Survival rates of teeth treated with bacterial photo-dynamic therapy during disinfection of the root canal system

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Key points

Explores methods of root canal disinfection in order to overcome the shortfalls of conventional chemo-mechanical disinfection.	Discusses Photo-Activated Disinfection (PAD), a novel disinfection method which uses a photosensitising agent and light energy at a compatible wavelength.	Evaluates the survival rates of teeth treated with PAD as an adjunct to conventional chemo-mechanical disinfection over a 10 year period.

Objective To ascertain the survival of teeth having undergone root canal therapy, when bacterial photo-dynamic therapy (bacterial PDT) was used as an adjunct during root canal system disinfection. **Design** Retrospective survival analysis (Kaplan-Meier method) of endodontically-treated teeth, when bacterial PDT was used as an adjunct during root canal system disinfection by a single operator in a private general dental practice. **Materials and methods** The records relating to endodontically treated teeth, performed between 27 May 2001 and 23 June 2016, were sourced. The details of these were placed into a database that permitted flexible interrogation. Survival data on de novo root canal treated teeth (RCT), and those requiring revision of the endodontic treatment (reRCT), were exported into a statistical package to permit survival analysis by the method of Kaplan-Meier. **Results** The number of teeth available for analysis were RCT = 620 and reRCT = 167. Percentage survival at two, four, six, eight, and ten years for RCT was 98.31, 97.38, 95.76, 91.81 and 91.80 respectively. When non-endodontic failures were excluded percentage survival was 99.27, 98.91, 98.28, 97.33 and 97.33 respectively. Percentage survival of teeth having undergone reRCT at the same time periods was 94.14, 92.77, 86.52, 84.09 and 84.09 respectively and respectively. When non-endodontic failures were excluded percentage survival was 96.01,96.01,93.67,63.67 and 93.67 respectively. **Conclusions** Within the limitations of the study, the survival rates of teeth treated with bacterial PDT, as an adjunct during root canal system disinfection, compare very favourably with previously published work where bacterial PDT was not used. The effectiveness of conventional chemo-mechanical disinfection of the root canal system may be enhanced by the adjunctive use of bacterial PDT, particularly in reRCT cases.

Introduction

Successful root canal therapy is dependent on the effective removal of necrotic pulpal tissue and the elimination of pathogenic microorganisms from the root canal system,[1] followed by the establishment and maintenance of a coronal seal.[2] It is widely recognised that residual bacterial contamination of the root canal system is the primary cause of treatment failure.[3,4,5,6,7] However, the complex anatomy of the root canal system,[8] coupled with the resistance of some pathogenic microorganisms to conventional chemo-mechanical decontamination methods, particularly in those cases which require to be retreated,[9] makes decreasing the microbial load challenging, if not impossible.[4,10,11]

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Refereed Paper.
Accepted 30 August 2018
DOI:10.1038/s41415-019-0026-z

The conventional method of decontaminating the root canal system consists of mechanical preparation of the root canals in conjunction with chemical irrigation. The primary function of mechanical preparation is to facilitate adequate penetration of the chemicals as 'mechanical instrumentation alone cannot sufficiently disinfect the root canals'.[1] Endodontic irrigants may be divided into two groups, based on their mode of action.[12] Chelating agents such as citric acid and ethylene diamine tetra-acetic acid (EDTA) remove the smear layer permitting access to the dentinal tubules of the canal walls.[13] Disinfecting chemicals may then be introduced into the root canal system to reduce the microbial load.[12] Solutions of sodium hypochlorite (0.2–5%),[14] chlorhexidine digluconate (2%), iodine potassium iodide and MTAD have been used.[1] Many clinicians prefer to use a chelating agent, in addition to a disinfecting chemical, in their protocol when preparing the root canal system; in an attempt to more efficiently remove infected dentine and decrease microbial loads.[15]

