Appendix E – Economic Modelling

A Markov model was constructed to evaluate the health and resource consequences of different recall intervals. A Markov model is a special type of decision tree that is used where events can occur or reoccur at any point over a long period of time (Beck and Pauker, 1983). When an event can occur at many different points in time, a probability tree would become complex, with many pathways and it would require the collection of a very large number of probabilities. A Markov model overcomes this problem by simply assuming that the event (or state) in each time period is determined probabilistically on the basis of the state in the previous period but is independent of the path taken in periods prior to that. Hence a Markov model is represented by a diagram that shows the transmission between health states from one period to another, as in Figure 1, rather than the whole pathway. Markov models have been used in dental caries research for some years (Lu, 1970).

Our model differed from the HTA Report model in the following respects:

> **For each strategy there was a Markov chain of 272 *three-month* cycles.**[2]

> **The model distinguishes between teeth that are DMF and those that are DMF-free, as did the HTA report model. However within DMF it distinguishes between those that have dentine caries, those that are are missing and those that are filled. More importantly, within DMF-free it distinguishes between teeth that are caries-free and those that have enamel caries. [See Figure 1]**

> **It was assumed that if enamel caries were detected during an OHR then the dentist could arrest or reverse the caries by the next cycle, effectively changing the tooth's status back to caries-free.**

> **The number of teeth that are reversed depends on**

- **the efficacy of the dentist (assumed to be 100% in the base case model);**
- **the accuracy (sensitivity and specificity) of the dentist in diagnosing enamel caries; and**
- **the frequency of the OHR, because more carious teeth will be detected (and reversed) at the enamel caries stage.**

> **The measure of oral health is DMFT-years rather than the number of teeth that are DMF-free at age 80. In addition to DMFT-years, we calculated quality-adjusted tooth-years (QATYs) (Birch 1986). Unlike DMFT, QATYs weight different tooth states according to the preferences of patients, this means, for example, that filled teeth are given a greater value than missing or decayed teeth but less value than a sound tooth.**

> **Given that the current level of NHS fees are under review and are unlikely to reflect the real cost of an oral health review, the costs of OHRs and treatment were incorporated in terms of the amount of dentists time (measured in minutes rather than pounds sterling). Cost-effectiveness is therefore measured in terms of the minutes of dentists' time per DMFT-year saved.**

[2] In the HTA Report model, the length of a cycle varied according to the recall interval being assessed. This difference is minor and does not affect the results of the analyses.

All of the model's base case parameters and their sources are given in Table 1.

The estimate of the duration of an OHR was taken from a recent NHS time and motion study. The upper confidence limit (15.8 minutes) rather than the mean (11.3 minutes) was chosen because, under the new arrangements, the proposed OHR will be more comprehensive and will take longer than the current dental examination. The estimate of the duration of a caries treatment session was taken from the same study.

The data on restoration survival and diagnostic accuracy were extracted from systematic reviews. It is possible that these estimates are optimistic, as a number of the contributing studies were carried out under optimal research conditions rather than in routine practice.

Dentists' time and tooth years were both discounted at the discount rates required by the Treasury for UK government evaluations.(HM Treasury 2003)

The quality-adjustments (or utilities) for different tooth states were taken from Fyffe and Nuttall (1992) and were the mean values elicited from 110 members of the Scottish general public using the standard gamble technique.

Estimating both the caries incidence and progression rates was problematic. For the progression rate we found a dated but comprehensive review (Pitts 1983). Given the lack of evidence, for our base case analysis we took an estimate that was the mid-point between the review and a recent Finnish study (Mejare et al. 1999; Pitts 1983). The rationale for this decision is that the two studies were conducted at different times corresponding to different 'eras' in the rate of progression of caries. The 1983 paper is a review of the literature on caries progression from many countries at a time when disease progression was more rapid and hence is probably an over-estimate. The Finnish study, by contrast, was conducted (1999) when the rate of progression of dental caries had slowed, in a country known to have a lower incidence of caries than England and Wales, and is more likely to give an under-estimate. We took the same approach with estimating the enamel caries incidence, a less commonly reported statistic. As the only relevant British study was in children and exhibited much higher rates than could be sustained in adults, again the mid-point between this and the Finnish study was used (Brabner et al. 1995). Tooth loss rates were derived from a study of molars in Scottish teenagers and had been used in a previous Markov analysis (Kay and Nuttall, 1993).

