The ultimate guide to restoration longevity in England and Wales. Part 5

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THE ULTIMATE GUIDE TO RESTORATION LONGEVITY IN ENGLAND AND WALES:5: CROWNS: TIME TO NEXT INTERVENTION AND TO EXTRACTION OF THE RESTORED TOOTH

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THE ULTIMATE GUIDE TO DIRECT RESTORATION LONGEVITY IN ENGLAND AND WALES: CROWNS

Abstract

Aim: It is the aim of this paper to present data on the survival of crowns in all teeth by analysis of the time to re-intervention on the crowns and time to extraction of the crowned tooth, and to discuss the factors which may influence this.

Results: Data for more than three million different patients and more than 25 million courses of treatment were included in the analysis. Included were all records for adults (aged 18 or over at date of acceptance). Overall, 1,202,005 crowns were included, of which 302,555 had a re-intervention over the duration of the dataset. Overall, 52% of crowns have survived at 15 years, with factors influencing survival being patient age, dentist age and patient treatment need. However, when the data are re-analysed with regard to time to extraction, while crowns provide a patient with a restoration which requires the least number of re-interventions, they perform poorly when time to extraction is examined. The placement of a pinned core appears to enhance the longevity of the subsequent crown, whereas the placement of a root filling or a metal post does not. With regard to tooth position, crowns placed on upper canine teeth perform worse than crowns placed on any other tooth, while crowns perform best on first molar teeth.

Conclusions:

Crowns may provide a patient with a restoration which requires the least number of re-interventions: however, they perform poorly when time to extraction is examined.

Introduction

Satisfactory survival of restorations in incisor teeth is of importance to patients, dental professionals, epidemiologists, third-party funders, governments, and other interested parties. The provision of accurate information on restoration survival, and the factors which may influence this, is therefore of relevance. It is also important that the data is derived from general dental practice, given that this is where the majority of dental treatment, worldwide, is provided, where the majority of dentists operate and where the majority of restorations are placed. Using the methodology described in Paper 1 in this series[1], it has been possible to produce precise information regarding the survival of crowns in all teeth and the factors which may influence this. In teeth within the aesthetic zone, patients may be particularly interested in the appearance of their restorations and the overall aesthetics of their teeth: compromised aesthetics may therefore be an additional reason (other than secondary caries, defective restoration margin, restoration fracture etc.) why a crown may be replaced/have a re-intervention. This might include discoloured margins or shade mismatch over time.

It is therefore the purpose of this paper to investigate the following:

- Survival of crowns, by assessing time to re-intervention, and the patient and dentist factors associated with this
- Time to extraction of teeth restored with a crown, and the factors which influence this.

Results

Characteristics of the Sample Population

More than three million different patient IDs and more than 25 million courses of treatment were included in the analysis, each of which includes data down to individual tooth level. Included were all records for adults (aged 18 or over at date of acceptance). Of these, a total of 1,203,441 teeth received crowns. Of these, “bonded full or jacket crown – gold” (otherwise called metal-ceramic crowns) predominated, there being 880,407 of these, with “precious cast full or jacket crown” being the second most frequently placed crown restoration, these numbering 139,681.

Survival of crowns, overall

When the survival of crowns is examined with respect to time to re-intervention, it is apparent that, overall, 53% of crowns have survived at 15 years, with 63% having survived to 10 years and 77% to 5 years (Figure 1 and Table 1). When the data are re-analysed with regard to time to extraction, it is apparent that 77% of crowned teeth have survived for 15 years, with 85% having survived to 10 years and 92% to 5 years (Figure 2 and Table 2).

Table 1 Survival to re-intervention of crowns compared with other restorations

	Survival (%) at				
Type of Treatment	1 year	5 years	10 years	15 years	n
Amalgam	91	66	51	41	7,292,564
Composite Resin	87	59	43	34	3,504,225
Glass-ionomer	84	53	37	28	1,592,566
Crown	**93**	**77**	**63**	**53**	**1,202,005**

Figure 1 Survival to re-intervention of crowns compared with other restorations

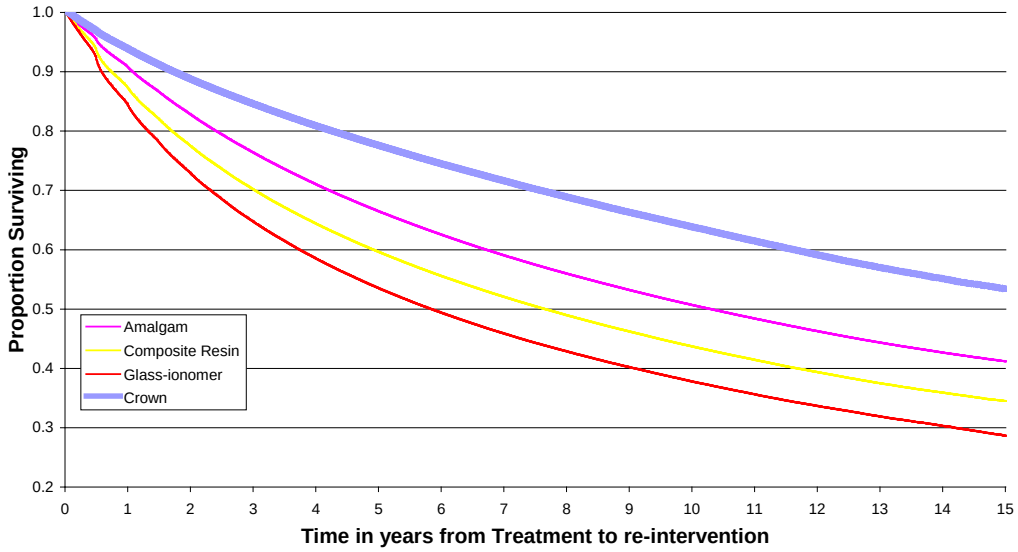
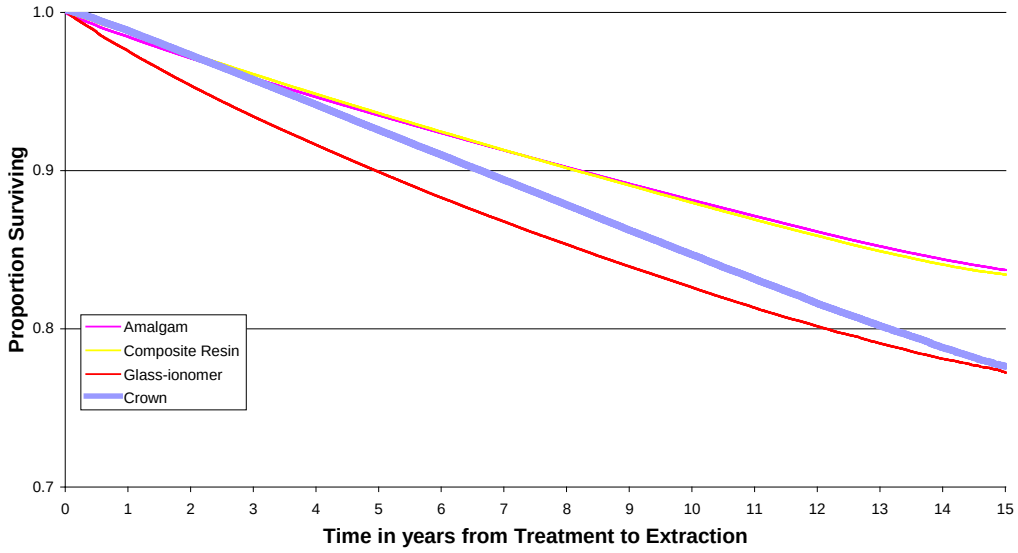


Table 2 Time to extraction of teeth restored with crowns

Type of Treatment	Survival (%) at 1 year	5 years	10 years	15 years	n
Amalgam	98.5	93.5	88.1	83.7	7,292,564
Composite Resin	98.7	93.6	87.9	83.3	3,504,225
Glass-ionomer	97.5	89.8	82.5	77.1	1,592,566
Crown	**98.7**	**92.4**	**84.5**	**77.4**	**1,202,005**

Figure 2 Time to extraction of teeth restored with crowns



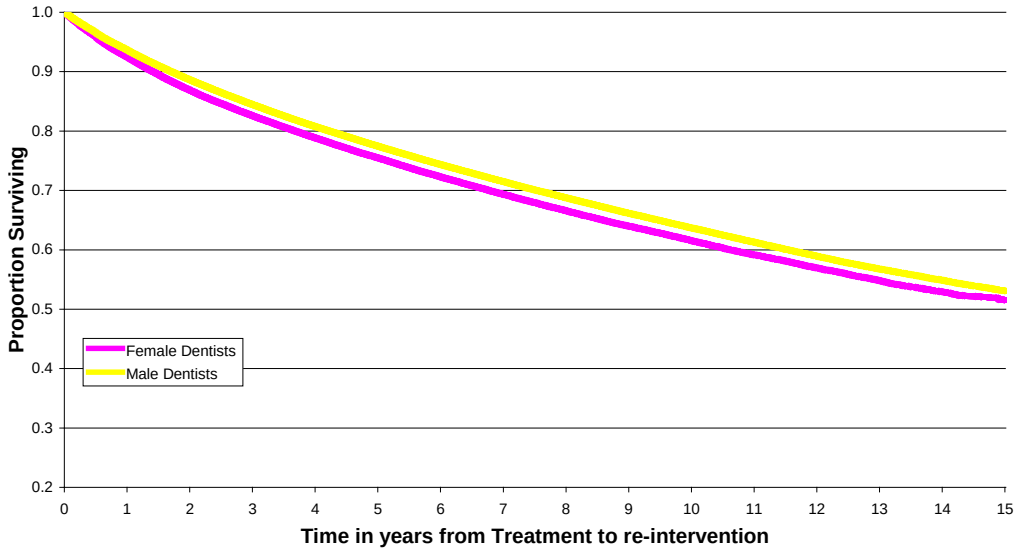
Influence of dentist factors (gender and age)

Regarding dentists' gender, there is a difference of *circa* two percentage points up to 15 years, with crowns placed by male dentists performing better in terms of time to re-intervention than those placed by female dentists (Figure 3 and Table 3). When time to extraction of the crowned tooth is examined with respect to dentists' gender, there is a smaller difference, of less than one percentage point, with crowns placed by male dentists performing better than those placed by female dentists.