Sodium hypochlorite solution is the most commonly used disinfecting irrigant.[16] It is a potent organic tissue solvent that is proteolytic and dissolves necrotic organic material. It releases free chlorine, which has a wide spectrum of bactericidal effects. Chlorine breaks peptide bonds in proteins to form amino acids and these amino acids are then degraded by hydrolysis through the production of antibacterial chloramine molecules.[12] The high pH of sodium hypochlorite solution denatures proteins and disrupts ideal cell conditions, with the hydroxyl ions damaging both bacterial lipid membranes and DNA. As the chemical is consumed, the free chloride ions diminish, so the solution must be constantly replenished for the irrigant to disinfect effectively.[16] A dwell time of 20–30 minutes has been recommended for the bactericidal properties to be effective.[17]

There are, however, some disadvantages associated with the use of sodium hypochlorite solution. It has a higher surface tension than water, so it does not wet the walls of the root canal as well as some other disinfecting solutions. As a result, the canal walls may not be completely covered and the biofilm is not fully disrupted. Moreover, as the concentration of sodium hypochlorite solution increases, so does its viscosity and surface tension. This further decreases its ability to access lateral canals and dentinal tubules, and therefore its effectiveness in disinfecting the root canal system.[16]

Furthermore, the therapeutic and toxic concentrations of sodium hypochlorite solution are undesirably close together.[18,19] No difference in the antibacterial effect between 0.5% and 5.25% solutions is seen, but the efficiency of weak solutions decreases rapidly. A solution with a concentration greater than 1% is required for pulpal tissue dissolution to occur. At higher concentrations the disinfecting process is faster but untoward tissue damage may occur; particularly if extruded into the periradicular tissues, as the chemical is more toxic at these concentrations.[16]

While the irrigation methods traditionally used in clinical practice are largely capable of reducing microbial load in the root canal system, it would be desirable if other agents or systems were available which were not toxic to the host tissues, required a shorter dwell time, had a lower surface tension, and were effective against all pathogens found in the root canal system. Therefore, it is in the interests of both patient and clinician to investigate other methods of disinfection of the root canal system.

Bacterial photo-dynamic therapy (bacterial PDT), formerly known as photo-activated disinfection (PAD), is a novel disinfection method which uses a photosensitising agent and light energy at a compatible wavelength. A number of systems are commercially available for use in endodontics. The system used in the present study utilises tolonium chloride (TC) (a pharmaceutical grade Toluidine Blue O), in a concentration of 12.7 mg/l solution, as the photosensitising agent and light energy, at a wavelength of 633 ± 2 nm, emitted by either a small diode laser or a light emitting diode (LED). TC is believed to be biologically inert and is taken up by liposomes on the cell walls of rapidly dividing cells. When exposed to light energy, this chemical becomes excited, producing singlet oxygen species which cause rupture of the cell wall by oxidative injury. As the turnover of microorganism cells is higher than those of the host, microorganisms are killed without collateral damage to the surrounding host cells.[20,21] This system is effective against many microorganisms found in the root canal system including: *Fusobacterium nucleatum*, *Prevotella intermedia*, *Streptococcus intermedius*, *Peptostreptococcus micros* and *Enterococcus faecalis*.[22,23] Microorganisms are unable to develop resistance due to the physical nature of the oxidative reaction.[21]

The use of bacterial PDT as an adjunct to conventional chemo-mechanical preparation of the root canal system has been shown to further eliminate microorganisms *in vitro*[24,25,26] and *in vivo*.[27,28,29] A systematic review by Arneiro *et al.*[30] concluded that bacterial PDT had better antimicrobial effects when used as an adjunct to sodium hypochlorite solution during endodontic treatment. Other studies have suggested that bacterial PDT is as effective against *Enterococcus faecalis* when compared against concentrations of both 2.5% and 5% sodium hypochlorite solution.[26,31]

