-adjusted life years (QALYs) or health state utility.

The UK Government has made a commitment to oral health and dentistry and there is currently a drive to improve the oral health of the population, particularly children (HMSO, 2010; Public Health England, 2014). While population oral health in England has improved significantly in recent decades, national data show marked regional differences for oral disease among children at 5 and 12 years old, with levels highest in areas described as being socially and economically deprived (Public health England, 2013a, 2013b). Poor oral health impacts the nation in terms of population health and wellbeing (Global Burden of Disease Collaboration, 2013) and NHS resources, as tooth decay is the most common reason for hospital admissions in young children (Health and Social Care Information Centre, 2013). Dental treatment for children under general anaesthesia (GA) can also be associated with a risk of life-threatening complications (Royal College of Anaesthetists, 2013).

Dental care services face challenges in closing the projected 2021/22 funding gap of £30 billion across the NHS as a whole (NHS England, 2015). With increased constraints placed on healthcare budgets, consideration of the economic impact in decision-making about new and existing health interventions has increased in importance. Since 2013, local authorities have been responsible for implementing public health programmes and are required to promote oral health in the local population (NHS Bodies and Local Authorities 2012). Local authorities use a range of approaches to maximise the value of investment, including using pooled budgets, collaborative commissioning across organisations and geographies, and cost-benefit analysis tools (Public Health England, 2014). One means of determining the economic impact of an intervention is to develop a decision analytic model to predict the health outcomes and health care costs associated with it (Drummond *et al*, 2005). NICE suggests public health recommendations be based on 'the balance between the estimated cost of each intervention and the expected health benefits' (NICE, 2012). Cost-utility analysis is the gold standard in evaluations of other healthcare interventions. When using this method, health outcomes are measured using QALYs to provide a common outcome so that different health care interventions can be compared. The aim of this paper is to describe two economic evaluations within the context of promoting oral health.

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The study utilises two case studies. A cost-utility analysis was used to assess the outcomes of the interventions described in the case studies, namely fluoride varnish and supervised tooth brushing, among 5 and 12 year olds in England at high risk of oral disease (those living in relatively deprived areas). The two interventions selected were the only two shown to be effective in reducing caries in a NICE systematic review. These case studies highlight the challenges of using the cost-utility methodology in the context of oral health due to gaps in the available evidence, and areas for future research are suggested.

Methods

Cost-effectiveness evidence

In addition to the systematic review of the effectiveness of community-based oral health promotion interventions, an additional literature search was undertaken to identify any economic evaluations (studies that captured both the cost and health impact) of oral health promotion programmes.

This review found that a range of approaches have been taken towards economic evaluations in oral health, including costings of a range of interventions, including provision of fissure sealants, fluoride additives (varnish, gel, toothpaste). However, of the 16 studies, 11 were judged to have potentially serious limitations and three were judged to have very serious limitations, based on the criteria of the Quality Appraisal Checklist (NICE, 2012). As such, it was concluded that there is little robust evidence about the economic value of community-based oral health promotion programmes to promote oral health in England.

Cost-Utility Analysis of supervised tooth brushing and fluoride varnish

A decision analytic model was therefore developed to estimate the reduction in expenditure on dental treatment and improvement in Quality of Life that would come about if oral health in high risk children was improved by community-based programmes delivering either supervised tooth brushing or fluoride varnish applications. The NICE systematic review of evidence about oral health improvement programmes had indicated that tooth brushing and fluoride varnish were the only interventions with sufficient effectiveness data to justify undertaking an economic analysis (Bazian, 2014). The model was designed to be in accordance with NICE public health guidance development insofar as it was possible to do so, given the paucity of evidence (NICE, 2012). The perspective considered was that of the public sector in the UK, where health promotion interventions costs are incurred by Local Authorities, and the treatment costs by the NHS.

Patient charges for dental treatment were excluded from this analysis. Figure 1 illustrates the steps in the model construction.