Results

For the base case assumptions, Table 2 shows the health outcomes, resource use and cost for each recall interval under consideration. As recall intervals are reduced step by step from 36 months to 3 months, there is a gradual improvement in health outcome, a decrease in the number of fillings but a net increase in the amount of dentists' time.

Table 3 shows how the incremental cost-effectiveness ratio increases as recall intervals get shorter and shorter. This means that as we continue to reduce the recall intervals from 36 months, dental health does continue to improve but this is at a greater and greater relative opportunity cost in terms of dentists' time. Hence for average patients, only if we are prepared to spend a lot of dentists' time per tooth-year saved would shorter recall intervals be justified.

Table 4 shows how the optimal strategy for patients would be different for patients in different risk subgroups. For this analysis we a) vary the threshold of minutes per DMFT-year saved (the maximum amount of time society is prepared to invest to save one DMFT-year), as this is not known; and b) represent subgroups indirectly as indicated by the relative risk for caries incidence and progression compared with the overall population. The top panel of this table (along with Table 2 and Table 3) is contingent on the clinical reversal rate being 100%. If we were to assume a clinical reversal rate of only 50%, there is a marked lengthening of the optimal recall intervals for each risk group (bottom panel of Table 4).

The other sensitivity analyses are presented in Table 5 for two recall interval comparisons. The results were not very sensitive to the following model parameters:

> **The duration of a treatment session**
> **Enamel caries incidence**
> **Sensitivity of dentists in detecting carious lesions**
> **Restoration survival**
> **Discount rate.**

However the results are relatively sensitive to:

> **The duration of an OHR**
> **Progression rate (from enamel to dentine)**
> **Specificity of dentists in detecting dentine lesions**
> **Clinical efficacy**

Limitations of the model

An overall optimal recall interval could not be estimated with any precision because:

> **The cost-effectiveness threshold (the maximum amount of time society is prepared to invest to save one DMFT-year or one QATY) for England and Wales has not been defined.**
> **The level of clinical efficacy (in reversing enamel caries) is not known.**
> **The estimates of the other model parameters were imprecise and often measured for specific populations. This lack of precision is particularly important where the model's results were found to be sensitive to changes in a specific model parameter (like, for example, the duration of an oral health review).**

For the base case we assumed that all enamel caries observed during an OHR would be reversed. Clearly this is optimistic because such efficacy depends on other factors such as the co-operation of the patient in taking on health promotion advice and also because some of the carious lesions would be reversed even in the absence of the OHR. However, it does not necessarily mean that clinical effectiveness has been over-estimated because the OHR could have contributed to a decrease in the caries incidence rate in addition to arresting lesions already present in the enamel.

The overall progression of caries appears to be substantially quicker in this model than in the HTA report model. For example with 36 monthly recall intervals the number of teeth that are DMF-free at age 80 are 4 and 12 respectively. One explanation might be the general imprecision or lack of generalisability in the baseline parameter estimates of both models. Another possible explanation is the omission of a spontaneous reversal / arrest rate for dentine caries within our model. This was omitted due to lack of empirical estimates. Interestingly, although the absolute numbers of DMFT differ between the models the incremental numbers between recall intervals are quite similar.

The prevention of dental caries was the only aspect of oral health captured by the model. Furthermore, the main health outcome measures (DMFT-years, and QATYs) may not fully capture health gain even within caries. More sophisticated outcomes have been developed but the transmission probabilities between states are even harder to ascertain.

Although, the impact of a patient's relative risk (for caries incidence and progression) on cost-effectiveness was assessed, it was not possible to explicitly compare the cost-effectiveness of each recall interval for different patient subgroups because of the lack of precision in the model parameters.

Implications of the model

Contingent on the assumptions and data used, the model implies the following:

In general as dental recall intervals become shorter, the cost savings in terms of reduced time spent in treating caries will only partially offset the extra time associated with the oral health reviews. This is consistent with the published evidence on recall intervals [See 2.4]. However, if OHRs were to reduce the incidence of caries as well as reverse existing enamel caries then overall cost savings could be possible. A Swedish study (Melkersson and Olsson

1999) using Poisson regression analysis on longitudinal data has suggested that for children with poor oral health, frequent visits to the dentist lead to fewer visits as an adult (and presumably better oral health). Therefore for this group narrower recall intervals could be cost saving.

As dental recall intervals become shorter, oral health (DMFT-years avoided) improves. (This is of course contingent on the assumption about a high clinical reversal rate – if clinical efficacy is in reality much lower or if dentists are much less specific in detecting dentine caries then shorter recall intervals will be harmful because healthy teeth will be filled unnecessarily).

