

REVIEW ARTICLE

Tooth survival after endodontic treatment

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Abstract

Background: There are several measures that are, or could be, in use in relation to estimating the outcome of endodontic treatments. It is important to reflect on when and why a certain outcome measure is used; when caring for an individual patient it is obvious that the goal always should be a tooth in a healthy state, that is striving to remove any infection and aim for the tooth to have healthy periapical tissues. For patients in general and for society, it is also interesting to know if endodontic treatments will lead to retention of teeth in a functioning state. From epidemiological studies, with high prevalence of root filled teeth with periapical radiolucencies, it is implied that dentists and/or patients accept the retention of a root filled tooth with persistent apical periodontitis. In conjunction with an endodontic treatment the prognosis is considered and since the prognostic factors seem to be somewhat different depending on whether one is considering for example the outcome 'healthy periapical tissues' or 'tooth survival' they are equally important to know. Factors affecting the outcome 'healthy periapical tissues' probably has to do with removal of infection and reconstituting the barrier to prevent leakage whilst 'tooth survival' is more likely associated with factors outside of the classical endodontic field such as restorability and avoidance of further destruction of tooth substance.

Objective: This narrative review will focus on tooth survival after endodontic treatment and root canal treatment will be the focus.

Method: The search was performed in PubMed.

Results: As a crude estimation, there is to be an annual loss of 2% of teeth which have received a root canal treatment.

Conclusion: Of the pre-, peri- and postoperative factors that have been studied in conjunction with root canal treatments the restoration of the tooth is the factor that has been most extensively studied. Many studies imply that root filled teeth restored with indirect restorations have a better survival than teeth restored with direct restorations, it is not possible to determine whether this indeed is a prognostic factor.

Registration: None.

KEYWORDS

endodontics, epidemiology, public health, tooth extraction, treatment outcome

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INTRODUCTION

Endodontic treatment is performed to avoid extractions and maintain the dentition. Root canal treatment is undertaken to eradicate or prevent an infection within the root canal system. Endodontic surgery has a similar purpose in that it aims to eradicate an infection and/or prevent microorganisms or their metabolites from accessing the periapical tissues. In most cases, endodontic surgery may be the final conservative treatment before deciding on extraction. As endodontic treatments are dealing with an infection which, without treatment, in the long term leads to an inflammatory reaction in the periapical tissues, it is reasonable to assess the outcome on what we have been set to do. If we have aimed at removing an infection, it seems reasonable to find out whether there are microorganisms left—or to investigate whether there is an inflammatory reaction in the periapical tissues. If such an outcome measure was to be used, a rather invasive procedure would be needed to assess the outcome of the treatment since neither the root filled canal nor the periapical tissues can be accessed easily. Instead, clinicians are using radiographs to assess the outcome; the inflammation is leading to changes of the bone structure, apical periodontitis (AP), which can be detected by radiographic techniques. Normal periapical conditions is an outcome measure widely accepted by clinicians and researchers (European Society of Endodontology, 2006).

Most patients seem to be satisfied to have completed a root canal treatment (Wigsten et al., 2021). At follow-up, it may come as a surprise to the patient to be informed that their asymptomatic root filled tooth has radiological signs of disease. It is known that discomfort or symptoms from root filled teeth are infrequent; perhaps, one out of 10 individuals with root filled teeth have symptoms. In addition, the pain intensity is mostly low, and the symptoms seem to have a low impact on daily activities (Jonsson Sjögren et al., 2019). An individual with a root filled tooth with more severe symptoms, impacting the individual's daily activities, will most probably make arrangement to have the tooth examined and likely request it be extracted or retreated. Regarding remedying a root filled tooth with persistent signs of disease, it needs to be stressed that root canal retreatments in many countries are frequent in a specialist clinic setting, but rare in general practice (Landys Borén et al., 2015; Wigsten et al., 2019).

Functional retention is a term proposed by Friedman and Mor (2004) as an outcome measure; that is, the tooth is preserved in the mouth and without causing the patient any discomfort. That paper was written in a time when there was a focus on implants—implants were by some considered to be the final and best solution to any problem (Albrektsson & Wennerberg, 2005). It became obvious

that it was biased to compare the success of implants to the success of root canal treatments since success of implants was equal to survival and success of root canal treatment was most often based on periapical conditions. However, without having functional retention or tooth survival as the explicit goal of each individual root canal treatment, epidemiological data suggest that this is how root filled teeth are followed up in many instances. This is substantiated by the fact that about 40 per cent of root filled teeth have AP when investigated in cross-sectional studies, that is the prevalence of AP associated with root filled teeth in a population at a given time (Jakovljevic, Nikolic, et al., 2020; Tibúrcio-Machado et al., 2021). The high prevalence of AP associated with root filled teeth suggests that most dentists, or patients, are not adhering to the European Society of Endodontology (ESE) guidelines (2006). The guidelines state that if normal periapical conditions are not achieved after a period, the case should be considered as a failure and the infection/inflammation should be treated. It needs to be stressed that the potential impact on the individuals' health of accepting the concept of functional retention is still mainly unknown (Jakovljevic, Duncan, et al., 2020; Liljestrand et al., 2021; Sebring et al., 2022).