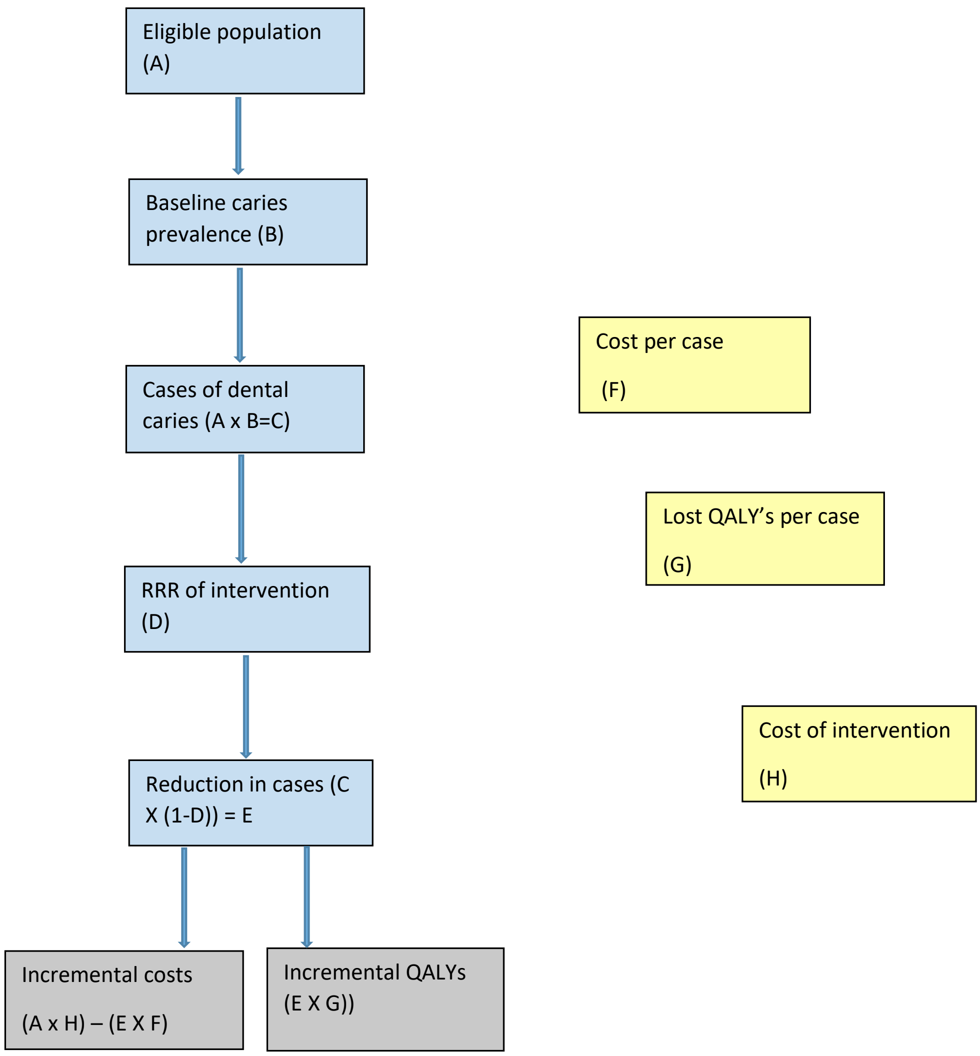

Figure 1. *Flow diagram of inputs to modelling*

Levels of tooth decay in children receiving no intervention were derived from the national prevalence rates for caries. The relative effect of each intervention was applied to this baseline rate to estimate caries levels in a hypothetical intervention population. The acute impacts of dental caries were as far as possible quantified and were assigned to the proportion of children who had experienced caries. The outcomes model was related specifically to the short-term impacts on oral health and did not capture all of the long-term consequences, since no longitudinal studies on lifetime effects of tooth decay were identified.