The outcome of endodontic therapy for both primary non-surgical orthograde (*de novo* root canal therapy, RCT) and secondary non-surgical orthograde treatment (root canal retreatment, reRCT) has been reported in the literature by measuring 'success' or 'survival'. Success may be defined as 'an asymptomatic tooth with normal periodontal architecture at the periapex, bony infill and the absence of infection',[32] which would clearly be considered as the gold standard and most desirable result. This may be contrasted with survival which, by definition, means the retention of the tooth in the mouth and includes those asymptomatic root filled teeth, despite incomplete healing of the surrounding hard tissue.[33,34] The increasing popularity of the implant-retained single unit as a viable treatment alternative to RCT has meant that, in recent years, studies on the survival of teeth have become more popular in an attempt to compare outcomes of both treatment modalities.[33,35] A case controlled study,[36] large epidemiological surveys,[37,38] and more recently systematic reviews, have been published using tooth survival as the reported outcome in both RCT and reRCT.[39,40] Some studies reporting tooth survival after endodontic therapy have sought to evaluate the survival of the restoration, rather than the endodontic treatment itself, with most of these studies being retrospective in nature.[39]

A systematic review of the literature reported that the survival of teeth having undergone RCT ranged between 86% and 93% over two to ten years when the data were pooled.[39] The same group of workers reported survival of reRCT of the pooled data at 77.2%.[40] In 2005, Friedman and Mor published survival rates of between 91% and 97% in both RCT and reRCT groups, having reviewed the literature containing mainly follow-up studies.[34] One prospective study boasted a cumulative tooth survival rate for RCT of 95.4% and 95.3% for reRCT, after four years.[41] An epidemiological study which looked at RCT, performed by dentists in private practice and endodontic specialists in the USA who are involved with one particular insurance provider, reported tooth retention of 97% at eight years for RCT cases[37] and 89% after five years for reRCT.[42] A similar study from Sweden described survival of 89.8% over six years for RCT done by general dental practitioners (GDPs), under the auspices of the Swedish Social Insurance Agency.[43] Burry *et al.* reported a pooled survival rate of 86% at ten years for RCT, again using data from an American insurance provider, but a significantly higher success rate for molars treated by endodontists (89%) as opposed to non-endodontists (84%).[44] Alley *et al.* reported survival rates for teeth having undergone RCT for GDPs were 89.7% as opposed to 98.1% for specialists after five years.[45] Both of these latter studies support other studies which have shown higher survival rates depending on the expertise of the clinician. However, due to the disparate protocols[33] of the studies cited, it is impossible to collate the results of these studies and arrive at one single figure for survival in each group (RCT and reRCT). Statistical comparison between studies is therefore not possible.

There are a number of clinical studies which have been carried out to evaluate the bactericidal effects of bacterial PDT,[27,28] but there are few studies which have studied the long-term survival of those endodontic cases treated with bacterial PDT within a clinical environment. The present study is a retrospective audit of all teeth, both RCT and reRCT cases, which underwent endodontic treatment where bacterial PDT was used as an adjunct to conventional chemo-mechanical disinfection of the root canal system, to determine their survival rates.

Materials and methods

The present study is a retrospective audit of teeth having undergone root canal therapy with bacterial PDT as an adjunct to root canal system disinfection between 27 May 2001 and 23 June 2016 by one operator (SJB) in a private general dental practice in Aberdeen, UK. These dates represent the first case in which bacterial PDT had been used by the operator and the last was the date of the commencement of the audit and analysis process. Ethical approval was not required as the study was a retrospective audit of case records.[46]

Root canal treatment (RCT)

In each case, a pre-operative periapical radiograph was taken using a long cone technique with a Rinn film holder to determine approximate canal length and canal morphology. After local anaesthetic had been administered, access to the pulp chamber was gained and the root canals were identified. Rubber dam was then placed and sealed with OraSeal caulking. The canals were accessed, their patency ascertained and the orifices prepared. After initial irrigation using either 20% citric acid solution or 15% EDTA solution, the canal working length was determined using the AFA Analytic Apex Locator or DentaPort ZX. The canals were then prepared, using either ProTaper files or Profile.04, using a crown down approach working to 2 mm short of the working length. The apical two millimetres were then prepared. Copious irrigation was used between instrumentations, alternating between 2.25% Tesco's bleach, 3% sodium hypochlorite solution, and one of the chelating irrigants mentioned earlier. All irrigants were introduced into the root canals using an endodontic micro-needle at ambient temperature. A cone fit radiograph was taken using an EndoRay film holder to verify the position of the gutta-percha (GP) master apical points before cementation. If the case was to be completed at a subsequent visit, a non-setting calcium hydroxide paste (UltraCal) was placed into the canal, a cotton wool pledget (Roeko) placed in the pulp chamber and the tooth was dressed with either IRM (Dentsply) or a glass polyalkenoate (ionomer) cement such as Chemfil Superior or GC Fuji IX Extra.