From an individual, or societal perspective, it is undoubtable that the perception of good oral health is considered important for people's general health. There are several indicators for oral health, but tooth loss is frequently used (US Department of Health and Human Services, 2000; Petersen, 2003; Nassani & Kay, 2011; Nordenram et al., 2013; Schutzhold et al., 2014). Health is a fundamental human right. Equity, which is defined as the absence of avoidable or remediable differences amongst groups of people, is something to strive for (World Health Organization). In many countries, there are tax-funded systems that attempt to reduce health inequity, also in terms of oral health. Tooth survival could be an outcome measure for studies revealing inequity due to different demographical factors, exemplified by a study conducted in England and Wales where tooth survival was lower for individuals who were entitled to extra financial support for their dental care (Lumley et al., 2008). Studies on tooth survival could be used to evaluate the performance of any system aiming to reduce inequity.

Tooth retention, or survival, is important when considering the outcome of dental treatments and perhaps even more when considering root canal treatment as it is performed to prevent extraction. When the ESE launched their work with the S3-level clinical practice guidelines, a consensus procedure was used to identify appropriate outcome measures to assess the effectiveness of endodontic treatments. Tooth survival was rated as the most critical patient-reported outcome measure (Duncan et al., 2021).

The objectives of this narrative review were to appraise selected literature on the outcome tooth survival after endodontic treatment and the factors that may influence the outcome. The literature search in this narrative review was not performed systematically, but rather from a broad search using 'tooth survival' and 'endodontics' in PubMed (National Center for Biotechnology Information, Bethesda, USA), a selection of studies was made; if a systematic review was found, this was used and complemented with additional studies published after the systematic review. Another objective was to make readers aware of certain methodological aspects on studies on tooth survival.

REVIEW

Methodological aspects on studies on tooth survival

The outcome measure tooth survival has been used in numerous studies, see examples in [Table 1](#). It needs to be stressed that the present narrative review focuses on tooth survival in the sense that the tooth has not been extracted. There is also the possibility to study the survival of the endodontic treatment, in other words, untoward events or that any further treatment of the endodontic conditions such as extraction, retreatment or endodontic surgery has been performed (Bhagavatula et al., 2021; Chen et al., 2008; Dawson et al., 2017; Lumley et al., 2008; Raedel et al., 2015b). As survival of the endodontic treatment includes extractions, reports of survival of the endodontic treatment will be inferior to survival of the tooth. Some examples, the 5-year tooth survival of root filled teeth in the Swedish population is calculated to be 91%, although the survival of the root canal treatment was 88% (Dawson et al., 2017), and in Taiwan, the equivalent numbers would be 93% for tooth survival and 90% survival of the root canal treatment (Chen et al., 2008). When interpreting data on tooth survival after root canal treatment, one should also bear in mind that there are most probably a substantial number of root canal treatments, which are initiated but never completed; if these should be considered in tooth survival analyses, a substantial lower tooth survival would be expected (Wigsten et al., 2022).

Most data are collected retrospectively, and it is common to use registries to retrieve data for studying tooth survival with the starting point of having completed an endodontic treatment and then following the tooth over time. The registries frequently allow big data to be analysed, although it is infrequent to gain extensive clinical information on the studied teeth (Fransson et al., 2016;

Kwak et al., 2019; Lazarski et al., 2001; Lin et al., 2014; Raedel et al., 2015b; Salehrabi & Rotstein, 2010). Therefore, it is rare to find data on presence of periapical radiolucency or quality of the root filling which most often influences the outcome when periapical health is the focus (Ng et al., 2008). However, there is also the possibility to study the survival of endodontically treated teeth by examining a randomly selected cohort from a general population. By re-examining the same cohort, the survival can be calculated, and such studies will likely provide information on periapical status etc. (Kirkevang et al., 2014, 2017).

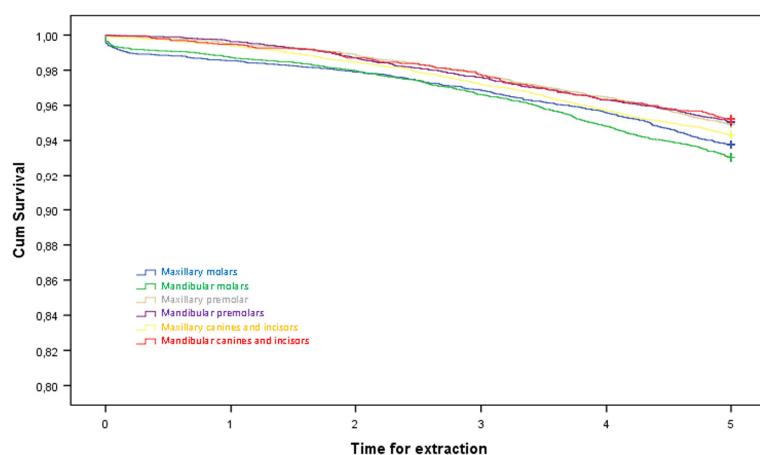
When the frequency of survival is reported, it will give information about the proportion of root filled teeth having survived at the end of the follow-up period, and this could be performed retrospectively, using historical data, or prospectively. Survival tables will provide more information as these will provide the frequencies of survival at several points in time, typically yearly until the end of the follow-up period. Survival curves illustrate continuous data and provide information on temporal changes, that is over time. In other words, it does not report the frequencies of extractions up until given time points as in survival tables, but they can potentially illustrate more exactly in time when there is a larger proportion of teeth being extracted. [Figures 1–3](#) show previously unpublished data from Swedish material (Fransson et al., 2016) to illustrate what information can be retrieved from survival curves. In the illustrations, the survival curves for teeth restored with indirect and direct restorations are almost linear, but this is not the case for the teeth with no registration of any type of restoration. In this group of teeth, there is a rather prominent, steep slope observed which could indicate a need to investigate the reasons for why teeth were extracted at this time [point](#).