Caries Risk

The baseline risk of caries in each age group in a population not receiving an intervention was derived from national data. Caries prevalence (%dmft/DMFT>0) and dental service use (%m/M>0, %f/F>0). Data were derived from the Dental Public Health Epidemiology Programme data base. The most deprived quintile (by IMD) was used to represent a high-risk population (Department of Communities and Local Government 2010). These data showed that, in England, caries prevalence in the most deprived quintile is 39.6% for 5-year olds and 42.4% for 12-year olds. This is substantially higher than the prevalence in the least deprived quintile: 17.5% among 5-year olds and 25% 12-year olds.

Among those with caries, the proportion who had had extractions in the most deprived quintile was double that observed among those in the least deprived quintile: 13.91% versus 6.5 % for 5-year olds; 13.46% versus 6.6% for 12-year olds. Among those with caries, the proportion with fillings was 20.94% for 5-year olds and 53.8% for 12-year olds in the most deprived quintile. This is lower than the figures observed for those in the least deprived quintile: 24.6% for 5-year olds and 66.8% for 12-year olds.

Effectiveness of interventions

In order to estimate the level of tooth decay in the population receiving an intervention, the relative treatment effect for the intervention was obtained from the published studies (Macpherson *et al*, 2013, Jackson *et al*, 2005, Pine *et al*, 2007, Moberg *et al*, 2005). Two of the identified studies were solely based on children at high risk of caries in areas of social deprivation (Jackson *et al*, 2005, Pine *et al*, 2007). The other two studies were based on mixed populations and outcomes were reported by deprivation category, with outcomes for the most deprived sector selected for use in the analysis (Macpherson *et al*, 2013, Moberg *et al*, 2005) The relative risk reductions (RRR) in caries were calculated using the data from these studies. To estimate the level of tooth decay in a population receiving an intervention, the RRR was applied to the baseline caries prevalence (39.6% in 5-year olds and 42.4% in 12-year olds). For supervised tooth brushing, the RRR for 5-year olds was 38% (Macpherson *et al*, 2013) and for 12-year olds 10.9% and 39% (Pine *et al*, 2007). For fluoride varnish, the RRR (preventative fraction) for 12-year olds was 69% (Moberg *et al*, 2005). This figure was also used in the model of 5-year olds.

Quality of Life (QoL):

The QALY is routinely used by the National Institute for Health and Care Excellence (NICE) in economic evaluations and incorporates the impact of an intervention on health in terms of both quantity and quality of life (QoL) (NICE, 2012). The QALY loss associated with the development of caries was determined by considering the temporary reduction in QoL encountered during a spell of acute toothache and a tooth extraction plus the morbidity risk from general anaesthetic (GA)

However, utility estimates for the impact of toothache and extraction were not available from the literature. Therefore, utility estimates for acute otitis media (a middle ear infection which also involves acute pain and hospital admissions) were used as an approximation of the impact of tooth decay when it causes pain and a need for hospitalisation. Three such utility estimates were found in the published literature: 0.72 (Oh *et al.*, 1996), 0.79 (Coco, 2007) and 0.882 (Dakin, 2010).

The total QALY loss caused by tooth decay was derived by estimating the reduction in QoL caused by acute pain and hospital admission and from the possibility of mortality from a GA for tooth extraction (see Table 1). The analysis assumed that the disutility of tooth loss through extraction impacted for a duration of 12 weeks. Lifetime impact of tooth loss was not considered in the analysis because no suitable data were available. For 5 year olds, missing teeth were assumed to have been extracted under GA. For 12 year olds missing teeth were assumed to have been extracted, with varying proportions, under GA.