Table 3 Survival of crown to re-intervention, with regard to dentist gender

Dentist Gender	Survival (%) at 1 year	5 years	10 years	15 years	n
Female Dentists	92	75	62	52	218,287
Male Dentists	94	77	64	53	983,718
All Restorations	93	77	63	53	1,202,005

Figure 3 Survival of crown to re-intervention, with regard to dentist gender



When dentists' age is examined, the chart indicates that crowns placed by dentists in the under-30 year old age group and in the over-60 year age group perform less well in terms of time to re-intervention than those placed by dentists in other age groups by *circa* four percentage points and *circa* two percentage points respectively at 15 years (Figure 4 and Table 4). When time to extraction of the crowned tooth is examined with respect to dentist age, the results are similar, with teeth restored with crowns placed by dentists in the under 30 and over 60 age groups performing less

well in terms of time to extraction than those placed by dentists in the other age groups (Figure 5 and Table 5).

Figure 4 Survival of crowns to re-intervention, with regard to dentist age

	Survival (%) at				
Dentist Age	1 year	5 years	10 years	15 years	n
Dentist age under 30	93	75	61	50	202,371
Dentist age 30-34	93	77	63	53	232,635
Dentist age 35-39	94	78	64	54	222,744
Dentist age 40-44	94	78	64	54	195,281
Dentist age 45-49	94	77	64	53	155,763
Dentist age 50-54	94	77	64	54	107,556
Dentist age 55-59	94	78	64	53	60,608
Dentist age 60 or over	94	77	63	52	25,008
All Restorations	93	77	63	53	1,202,005

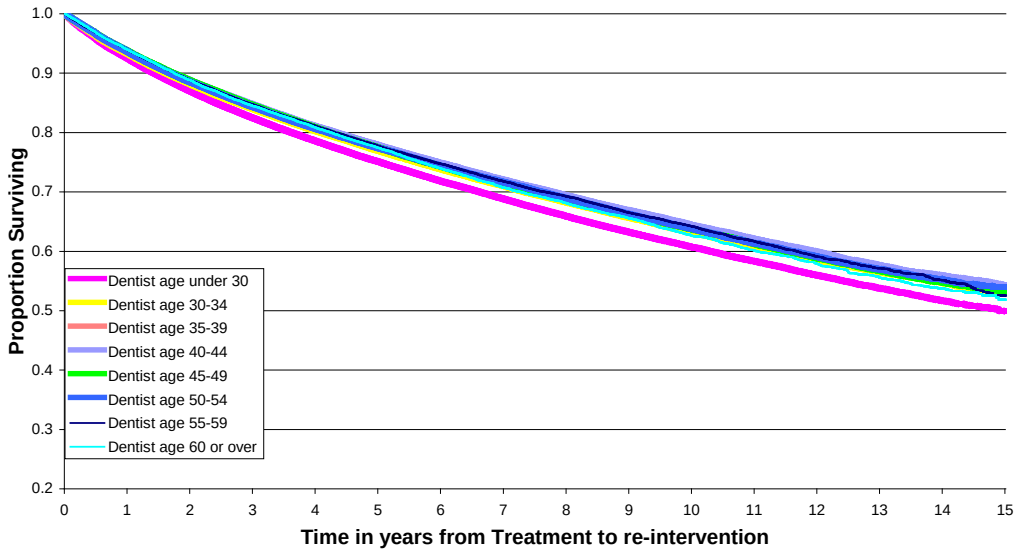
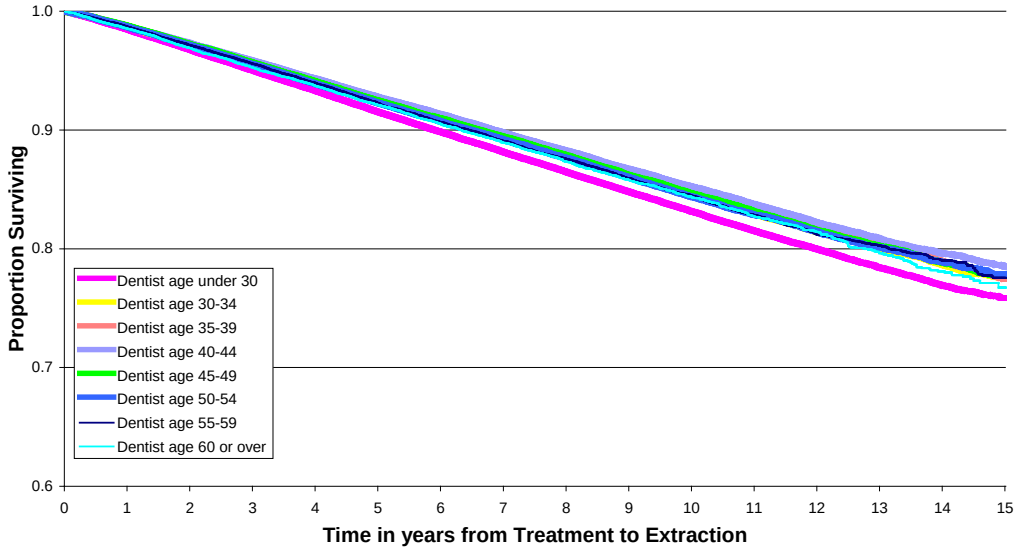


Table 5 Time to extraction of teeth restored with crowns, with regard to dentist age

	Survival (%) at				
Dentist Age	1 year	5 years	10 years	15 years	n
Dentist age under 30	98	92	83	76	202,371
Dentist age 30-34	99	93	84	77	232,635
Dentist age 35-39	99	93	85	77	222,744
Dentist age 40-44	99	93	85	79	195,281
Dentist age 45-49	99	92	85	78	155,763
Dentist age 50-54	99	92	84	78	107,556
Dentist age 55-59	99	92	84	78	60,608
Dentist age 60 or over	99	92	84	77	24,992
All Restorations	99	92	84	77	1,202,005

Figure 5 Time to extraction of teeth restored with crowns, with regard to dentist age



Influence of patient factors

Patient gender and age

Figure 6 presents time to re-intervention of crowned teeth with regard to patient gender, indicating that crowns placed on the teeth of female patients perform *circa* three percentage points better at 15 years than those placed for male patients (Table

6). The results for time to extraction of crowned teeth are similar (Figure 7 and Table 7).

Table 6 Time to re-intervention of crowns, with regard to patient gender

	Survival (%) at				
Patient Gender	1 year	5 years	10 years	15 years	n
Female Patients	94	78	64	54	650,797
Male Patients	93	76	62	51	551,208
All Restorations	93	77	63	53	1,202,005

Figure 6 Time to re-intervention of crowns, with regard to patient gender

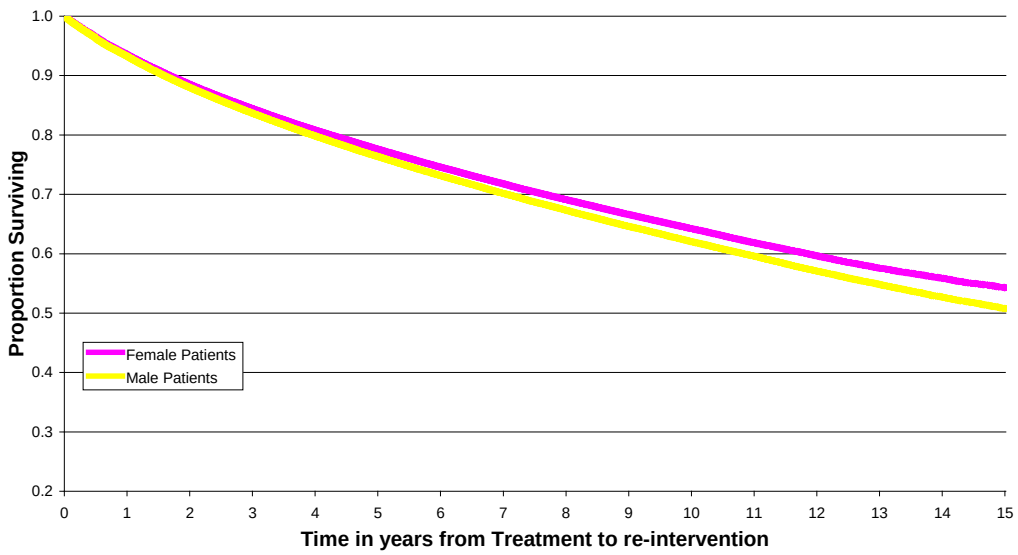


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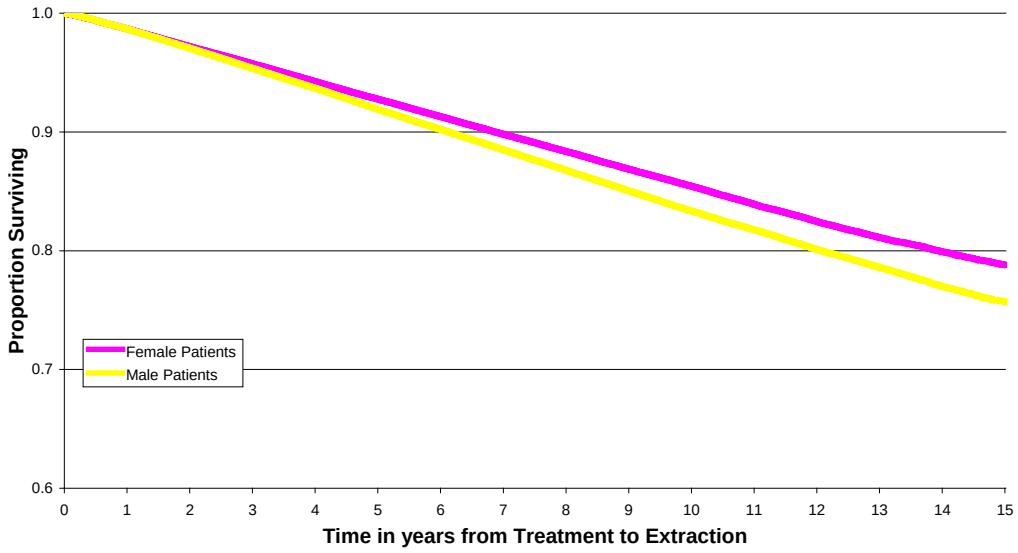
Table 7 Time to extraction of teeth restored with crowns, with regard to patient gender

	Survival (%) at				
Patient Gender	1 year	5 years	10 years	15 years	n
Female Patients	99	93	85	79	650,797
Male Patients	99	92	83	76	551,208
All Restorations	99	92	84	77	1,202,005

Figure 7 Time to extraction of teeth restored with crowns, with regard to patient gender



When patient age is examined, it is apparent that, with respect to time to reintervention, crowns perform best in patients in the 30 to 60 year old age groups, with crowns placed in patients aged under 30 or over 60 years performing least well (Figure 8 and Table 8). However, when time to extraction of the crowned tooth is examined (Figure 9 and Table 9), the chart tells a different story, with time to

extraction being best in the age groups of 18 to 39 years, but again, teeth restored with crowns performing worst in terms of time to extraction in the over 60 year old age groups.