Before considering, if the survival rates could be transferred to one own's practice, it is advisable to see where the study has been conducted and in which type of population. It is likely that tooth survival will be highly influenced by factors other than the actual endodontic treatment outcome. Extractions of root filled teeth may be due to failure of the endodontic treatment; however, the main reasons have been reported to be caries, cracks and fractures, leading to a non-restorable condition (Chen et al., 2008; Göransson et al., 2021; Landys Borén et al., 2015; Pratt et al., 2016; Tzimpoulas et al., 2012; Zadik et al., 2008). It is possible that cultural priorities, patients' and dentists' attitudes and the benefits available under the prevailing dental care reimbursement system will affect the decision as to whether removal of the root filled tooth is recommended rather than further endodontic retreatment or simply leave it without any intervention.

TABLE 1 Data on tooth survival (no extraction) after root canal treatment from a systematic review (Ng et al., 2010) and a selection of studies published thereafter

	Individuals and/or teeth/ treatments (n)	Source of data	Follow-up (years)	Tooth survival (%)
Ng et al., 2010		Systematic review	2–10	86–93
Ng et al., 2011b	572 individuals, 759 teeth and 642 individuals, 858 teeth	Selected population. Prospective. Primary RCT and retreatments performed by endodontic postgraduate students, UK	4	95
Lin et al., 2014	517234 teeth	Nationwide population based, Taiwan	3	94
Landys Borén et al., 2015	330 individuals, 420 teeth	Sample from referrals to endodontic specialist clinic, Sweden	10	82
Raedel et al., 2015b	556067 treatments	Insurance company, registry, Germany	3	89
Fransson et al., 2016	217047 individuals, 248 299 teeth	Nationwide population based, registry, Sweden	5–6	90
Pratt et al., 2016	880 individuals, 882 teeth	Retrospective, posterior teeth treated by postgraduate students, USA	8	88
Ramey et al., 2017	1960 treatments	Sample from an Air Force Dental Service, posterior teeth treated by GDPs and endodontists. Retrospective, USA	4	94
Khalighinejad et al., 2017	315 teeth	Sample from patients with molars treated at specialty education programme in endodontics, USA	9	94
Fernández et al., 2017	132 teeth	Sample from patients treated at postgraduate programme, retrospective, USA	10	92
Pirani et al., 2018	94 individuals, 213 teeth	Retrospective, treatments performed by post- graduate students, Italy	4–6	88
Kwak et al., 2019	2.5 million individuals, >3 million teeth	Nationwide population based, registry, Korea	5	91
Kebke et al., 2021	280 individuals/teeth	Historical cohort of patients treated by GDPs, Sweden	10	82

Abbreviations: GDP, general dental practitioner; RCT, root canal treatment.

**FIGURE 1** Kaplan–Meier graph of teeth reported to be root filled in 2009 in Sweden and subsequently reported restored with an indirect restoration within the following 6 months and followed for 5 years or until the tooth was reported extracted. Teeth grouped according to tooth group.

Tooth survival after root canal treatment

Ng et al. (2010) published a systematic review with tooth survival after root canal treatment as the outcome

measure. Table 1 summarizes a selection of studies on tooth survival. These studies of root canal treatment report survival of 82%–95% of teeth over 2–10 years and are based on the aforementioned systematic review and a selection

FIGURE 2 Kaplan–Meier graph of teeth reported root filled in 2009 in Sweden and subsequently reported restored with a direct restoration within the following 6 months and followed for 5 years or until the tooth was reported extracted. Teeth grouped according to tooth group.

