Survival of surgical endodontic treatment performed in a dental teaching hospital: a cohort study

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Abstract

Wang Q, Cheung GSP, Ng RPY. Survival of surgical endodontic treatment performed in a dental teaching hospital: a cohort study. *International Endodontic Journal*, **37,** 764–775, 2004.

Aim To assess the survival function of surgical endodontic treatment performed at least 1 year before in a dental teaching hospital.

Methodology A total of 194 teeth surgically treated between 1991 and 2001 were recalled and examined clinically and radiographically using a set of strict criteria. The Kaplan–Meier method and log rank test were used to evaluate the survival time. Confounding factors were examined by Cox regression analysis.

Results The median survival time of the 154 first-time surgically treated teeth was 92.1 months (95% CI: 40.9–143.4) and that of the 40 resurgery cases was 39.1 months (95% CI: 6.1–72.1) up to the date of recall. There was a significant difference in the length of survival between the two groups. For those first-time surgery cases, the preoperative marginal bone loss and the operator had a significant influence on the survival time ($P < 0.05$).

Conclusions The survival of surgical endodontic treatment declined nonlinearly with time. The preoperative marginal bone loss, operator and resurgery were important factors affecting the survival of this treatment modality.

Keywords: failure, periapical surgery, success, survival analysis, treatment outcome.

Received 24 February 2004; accepted 24 June 2004

Introduction

Periapical surgery is a well-established and accepted endodontic procedure for the preservation of teeth with persistent periapical pathology or following failed non-surgical root canal treatment. Its outcome has been assessed in numerous studies with a reported success rate ranging from 41 to 94% (Table 1). The wide variation might be related to differences in sample size, tooth types, indications for the operation, observation period, treatment procedures and materials used, as well as the criteria for success and the recall rate.

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Various factors may influence the prognosis of periapical surgery. These include the quality of the orthograde root canal filling (Harty *et al.* 1970, Ericson *et al.* 1974, Finne *et al.* 1977, Lyons *et al.* 1995) and of the apical root-end filling (Nordenram & Svärdström 1970, Rud *et al.* 1972b, Persson 1973, Lustmann *et al.* 1991), size of the periapical destruction (Lehtinen & Aitasalo 1972, Persson *et al.* 1974, Tay *et al.* 1978, Hirsch *et al.* 1979), experience of the operator (Malmström *et al.* 1982, Lyons *et al.* 1995), the type of periapical pathology (Rud & Andreasen 1972, Mikkonen *et al.* 1983), use of antibiotics (Altonen & Mattila 1976), status of the coronal restoration (Rud *et al.* 1972c, Rapp *et al.* 1991, Rahbaran *et al.* 2001), and the method of preparing the apical root-end cavity (Friedman 1991, Carr 1992, Bader & Lejeune 1998, Testori *et al.* 1999, Maddalone & Gagliani 2003).

Table 1 Some studies (with observation period of 1 year or above) on success and failure of periapical surgery

Author	Period of operation included in the research	Type of practice	Sample size (teeth)	Evaluation method	Recall rate (%)	Mean success rate (%)	Observation period (years)	Remark
Maddalone & Gagliani (2003)	Not mentioned	A district hospital	120	C + R	78	78	3	
Rahbaran *et al.* (2001)	1990–1995	Dental school	176	C + R	44	70	4	
Testori *et al.* (1999)	1985–1994	Dental clinic	302	C + R	74	75	1–10	
Lyons *et al.* (1995)	1988–1989	A district general hospital	97	C + R	54	89	5	First-time surgery and resurgery were evaluated together
Cheung & Lam (1993)	Not mentioned	Dental school	32	C + R	Not mentioned	62	2	Posterior teeth only
Malmström *et al.* (1982)	1969–1978	Dental school	182	R + C[a]	25	65.4	>1[b]	First-time surgery and resurgery were evaluated together
Hirsch *et al.* (1979)	1969–1973	Dental school	572	C + R	88	46.7	3	
Finne *et al.* (1977)	1970–1972	Dental clinic	214	C + R	Not mentioned	50	3	Subject same as Persson *et al.* (1974)
Persson *et al.* (1974)	1970–1972	Dental clinic	220	C + R	Not mentioned	41	1	
Rud *et al.* (1972b)	Not mentioned	Dental school	1000	R	Not mentioned	76	1–15	
Lehtinen & Aitasalo (1972)	1964–1967	Dental school	188	C + R	33	94.1	>1[b]	

C, clinical; R, radiographic examinations.
[a]Clinical symptoms from patient's record, not from clinical examination.
[b]Over 1 year but exact period not mentioned.