If the case was to be obturated at the same visit, the canal was washed thoroughly with sterile water to remove any residual irrigants and dried using paper points. PAD solution (Denfotex) was then introduced into the canal using a sterile endodontic micro-needle, ensuring that the fluid passed to the working length. This liquid was agitated in each canal for 60 seconds using a.02 nickel-titanium hand file, two sizes smaller than the master apical file (MAF). The PAD endodontic emitter (Denfotex) was then inserted into the canal until it was within 4 mm of the measured working length. The light was then activated at 100 mW for a period of 120 seconds. The emitter was moved up and down by about 3 mm, at 20 second intervals, during the irradiation time. The photosensitising solution was removed from the canal by a final flush of sodium hypochlorite solution and the canal dried. Upon satisfactory radiographic report of the trial point radiograph, each canal was obturated using GP greater taper points (QED Pro-Fit.04) or ProTaper Universal Gutta-Percha-Points and a zinc oxide eugenol-based sealer TubliSeal EWT or AH Plus using System B apically and by backfilling using Obtura II and αphase GP. This was condensed vertically using a Buchanan plugger, and Vitrebond or Vitrebond Plus (3M ESPE) was placed over the GP and pulpal floor to create a coronal seal. The access cavity was either temporised as previously described if the tooth was to receive an indirect restoration or restored directly using either dental amalgam or resin-based composite. Finally, a post-operative periapical radiograph was taken using a long cone technique in a Rinn film holder.

For those cases which were not obturated at the same appointment, a subsequent visit was scheduled with the patient being asked about symptoms that they had experienced following the canal preparation appointment. Local anaesthetic was administered, and rubber dam was placed and sealed, as described previously. The temporary restoration was removed to gain access to the pulp chamber and the canals were flushed with the irrigants previously described. The canals dried with sterile paper points before being obturated and the access cavity restored, as discussed earlier.

reRCT

In the case of root canals which had been previously treated, the root filling material was removed using ProTaper Universal retreatment files and chloroform, and the canals treated by following the protocol described above.

Data extraction

Prior to the entry of patient details into the study records, a trial database, capable of being flexibly interrogated, was constructed using Excel 2003 and thoroughly tested. This permitted data under the following headings to be entered:

1. Patient's forename
2. Patient's surname
3. Patient's date of birth
4. Patient's age
5. Tooth treated (recorded using the FDI classification)
6. Protocol used
7. Type of treatment (RCT or reRCT)
8. Light emitter tip used
9. Diagnosis of tooth treated
10. History of trauma (yes/no)
11. Preoperative sensibility of tooth
12. Symptoms present at diagnosis
13. Obturation method
14. Date of bacterial PDT treatment
15. Most recent date of follow-up
16. Survival or failure of tooth at last appointment
17. Reasons for failure or a note of lack of follow-up
18. Additional notes on treatment.

After the database had been designed, the first 20 sets of data were inputted and robustly interrogated to ensure that when the remaining data was entered, the information that was required could be easily retrieved and analysed. This process allowed the design of the database to be modified to further ensure efficient and accurate data entry, before the study data was inputted into the database.

Survival end date was determined by a need for re-treatment or extraction of the tooth in question. All teeth requiring further intervention or removal were treated as having failed. Subsequent analysis excluded teeth which had failed due to non-endodontic reasons and survival data was recalculated using the same method. This data was exported into Prism and survival curves were generated by the method according to Kaplan-Meier.

Results

Over the period of the study (5,506 days), 787 teeth were treated with one of the above protocols, of which 620 teeth were RCTs and 167 were reRCTs. Figure 1 presents the survival curves for both RCT and reRCT teeth over a ten-year period. Teeth which required extraction or revision of the RCT were deemed to have failed. Table 1 presents the percentage survival rates in raw form at time frames of two, four, six, eight and ten years, for both RCT and reRCT groups.