The model shows it to be both more effective and more cost-effective to have shorter recall intervals in patient subgroups with high caries risk and longer recall intervals in patient subgroups with low caries risk. This assumes dentists ability to reverse or arrest enamel caries is similar for high- and low-risk groups.

Comparisons with other studies

To decide which recall intervals represent good value for money, it would be useful to compare the cost-effectiveness figures in Table 4.4 with those for other oral health interventions. No other study has estimated cost-effectiveness in terms of the dentists time per DMFT-year saved, however two studies have measured the cost per DMFT-year saved.

One study predicted the benefits and costs of water fluoridation for hypothetical populations, which were differentiated by the proportion of high-risk children (Akehurst et al. 1993). They used a 'value' of £10 per dmft/DMFT averted in their calculations; however, it was not clear how this was derived. They concluded that water fluoridation was the most cost-effective strategy in caries prevention; however, it seems unclear whether this was really evidence-driven.

Another study estimated the cost-effectiveness of administering school milk and water fluoridation for the prevention of dental caries in the UK (Calvert et al. 2000). With fluoridated milk provided over 10 years, high caries risk children would benefit by 5.47 dmft/DMFT years saved and low caries risk children would benefit by 1.49 years. The model estimated 60% and 54% reductions in dmft/DMFT at 8 and 14 years of age with water fluoridation for high caries area and 40% and 34% reductions in dmft/DMFT for low caries area. The cost-effectiveness ratio for milk fluoridation was estimated to be between £57.91 and £69.50 per dmft/DMFT year saved for low caries areas and between £15.84 and £19.00 for high caries areas. The estimates for water fluoridation varied from £2 to £38 per dmft/DMFT year saved.

Our base case estimates seem comparable to these figures, however, given the uncertainty around the model parameters and especially clinical efficacy, conclusions about the relative cost-effectiveness cannot be drawn.

TABLE 1: Model parameters

MODEL PARAMETER		BASE CASE ESTIMATE	SOURCE
Dentist time (minutes)			
OHR		15.8	(Bearne et al. 2000)
Filling		25.5	(Bearne et al. 2000)
Incidence rates (3 months)			
Incidence of enamel caries	P1	2.1%	(Brabner et al. 1995; Mejare et al. 1999)
Progression rate (enamel to dentine)	P2	3.1%	(Mejare et al. 1999; Pitts 1983)
Progression rate (dentine to missing)	P7	2.0%	Kay and Nuttall (1993)
Progression rate (filled to missing)	P8	0.5%	Kay and Nuttall (1993)
Accuracy			
Sensitivity (enamel caries)	P3	66%	(Bader et al. 2001a)
Sensitivity (dentine caries)	P4	63%	(Bader et al. 2001a)
Specificity (dentine caries)	P5	89%	(Bader et al. 2001a)
Clinical efficacy			
Reversal rate	P6	100%	Assumed (subject to sensitivity analysis)
Restoration survival (years)			
Median survival		12	(Chadwick et al. 2001) [as used in HTA report]
Discount rates			
0-30 years		3.5%	(HM Treasury 2003)
Beyond 30 years		3.0%	(HM Treasury 2003)
Tooth quality weightings			
No caries or enamel caries		1	Assumed
Missing		0	Assumed
Dentine caries		0.49	Fyffe and Kay (1992)
Filled		0.70	Fyffe and Kay (1992)

TABLE 2: Model outcomes for base case

DENTAL RECALL INTERVAL	3 months	6 months	12 months	18 months	24 months	36 months
Undiscounted results						
Health outcome (at age 80)						
Teeth at age 80	19.2	18.4	17.2	16.2	15.3	13.8
DMFT-free teeth at age 80	10.8	9.7	7.9	6.6	5.7	4.3
Quality-adjusted teeth at age 80	16.7	15.8	14.4	13.3	12.3	10.9
Health outcome (overall)						
Tooth years	1672	1649	1607	1569	1535	1476
DMFT-free tooth years	1238	1184	1096	1028	973	892
Quality-adjusted tooth-years (QATYs)	1542	1509	1452	1404	1362	1292
Resource use						
Number of OHRs	272	136	68	46	34	23
Number of fillings	48	51	56	60	61	65
Time cost						
Hours – OHRs	72	36	18	12	9	6
Hours – fillings	20	22	24	26	26	28
Total hours	92	58	42	38	35	34
Results discounted at 3.5% (3% after 30 years)						
Health outcome						
DMFT-free tooth years	**571**	**555**	**530**	**510**	**494**	**469**
Quality-adjusted tooth years (QATYs)	**663**	**654**	**639**	**626**	**614**	**594**
Time cost						
Total hours	**35**	**22**	**16**	**14**	**13**	**12**