With the exception of a few studies, most investigations evaluated the prognostic factors based on the percentage of successful or failed cases and by virtue of the statistical method used, did not consider the presence of any confounding factors. In addition, often only one time-point was selected to determine the success rate and no attempt was made to examine how this rate might change with time. Survival analysis has been used to evaluate the outcome of many medical or surgical treatment modalities (Aletaha *et al.* 2003, Grossman *et al.* 2003). The same has been used in dentistry to evaluate such diverse subjects as the natural history of caries (Carlos & Gittelsohn 1965), the success of pulpotomy techniques (Rölling & Thylstrup 1975), performance of osseointegrated implants (Babbush & Shimura 1993) and primary nonsurgical root canal treatment (Cheung 2002, Cheung & Chan 2003). It has the advantage of using all the information provided by cases that had been examined or had failed (Kleinbaum 1996), permitting assessment of the survival function over time and allowing prediction of the longevity of a treatment modality (Mitchell & Walls 1991).

The purpose of this study was to determine by means of survival analysis, the long-term treatment outcome of endodontic surgery performed in a dental teaching hospital in an attempt to identify factors that might affect the survival of teeth so treated.

Material and methods

The Prince Philip Dental Hospital (PPDH) is a teaching hospital for undergraduate and postgraduate dental training in Hong Kong. All treatments have been recorded in a computer database since the inception of the Hospital in 1980. Periapical surgery or surgical endodontic treatment is performed in both the departments of Conservative Dentistry and of Oral and Maxillofacial Surgery, but the procedure shares a common computer code and hence may be identified regardless of where it was performed.

A total of 238 surgical endodontic procedures were recorded in 203 patients between 1991 and 2001. The patients were identified and were invited either by telephone or in writing to return for a review appointment. A predesigned form was used to collect the relevant clinical findings at the recall examination. This was done prior to studying the written patient records to avoid the possibility of any bias when seeing the patients or evaluating the radiographs. At the review, the patient was asked about the presence of pain (spontaneous, or upon chewing or pressure) from the treated tooth which was then examined clinically for any swelling, sinus tract, tenderness to percussion and palpation, mobility and periodontal pockets. The presence of any defective margin, fracture or loss of retention of the coronal restoration was recorded. A long-cone paralleling periapical radiograph was taken with a size 2 dental X-ray film (Ektaspeed Plus; Eastman Kodak, Rochester, NY, USA) and a positioning device (Rinn XCP Instruments; Rinn Corporation, Elgin, IL, USA). In the case of posterior teeth, a bitewing radiograph was also taken to aid the examination of the coronal restoration. The exposure time for each tooth type was standardized and the same X-ray unit was used. An automated film processor (Velopex Intra-XE; Medivance Instruments, London, UK) was used to produce radiographs of optimal quality. All examinations were performed by one examiner (QW). For those who failed to attend the recall, the written patient records were studied and the most recent clinical and radiographic findings were noted. If the record showed that the patient had been reviewed not less than 1 year after the surgery, the most recent radiograph was included in the analysis below. Eight patients were eliminated from the study because a fracture line was detected during surgery and the teeth were extracted at the same time. Another 41 patients were excluded because no postoperative review radiographs could be found and the patients failed to attend; six others were excluded due to preexisting periodontal-endodontic problems. Explorative surgery was carried out in four cases, which were also excluded from the analysis. In short, 144 patients with 194 surgical endodontically treated teeth were included, of which 154 were first-time surgery and 40 were resurgery. The mean age of patients excluded from the analysis ($n = 59$) was 41.6 years with 24 males (40.7%) and 35 females (59.3%), whereas for the analysed records the mean age was 47.3 years with 61 males (42.4%) and 83 females (57.6%).