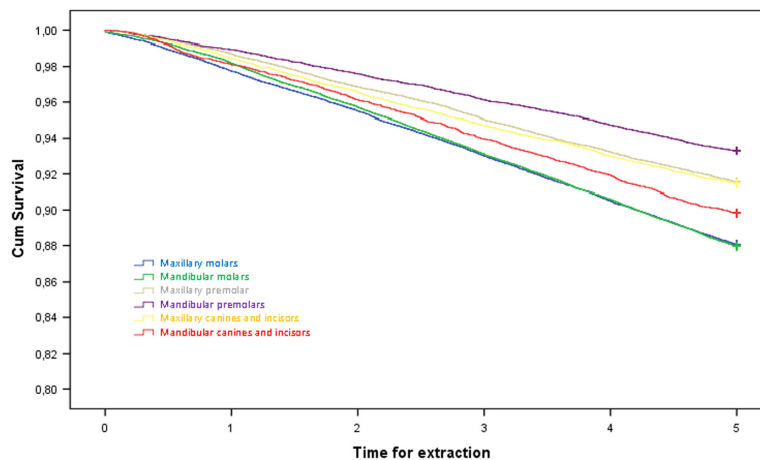
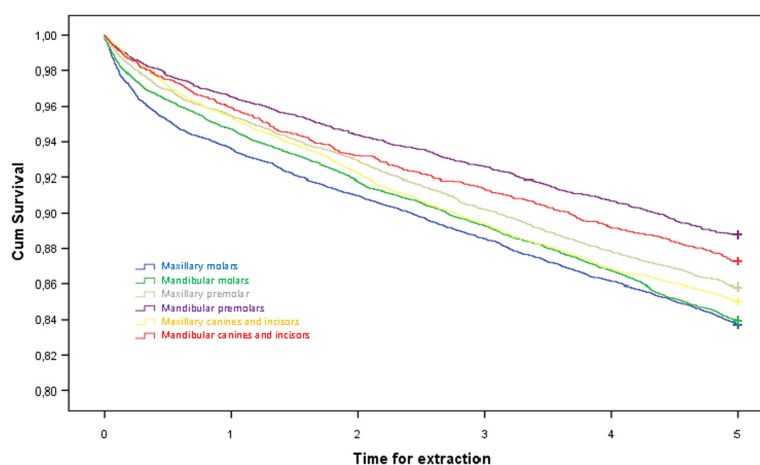


FIGURE 3 Kaplan–Meier graph of teeth reported root filled in 2009 in Sweden with no reported restoration within the following 6 months and followed for 5 years or until the tooth was reported extracted. Teeth grouped according to tooth group.



of studies based on a variety of cohorts of different populations. When root canal treatment is performed, one would expect that this rather costly and time-consuming treatment is meant to retain the tooth for a long period of time, though long perspective data is so far scarce (Wigsten et al., 2018, 2022). In two studies from Sweden with longer observation periods, the tooth survival was 65% and 71% over 20 years (Eckerbom et al., 2007; Pettersson et al., 2016).

Tooth survival after endodontic surgery

Studies on tooth survival after endodontic surgery are less frequent than after root canal treatment. Torabinejad et al. (2015) published a systematic review with tooth survival as the outcome measure. Table 2 summarizes a selection of studies on tooth survival following endodontic surgery. These studies of endodontic surgery report survival of 48%–88% of teeth over 3–10 years. It has not been possible to find any studies with extended follow-up periods after endodontic surgery.

Preoperative factors associated with tooth survival/extraction

As previously stated, many studies on tooth survival after root canal treatment provide less clinical information than typical studies with periapical health as the outcome measure and the evidence for the effect of prognostic factors on tooth survival has been reported to be weak (Ng et al., 2008, 2010).

Age

One factor that might influence tooth survival may be the age of the patients, especially since the immune system of elderly may be different to younger individuals (Ginaldi et al., 2016). In a systematic review with the aim of evaluating the influence of increased patient age on longitudinal outcomes assessed on radiographs, that would be equivalent to periapical health, concluded that increased patient age did not decrease the success of root canal treatment (Shakiba et al., 2017). This is an important

TABLE 2 Data on tooth survival after endodontic surgery from a systematic review (Torabinejad et al., 2015) and a selection of studies published thereafter

	Individuals/teeth in analysis (n)	Source of data	Follow-up (years)	Tooth survival (%)
Torabinejad et al., 2015		Systematic review	4–6	88
Raedel et al., 2015a	77 636 individuals, 93 797 teeth	Insurance company, registry, Germany	3	82
Riis et al., 2018	45 individuals, 47 teeth	Incisors and canines treated by single operator at university clinic, Sweden	10	74
Beck-Broichsitter et al., 2018	124 individuals, 147 teeth	Cohort from referrals sent to one private practice, retrospective, Germany	6	48
Huang et al., 2020	83 individuals, 94 teeth	Cohort from referrals at national dental centre, retrospective, Singapore	5–9	78

finding, especially since the elderly have a larger need for endodontic treatment than the general adult population (Hamedy et al., 2016). Nevertheless, many studies on tooth survival show inferior outcomes for the elderly (Fransson et al., 2021; Kwak et al., 2019; Landys Borén et al., 2015; Lumley et al., 2008). The reasons for the difference in the results based on the different outcome measures are important to reflect on: It is not the age *per se* that influences our ability to do effective root canal treatments or the healing process to occur but is more likely to do with teeth in older individuals have been in function for a long time. The teeth have probably less remaining tooth structure which affects the restorability. The older individuals are more likely to have other conditions such as marginal periodontitis, which can affect the survival of root filled teeth (Khalighinejad et al., 2017; Nazir et al., 2020). One may also speculate on that some elderly patients accept extractions to a greater extent than younger individuals. It may also be due to larger treatment needs; perhaps, the insurance system drives extractions and replacement with fixed bridges or implants. Maybe the slightest doubt on the prognosis under such circumstances results in extraction.