Table 8 Time to re-intervention of crowns, with regard to patient age

	Survival (%) at				
Patient Age	1 year	5 years	10 years	15 years	n
18 or 19	94	77	62	49	15,985
20 to 29	93	76	62	51	157,811
30 to 39	93	78	64	54	290,257
40 to 49	94	78	65	55	295,393
50 to 59	94	78	64	53	233,209
60 to 69	93	76	61	50	139,429
70 to 79	92	73	57	43	58,250
80 or over	91	70	56	-	11,671
All Restorations	93	77	63	53	1,202,005

Figure 8 Time to re-intervention of crowns, with regard to patient age

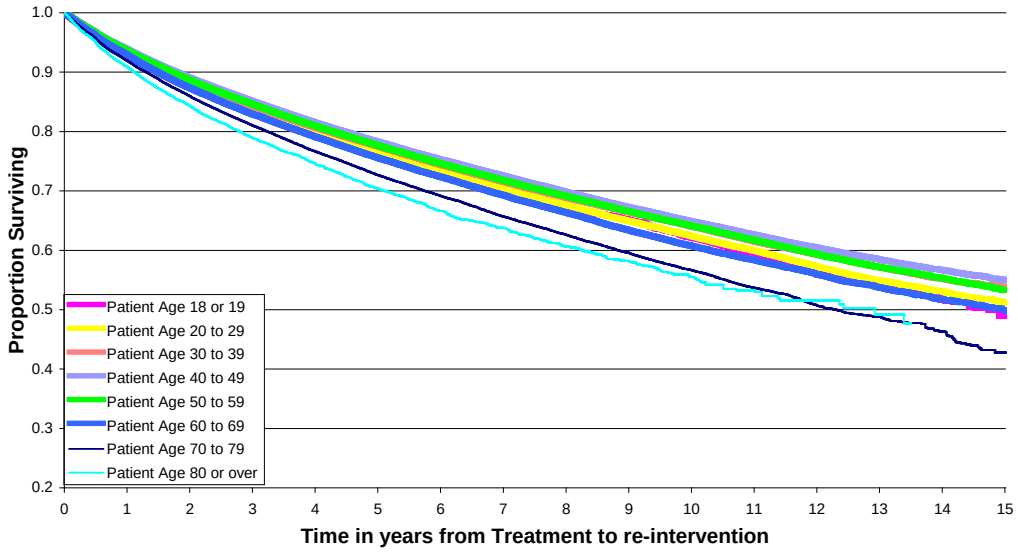
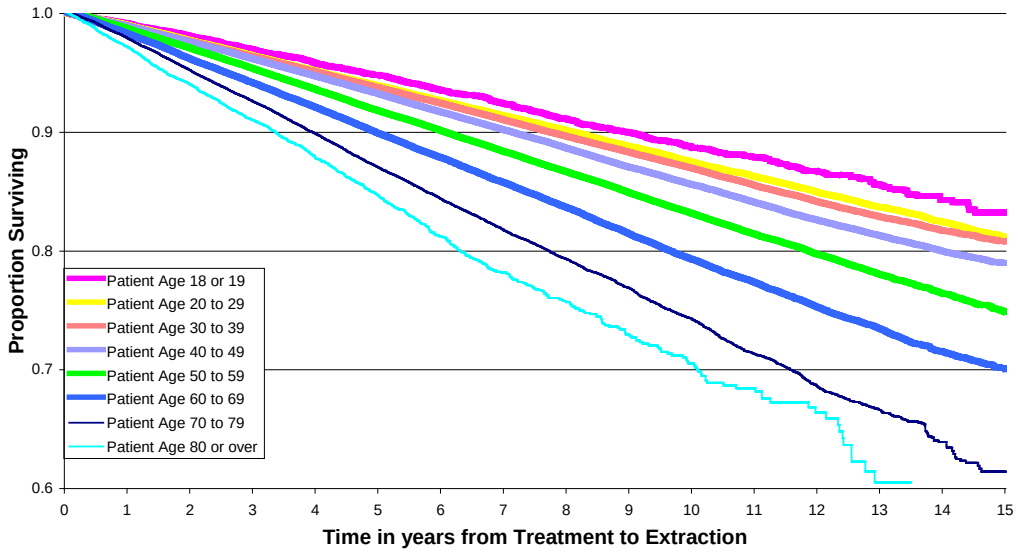


Table 9 Time to extraction of teeth restored with crowns, with regard to patient age

	Survival (%) at				
Patient Age	1 year	5 years	10 years	15 years	n
18 or 19	99	95	89	83	15,935
20 to 29	99	94	87	81	157,811
30 to 39	99	94	87	81	290,257
40 to 49	99	93	85	79	295,393
50 to 59	99	92	83	75	233,209
60 to 69	98	90	79	70	139,429
70 to 79	98	87	74	61	58,250
80 or over	97	84	70	-	11,671
All Restorations	99	92	84	77	1,202,005

Figure 9 Time to extraction of teeth restored with crowns, with regard to patient age



Did the patient have to pay for treatment?

Patients may be exempt or remitted from payment within the GDS Regulations.

When the influence of patients who have exemption from, or remission of payment for treatment is examined, there is *circa* 9% difference on survival to re-intervention

of crowns with crowns placed in patients who were exempt from payment performing less well (Figure 10 and Table 10). When this exercise is repeated with regard to time to extraction of the crowned tooth, the chart indicates a *circa* 5% difference at 15 years, with the teeth of charge-payers surviving longer than those who did not pay (Figure 11 and Table 11).

Table 10 Survival of crowns to re-intervention, by patients who paid for treatment and those who were exempt from payment

	Survival (%) at				
Charge Paying Status	1 year	5 years	10 years	15 years	n
Full Charge	94	79	66	56	729,897
Exemption or Remission	92	74	59	47	472,108
All Restorations	93	77	63	53	1,202,005

Figure 10 Survival of crowns to re-intervention, by patients who paid for treatment and those who were exempt from payment

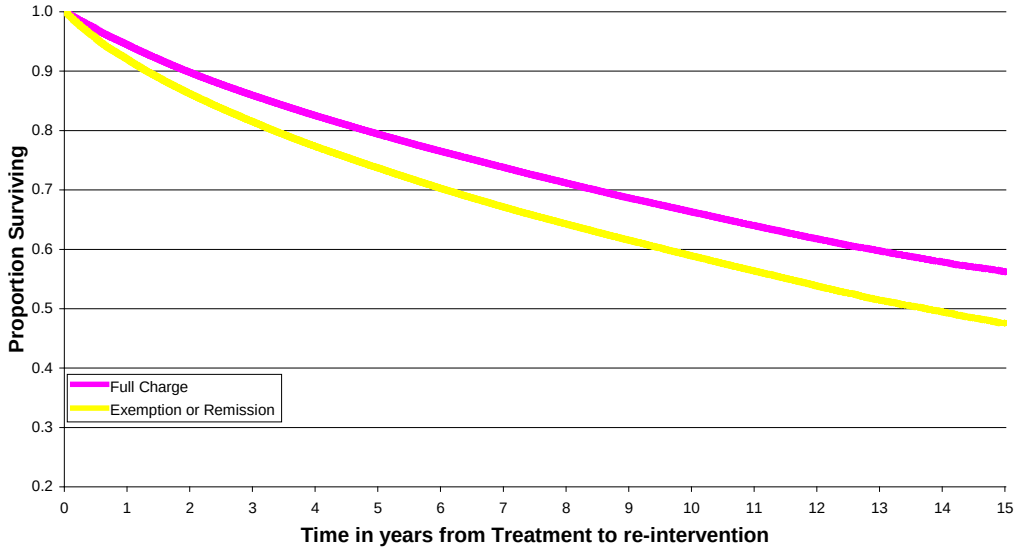
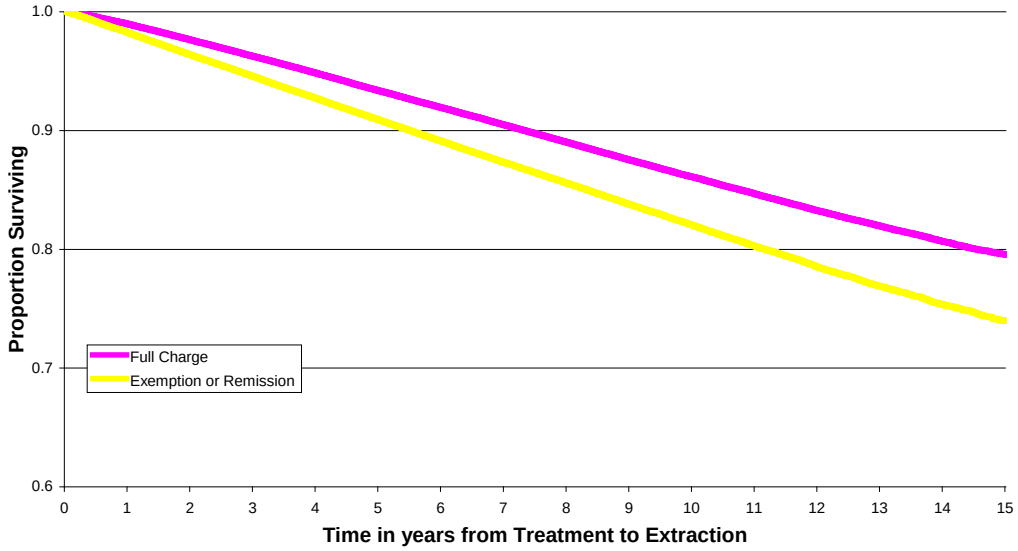


Table 11 Time to extraction of crowned teeth, by patients who paid for treatment and those who were exempt from payment

	Survival (%) at				
Charge Paying Status	1 year	5 years	10 years	15 years	n
Full Charge	99	93	86	79	729,897
Exemption or Remission	98	91	82	74	472,108
All Restorations	99	92	84	77	1,202,005

Figure 11 Time to extraction of crowned teeth, by patients who paid for treatment and those who were exempt from payment



Patient's state of oral health as assessed by Average Annual Fees

Two different proxies for the patient's state of oral health have been considered, namely, the annual average cost of GDS dental treatment for the patient, and the median interval between courses of treatment for the patient. The average cost of treatment will be considered for the present analysis. Figures 12 and 13 show clearly that the patient's history of dental treatment is a major factor in determining the likely survival of crowns, both to time to re-intervention and time to extraction. For time to re-intervention, survival at fifteen years is 84% for those with low annual expenditure on dental treatment, and 44% for those with high annual dental treatment expenditure (Table 12). For time to extraction the corresponding figures are 94% and 71% (Table 13).