Two examiners (QW and RN) were calibrated before the commencement of study by using well-defined instructions and reference radiographs depicting different periapical conditions (Molven *et al.* 1987, 1996). QW examined all and RN examined half of the radiographs independently under standardized, optimal viewing condition comprising an illuminated view-box and ×2 magnification. When the two examiners disagreed, the radiograph was subjected to joint evaluation. A random selection of 10% of all films were

re-examined at least 4 weeks later to check the consistency of the radiographic evaluation. Radiographic signs of healing were classified according to Rud *et al.* (1972a) into four categories:

A. *Complete healing*: normal or slight increase in width of periapical periodontal space, but which was less than twice the width of noninvolved parts of the root; tiny defect in the lamina dura (maximum 1 mm); complete bone repair;

B. *Incomplete healing*: the rarefaction had decreased in size or remained unchanged, and was characterized by signs of bone healing at the periphery of the rarefaction;

C. *Uncertain healing*: the rarefaction had decreased in size, with one or more of the following characteristics: the radiolucency was larger than twice the width of the periodontal space, was bordered by a lamina dura-like structure, had a circular or semicircular periphery, or was located symmetrically around the apex as a funnel-shaped extension of the periodontal space;

D. *Unsatisfied healing or failed*: the rarefaction had enlarged or remained unchanged for over 4 years after surgery.

Any of the following was deemed to be a failure of the treatment: (i) radiographically unsatisfactory healing, i.e. category D above; (ii) radiographically uncertain healing (category C) after 4 years or more (Molven *et al.* 1987); (iii) sinus tract traced to the treated teeth; (iv) retreatment of the tooth surgically or nonsurgically; and (v) extraction of the tooth, except for those cases where the established pathology was of nonendodontic origin, in which case the sample would be excluded. For teeth presented with clinical symptoms such as tenderness to percussion or palpation, presence of mobility (grade I or II, without excessive probing depths) but with radiographically complete healing, the status was recorded as uncertain. If intervention was deemed necessary, the case was considered as failed. The nature and chronology of any failure were also studied. If in the patient's record, he or she had attended as an emergency or complained of acute pain, swelling or tooth fracture after the surgery leading to further treatment, the case was regarded as an 'emergent' failure. Other signs or symptoms that had escaped the patient's attention but which had fulfilled the criteria for failure described above were considered as 'inconspicuous'. The preoperative status, technical quality of the apical root-end filling, radiographic quality of coronal seal at the most recent and this recall, and the quality of preoperative root filling were also determined from the radiographs by the two examiners. This was done after the review appointment. QW also examined the quality of the root filling before and after the surgery.

Statistical analysis

Taking the date of surgery D_0 as the origin for time measurement, treatment might be considered 'good' at the date of recall examination D_G and the period of service (in months) was calculated as $T_G = D_G - D_0$. However, the date of failure might not be that certain and hence would require careful consideration. As failure may develop over time and may not be noticed until a review appointment (inconspicuous failure) or onset of acute symptoms or occurrence of a catastrophe (emergent failure), the two situations should be handled differently. For emergent failures, the 'failure date', D_F, would be rather well defined and the time to failure would become $T_F = D_F - D_0$; no reference to T_G was made in this case. For those inconspicuous failures, the onset of failure would escape any notice until at a recall; this date of 'diagnosed failed' was recorded as D_f. Then the date of the latest recall when the treatment was judged to be successful or still not considered as failed was taken as the 'last-known-good-date', D_g. Thus the two intervals: T_f $(=D_f - D_0)$ and T_g $(=D_g - D_0)$ denoted the times to the diagnosed failure and of service, respectively. They formed the basis for an estimation of the time to failure T_F using the following formula based on the geometric mean (Cheung & Chan 2003):

$$T_F = [(T_g + 1) \times (T_f + 1)]^{1/2}$$

The constant '1' (in months) was inserted to bypass the ambiguous condition for $T_g = 0$ whilst maintaining the absolute interval between D_g and D_f (Cheung & Chan 2003). As the present investigation was a cohort study, survival analysis was the statistical method of choice to analyse the results. The contribution of 23 co-variables to the survival function was further analysed using the Kaplan–Meier estimator and log rank test (SPSS 11.5 for Windows; SPSS Inc., Chicago, IL, USA). Those co-variables with $0 < P < 0.3$ in the log rank test were entered as possible confounders in a Cox regression analysis.