The causes of failure were then analysed, as it was apparent that a number of teeth had been lost unrelated to endodontic failure (Figs 2 and 3). These were root fracture (6 RCT/5 reRCT), caries rendering the tooth unrestorable (1 RCT), restoration failure leading to the unrestorability of the tooth (3 RCT/1 reRCT), chronic periodontitis (2 RCT/2 reRCT), root resorption (1 RCT/0 reRCT), and one tooth (otherwise signless and symptomless with radiographic evidence of good peririadicular healing) was recommended for extraction by the restorative department at the Institute of Dentistry, as it would be in the field to be treated when the patient was referred by his oncologist for a pre-radiotherapy opinion (1 RCT). These failures were excluded and new survival rates were determined as per the previous method. The survival curves are shown in Figure 4 and tabulated as raw data in Table 2.

Fig. 1 Kaplan Meier survival curves of RCT and reRCT cases treated with bacterial PDT (including 95% confidence limits) up to a ten-year period

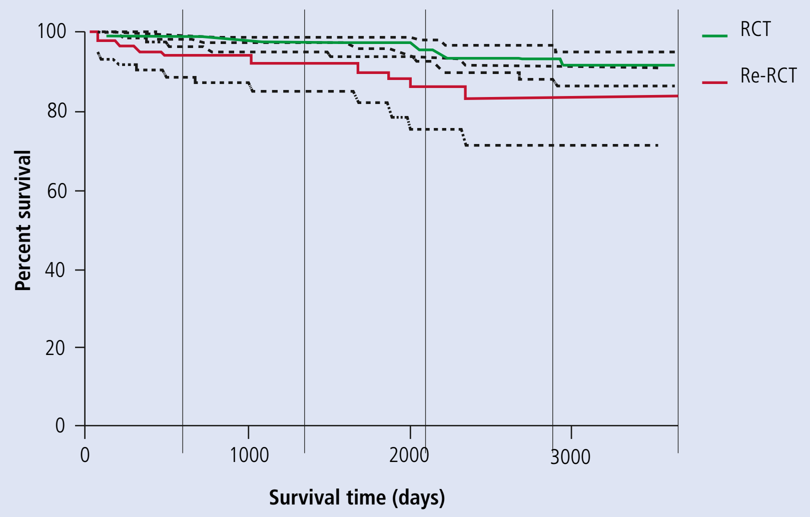
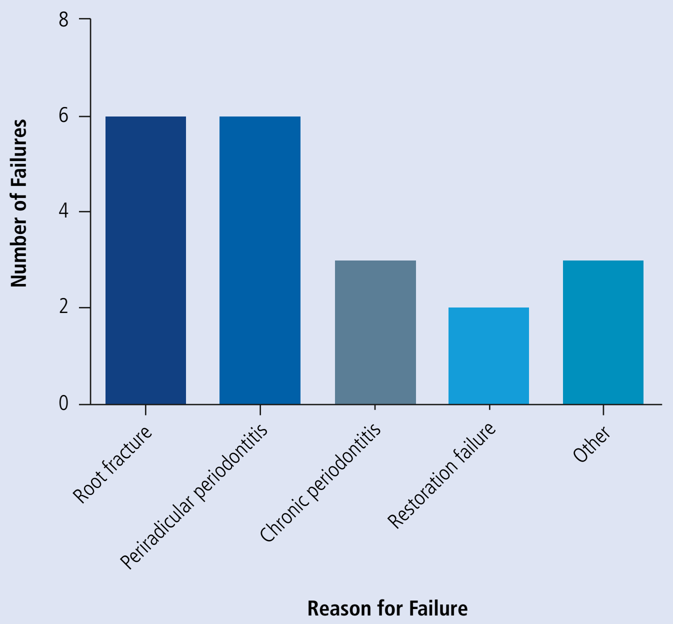