Table 12 Survival of crowns to re-intervention, with regard to the mean annual treatment expenditure

Mean Annual Fees	Survival (%) at 1 year	5 years	10 years	15 years	n
Up to £20 per annum	98	95	90	84	15,158
£20 to £60 per annum	96	85	75	66	368,476
Over £60 per annum	92	72	56	44	778,454
All Restorations	93	77	63	53	1,202,005

Figure 12 Survival of crowns to re-intervention, with regard to the mean annual treatment expenditure

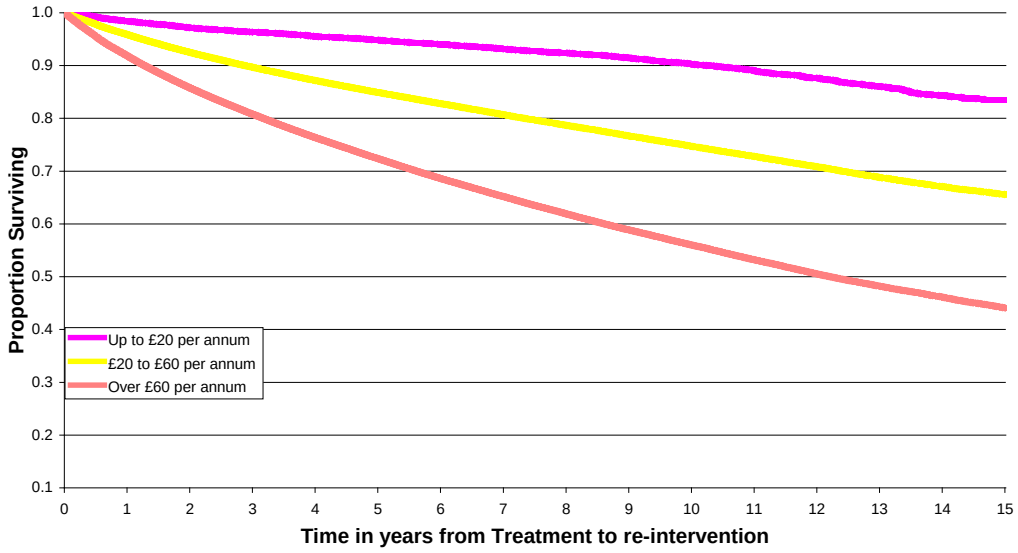
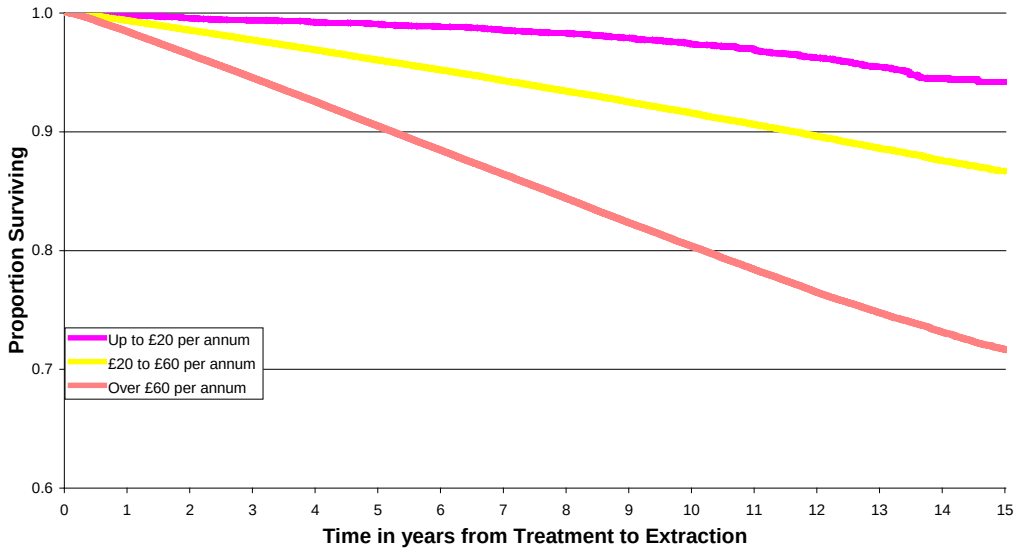


Table 13 Time to extraction of crowned teeth, with regard to the mean annual treatment expenditure

Mean Annual Fees	Survival (%) at 1 year	5 years	10 years	15 years	n
Up to £20 per annum	100	99	97	94	15,141
£20 to £60 per annum	99	96	91	87	368,476
Over £60 per annum	98	90	80	71	778,454
All Restorations	99	92	84	77	1,202,005

Figure 13 Time to extraction of crowned teeth, with regard to the mean annual treatment expenditure



Influence of tooth position

With regard to tooth position, there is a difference of *circa* 17 percentage points in survival of crowns in lower incisor teeth and in upper incisor teeth, with crowns in lower incisor teeth performing better in terms to time to re-intervention (Figure 14 and Table 14) and crowns in upper canine teeth performing worst. When tooth notation is examined (Figure 15 and Table 15), it is apparent that crowns placed on molar teeth perform better, in terms of time to re-intervention, than crowns placed on incisor or canine teeth, and with crowns placed on lateral incisors performing c*irca* seven percentage points less well than those placed on central incisors

Table 14 Survival of crowns to re-intervention, with regard to tooth type

Tooth Type	Survival (%) at 1 year	5 years	10 years	15 years	n
Upper Incisor	92	73	58	46	358,959
Lower Incisor	95	83	72	63	41,271
Upper Canine	89	65	49	37	74,059
Lower Canine	95	80	67	55	17,077
Upper Premolar	94	78	65	54	241,686
Lower Premolar	94	78	65	56	129,724
Upper Molar	96	83	70	61	138,340
Lower Molar	95	81	69	60	200,889
All Restorations	93	77	63	53	1,202,005

Figure 14 Survival of crowns to re-intervention, with regard to tooth type

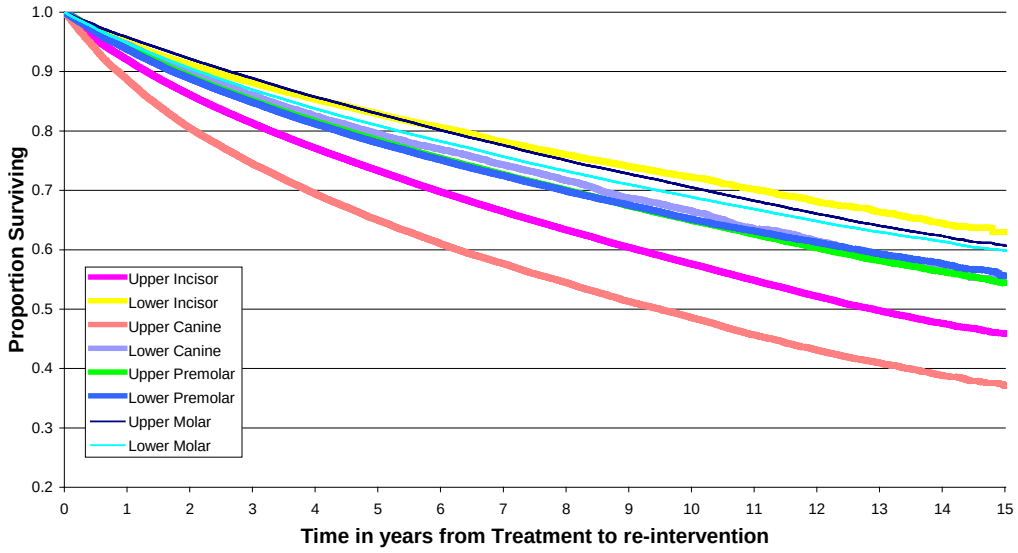
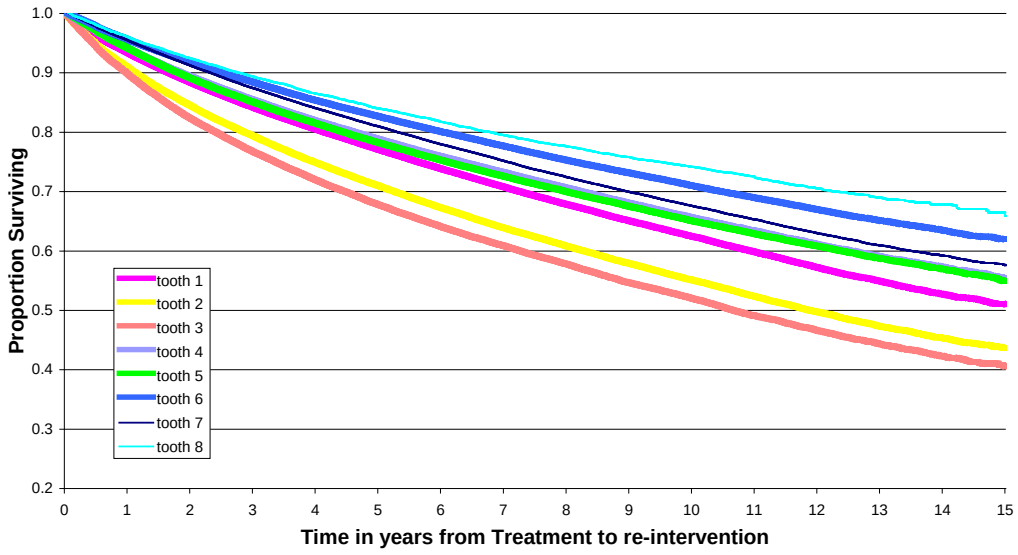


Table 15 Survival of crowns to re-intervention, with regard to tooth notation

Tooth Position	Survival (%) at 1 year	5 years	10 years	15 years	n
tooth 1	93	77	62	51	220,088
tooth 2	91	71	55	44	180,142
tooth 3	90	68	52	40	91,136
tooth 4	94	79	65	55	156,181
tooth 5	94	78	65	55	215,229
tooth 6	95	82	71	62	205,366
tooth 7	95	81	67	57	119,081
tooth 8	96	83	74	65	14,782
All Restorations	93	77	63	53	1,202,005

Figure 15 Survival of crowns to re-intervention, with regard to tooth notation



However, when time to extraction of crowned teeth is examined (Figure 16 and Table 16), it is apparent that crowns in first and second molar teeth perform optimally, while crowns placed on lateral incisor and canine teeth perform least well, with the difference in time to extraction between the worst performing crowned teeth

and the best being *circa* 18 percentage points in cumulative survival. This trend is repeated when time to extraction of different tooth types is examined (Figure 17 and Table 17). When the upper and lower arches are compared (Figure 18 and Table 18), it is apparent that crowns placed on lower teeth perform better in terms of time to extraction of the crowned tooth than crowns placed on upper teeth.