Results

The first-time surgical treatment ($n = 154$) fared significantly better compared with resurgery cases (Fig. 1). Seventeen of the 40 resurgery cases (42.5%) healed,

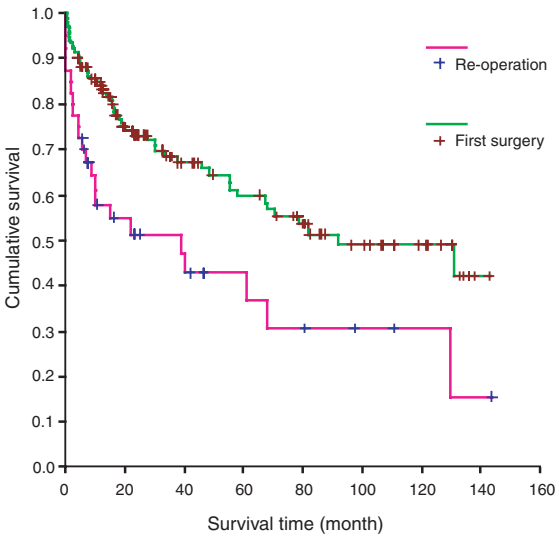

Figure 1 Overall survival curves for first-time surgery ($n = 154$) and resurgery cases ($n = 40$).

with a median survival of 39.1 months (95% CI: 6.1–72.1) and mean of 56.3 months; see Table 2 for reasons for failure. Amongst the first-time surgery cases, 15 teeth were classified as having 'uncertain' healing – they either had a review period of less than 4 years or presented with clinical symptoms but with radiographically 'complete healing'. As no active intervention was warranted at this stage, these cases were treated as censored data. The median survival of all first-time cases was 92.1 months (95% CI: 40.9–143.4), with a mean life of 86.1 months up to the date of recall (Fig. 1). A total of 54 first-time surgically treated teeth (35.1%) were deemed to have failed; some 46% of them were classified as 'emergent' failures (Table 2). The influence of 23 co-variables tested was summarized in Table 3. Teeth with less than 4 mm preoperative marginal bone loss from the cemento-enamel junction (CEJ) had a significantly longer survival time than those with more than 4 mm marginal bone loss preoperatively. Teeth treated by postgraduate dental students had a significantly higher survival probability compared with those treated by staff. The outcome for anterior teeth and premolars was better than that for molars – but tooth type as a co-variable was also eliminated after Cox regression analysis (Table 4). The factors that remained significant in affecting the survival of first-time surgery were operator (Fig. 2) and preoperative marginal bone loss (Fig. 3).

The intra- and inter-observer reliability of both examiners' evaluation was fairly good for preoperative apical rarefaction, marginal bone loss and the technical quality of the apical root-end filling; the Cohen's Kappa value ranged from 0.46 to 1 (Table 5). That for the quality of preoperative root filling was rather low ($0.03 < \kappa < 0.27$). Nonetheless, a longer survival time was noted for the surgically treated teeth when the root fillings followed the root canal form and were homogenous, compared with those that showed some deviations from the canal outline or the presence of voids. However, the differences were not statistically significant (Table 3).

Table 2 Reasons for failures

Reason for failure	Teeth examined at recall and deemed to have failed	Documented failure in patient's record	Subtotal (% of all resurgery)
Resurgery ($n = 40$)			
Tooth extracted	1	4	5 (13)
Further treatment required	1	1	2 (5)
Sinus tract and/or swelling	6	6	12 (30)
Radiographically failed	1	3	4 (10)
Total	9	14	23 (58)
	No. of emergent failures	**No. of inconspicuous failures**	**Subtotal (% of all first-time surgery)**
First-time surgical treatment ($n = 154$)			
Tooth extracted	12	4	16 (10)
Further treatment required	2	5	7 (5)
Sinus tract and/or swelling	10	2	12 (8)
Radiographically failed	1	15	16 (10)
'Uncertain' healing for over 4 years	0	3	3 (2)
Total	25	29	54 (35)

Table 3 Mean survival time of first-time surgical endodontic treatment by categorical co-variables