Table 1 Raw data presenting percentage survival rates of teeth in both groups at the stated time periods including the subjects at risk giving an indication of the number of teeth still included at that time period

Year	2	4	6	8	10
RCT survival	98.31	97.38	95.76	91.81	91.80
Subjects at risk	346	222	144	81	32
Re-RCT survival	94.14	92.77	86.52	84.09	84.09
Subjects at risk	76	52	38	21	14

Fig. 2 Reasons for failure of RCT cases. 'Other' comprised of radiotherapy (one case), resorption (one case) and caries (one case)



Discussion

Retrospective audits to investigate treatment outcomes are an important part of clinical governance. This provides valuable information to the clinician to enable reflective learning thus facilitating quality assurance and improvement. It also allows the operator to inform patients as to the likely treatment outcome by that particular clinician during the conversation of gaining valid consent. The present study examined the survival rates of teeth treated by a single operator. While this is advantageous in terms of reporting treatment outcomes to patients, the results of the study would have been more statistically meaningful had the cases of a number of operators been pooled as it would have reduced potential bias. Another potential for bias in a study of this design is if the operator analyses the clinical records and therefore their own work. In the present study, the lead author (JAL) did all of the data collection and statistical analysis completely independently of the clinician who carried out all of the treatment (SJB) in an attempt to eliminate this bias.

In order to extract the pertinent data in a retrospective study, it is critical that all information required is present in the clinical records. The quality of the clinical records is, therefore, paramount to realise the information required. Clinical note keeping may be facilitated and enhanced by the use of computerised clinical records. All

Fig. 3 Reasons for failure of reRCT cases

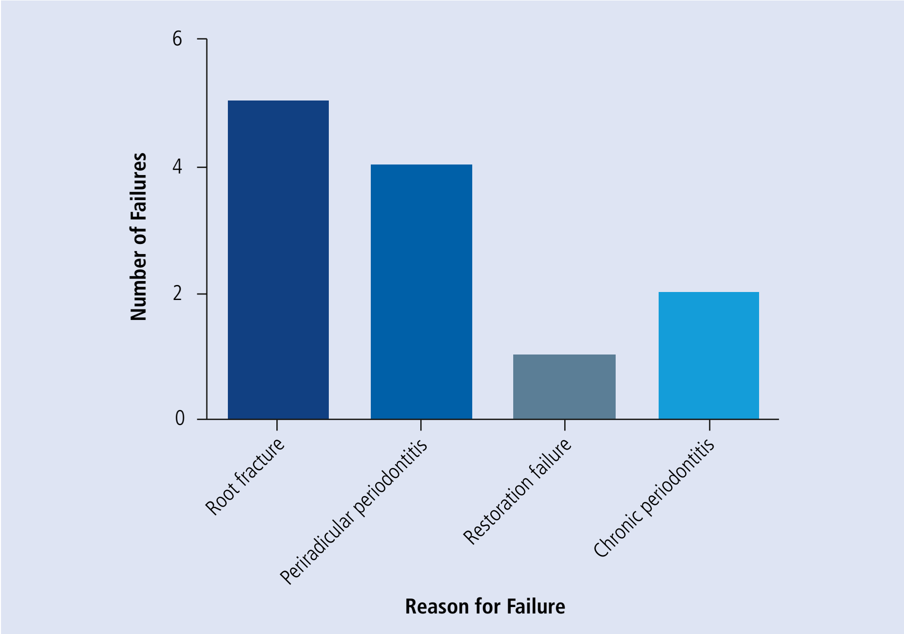


Fig. 4 Kaplan-Meier survival curves, with 95% confidence interval error envelopes for the RCT and reRCT groups; when failures for non-endodontic reasons were excluded