TABLE 3: Incremental cost-effectiveness
(as recall intervals are shortened from 36 months to 3 months) – base case analysis

	INCREMENTAL TIME (MINUTES) PER DMFT-YEAR SAVED (DISCOUNTED)	INCREMENTAL TIME (MINUTES) PER QATY GAINED (DISCOUNTED)
From 36 months to 24 months	2	4
From 24 months to 18 months	3	7
From 18 months to 12 months	5	11
From 12 months to 6 months	15	29
From 6 months to 3 months	52	105

TABLE 4: Optimal recall interval (months), by cost-effectiveness threshold and caries relative risk

CARIES RELATIVE RISK	COST-EFFECTIVENESS THRESHOLD: MINUTES PER DMFT-YEAR SAVED						
	1	2	4	8	16	32	64
Assuming 100% clinical reversal rate							
0.25	36	36	36	36	36	24	18
0.50	36	36	36	24	18	12	6
0.75	36	36	24	12	12	6	6
1.00	**36**	**24**	**18**	**12**	**6**	**6**	**3**
1.25	36	24	18	12	6	6	3
1.50	36	24	12	12	6	3	3
1.75	36	36	12	6	6	3	3
2.00	36	36	12	6	6	3	3
Assuming 50% clinical reversal rate							
0.25	36	36	36	36	36	36	24
0.50	36	36	36	36	18	12	6
0.75	36	36	36	24	12	6	6
1.00	**36**	**36**	**36**	**18**	**12**	**6**	**3**
1.25	36	36	36	18	12	6	3
1.50	36	36	36	18	6	6	3
1.75	36	36	36	24	6	6	3
2.00	24	24	24	24	6	6	3