Table 16 Time to extraction of crowned teeth, with regard to tooth notation

	Survival (%) at				
Tooth Position	1 year	5 years	10 years	15 years	n
tooth 1	99	93	85	78	220,088
tooth 2	98	89	79	70	180,142
tooth 3	98	88	76	66	91,136
tooth 4	99	92	84	77	156,181
tooth 5	99	93	86	79	215,229
tooth 6	99	95	89	84	205,366
tooth 7	99	94	87	81	119,081
tooth 8	99	94	89	83	14,773
All Restorations	99	92	84	77	1,202,005

Figure 16 Time to extraction of crowned teeth, with regard to tooth notation

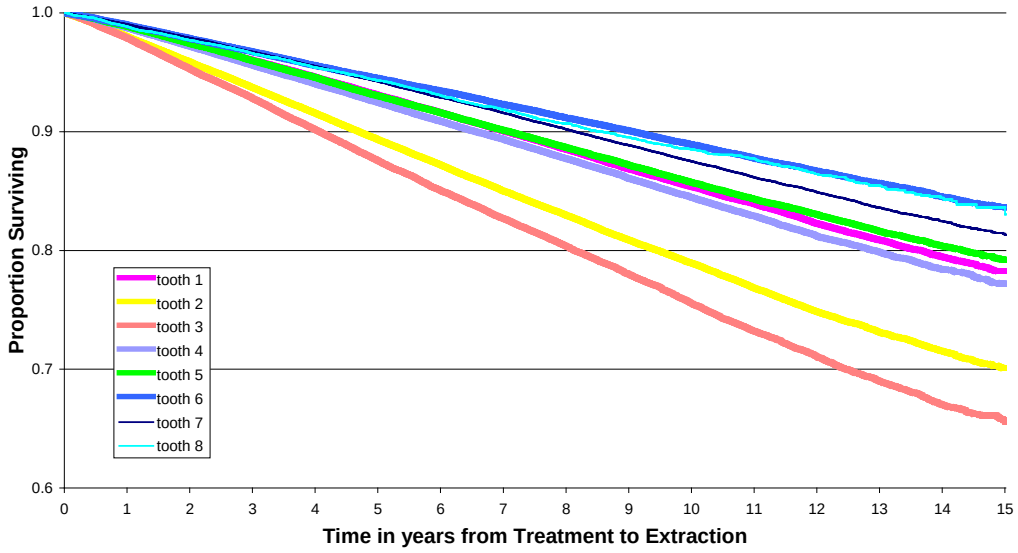


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Table 17 Time to extraction of crowned teeth, with regard to tooth type

Tooth Type	Survival (%) at 1 year	5 years	10 years	15 years	n
Upper Incisor	98	91	82	74	358,959
Lower Incisor	99	94	87	81	41,233
Upper Canine	98	86	74	63	74,059
Lower Canine	99	93	84	76	17,043
Upper Premolar	99	92	85	77	241,686
Lower Premolar	99	93	86	80	129,724
Upper Molar	99	94	88	82	138,340
Lower Molar	99	94	89	84	200,889
All Restorations	99	92	84	77	1,202,005

Figure 17 Time to extraction of crowned teeth, with regard to tooth type

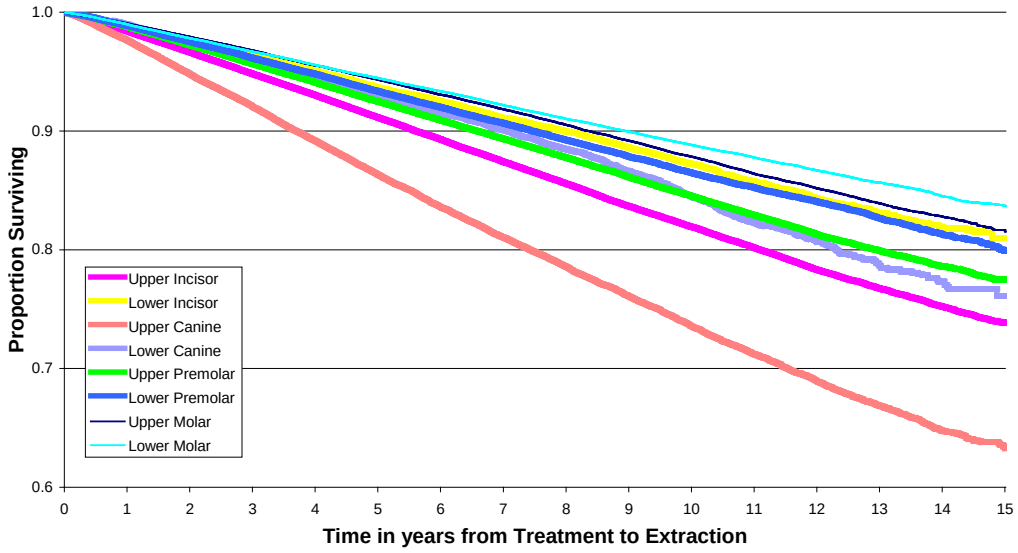
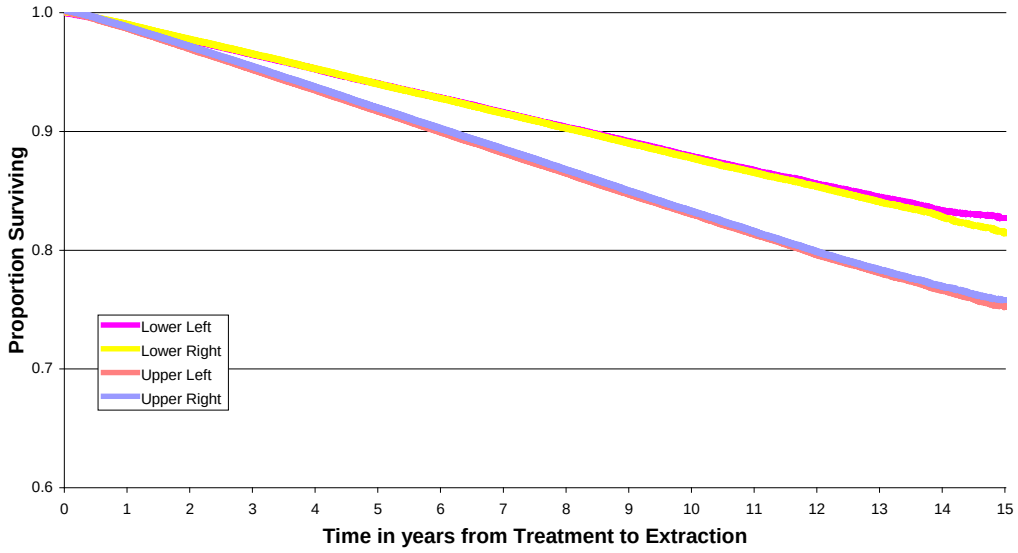


Table 18 Time to extraction of crowned teeth, with regard to upper/lower arch

Quadrant	Survival (%) at 1 year	5 years	10 years	15 years	n
Lower Left	99	94	88	83	194,140
Lower Right	99	94	88	81	194,821
Upper Left	99	92	83	75	406,875
Upper Right	99	92	83	76	406,169
All Restorations	99	92	84	77	1,202,005

Figure 18 Time to extraction of crowned teeth, with regard to upper/lower arch



Type of crown

More than ten different types of materials are available for crowns within the GDS Regulations. Given that crowns constructed in some materials (such as synthetic resin) are placed only in small numbers, the present analysis will concentrate upon those types which are most commonly placed. Figure 19 presents this analysis with regard to time to re-intervention, with the results indicating best performance from all-metal crowns and bonded (i.e. metal-ceramic) crowns, while all-ceramic crowns perform *circa* 20 percentage points worse at 15 years (Table 19). Figure 20 presents time to extraction of the crowned tooth: in this measure, the results indicate an improved performance of the porcelain jacket crown and only five percentage points

difference in time to extraction of the crowned tooth between the three most commonly prescribed crown types, namely, all metal, bonded metal to ceramic and all-ceramic (Table 20).

Table 19 Survival of crowns to re-intervention, with regard to material in which the crown is constructed

	Survival (%) at				
Type of Crown	1 year	5 years	10 years	15 years	n
metal crown	95	81	68	58	226,358
porcelain crown	91	66	47	35	34,173
bonded crown	93	77	63	53	939,376
other crown	83	54	37	31	2,098
All Restorations	93	77	63	53	1,202,005

Figure 19 Survival of crowns to re-intervention, with regard to material in which the crown is constructed

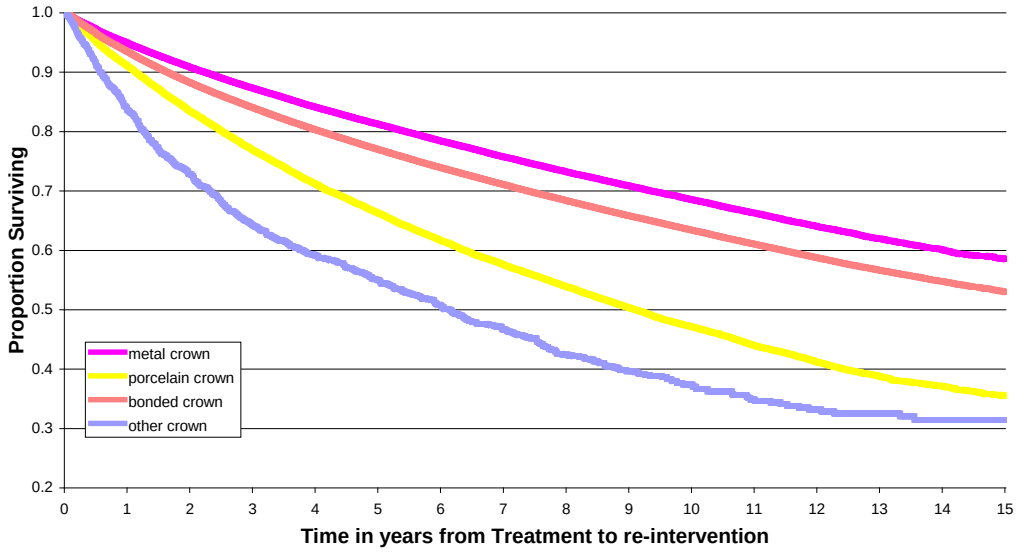
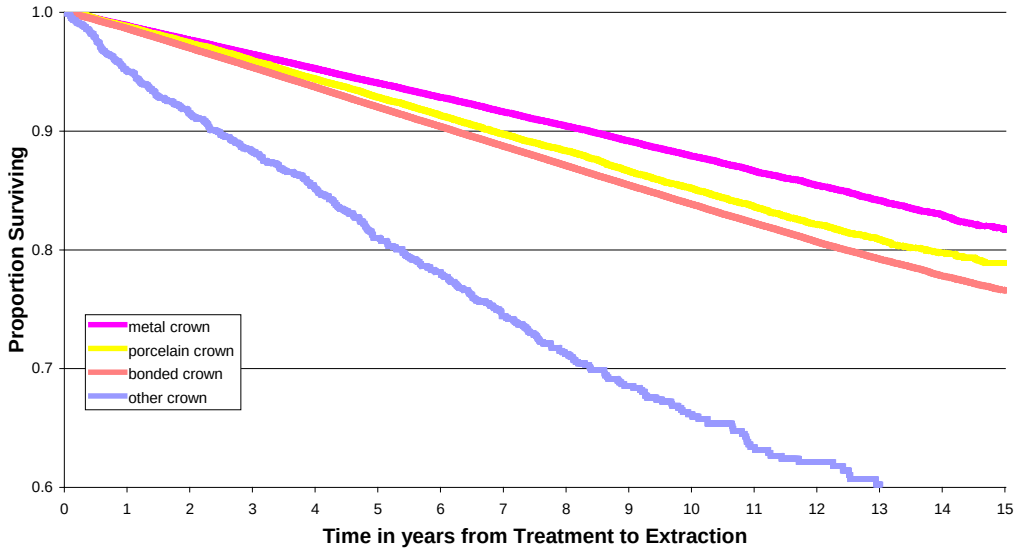