Sex

Small differences have been detected in individual studies though a systematic review failed to report any statistically significant differences (Fransson et al., 2021; Kwak et al., 2019; Ng et al., 2010).

Systemic health

Diabetes mellitus has been shown in a systematic review of longitudinal studies to be associated with a lower tooth survival after root canal treatment (Cabanillas-Balsera

et al., 2019; Mindiola, 2006; Ng et al., 2011b; Wang et al., 2011). Coronary artery disease has been studied as a factor affecting tooth extraction after root canal treatment, though in a multivariable analysis, there was no association with tooth extraction (Wang et al., 2011).

Tooth type

Tooth type, especially non-molar teeth, was recognized by Ng et al. (2010) to be a prognostic factor favouring tooth survival following root canal treatment, and this is what more recent studies also have concluded (Fransson et al., 2021; Kwak et al., 2019). However, it is noteworthy to investigate the study by Raedel et al. (2015b), which report a somewhat contradictory result. The study is based on data from an insurance company and includes half a million teeth; the overall tooth survival over 3 years is equivalent to other studies though they present data with very little difference in survival between multi-rooted teeth and single-rooted teeth. This does not necessarily imply greater endodontic skills in Germany but could probably be attributed to a selection process. The specific insurance company does have strict criteria regarding reimbursement of root canal treatment of multi-rooted teeth.

Preoperative status of pulp and periradicular tissue

From German studies, it has been reported that teeth with vital pulps had a higher overall survival rate compared with teeth with non-vital pulps and that teeth with a periapical lesion were less likely to survive than teeth without periapical lesion (Dammaschke et al., 2003; Raedel et al., 2015b; Stoll et al., 2005). In a study based on a general population from Denmark, baseline apical

periodontitis was a predictive factor for tooth extraction (Kirkevang et al., 2017).

Primary or secondary treatment

The survival of teeth receiving root canal treatment for the first time seems to have a somewhat better tooth survival. Ng et al. (2011b) reported the tooth survival for primary root canal treatment to be 95.4% and 95.3% for retreatments performed by post-graduate students in a prospective study with a 4-year follow-up. In a large registry study including over 3 million teeth from Taiwan, the survival rate for teeth undergoing root canal treatment for the first time was higher (90.9%) than for retreated teeth (88.4%) after 5 years (Kwak et al., 2019).

Perioperative factors associated with tooth survival/extraction

In large registry studies from Taiwan and Korea, it was concluded that registration of usage of a rubber dam significantly positively affected the 5-year tooth survival rate (Kwak et al., 2019; Lin et al., 2014).

Regarding the length of the root filling, the tooth survival rate was higher for teeth where the root filling ended 0–1 mm from the radiographic apex (Dammachke et al., 2003). In a population-based study, it was demonstrated that the probability for extraction was higher for teeth with inadequate root filling quality (Kirkevang et al., 2014). The survival rate was higher for teeth with a root filling judged to be of high quality in a retrospective study of teeth root filled by general dental practitioners (Görransson et al., 2021).

Postoperative factors associated with tooth survival/extraction

After root filling, the final step is to permanently restore the tooth; to achieve a tight seal against re-infection of the root canal system; and to improve the ability of the tooth to withstand forces from loading, protecting it against fractures. Thus, the restoration will be of importance for the outcome of the root canal treatment, for 'healthy periapical tissues' and for 'tooth survival' (Ng et al., 2008, 2011a, 2011b).

A satisfactory coronal restoration has been found to significantly improve the outcome of the root canal treatment, using 'healthy periapical tissues' as a measure for a successful outcome (Ng et al., 2008, 2011a). Whilst no relationship has been found between the restoration type

(direct versus indirect) and 'healthy periapical tissues' (Ng et al., 2011a), a significant association between the type of restoration and 'tooth survival' has been reported (Ng et al., 2010, 2011b). In addition, other restorative factors such as teeth functioning as abutment for prosthesis, the presence of a post and timing of the restoration have all been suggested as factors influencing the survival of root filled teeth (Mindiola, 2006; Pratt et al., 2016). Likewise, postoperative factors, but not related to the restoration, are likely to have an impact on tooth survival after root canal treatment, for example the number of proximal contacts, tooth location (terminal or not) and remaining tooth substance (amount and quality) (Al-Nuaimi et al., 2020; Ng et al., 2010). Whilst several postoperative factors seem to be significant for tooth survival, they appear to be less important for a successful outcome in terms of 'healthy periapical tissues'. Except for a satisfactory coronal restoration, well-known postoperative factors influencing 'healthy periapical tissues' are sparse. Although the amount of remaining tooth substance is likely of importance for 'healthy periapical tissues' (Al-Nuami et al., 2017), this warrants further exploration. Below, the evidence for various postoperative factors possibly influencing tooth survival is reviewed.