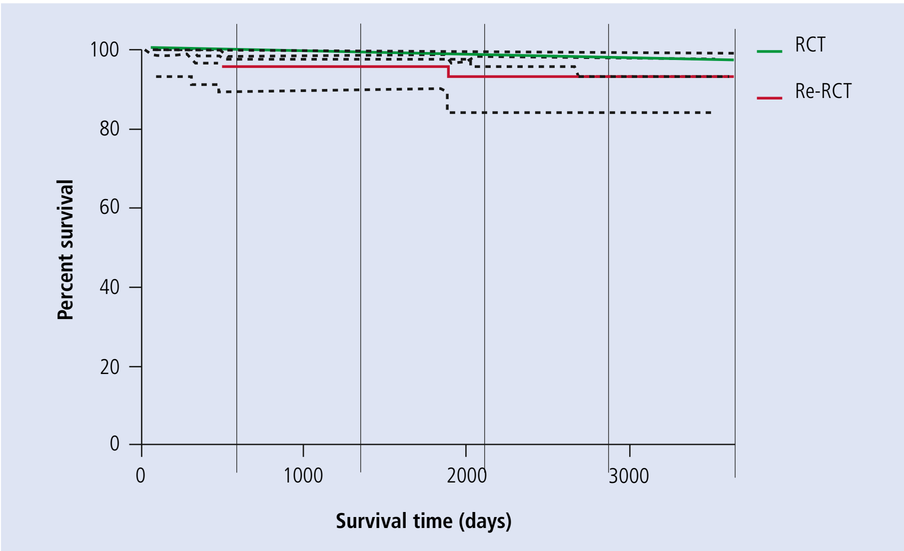


Table 2 Raw data presenting percentage survival times of teeth after non-endodontic failures were excluded in both groups at the stated time periods with subjects at risk

Year	2	4	6	8	10
RCT survival	99.27	98.91	98.28	97.33	97.33
Subjects at risk	337	214	140	79	30
Re-RCT survival	96.01	96.01	93.67	93.67	93.67
Subjects at risk	71	48	36	20	13

of the clinical notes in the present study were maintained by Exact Professional, where the custom screen feature may be used. This tool allows the clinician to enter information in a standardised way, guided by best practice, as an *aide memoire* to ensure that the appropriate information is recorded.

Quality of content of clinical records may also be improved by the use of a clinical audit. A clinical audit is used frequently in the practice, where the clinical work was provided with at least two formal audits having been performed, looking specifically at clinical note keeping. This process resulted in high quality clinical records which enabled easy extraction of the information required.

One of the limitations of this type of retrospective study, especially encompassing a long time frame, is that changes in clinical technique may occur as a result of attendance at postgraduate courses, changes in best practice or new knowledge becoming available as a result of published research. An attempt has been made in the materials and methods section to indicate which materials or equipment had changed during the *circa* 15-year period. Three protocols were used to disinfect the root canal system during the period of the study. These were:

1. Conventional chemo-mechanical preparation, as previously described, then bacterial PDT using the first design of the emitter tip[28]
2. Bacterial PDT using a redesigned emitter tip, then conventional chemo-mechanical preparation[27]
3. Conventional chemo-mechanical preparation, then bacterial PDT using the redesigned emitter tip.

As bacterial PDT was used in all cases, then the change of protocol, as described above, would not have had a bearing on the results except for one issue. A design fault became apparent when the light emitter tip became bent during clinical use. This resulted in a reduced light output by 90% when subsequently tested by the manufacturers. The effect of this was to render the system ineffective, as successful operation of the system relies on a combination of both the photosensitising agent at the correct concentration and light at the compatible wavelength and sufficient energy. This accounts for the failure of one of the cases in the initial study done by this group of workers.[28] This failure impacted negatively on the results in the present study for one of the RCT cases. The subsequently redesigned tip suffered no such malfunction. This is another example of how systems and materials may change in a study extending over a long time period.

Other factors which are known to influence the success of endodontic treatment, and therefore likely survival, were recorded in the initial database to allow further interrogation of the database to see if these other factors had contributed to failure. These were: diagnosis of tooth treated, history of trauma, pre-operative sensibility of tooth, symptoms present at diagnosis, and obturation method. An attempt was made to analyse the results gained but the numbers in each category made the sample size too small to make any conclusions statistically meaningful.