TABLE 5: Sensitivity analysis – Incremental time (minutes) per DMFT-year saved

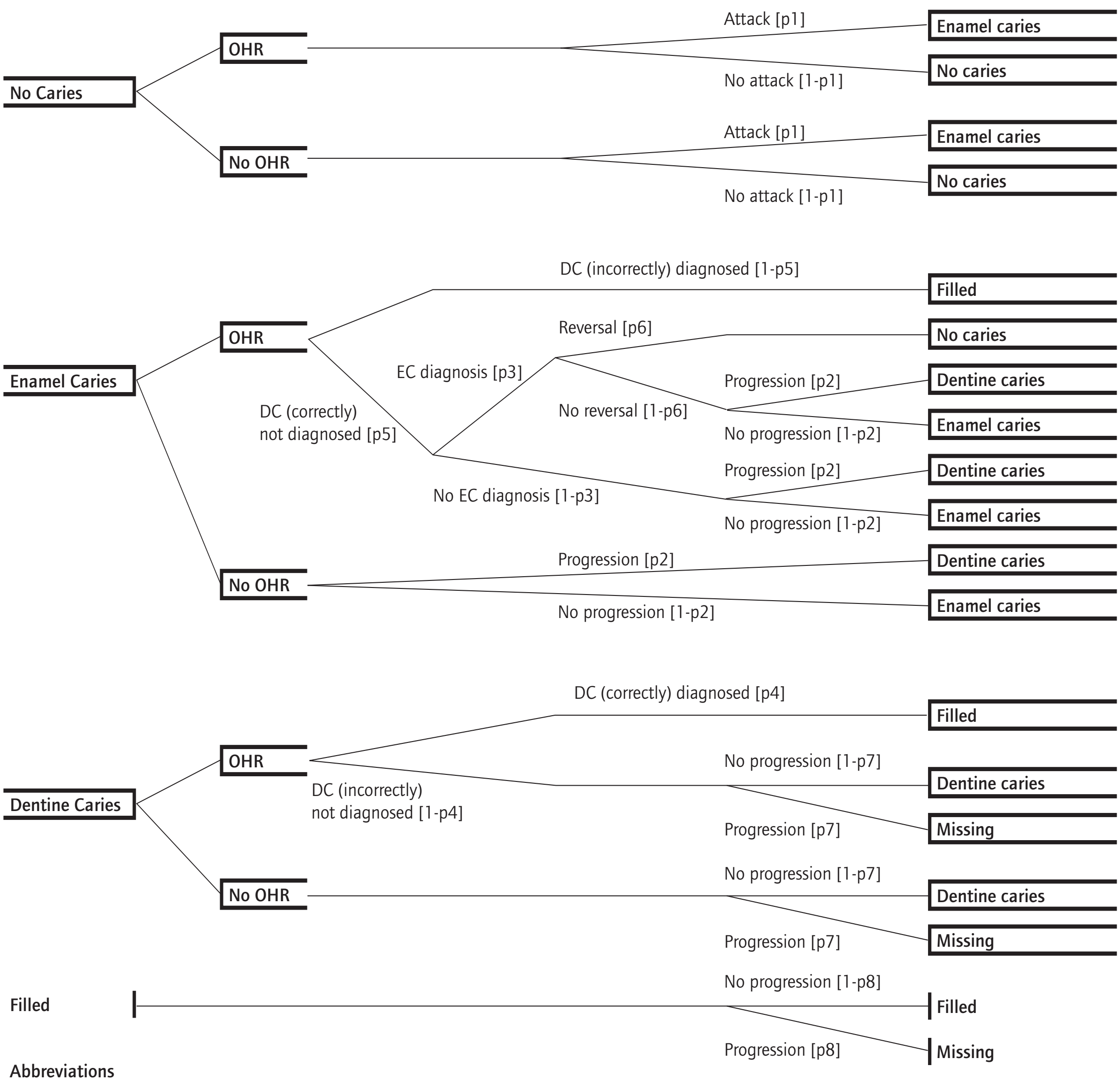
	DURATION OF OHR					
	5	10	16	20	25	30
From 12 months to 6 months	3	9	15	19	24	30
From 18 months to 12 months	1	3	5	7	9	12
	DURATION OF CARIES TREATMENT EPISODE					
	10	20	26	40	50	60
From 12 months to 6 months	16	15	15	14	13	12
From 18 months to 12 months	6	6	5	4	4	3
	3-MONTH ATTACK RATE					
	0.1%	1.5%	2.1%	2.5%	3.0%	3.5%
From 12 months to 6 months	22	17	15	14	14	14
From 18 months to 12 months	8	6	5	5	5	5
	3-MONTH PROGRESSION RATE					
	1.1%	2.1%	3.1%	4.1%	5.1%	
From 12 months to 6 months	66	24	15	11	9	
From 18 months to 12 months	24	9.	5	4	3	
	SENSITIVITY (ENAMEL)					
	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%
From 12 months to 6 months	15	15	15	15	15	15
From 18 months to 12 months	6	9	6	5	5	5
	SENSITIVITY (DENTINE)					
	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%
From 12 months to 6 months	15	15	15	15	15	15
From 18 months to 12 months	5	5	5	5	5	5
	SPECIFICITY (DENTINE)					
	75.0%	80.0%	85.0%	89.0%	95.0%	100.0%
From 12 months to 6 months	50	31	21	15	9	5
From 18 months to 12 months	19	12	8	5	3	1
	CLINICAL REVERSAL RATE					
	25.0%	50.0%	75.0%	100.0%		
From 12 months to 6 months	62	20	15	15		
From 18 months to 12 months	35	9	6	5		
	MEDIAN RESTORATION SURVIVAL					
	4	8	12	16	20	
From 12 months to 6 months	14	14	15	15	15	
From 18 months to 12 months	5	5	5	5	6	
	DISCOUNT RATE (FIRST 30 YEARS)					
	0.5%	2.0%	3.5%	5.0%	6.5%	
From 12 months to 6 months	12	13	15	16	19	
From 18 months to 12 months	4	5	5	6	7	

FIGURE 1: Markov model for dental recall intervalls

This diagram shows how the status of a tooth during any (3-month) period is dependent probablistically on:

a) the status in the previous period; and

b) whether there was an oral health review in the last period



Abbreviations
OHR=oral health review
DC=dentine caries
EC=enamel caries

Probabilities

p1 Incidence of enamel caries (attack rate)	p5 Specificity (dentine caries)
p2 Progression rate (enamel to dentine)	p6 Reversion rate
p3 Sensitivity (enamel caries)	p7 Progression rate (dentine to missing)
p4 Sensitivity (dentine caries)	p8 Progression rate (filling to missing)

Notes
NB1 – All teeth are in the 'No caries' in the first period of the model
NB2 – False enamel caries diagnoses are not represented because it is assumed that they won't affect tooth status.
NB3 – Status refers to the 'true' underlying status of the tooth rather than the clinical diagnosis