Table 20 Time to extraction of the crowned tooth, with regard to material in which the crown is constructed

	Survival (%) at				
Type of Crown	1 year	5 years	10 years	15 years	n
metal crown	99	94	88	82	226,358
porcelain crown	99	93	85	79	34,162
bonded crown	99	92	84	77	939,376
other crown	95	81	66	-	2,096
All Restorations	99	92	84	77	1,202,005

Figure 20 Time to extraction of the crowned tooth, with regard to material in which the crown is constructed



Other factors

When the difference between teeth which were crowned and root filled on the same course of treatment, the chart indicates a *circa* 14 percentage point difference in

overall survival of crowns (Figure 21 and Table 21), with crowns on teeth which have received root fillings performing less well. When time to extraction of the restored tooth is examined (Figure 22 and Table 22), the chart indicates a *circa* 12 percentage point difference at fifteen years, this equating to six years extra life for teeth without a root filling.

Table 21 Survival of crowns to re-intervention, with regard to whether the crowned tooth received, or did not receive a root filling on the same course of treatment

	Survival (%) at				
Root filling in same course	1 year	5 years	10 years	15 years	n
root filled	92	70	53	41	191,476
root not filled	94	78	65	55	1,010,529
All Restorations	93	77	63	53	1,202,005

Figure 21 Survival of crowns to re-intervention, with regard to whether the crowned tooth received, or did not receive a root filling on the same course of treatment

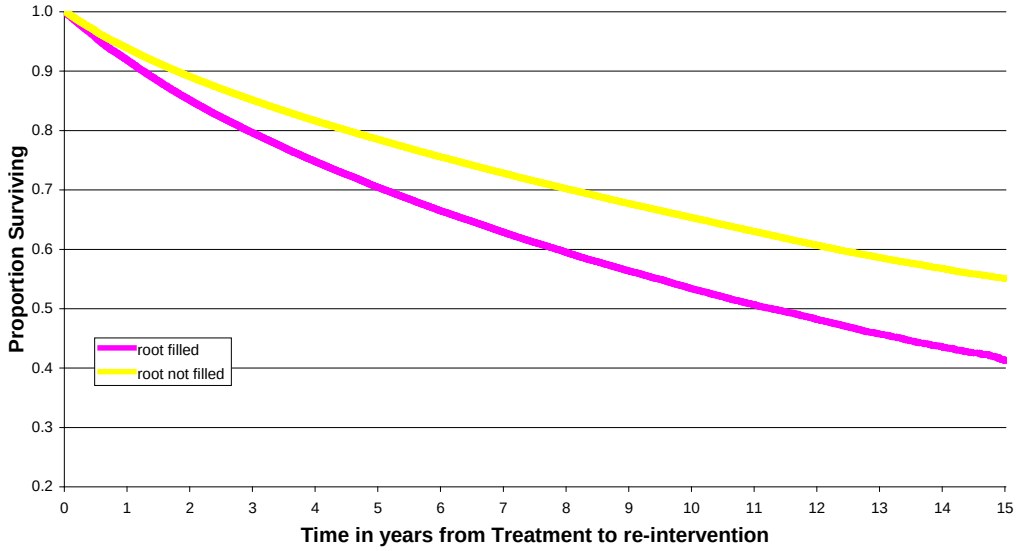
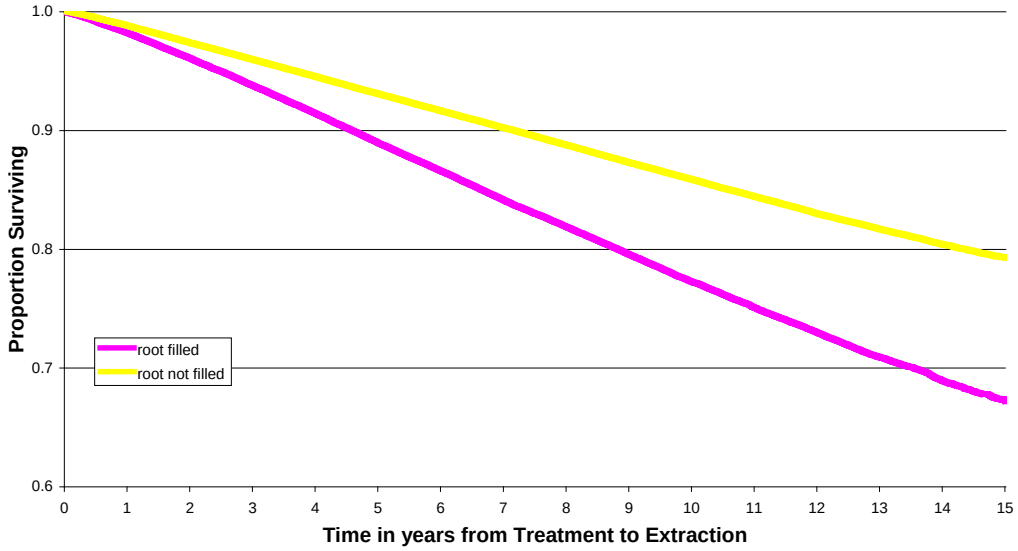


Table 22 Time to extraction of the crowned tooth, with regard to whether the crowned tooth received, or did not receive a root filling on the same course of treatment

	Survival (%) at				
Root filling in same course	1 year	5 years	10 years	15 years	n
root filled	98	89	77	67	191,476
root not filled	99	93	86	79	1,010,529
All Restorations	99	92	84	77	1,202,005

Figure 22 Time to extraction of the crowned tooth, with regard to whether the crowned tooth received, or did not receive a root filling on the same course of treatment



The need to place a post to retain a crown might generally be indicated because of a lack of coronal tooth substance. Figures 23 and 24 indicate that teeth receiving a crown, in which a post is also placed, have a reduced survival, whether this is assessed by survival of the overall restoration or the time to extraction of the restored tooth. In this regard, survival to next re-intervention is reduced by *circa* 26% (Table 23) and time to extraction of the post-crowned tooth is reduced by circa 19% (Table 24) compared with crowned teeth which did not receive a post.

Table 23 Survival of crowns to re-intervention, with regard to whether the crowned tooth received, or did not receive a post

	Survival (%) at				
Use of metal post	1 year	5 years	10 years	15 years	n
metal post	87	61	43	32	251,062
no metal post	95	81	68	58	950,943
All Restorations	93	77	63	53	1,202,005

Figure 23 Survival of crowns to re-intervention, with regard to whether the crowned

tooth received, or did not receive a post

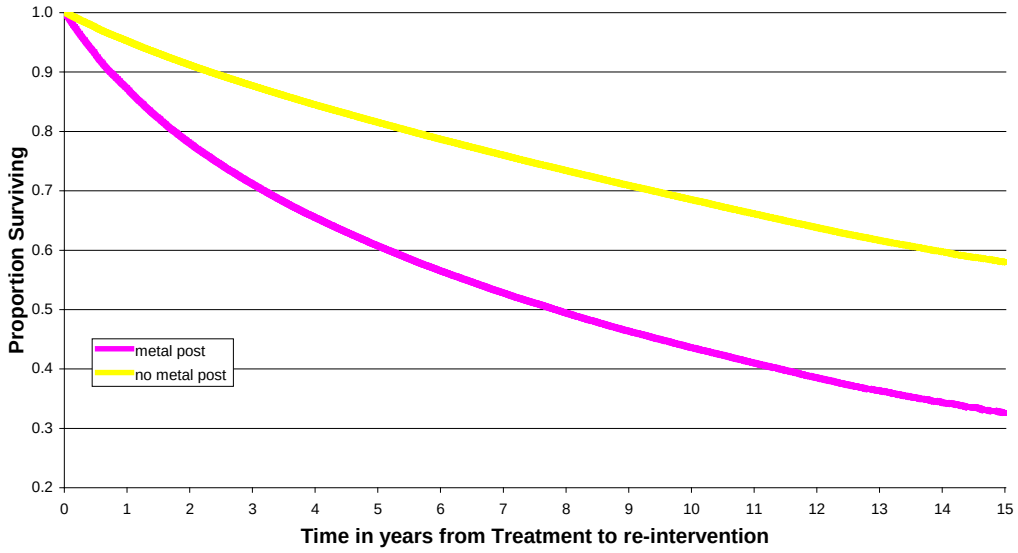
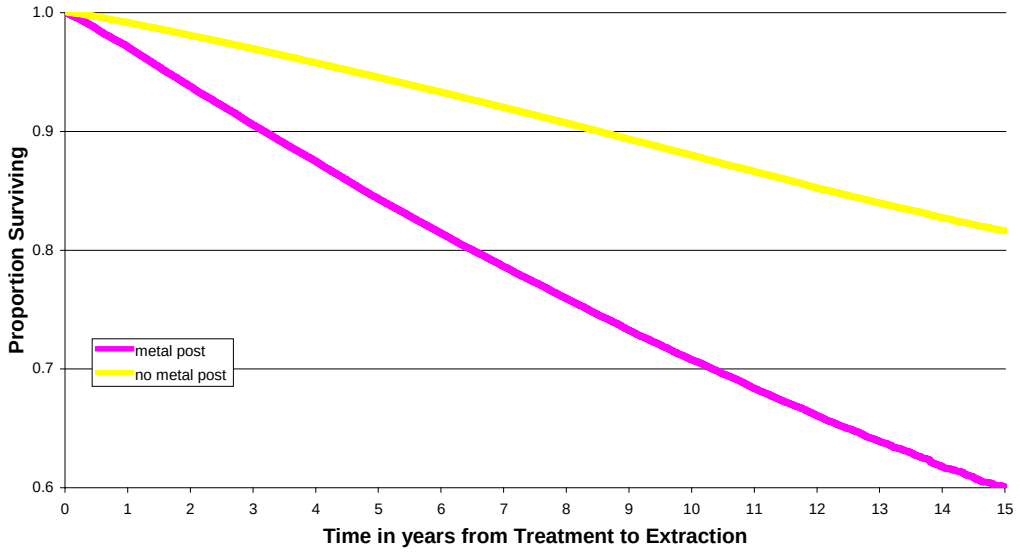