One of the features of the Kaplan-Meier method is that as time goes on (that is, as the plot on the *x* axis gets further from the *y* axis) the results are less reliable. This is because the denominator decreases to account for the loss of subjects to follow-up (censored data), and as such the sample size decreases, and so potentially making the result statistically meaningless. In contemporary statistical practice, risk groups are listed under the Kaplan-Meier plot to illustrate the denominator and to allow the reader to gauge the significance of whether, for example, a small number can be relied on to provide a meaningful result. Although the period of the study extended to just over 15 years, it was decided that periods of up to and including ten years should be reported as the sample size and after that time frame was deemed insufficient to give credence to the results. Time frames of two, four, six, eight and ten years were, therefore, chosen to allow some indication of comparison with previously published data.

The operator accepts referrals from other local general dental practitioners of endodontic cases, both RCTs and reRCTs of more complexity. Once the treatment has been carried out, the patient is referred back to the original referring practitioner and so the patient would normally be lost to follow-up. The exception to this is if there was a problem with the treatment, in which case the patient may be referred back, or if information was gained from the referring practitioner as to the continuing presence of the tooth in the mouth. No attempt was made to obtain such information but, as mentioned earlier, the method of Kaplan-Meier accounts for such loss of subjects and therefore would have no bearing on the results presented.

One of the original intentions of this investigation was to compare the survival rates gleaned from the present study using bacterial PDT as an adjunct to chemo-mechanical disinfection with those already published in the literature relating to survival rates of both RCT and reRCT not treated with bacterial PDT; in order to determine whether there was a statistical significance or otherwise between the groups. Due to the disparate protocols and differences in reporting methods of the results of the published studies, it was impossible to derive one global figure for each group from which to compare. By extension, a logrank (Mantel-Cox) test comparing these figures to determine statistical significance would be invalid and meaningless. Therefore, in the present study, it was only possible to report the survival rates of both RCT and reRCT in a descriptive manner. That said, the survival rates of the present study compare favourably with those published in the literature figures, especially in the reRCT cases. This could be explained as bacterial PDT is effective against all microorganisms found in the root canal system, unlike sodium hypochlorite solution which is the most commonly used disinfecting irrigant utilised in contemporary endodontics. The effectiveness of conventional chemo-mechanical disinfection of the root canal system may, therefore, be enhanced by the adjunctive use of bacterial PDT, particularly in reRCT cases. Further research work is indicated to investigate whether this is indeed the case by carrying out a study such as a prospective randomised controlled trial to compare the results of those cases treated with bacterial PDT with those cases treated by the same operator without bacterial PDT. Ideally, a number of operators would be involved in such a study, as previously discussed.

The present study made no attempt to measure periradicular healing, and therefore 'success', but only reported survival rates. In order to measure the success of periradicular healing, radiographic findings need to be evaluated. Survival rates do not necessarily correlate with success, with the figure quoted for survival likely to exceed that for success.[40,47] Radiographic analysis of the cases included in the present study would be desirable to ascertain whether periradicular healing has occurred. It is hoped that this group of workers will go on to investigate success rates and to determine if periradicular lesion resolution in teeth treated with bacterial PDT is promoted either in time or quality, compared with conventional disinfection methods.

Conclusion

Within the limitations of the study, the percentage survival rates of teeth treated with bacterial PDT as an adjunct during root canal system disinfection were 91.80 and 84.09, for RCT and reRCT respectively, over a ten-year period. However, when teeth which failed for non-endodontic reasons were excluded, the survival rates were 97.33% for RCT and 93.67% for reRCT over the same time frame. These results compare favourably with previously published work, however due to disparate protocols and different methods of reporting, they cannot be directly compared with any statistical validity. The survival rate for reRCT cases is more marked when compared with the rates published elsewhere in the literature. This could be accounted for as bacterial PDT is effective against all microorganisms found in the root canal system; unlike sodium hypochlorite solution, the most commonly used disinfecting irrigant used in contemporary endodontics. Further longitudinal studies, such as randomised controlled trials of the use of bacterial PDT in endodontics, are required to compare the system against conventional disinfection methods. The effectiveness of conventional chemo-mechanical disinfection of the root canal system may be enhanced by the adjunctive use of bacterial PDT, particularly in reRCT cases.

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