Co-variable examined	Subgroup examined	Number of teeth	Median survival (months)[a]	95% confidence interval of median (months)[b]	Time when 25% of sample had failed[a]	*P*-value from Kaplan–Meier estimator (log rank test)
Gender	Female	90	82	–	19	0.79
	Male	64	131	47–214	21	
Presence of voids in the preoperative root canal filling[c]	None	81	–	–	19	0.08
	Apical third	45	56	18–94	16	
	Middle/coronal third	15	–	–	–	
Extent of preoperative root canal filling[c]	0–2 mm	91	92	54–130	17	0.98
	>2 mm	26	–	–	19	
	Overfilled	24	–	–	23	
Profile of preoperative root canal filling[c]	Follow root canal form	122	131	44–218	19	0.34
	Ledge/deviation/transportion	19	56	2–110	16	
Homogeneity of preoperative root canal filling[c]	Homogeneous, good condensation, no discernible void	75	92	–	19	0.58
	Inhomogeneous, voids discernible	66	131	33–229	19	
Preoperative periapical rarefaction[d]	None	12	–	–	79	0.26
	Less than or equal to 5 mm	61	71	16–126	16	
	More than 5 mm	79	131	46–215	30	
Preoperative marginal bone loss	Less than or equal to 4 mm from the CEJ	131	131	61–200	30	0.02
	More than 4 mm from the CEJ	23	46	1–92	5	
Preoperative symptoms	Symptomatic	126	92	66–118	19	0.39
	No symptom	28	–	–	28	
Procedure of the periapical surgery	Curettage only	5	19	0–43	19	0.40
	Root-end resection but without filling	36	–	–	46	
	Root-end resection and filling	113	82	38–126	17	
Method of preparing retrograde cavity[e]	With ultrasonic	13	56	–	17	0.74
	Other (usually by burs)	100	82	37–127	17	
Technical quality of retrograde filling[e]	Good	19	–	–	17	0.92
	Not good	94	82	37–128	19	
Root-end filling material[e] (except two cases filled with other material)	Amalgam	79	82	54–110	17	0.74
	IRM	32	–	–	30	
Radiographic quality of coronal seal on final recall (with two missing data)	Acceptable	142	131	61–201	23	0.74
	Gaps discernible	10	56	0–127	17	
Postoperative radiographic quality of root canal filling	Acceptable	124	131	60–201	21	0.37
	Voids present	30	67	39–95	19	
Operator (excluding four cases by undergraduate students)	Staff	73	49	19–78	13	0.002
	Postgraduate student	77	131	–	67	
Use of systemic antibiotics	Yes	62	–	–	38	0.24
	No	92	79	24–134	17	

Table 3 Mean survival time of first-time surgical endodontic treatment by categorical co-variables

Co-variable examined	Subgroup examined	Number of teeth	Median survival (months)[a]	95% confidence interval of median (months)[b]	Time when 25% of sample had failed[a]	*P*-value from Kaplan–Meier estimator (log rank test)
Department	Conservative department	50	68	39–97	19	0.76
	Oral and maxillofacial surgery	88	–	–	19	
	Others	16	82	66–99	71	
Final restoration	Crown	73	82	55–109	21	0.58
	Intracoronal filling	81	–	–	19	
Tooth type	Incisor and canine	101	131	60 201	46	0.006
	Premolar	30	–	–	28	
	Molar	23	30	13–47	13	
Pathology[f]	Cyst	31	–	–	67	0.63
	Granuloma	43	–	–	28	
	Others	9	–	–	34	
Prior orthograde retreatment	No reRCT	121	82	55–109	19	0.11
(with one missing data)	Retreated before surgery	13	–	–	17	
	Surgery and root fill at the same time	19	–	–	–	
Age	10–19	15	–	–	23	0.53
	20–29	25	–	–	13	
	30–39	40	131	–	56	
	40–49	28	79	29–129	19	
	50–59	22	92	8–176	16	
	60 or above	24	67	40–95	5	
Total		154	92	41–143	21	
Nature of operation	First-time surgery	154	92	41–143	21	0.002
(all cases included, $n = 194$)	Resurgery	40	39	6–72	4	

[a]Empty reading indicated that the survival curve did not drop below 0.5 or 0.75, respectively.
[b]Standard error could not be estimated for some subgroups.
[c]Excluding 10 cases with missing data and three other with no root canal filling present (i.e. $n = 141$).
[d]Exclude 12 cases with relevant data missing ($n = 142$).
[e]Only for those with a root-end filling ($n = 113$).
[f]Excluding 71 cases without a histopathological report ($n = 83$).