Table 24 Time to extraction of the crowned tooth, with regard to whether the crowned tooth received, or did not receive a post on the same course of treatment

	Survival (%) at				
Use of Metal Post	1 year	5 years	10 years	15 years	n
metal post	97	84	71	60	251,062
no metal post	99	94	88	81	950,943
All Restorations	99	92	84	77	1,202,005

Figure 24 Time to extraction of the crowned tooth, with regard to whether the crowned tooth received, or did not receive a post on the same course of treatment

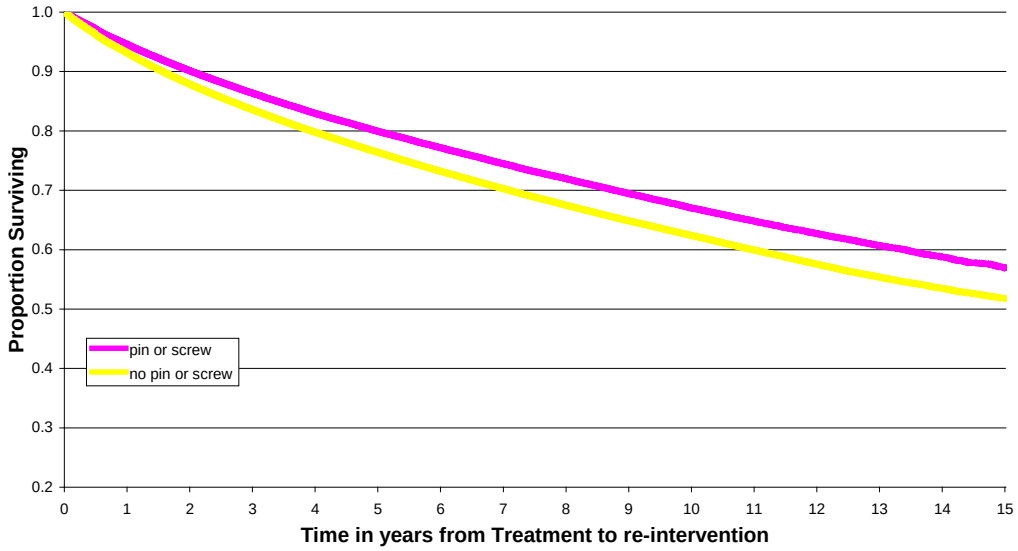


The dataset also contains a possible entry for pin or screw retention of a core supporting a crown, so it is of interest to assess whether the presence of a pinned core has a positive or a detrimental effect on the survival of the crown. Figure 25 therefore presents the time to re-intervention of teeth which did, or did not, receive a core to retain the crown, indicating that teeth which received a pinned core performed *circa* five percentage points better than those which did not (Table 25). Time to extraction was also enhanced, by *circa* two percentage points when a pinned core was placed.

Table 25 Survival of crowns to re-intervention, with regard to whether the crowned tooth received, or did not receive a pinned core

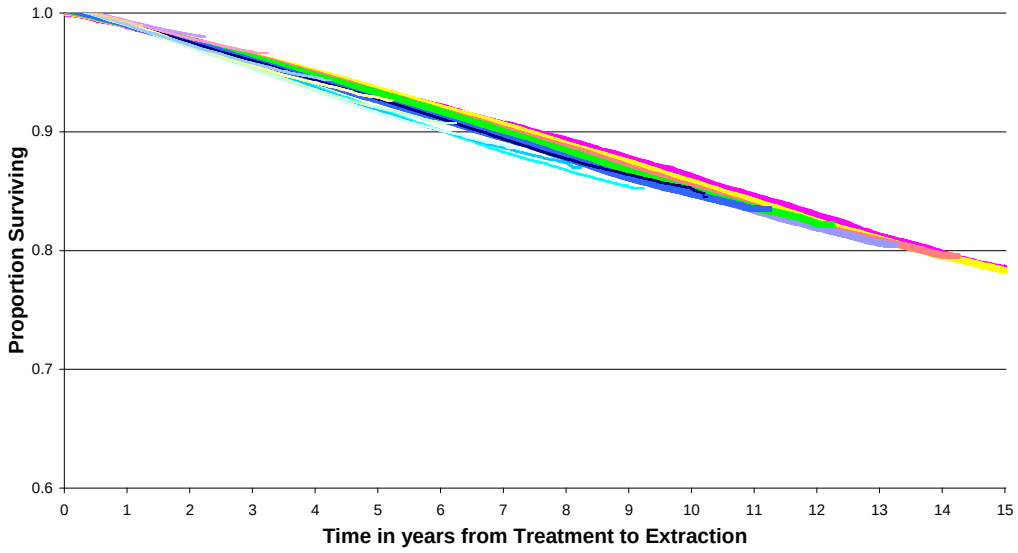
Pin or Screw	Survival (%) at 1 year	5 years	10 years	15 years	n
pin or screw	95	80	67	57	236,980
no pin or screw	93	76	62	52	965,025
All Restorations	93	77	63	53	1,202,005

Figure 25 Survival of crowns to re-intervention, with regard to whether the crowned tooth received, or did not receive a pinned core



Finally, the charts illustrating the performance of crowns, overall, indicate little differences in performance over the time of the study, either in terms of survival of restorations to re-intervention or time of the restored tooth to extraction (Figure 26).

Figure 26 Time to extraction of the crowned teeth, throughout the years of the dataset



Discussion

This work presents the analysis of 25 million courses of treatment being linked over 15 years, using a new dataset which was released to the research community in August 2012 by the UK Data Service[2]. This dataset is the largest ever to become available for analysis of the survival of dental treatment. Not only does this therefore facilitate a means of assessing restoration survival to re-intervention but it also allows the analysis of survival of the restored tooth to extraction. In other words, survival of the tooth rather than survival of the restoration *per se*. Other factors can come into play to lead to extraction, such periodontal problems.

In the present work, only the most frequently placed crown types have been subjected to analysis, and others have largely been ignored, as their numbers are small.

Crown survival

Overall, *circa* 52% of crowns have survived at 15 years, with circa 63% having survived to 10 years and 75% to 5 years (Figure 1). When the data are re-analysed with regard to time to extraction (Figure 2 and Table 2), it is apparent that *circa* 77% of crowned teeth have survived for 15 years. However, further examination of Figures 1 and 2 provide a very important message to dentists who are contemplating crowning a given tooth when there is sufficient remaining tooth substance to facilitate placement of a direct restoration. Figure 1 indicates that, in terms of re-intervention, crowns perform optimally when compared with amalgam, glass ionomer (GI) and composite direct-placement restorations. However, examination of Figure 2 (which presents time to extraction of the restored tooth) indicates that the crown is now the worst performing restoration, alongside GI restorations. The reason for this can only be surmised, but may be considered to be as a result of the crown preparation and the attendant removal of the enamel which provides stiffness to the tooth. This means that, while the crown provides the patient with a restoration which needs fewer interventions than direct placement restorations, when it fails, it fails more catastrophically. The message for clinicians is therefore very clear: Keep teeth functioning with direct placement amalgam (in posterior teeth) and resin composite (in anterior teeth) restorations for as long as possible.

Of course, there are clinical situations in which the clinician has few alternatives to crowning a given tooth, trauma of an anterior tooth being one. In such cases, in

younger patients, it is heartening to note that the performance of crowns to extraction in the age group less than 40 years is better than among older patients.

Effect of tooth position

When the performance of crowns in individual teeth is examined, it is apparent that crowns placed on lower incisor teeth perform better than crowns placed on upper incisor teeth, with this effect being seen both for survival to re-intervention and time to extraction of the crowned tooth. This effect might seem contrary to the perceived wisdom, in which the (smaller) lower incisor teeth may be more prone to fracture of their dentine core or pulp death due to the closer proximity to the pulp in the lower incisor teeth, given that the preparation depth to allow space for the crown material is the same for both upper and lower teeth. On the other hand, crowns on lower incisor teeth may not be so visible and/or prone to (potentially unsightly) gingival recession as crowns in upper incisor teeth, where the aesthetic demands upon the crown are likely to be greater. In this regard, it is interesting to note the difference in performance between all-metal crowns and bonded (metal-ceramic) crowns. It may be considered that both are formed in a similar manner, namely, a casting, with the metal-ceramic crown being used in the aesthetic zone and having a layer of porcelain bonded to the metal surface. Replacement due to aesthetic concerns may therefore account for the difference of *circa* five percentage points in time to re-intervention between all-metal crowns and metal-ceramic, as illustrated in Figure 19. On the other hand, all-metal crowns will predominantly be placed on molar teeth and the data presented in Figures 15 and 16 indicate that crowns placed on molar teeth outperform crowns placed on other teeth, both in terms of time to re-intervention and time to extraction of the restored tooth.

Throughout the analysis, crowns placed on upper canine teeth perform less well than crowns on any other tooth (Figures 14 and 17): the reason for this can only be subject to speculation. Perhaps this relates to the heavy occlusal loading on these teeth, in particular in lateral excursions, despite their roots being the longest in the arches. This, in itself, has previously been noted as a reason for poor performance of root fillings in these teeth[3], given that their roots may be longer than the most frequently used endodontic files.

In the present work, crowns placed in the lower arch perform significantly better than those placed in the upper arch. This may be, in part, due to the greater number of crowns placed in upper anterior, as opposed to lower anterior teeth and this is tied into the better performance of crowns placed in molar teeth. On the other hand, this result may be considered surprising, given the greater difficulties in achieving isolation in the lower arch. One previous study[4] compared the performance of restorations in the upper and lower arches, finding no difference, except for incisors, with restorations in lower incisor teeth surviving significantly longer than those in upper incisor teeth, similar to the result identified in the present data. However, this paper did not specify the types of restoration included in the study.