The type of restoration

Several studies have reported tooth survival after root canal treatment in relation to the type of restoration. Although the studies vary with respect to design, follow-up time and region, which may involve different reimbursement systems and cultural priorities, the results are consistent, disclosing a higher survival rate for teeth restored with an indirect restoration than those receiving a direct restoration (Fransson et al., 2021; Landys Borén et al., 2015; Ng et al., 2010, 2011b; Pratt et al., 2016; Suksaphar et al., 2018). The lowest survival rates were reported for teeth not receiving a permanent restoration following the root canal treatment (Fransson et al., 2021; Mindiola, 2006; Ng et al., 2011b; Pratt et al., 2016). In the meta-analysis by Ng et al. (2010), teeth restored with a crown were found to have 3.92 times higher chance for survival than teeth not receiving a crown after root canal treatment. The follow-up time in the included studies ranged from 2 to 10 years (Alley et al., 2004; Aquilino & Caplan, 2002; Lazarski et al., 2001; Lynch et al., 2004). In a registry-based study including 216 764 teeth, the type of restoration was found to be significantly associated with the 5-year survival. Compared with teeth restored with an indirect restoration and a cast post and core, teeth with no registration of a restoration had the highest odds ratio (OR = 3.3) for extraction whilst the ORs for teeth with a direct composite

restoration were reported to be 2.2–3.2, depending on the size of the restoration and the use of a direct post and core or not (Fransson et al., 2021), in accordance with previous studies (Mindiola, 2006; Ng et al., 2011b; Pratt et al., 2016).

Although it is plausible to assume that an indirect restoration provides a root filled tooth with better protection against fractures, and potentially, a better seal against microbial leakage with improved survival rates as a result, the scientific evidence is insufficient to make any valid conclusions about the impact of the type of restoration on tooth survival (Sequeira-Byron et al., 2015). Previous studies are not randomized controlled clinical studies; therefore, selection bias cannot be excluded—that is, dentists and patients are less likely to choose indirect restorations for teeth with uncertain prognosis. In a study by Chugal et al. (2007), teeth with preoperative AP were found to be less likely to receive a crown restoration after root canal treatment than teeth without preoperative AP. Moreover, the choice of a crown restoration has been reported to be significantly more common for teeth with high-quality root fillings (Göransson et al., 2021), indicating possible selection bias. The decision-making process on how to restore a root filled tooth involves several factors and may be complex; despite the actual need for a crown, some teeth are, after all, restored with a direct restoration (Dawson et al., 2021).

As the masticatory forces are different in anterior and posterior teeth, with higher forces on posterior teeth (Kumagai et al., 1999), it is plausible that an indirect restoration may be of greater significance for survival of posterior than anterior teeth; however, this has not been confirmed.

Whilst an indirect restoration is certainly critical for survival of the root filled tooth in many cases, it may not be necessary in every case. Whether a direct or an indirect restoration is required for an optimal seal and protection of the root filled tooth, whilst preserving as much tooth structure as possible, needs to be assessed in each individual case including the patient's views.

Teeth functioning as abutment for prosthesis

After root canal treatment, some teeth will be used as abutment for fixed partial dentures (FPD) or removable partial dentures (RPD). In a systematic review on tooth survival after root canal treatment, a meta-analysis including three studies (Alley et al., 2004; Lazarski et al., 2001; Salvi et al., 2007) was conducted (Ng et al., 2010). The authors concluded that the probability for tooth survival was significantly higher (70%) for teeth not used as abutment for FPD or RPD compared with teeth used as abutments for FPD, but with limited evidence (Ng et al., 2010). On the

contrary, in a prospective study, the factor 'teeth functioning as abutment for FPD or RPD' was not found to have any significant impact on tooth survival (Ng et al., 2011a). The authors stressed that, although there was a trend in favour of teeth not being abutment, the number of included abutment teeth was too small to reach statistical significance. A recent retrospective study reported the proportion of extracted root filled teeth to be similar for teeth used as abutments compared with those which were not, 9% compared with 8.9% respectively (Göransson et al., 2021); however, the number of teeth used as abutment was small.

In general, root filled teeth functioning as abutment teeth for FPDs or RPDs are subjected to higher and more unfavourable distribution of occlusal forces than teeth not used as abutments, increasing the risk for loss of retention, fracture and caries, eventually leading to extraction. Even though the 'use of the teeth as abutment for FPD or RPD' is suggested as a potential risk factor for extraction, high survival rates may still be expected (Lazarski et al., 2001; Salvi et al., 2007), provided that the loading conditions are favourable.