Table 4 Cox regression survival analysis (original model with seven independent co-variables included)

Co-variable	Subgroup	*B*	SE	Exp(*B*)	*P*-value
Presence of voids	No void	0.78	0.76	2.17	0.34
	Apical third	1.05	0.78	2.86	
	Middle and coronal third[a]	0		1	
Operator	Staff	0.74	0.33	2.09	0.03
	Postgraduates[a]	0		1	
Tooth group	Anterior	0.09	0.32	1.10	0.77
	Posterior[a]	0		1	
Prior orthograde retreatment	No retreatment	1.36	1.07	3.91	0.19
	Retreatment	2.00	1.14	7.37	
	Through-and-through procedure[a]	0		1	
Use of systematic antibiotics	Yes	−0.44	0.34	0.65	0.20
	No[a]	0		1	
Preoperative marginal bone level	≤4 mm below CEJ	−0.81	0.36	0.45	0.03
	>4 mm from CEJ[a]	0		1	
Presence of preoperative periapical area	None	−1.54	1.04	0.21	0.23
	Diameter ≤ 5 mm	0.21	0.30	1.24	
	Diameter > 5 mm[a]	0		1	

[a]Reference category.

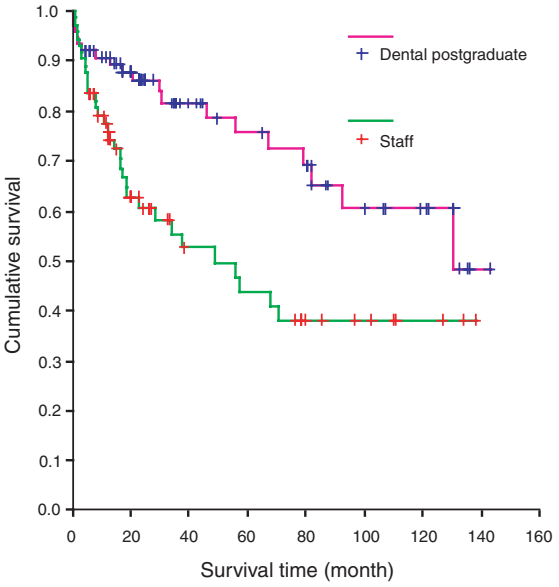

Figure 2 Survival curves of first-time surgery as a function of operator (except four cases operated by undergraduate student, i.e. $n = 150$).

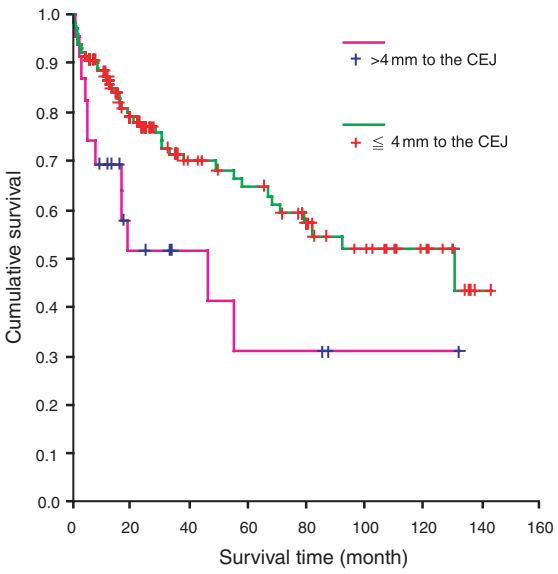

Figure 3 Survival curves as a function of the preoperative marginal bone loss status (first-time surgery only, $n = 154$).

Surgery performed in different departments did not show any significant difference in the outcome. Relatively more cases had received orthograde root canal retreatment in the Conservative department before the surgery, whereas oral surgeons did more 'through-and-through' procedures especially in anterior teeth (Table 6). More premolars or molars were operated by staff than students (Table 7). The longest survival time tended to be found in teeth treated with the 'through-and-through' approach.

Discussion

The ultimate success of surgical endodontic surgery is dependent on a myriad of factors, which may range

Table 5 Intra- and inter-observer reliability amongst different evaluation criteria

Items	Operator	Cohen's Kappa value
Periapical healing	A	0.57
	B	0.34
	A versus B	0.46 (moderate agreement)
Preoperative apical rarefaction	A	0.62
	B	0.71
	A versus B	0.48 (moderate agreement)
Marginal bone loss	A	0.71
	B	0.71
	A versus B	0.80 (substantial agreement)
The technical quality of retrograde filling	A	0.66
	B	1.00
	A versus B	0.50 (moderate agreement)
The postoperative quality of the root-end filling (homogeneity and length)	A	0.16
	B	0.03
	A versus B	0.27 (poor agreement)