Dentist factors

Other publications in this series have indicated that younger dentists place direct restorations of better longevity than older dentists[5,6]. However, when the present data are analyzed, it is apparent that this is not the case with regard to crowns (Figures 4 and 5). These charts indicate that dentists under the age of 30 years provide crowns of significantly reduced longevity, both in terms of time to re-intervention and time to extraction of the crowned tooth. The reasons for this can

only be surmised, but it appears that an increased amount of experience is needed for the placement of successful crowns, whereas this is not the case for direct-placement restorations. Furthermore, given that the number of crowns placed is less than the number of direct-placement restorations, the building of experience in this area of restorative dentistry comes slower than the achievement of experience in direct placement restorations. This may also be as a result of the fewer numbers of crowns placed at undergraduate level in comparison with direct-placement restorations and/or the deficiencies in crown preparations which were apparent when the preparations of recently qualified dentists were assessed[7]. These comments may also help to explain why male dentists appear to place crowns of better longevity to re-intervention and time to extraction than female dentists (Figures 3 and 4), given that female dentists may predominantly be in younger age groups than male dentists, given the increasing feminisation of the dental profession which is being seen in the UK [8]. Another possible explanation is anecdotal information which suggests that the younger dentists in a given practice may also see more of the high need/irregularly attending patients while more established dentists will have an established patient list and therefore not have the time (or inclination) to see new and/or irregular attenders. It may also be worth making the point that the present study is of an observational nature, rather than a controlled clinical trial.

Patient factors

Crowns placed on teeth of female patients perform better than crowns placed on the teeth of male patients, both in terms of time to re-intervention and time of the crowned tooth to extraction (Figures 6 and 7). There is no evidence to suggest that the female patient has better oral hygiene or less potential for caries than the male

patient, so the reason for the enhanced performance of crowns in female patients might be likely to be the less well developed musculature of the female patient placing less force on crowns.

Crowns placed for patients who are exempt from payment perform less well than those patients who are charge payers (Figures 10 and 11). This effect is apparent throughout the analyses and may be related to socio-economical factors whereby patients from lower socio-economic groups have a more cariogenic diet and poorer oral hygiene[9]. In this regard, patients with high treatment need (as measured by the average spend on dental treatment) also receive restorations with reduced longevity, both in terms of time to re-intervention and time to extraction of the restored tooth. Figures 12 and 13 show clearly that the patient's history of dental treatment is a major factor in determining the likely survival of crowns, both to time to re-intervention and time to extraction. For time to re-intervention, the difference is dramatic at fifteen years, with survival being 84% for those with low annual expenditure on dental treatment, and 44% for those with high annual dental treatment fees (Table 12). For time to extraction the corresponding figures are 94% and 71% (Table 13). Looked at in terms of tooth loss, patients with high annual dental expenditure therefore face the prospect of losing *circa* 30% of their crowned teeth within 15 years, compared with 6% for patients with low annual dental treatment need, as measured by mean annual expenditure on dental treatment. Given this demonstrably poor performance of crowns in patients with high treatment need, and by inference high caries activity, perhaps the question should be asked – in patients with high levels of dental disease (as measured by annual treatment need), is placing a crown in the mouth of such a patient an appropriate treatment and/or an appropriate use of taxpayers' money?

Patient age plays a part in crown longevity, with crowns, overall, performing optimally in the 40 to 60 year age groups, in terms of time to re-intervention, and with crowns in the age groupings above and below this performing less well (Figure 8). However, when time to extraction of the crowned tooth is examined (Figure 9), the results are different, given that crowns placed in the 18 to 39 year age groups perform best, and better than crowns placed in the 40 to 69 year age groups and the over 70 age group providing the worst performance. These results may be considered surprising, since a tooth which is crowned at an early age (for example in an 18 or 19 year old patient) is likely to either have been subjected to trauma and/or the tooth reduction which is involved in crown preparation, both of which could be considered to weaken the tooth. On the other hand, the older the patient the more wear and tear the teeth will have accumulated, so it appears that age trumps trauma when it comes to crown restoration. However, although the performance of crowns deteriorates with age, it does so at a more gradual rate than other types of restoration[5,6]. Crown performance is therefore less age-dependent than other restorations, this being borne out, for example, by comparison of Figure 9 in the present work with Figure 8 of paper 2 in this series[5]. This has important implications for the choice between crowns and direct restorations for patients of different ages, and this will be explored in later papers in this series, when restorations in different tooth types will be examined.

Other factors

When a pinned core is placed in the same course of treatment as a crown, the performance of the crown is optimized, both in terms of time to re-intervention (Figure 25) and time to extraction. In general, a pinned core will be necessary in a posterior tooth which has a reduced amount of tooth substance, that in itself being a

potentially adverse clinical situation. However, the data indicate that the placement of a core enhances the performance of the subsequent crown, presumably because the resistance and retention form of the crown preparation is improved. The message for clinicians is therefore clear, optimizing the retention of a crown by placement of a core makes clinical sense. The material from which the core was formed is not known, but is likely to have been dental amalgam in a high proportion of cases. However, the need to place a post when placing a crown results in a restoration which performs less well (Figures 23 and 24), no matter which of our two parameters of survival are used. This may be considered to represent a further loss of tooth substance when compared with those teeth which received a core (i.e. there was sufficient coronal tooth substance remaining for this) as opposed to those teeth which required the placement of a post (i.e. insufficient coronal tooth substance remaining). This also adds the need for the placement of a root filling (with the attendant reduction in survival) (*vide infra*)[3]. Whether this is a “chicken and egg” situation, or not, cannot be surmised from the present work. However, the results do appear to indicate that, when a post is placed to retain a crown, the survival of the tooth is compromised.

What also is clear that the provision of a root filling in the same course of treatment as a crown leads to less good clinical performance of the crown, both in terms of age to re-intervention but also time to extraction of the crowned tooth (Figures 21 and 22). There is another clear clinical message here. Keeping teeth alive results in an optimal clinical performance. This may relate both to the demonstrable failure rate of root fillings[3] or the potentially weakening effect of the root canal access cavity and treatment on the strength of the tooth, although there is no effect, *per se,* of the root canal treatment on the moisture content or brittleness of the treated tooth.[10,11].

Comparison with other work

There are no papers which can be directly compared with the present work. However, several papers present data from general dental practice which may be considered worthy of mention:

- In the study by Leempoel and colleagues[12], 601 crowns (442 in vital teeth) in 174 patients were followed up over periods of one to eleven years, with 71% of the patients having one or two teeth with an individual crown and the remaining 29% having from three crowns to a maximum of sixteen. A total of 21 restorations (4.8%) failed: all clinical treatment was carried out by one private practitioner, a part time Faculty member of the Department of Occlusal Reconstruction at the University of Nijmegen, so the results may perhaps not be considered typical of a busy NHS general dental practice in England and Wales.
- Terry Walton, a specialist Prosthodontist in private practice and Clinical Associate Professor at the University of Sydney, Australia, has collected a wealth of data from his practice[13]. In 1993, he recalled patients with 688 single-unit metal-ceramic crowns placed in his practice between 1984 and 1992, with the examination covering 87% of the crowns placed. Clinical and laboratory procedures were standardized in order to eliminate operator or technical variation. Crowns placed on maxillary anterior teeth predominated, with the author commenting that “esthetics was a major reason that patients presented for crowns”. Walton added a further comment, that “the small number of crowns involving mandibular incisors reflected the authors bias against crowning these teeth because of their size”. The overall repair and failure rate during 5 to 10 years of clinical service was 3% for both, with

crowns on non-vital teeth having a significantly higher failure rate than those on vital teeth. The maxillary lateral incisor tooth was the tooth which accounted for 32% of retreatments, but only for 17% of the crowns, this result being reflected in the results for the present study which also indicated poorer performance of this tooth.

- The survival of all-ceramic crowns in the present study was poorer than the other crowns types, so it may be considered to be of interest to examine the results of a paper from Segal[14], a US-based practitioner, which documents the performance of 546 all-ceramic InCeram (Vident, CA, USA) crowns over a six year period. Thirty-two per cent of crowns were placed on anterior teeth, the remainder on posterior teeth, with an overall failure rate of 0.9% during the observation period. The material from which the crowns were formed uses an alumina core: it is possible that some crowns placed in the present study may have utilised this material, but, since the data does not include the actual make of crown, only the generic type, it can only be conjectured as to whether the results of the present work might have been improved when materials such as that in Segal's study are employed.
- The systematic review of Pjetursson and co-workers[15] is also worthy of mention, as they examined survival of all-ceramic and metal-ceramic single crowns after an observation period of three years. Thirty-three papers (from 86 articles selected for full text review) were included, with the results indicating a 93% and 96% 5-year survival of all-ceramic crowns and metal-ceramic crowns respectively. Regarding the types of all-ceramic crown included in the study by Pjetursson and co-workers, the all-ceramic crowns were divided into specific types (according to their construction), with the

glass-ceramic type probably being closest to the materials used by practitioners in the present study: their estimated survival varies between 80% and 90% at five years, indicating a not dissimilar 5-year performance to the all-ceramic crowns in the present work, that being *circa* 70% (Figure 19). Regarding the 5-year performance of metal-ceramic crowns recorded by Pjetursson and co-workers, this varies from 92% to 100%, while the 5-year performance of such crowns in the present work is in the region of 80%.

- Finally, in an era when writing about aesthetic restorations prevails, it falls to Donovan and colleagues[16] to discuss the unfashionable, but essential, task of the survival of 1,314 cast gold restorations in service from 1 to 52 years. This involved a random review of charts treated by one dentist (RV Tucker) in a private dental office, which resulted in an invitation to patients to participate in an examination of their restorations. A total of 1,314 restorations were examined, in the 114 patients who reported for examination. Of particular interest to the present study were the 27% of restorations which were complete metal crowns (n=355) and the 9% which were three-quarter or seven-eighth crowns (n=118). The results indicated that the earliest restoration loss was at seven years and 72% of restorations were still in patients' mouths after 20 years, with 13% of full crowns having failed after 10 to 19 years. While these data indicate enhanced performance compared with the data in the present study, it might be worthy of note that the clinician involved was an enthusiastic user of gold restorations which resulted in the establishment of the RV Tucker gold study clubs.

Finally, it may be considered that some improvements might have been made in the materials for crowns and/or luting cements employed over the 16 years of the data collection for the present work, with luting materials becoming available which are less soluble[17] and crown materials (in particular ceramics) which may be considered to have improved physical properties. However, Figure 26 indicates that these improvements have not resulted in improved performance of the crowns in the study, or, that these improvements have not found their way into dentistry carried out under the GDS Regulations.

Conclusions

- Overall, *circa 52*% of crowns, overall, have survived at 15 years.
- While crowns provide a patient with a restoration which requires the least number of re-interventions, they perform poorly (indeed, as poorly as GI) when time to extraction is examined.
- Factors influencing crown survival are patient age and patient treatment need, with patients with high treatment need having crowns which perform suboptimally.
- Factors influencing crown survival also include dentist age, but, in comparison with direct restorations in which younger dentists out-perform older dentists, for crowns, dentists in the 30 to 60 age group provide crowns with optimum performance.
- Crowns placed on upper canine teeth perform worse than crowns placed on any other tooth: crowns perform best on first molar teeth

- The placement of a pinned core appears to enhance the longevity of the subsequent crown, whereas the placement of a root filling or a metal post in the same course of treatment as the crown placement does not.

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