Table 1 displays the series of calculations used to obtain an estimate for the average QALY loss per child with caries, using the proxy data from studies of the disutility of otitis media (OM). The disutility estimate for otitis media from Oh *et al* (1996) was used to calculate the QALY loss from tooth extraction. Applying the same calculation, but using the utility estimate from the two other OM studies provided QALY loss values of 0.004 and 0.0019. A range of values for QALY loss per child having a tooth extraction, were therefore modelled, from 0.002 (low) to 0.007 (high) for caries, in order to ensure that the model accounted for the uncertainty about how disutility values measured for otitis media mapped onto the experience of toothache and extraction. The average QALY loss per extraction was then weighted by the proportion of children with caries who have an extraction experience.

NHS Treatment Costs:

Costs to the NHS of treating a decayed tooth were estimated by taking into account two elements. First, costs associated with an extraction were estimated. All extractions in five-year olds and variable proportions of extractions in 12-year olds were assumed to be under GA. The cost of an inpatient tooth extraction was estimated to be £1,165 per extraction (PSSRU, 2014). The remaining tooth extractions were assumed to take place under local anaesthetic, and it was assumed that, in accordance with best practice, all carious teeth would be removed when a child was given GA for tooth extraction. The model also included the cost of restorations, where the overall cost of filling a decayed tooth takes into account that fillings have a finite lifespan and will be replaced. This was calculated by converting the median survival time of the restoration (Burke *et al*, 2005) into an annual probability of failure (requiring further dental treatment). The costs of each restoration were based on a unit of dental activity costing £25 in primary care. To estimate the lifetime cost of a restoration, each restoration was assumed to be replaced by a more complex restoration (Elderton, 2003). Future costs were discounted at 1.5%.

Table 1. Calculation of QALY loss

Parameter	*Value*	*Calculation/comment/source*
Baseline utility	0.94	General population utility for under 25s (Dolan *et al.*, 1995)
Disutility of extraction (estimated from OM)	0.72	(Oh *et al.,* 1996)
Duration of disutility (weeks)	12	Assumption
QALY loss for extraction	0.0509	Difference between disutility of decayed and extracted tooth (20), multiplied by the time for which pain/extraction impacted acutely = (0.94-0. 72)*(12/52)
Proportion of extractions under GA	100%	Assumption
Mortality rate of GA	0.0003335	1 in 300,000 - assumption
QALY loss if death	40	Estimated from the number of QALY's that would be lost, assuming an average lifespan and utility estimates for the general population. Future QALYs discounted at 1.5%.
Expected QALY loss from GA extraction	0.00013	The QALY loss weighted by the probability of death and proportion of extractions under GA =100%*0.000333%*40
QALY loss from a extraction	0.0509	Incorporates the disutility of tooth extraction and loss due to the mortality risk of GA = 0.058 (disutility of tooth extraction (see above) +0.00013 (disutility of GA (see above)
Children with caries who have extraction experience	13.91%	Extracted from Dental Public Health dataset
Mean QALY loss per child with caries	0.0071	0.0509*13.91%

To take into account that not all decayed teeth receive restorative or extraction treatment, the proportion of extractions per decayed tooth, and the proportion of restorations per decayed tooth (the proportion of children with m/M> 0 and F<0) were used to calculate treatment costs per decayed tooth.

Intervention Costs:

Intervention costs (i.e. the cost of the preventative programmes) were rarely reported in any oral health studies (Collin *et al.*, 2013). It was therefore not possible to accurately cost any intervention, so an alternative approach was taken, calculating the maximum cost per child per intervention (for the length of time the child is in the programme), for the intervention to be considered cost-effective at a QALY threshold of £20,000, (the value used by NICE in economic evaluations) (NICE, 2012). The results are presented in Tables 1-4. The studies used for this analysis reported reduction in risk at three years, so the maximum cost is the cost of being in the programme for 3 years

Results

Results are presented for a range of QALY loss assumptions based on the different disutility estimates for acute toothache and extraction (low = 0.002, medium = 0.005, high = 0.007) and different costs of treating tooth decay (£175-£225). This allows for a range of estimates for the maximum intervention cost per child to be considered.