Table 6 Summary statistics of the practice in different departments (first-time surgery only)[a]

Department	No reRCT (% of subtotal)	reRCT (% of subtotal)	Surgery and root canal filling done at the same time (% of subtotal)	Subtotal
Conservative dentistry				
Staff	13 (93)	1 (7)	0	14
Student	21 (60)	9 (26)	5 (14)	35
Oral and maxillofacial surgery				
Staff	43 (86)	1 (2)	6 (12)	50
Student	31 (82)	1 (3)	6 (16)	38
Other departments				
Staff	7 (78)	1 (11)	1 (11)	9
Student	6 (86)	0	1 (14)	7

[a]The data on prior retreatment of one case was missing (thus $n = 153$).

Table 7 Frequency of each tooth type treated by different operators (first-time surgery only, $n = 154$)

Operator	Anteriors (%)	Premolars (%)	Molars (%)	Subtotal
Staff	42 (58)	17 (23)	14 (19)	73
Students	59 (73)	13 (16)	9 (11)	81
Total	101 (66)	30 (19)	23 (15)	154

from the patient's systemic condition to the history of the individual teeth, case selection, surgical materials and techniques, and the surgeon's interpretation of the short- and long-term clinical and radiographic findings (Gutmann & Harrison 1991). However, coupled with the complexities of decision-making in success and failure, a realistic perspective must be maintained. With an apparent radiographic success but questionable clinical symptoms, most clinicians and patients may prefer to keep the teeth under review. Thus, this kind of patient was treated as censored data in this study. In assessing the outcome of treatment, the radiographic criteria established for the complete healing group and the unsatisfactory group have been found to be highly reliable (Rud *et al.* 1972a, Molven *et al.* 1987). It has been reported for those cases of incomplete, i.e. category B healing, that the presence of scar tissue could often be identified histologically, some 61% of which also showed moderate or severe inflammation (Rud *et al.* 1972a). But most such cases were found to have healed or remain stable when examined clinically and radiographically in the long term (Molven *et al.* 1996). Hence the incomplete healing was not considered as a failure in this study. On the contrary, cases of 'uncertain' healing (category C) that remained 4 years or longer after the operation were regarded as failed. Histological findings indicated that cases of 'uncertain' healing should be treated as failures from a therapeutic point of view (Rud *et al.* 1972a,b). As radiographs constituted the main form of assessment in this study, precalibration of the two observers and the use of standardized criteria should increase the chance of reaching a true diagnosis and increasing the reliability of the investigation (Molven *et al.* 1987). However, the

reliability of radiographic evaluation of the 'quality' of the root filling was rather low (which was not significant in influencing the survival outcome). This underlined the difficulty of making an accurate assessment of the three-dimensional fill on a two-dimensional radiographic film.

It is apparent from the results that the survival function of surgical endodontic treatment is not linear; the same has been reported for nonsurgical root canal treatment (Cheung 2002, Cheung & Chan 2003). Hence, merely reporting the percentage of successful cases after a period of observation can be erroneous, because this 'rate' represents only a snapshot of the situation at that particular point in time, which would vary according to the position along the survival curve. The endodontic literature has seldom considered the nature of failures apart from simply reporting the causes. This study is possibly the first to treat the 'emergent' and 'inconspicuous' failures differently. Examination of the reasons for these two types of failures for first-time surgery cases indicated that majority of emergent failures could be attributed to some form of symptoms or emergencies leading to extraction or decision to intervene. Re-examination of the written patients' records revealed that many emergent failures occurred soon after the treatment and the teeth were either re-operated or extracted. Three cases of emergent failure ('further treatment required' = 2, 'radiographically failed' = 1) that possibly had a preexisting radiographically discernible lesion were noted. It is arguable that if these cases had been reviewed before symptoms occurred, failure might have been diagnosed sooner. If so, the net effect would be a steeper decline of the survival curve early in the observation period, but the long-term survival would hardly be affected. The relatively small number of such cases was unlikely to influence the results here. It appears that the present method has provided a reasonable means to combine the data arising from failures of different nature for statistical tests using the Kaplan–Meier's method. The authors recognize that the calculation based on the geometric mean (equivalent to taking the mid-point between T_f and T_g on logarithmic scales) is only a means of estimating the actual time to failure. It may be true that frequent, regular reviews can generate a better estimate of this time for entry into a life-table analysis. However, unless the tooth is examined radiographically in every such visit, which may not be ethically feasible if the interval is set at 6 months or shorter, some degree of tolerance in the time to failure is inevitable.