The presence of post

The presence of a post and core, for increased retention of the restoration, has been suggested to influence the survival of root filled teeth restored with an indirect restoration; however, the results are not consistent. In a study by Ng et al. (2010), a meta-analysis based on five studies (Alley et al., 2004; Aquilino & Caplan, 2002; Dammaschke et al., 2003; Lazarski et al., 2001; Salvi et al., 2007) was conducted, disclosing no significant association between the presence of post and core with tooth survival, both prefabricated and cast posts were included (Ng et al., 2010). On the contrary, in a prospective clinical study, extractions were 2.6 times more likely for teeth restored with a cast post and core than those without (Ng et al., 2011a). In a retrospective study using mainly fibre posts, the presence of a post did not influence tooth survival (Pratt et al., 2016). In a systematic review conducted by Naumann et al. (2018), including seven randomized clinical trials (RCTs) and one prospective clinical trial, seven of the individual studies did not report any positive effect on tooth survival by the placement of a post; however, no meta-analysis was conducted and the risk of bias was judged as low for only three studies (Naumann et al., 2018). In a registry-based study, Fransson et al. (2021) found no difference in tooth survival for teeth with indirect restoration compared with teeth restored with an indirect restoration in combination with a cast post and core. On the contrary, the survival rate was significantly lower for indirectly

restored teeth in combination with a direct post and core; however, the difference was small (Fransson et al., 2021).

Altogether, previous studies indicate that tooth survival does not seem to be enhanced by the placement of a post and core for retention of the restoration, whilst some studies imply an increased risk for extraction when posts are placed. As the results are inconsistent, further investigation is warranted.

Timing of the restoration

Besides *how* the root filled tooth is restored, the timing of the restoration also seems to be relevant for tooth survival. Since root filled teeth with temporary restorations are at higher risk for microbial leakage (Balto, 2002) and unrestorable fractures (Pratt et al., 2016), a relationship between timing of the permanent restoration and tooth survival seems plausible. However, such studies are sparse, but in two retrospective studies, a correlation has been reported (Mindiola, 2006; Pratt et al., 2016). In a study by Mindiola (2006), the absence of a permanent restoration within 90 days after root canal treatment was found to be the most significant factor associated with extraction. Pratt et al. (2016) disclosed that teeth receiving a crown >4 months after root canal treatment were almost 3 times more likely to be extracted than teeth receiving a crown within 4 months. The results suggest a higher risk for extraction if placement of the permanent restoration is delayed >3 months. However, as the evidence for timing of the restoration and tooth survival is limited, further investigation is warranted.

Proximal contacts and tooth location

The number of proximal contacts of root filled teeth has been reported in some studies as a factor affecting tooth survival (Ng et al., 2010, 2011b). In a meta-analysis based on two retrospective studies (Alley et al., 2004; Aquilino & Caplan, 2002), the probability for tooth survival was three times higher for teeth having both mesial and distal contacts than for teeth having just one or missing proximal contacts, although the evidence was limited (Ng et al., 2010). The results were confirmed in a prospective study by Ng et al. (2011a), reporting a lower risk of extraction after root canal treatment for teeth having two proximal contacts compared with teeth with <2 proximal contacts. On the contrary, no significant difference was found between the groups of teeth having proximal contacts compared with those without (Göransson et al., 2021), but the number of teeth without proximal contacts was small.

A more favourable distribution of occlusal forces, during function and parafunction if present, in case of two proximal contacts may be a likely explanation as neighbouring teeth will take some of the load from the occlusal forces. Thus, an association between the presence of proximal contacts and survival of root filled teeth seems plausible. The possible influence of the dentition in the opposite jaw, on the contrary, is less explored. Except for one study, reporting the presence and type (natural or fixed prosthodontics) of an antagonist to have no significant influence on the survival rate (Pratt et al., 2016), further studies are sparse.

Teeth located at the most distal in the arch, that is terminal teeth, have been found to be associated with a lower survival rate than those not being terminal teeth (Aquilino & Caplan, 2002; Ng et al., 2011b; Tan et al., 2006). However, tooth location may in part be correlated with the number of proximal contacts, as terminal teeth at the most have only one neighbouring tooth. In a study by Aquilino and Caplan (2002) higher extraction rates were reported for second molars compared with other tooth types, whilst Tan et al. (2006) found terminal teeth with preoperative cracks to have a lower 2-year survival than teeth not located last in the arch. Likewise, in a prospective study by Ng et al. (2011b), terminal teeth had almost 96% higher risk for extraction than non-terminal teeth. Although the results are consistent, the evidence is limited and needs further exploration.

The amount of remaining tooth substance

The majority of teeth, in which root canal treatment is initiated, are structurally compromised. In a study conducted in a public dental service, Wigsten et al. (2019) found that teeth in which root canal treatment was initiated, most were previously restored (83.5%), the majority with a direct composite restoration. Furthermore, 71.3% of the teeth had a substantial loss of tooth substance corresponding to >1/3 of the crown.