Table 2 shows that spending £55 per child on supervised tooth brushing or £100 per child for fluoride varnish could be considered cost-effective at the NICE threshold, for children aged 5 years in most deprived quintile in England. This assumes that 100% of all extractions occur under GA, the cost of restoration is £225, and that QALY loss from tooth extraction is high. If QALY loss from tooth extraction is low and cost of treatment is £175, supervised tooth brushing needs to cost less than £32 per child and fluoride varnish less than £59 per child to be considered cost-effective.

Table 3 shows that spending £23 per child for tooth brushing interventions that reduce caries risk by 11% among 12-year olds in the most deprived quintile in England may be justifiable on the basis of £20,000 per QALY, assuming that the resultant extractions are commonly (80%) carried out under GA, QALY loss is high and cost of treatment is £350. If the extraction rate under GA drops to 50%, the QALY loss is low and cost of treatment is £150, spending £9 or less per child would be considered cost effective. However, if the relative risk reduction for caries when supervised tooth brushing takes place is 39%, at maximum GA rates, maximum QALY loss and maximum cost of treatment, spending £81 per child would be justified at the NICE £20,000 per QALY threshold.

Table 4 shows that spending £129 per child on fluoride varnish would be considered cost effective at the NICE threshold of £20,000/QALY for the most high-risk 12-year olds in England, in whom baseline caries risk is 42.2%, assuming 50% of extractions occur under GA, QALY loss is high and cost of treatment is £300. If the rate of extractions under GA is 80%, the intervention may cost up to £143 per child.

Table 2. Cost-effectiveness of interventions for children age 5 years in the most deprived quintile in England

Children age 5 years in most deprived quintile in England: baseline risk 39.62%		
Study	*QALY loss*	*Cost effective for max cost intervention**
Childsmile RRR 38% (Macpherson et al., 2013)		*Over one year*
100% extractions under GA	Low=0.002	£32-£40
	Med=0.005	£41-£49
	High=0.007	£47-£55
Fluoride varnish RRR 69% (Moberg et al., 2005)		*Over 3 years*
100% extractions under GA	Low=0.002	£59-£72
	Med=0.005	£75-£89
	High=0.007	£86-£100

* Assumes cost of caries to NHS is between £175-£225

Table 3. Cost-effectiveness of supervised toothbrushing for school children in the most deprived quintile in England

Children aged 12 years in most deprived quintile in England: baseline risk 42.4%		
Study	*QALY loss*	*Cost effective for maximum cost intervention**
Supervised tooth brushing RRR 11% (Jackson, 2005)		*Over one year*
50% extractions under GA	Low=0.002	£9-£16
	Med=0.005	£12-£19
	High=0.007	£14-£21
80% extraction under GA	Low	£11-£18
	Med	£14-£21
	High	£16-£23
Supervised tooth brushing RRR 39% (Pine, 2007)		*Over one year*
50% extractions under GA	Low=0.002	£31-£56
	Med=0.005	£41-£66
	High=0.007	£48-£73
80% extractions under GA	Low	£40-£64
	Med	£50-£74
	High	£56-£81

* Assumes cost of caries to NHS between £150-£300 for 50%, £200-£350 for 80%

Table 4. Cost-effectiveness of fluoride varnish for school children in the most deprived quintile in England

Children age 12 years in the most deprived quintile in England; baseline risk 42.4%		
Fluoride varnish RRR 69%	*QALY loss*	*Cost effective for maximum cost intervention**
50% extractions under GA	Low=0.002	£56-£99
	Med=0.005	£73-£117
	High=0.007	£85-£129
80% extractions under GA	Low	£70-£114
	Med	£88-£132
	High	£99-£143

*Range in maximum cost refers to minimum and maximum cost of caries. Assumes cost of caries is between £150-£300 for 50%, £200-£350 for 80%

If QALY loss is low, cost of treatment is £150, and the proportion of extractions under GA is 50%, spending up to £56 per child would be considered cost effective.