Complete canal debridement is important for success in both nonsurgical and surgical root canal treatment (Klevant & Eggink 1983, Pitt Ford 1998). Although attainment of this goal may not be possible even with the most sophisticated cleaning and shaping procedures (Lin *et al.* 1992), there is some evidence to suggest that high levels of quality cleaning can occur with proper chemomechanical techniques (Byström & Sundqvist 1985, Sjögren *et al.* 1991). The best survival rate tended to be found in those teeth where the root filling and surgery were carried out simultaneously, which corroborates with the conclusion of Friedman (1991). This may be related to the thorough cleaning of the canal space and periapical tissues that was attained during the operation. The least favourable results were achieved when teeth underwent a resurgery – a view supported by Nordenram & Svärdström (1970) and Persson (1973). Only some 42% of the resurgery cases here were judged to have healed at the time of recall (mean observation period = 56 months), which was in general agreement with the rate of some 35% indicated by Peterson & Gutmann (2001). Although factors like anatomy of the roots, proximity to vital structures and clinical accessibility would increase the level of technical difficulty of periapical surgery of molars, the outcome should be the same as that for anterior teeth if the biological principles of treatment were met, namely removal of microorganisms from, and ensuring a good seal of the root canal system. This might explain the lack of influence of tooth type in the survival outcome after Cox regression analysis.

A shortened survival time was noted in teeth with noticeable marginal bone loss in this study, which concurred with the findings by other investigators (Rud *et al.* 1972c, Finne *et al.* 1977, Hirsch *et al.* 1979). As unfilled lateral canals might connect a periodontal pocket and the root canal system, they might present as a possible route of spread of periodontal pathogen to the root canal and later to the periapical area. In addition, when periapical surgery was performed on teeth with reduced marginal bone level, the root was further shortened by the apical root-end resection procedure, leaving a rather compromised periodontal support to the tooth so treated.

As for the experience of the operator, whilst it is logical to assume that senior surgeons are able to proceed skilfully as well as to create the best possible conditions for healing, the contrary seemed to be the case in this study. Treatment carried out by dental

postgraduate students enjoyed a better prognosis than that by staff. One possible reason could be that the more difficult cases (e.g. molars and premolars) and those that were judged to have a lower chance of success or might generate difficulties during treatment were generally handled by a staff member. The fact that staff with different degrees of competence would not be distinguished in the computer records might also have masked the true picture. The result here suggested the importance of case selection to enhance the prognosis of treatment.

The sample size is relatively small considering the 11-year period from which the samples were drawn. This may be related to the increasing use of orthograde retreatment, which is indicated in most cases of endodontic failures (Cheung 1996, Sundqvist *et al.* 1998). Nonetheless, this study provided some trends and correlations, but the findings might only be applicable to specifically controlled cases presented here and the characteristics of a cohort study. The following limitations are identified: (i) most subjects in this study came from the teaching hospital whilst some were referred. Thus, the sample might be biased, because they might not represent a true sample from the general population; (ii) the retrospective nature of this study gave another inherent bias because certain variables, such as the surgical technique, had not been controlled or identified; (iii) not all patients returned for examination and evaluation – this would lead to another kind of bias, namely recall bias, because it is unknown whether healthy or symptomatic patients would be more likely to respond to the request for a recall. A randomized clinical trial will be more revealing, although it is inherently much more difficult to design and perform in view of the number of potential variables involved.

Conclusion

Within the limitations of this study, the following conclusions may be drawn: **1.** The survival of surgical endodontic treatment declined nonlinearly with time and hence simple reporting of percentage of successful cases is not appropriate. **2.** First-time surgical endodontic treatment survived significantly longer than resurgery cases. **3.** Marginal bone loss (more than 4 mm from CEJ), the operator and resurgery showed a significant effect to the long-term prognosis of teeth so treated.

Acknowledgements

The authors were indebted to Dr Brian W. Darvell, Reader in Dental Materials Science, and Ms May Wong, Assistant Professor in Dental Public Health, both of the Faculty of Dentistry of the University of Hong Kong for valuable discussion and assistance in the statistical analysis.

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