Reasonably, the amount of residual tooth structure has an impact on the survival of root filled teeth. Although this has not been extensively studied, some studies suggest an association (Al-Nuaimi et al., 2020; Nagasiri & Chitmongkolsuk, 2005). Nagasiri and Chitmongkolsuk (2005) concluded that the amount of remaining tooth substance is a factor associated with tooth survival for teeth not being crowned after root canal treatment; the survival rate was highest for teeth with a maximal amount remaining, corresponding to a Class I cavity with a minimum of 2 mm thickness of the surrounding cavity walls, whilst a lower survival rate was observed for teeth with a less amount remaining. Al-Nuaimi

et al. (2020) reported the extraction rates to be three times higher for molars with a volume of remaining tooth substance corresponding to less than 30% (12.5%) compared with teeth with >30% remaining (3.5%); however, the difference was not statistically significant. The teeth were restored within 1 month after root canal retreatment with a cuspal coverage restoration. On the contrary, unfavourable outcomes, as evaluated on radiographs, were significantly more frequent in the group of teeth with less than 30% remaining tooth substance compared with their counterpart; this risk was increased by 2.58 (Al-Nuami et al., 2017). An unsuccessful outcome at the 1-year follow-up, using 'healthy periapical tissues' as an outcome measure, was concluded to be a predictor for extraction of root filled teeth within 4 years (Al-Nuaimi et al., 2020). The association between a small amount of remaining tooth substance and unfavourable outcomes may be explained by technical difficulties that may arise during treatment of such teeth. Achieving adequate isolation with rubber dam and restoration of the tooth may be more demanding procedures, which may adversely affect the seal against microbial leakage and the longevity of the restoration (Creugers et al., 2005; Fokkinga et al., 2007). Thus, an association seems plausible even though the precise impact of the amount of tooth substance on tooth survival needs further exploration. Anyway, striving to preserve a maximal amount of tooth structure will be in favour of a successful outcome.

The possible impact on who is making the coronal restoration and tooth survival, that is a GDP or a specialist with a possible difference in the quality of the restoration, is unknown.

The presence of cracks

The definition of a cracked tooth, approved by ESE, is 'a tooth with 1 or more incomplete, longitudinal fractures originating in the coronal tooth structure and extending apically; the crack typically orients mesiodistally, involves the marginal ridges, and includes the proximal surfaces of the tooth' (European Society of Endodontology, 2021). Even though the presence of a crack potentially may have an adverse effect on tooth survival, high survival rates have been reported. Based on a meta-analysis, including seven retrospective studies, the 1-year survival rate was estimated to 88% (Olivieri et al., 2020). In a 2-year perspective, the survival rates for root filled cracked teeth that were restored with a crown have been reported to be 85.5%–100% (Davis & Shariff, 2019; Kang et al., 2016; Tan et al., 2006) whilst the 5-year survival rates in two studies ranged between 68% and 97% (Nguyen & Jansson, 2021; Sim et al., 2016). In a systematic review including four

studies, Leong et al. (2020) reported the overall 5-year survival as 84.1%. One study reported a 10-year survival rate of 54%; otherwise, reports on long-term survival rates are sparse (Nguyen & Jansson, 2021).

In one study, the 5- and 10-year survival rates were significantly higher for teeth receiving a crown after root canal treatment, 97% and 95%, compared with teeth receiving a direct composite restoration, 57% and 37%, respectively (Nguyen & Jansson, 2021). Similarly, in several studies reporting high survival rates, the cracked teeth had been restored with a crown restoration after root canal treatment (Davis & Shariff, 2019; Kang et al., 2016; Sim et al., 2016; Tan et al., 2006).

Multiple cracks (Tan et al., 2006), the preoperative presence of a periodontal pocket associated with the crack (Olivieri et al., 2020), terminal teeth (Tan et al., 2006) and cracks extending to the root (Sim et al., 2016), have been reported to adversely affect the survival rates, which is in accordance with Leong et al. (2020), suggesting these factors to be of importance, although the results were not statistically significant. On the contrary, in a prospective study by Davis and Shariff (2019), no significant differences in survival rate were found for teeth with periodontal pocketing (up to 7 mm) at the site of the crack, involvement of the marginal ridges, crack depth or pre-treatment diagnoses.

Altogether, whilst the survival of root filled teeth may be adversely affected by one or more cracks, high survival rates may be achieved for teeth receiving a crown restoration after root canal treatment.

CONCLUSION

Even though the goal for any endodontic treatment should be a healthy tooth and periapical region, the outcome 'tooth survival' is of interest to both the patient, the dentist and society in general. However, there is a need to learn more about the risk for individuals with AP associated with a root filled tooth. What is the probability for having acute symptoms? Or what is the probability to experience more serious infections such as cellulitis? And how is general health affected by having AP on a previously root filled tooth? Even though we eventually get solid data, on the probability of acute pain and serious infections from root filled teeth with AP, we still need to know more about what an acceptable risk would be in relation to root filled teeth with AP.

Dentists should indeed, when performing root canal treatments, continue to strive to remove any infection and try their best to achieve root fillings with good quality with the aim of achieving healthy periapical conditions. Nevertheless, there are several outcome measures that can be used, but for different purposes.

From this narrative review, it is obvious that studies on prognostic factors regarding the survival of root filled teeth are largely missing but the prognosis is likely dependent on tooth-related conditions such as restorability, the impact of using different restorations such as posts.

AUTHOR CONTRIBUTION

Helena Fransson and Victoria Dawson were equally involved and responsible for all aspects of this manuscript.

CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

Data sharing not applicable - no new data generated

ETHICS STATEMENT

No ethical approval was necessary for this narrative review. Fig 1–3 derive from a study approved by the Regional Ethical Board at Lund University, Sweden (Dnr 211/800).

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