Discussion

Cost-utility analysis is one of the main methods for appraising healthcare programmes and has a crucial role in allocating scarce resources. However, its use in oral health is extremely limited. For oral health programmes to compete with other public health programmes for resources, it is vital that sufficient and appropriate data about the impact of caries are available in order to enable QALY-based analyses.

The current analysis aimed to evaluate the economic impact of two oral health programmes using established methods for assessing the cost effectiveness of disease prevention. There were several limitations associated with the analysis, most notably regarding the lack of evidence. As such, the model was designed around five key parameters to reduce the uncertainty around the model outcomes. These included baseline risk of caries, effectiveness of the intervention reported as the RRR of dental caries, QALY loss from each case, cost of treating each case and intervention cost per child. The analysis shows that supervised tooth brushing, or fluoride varnish may be cost cost-effective interventions for children aged 5 and 12 years with a high baseline risk of caries, under a wide range of scenarios. The analyses derived in this economic model focused on the acute and quantifiable impacts on QoL that occur if caries in children is not prevented; i.e. pain and hospital admission (common occurrences in small children) or the cost and unpleasantness of restoration.

It is almost two decades since it was first suggested that economic models are needed to inform appropriate decisions about resource allocation in dental public health, (Kay and Locker, 1997) yet these types of analyses have been slow to evolve because relevant data to build and construct such models for dentistry have either not been collected or remain unpublished. These are key areas where robust and detailed data are urgently needed. There is a lack of data on the impact of tooth decay on QoL, or the impact of increased caries intensity i.e. number of affected teeth per mouth. The present analysis used acute otitis media utility measurements as a proxy for the effect on QoL of hospital admissions for an operative procedure to relieve pain, but it is not known whether this over or underestimates the impact of tooth decay and consequences. Further research is needed to directly measure QALY loss from acute toothache to confirm the assumption that acute toothache would affect a child's quality of life as significantly as otitis media.

Improved oral health outcomes are achievable in the long term, but require sustained investment and collaborative working to allow the benefits to be realised. Adopting a longer-term horizon for this analysis would have allowed for the benefits of the intervention to be more carefully captured. As such, the analysis is conservative, and potential cost savings may be underestimated. However, insufficient data on the long-term impact of the interventions and the fact that no longitudinal studies estimating the lifetime effect of such programmes on caries development exist, prevented a longer time frame being robustly modelled.

Another area for research requiring urgent attention is in the detailed reporting of intervention costs. For the few studies of oral health promotion that reported such costs, the level of detail provided was often insufficient to inform proper economic analysis. A recent cost analysis of a supervised tooth brushing programme in Scotland reported the estimated total cost of the programme, and noted that costs varied from area to area (Anopa *et al*, 2015). Studies of caries prevention need to report unit cost, and cost per child to run the programme (such as for administrators, nurses) and their associated on-going costs (such as travel expenses); in addition set-up costs of the programme, including staff training, recruitment advertising and overheads need to be assessed and reported.

A further area of concern was the appropriateness of the measures of effectiveness currently and traditionally used in caries prevention programmes. Clinical measures such as DMFS/dmft, preventative fraction, caries prevalence etc, are commonly used to report the impact of interventions. Failure to report the magnitude of the effects (such as relative risk or odds ratio) makes it difficult to directly compare different interventions. Researchers and authors should be encouraged to include outcomes that can readily be translated into utilities, and therefore QALYs.

In addition, where DMFS and DMFT are reported, they should ideally be disaggregated, with the mean change in DT and DS, MT, and FT and FS over the study period presented for each intervention under investigation.

In conclusion, economic modelling and cost utility studies are increasingly important in health policy making and resource allocation. It is, therefore, essential that primary studies of oral health interventions ensure they include adequate and appropriate information. This would include as a minimum, a measured disease impact, and data reported in terms of reduction in relative risk rather than reduction in DMF, plus appropriate costings in the outcome data. All direct and indirect costs, staff and administrative time, as well as material resources should be reported.

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