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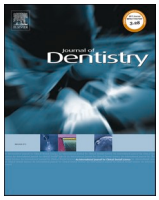

How long must a post be? A retrospective survival analysis on a large cohort with long follow-ups

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ABSTRACT

Objectives: Post and core (PC) is frequently used, but clinical evidence concerning how long a post must be is scarce. Recommendations in dental literature range from half of the root which should be incorporated, to post space preparations conducted as deep as possible increasing the risk for root perforation thus tooth loss. Therefore, the aim of this retrospective survival analysis is to evaluate the post length as well as the post-clinical crown ratio on a large patient cohort with long follow-ups.

Materials and methods: Overall 1026 PC in 731 patients could be included in this study (2004–2023). The files were analysed due to the parameters post length and post-clinical crown ratio on X-Ray. Furthermore, the influence of the type of covering prosthetic restoration, location, type of tooth, luting material, PC material, bone attachment and therapist was evaluated. The statistical analysis was assessed using Kaplan-Meier (univariate influences) and Cox regression (multifactorial influences).

Results: Survival until extraction as well as decementation was significantly influenced by bone attachment and covering prosthetic restoration. Posts reaching the middle third of the root showed highly significant ($p < 0.001$) better survival probabilities than those reaching the coronal or apical third. Regarding the post-clinical crown ratio, no significant difference was found for post = crown/post > crown, whereas post<crown showed highly significant lower survival probabilities ($p < 0.001$).

Conclusions: The post space preparation should not be extended over the middle third of the root, but has to be deep enough to ensure that the post is at least as long as the clinical crown.

Clinical significance: Against the background of the large sample size and the long follow-ups, the results of this retrospective survival analysis are suitable to give general recommendations regarding how long a post has to be in order to ensure the best survival probability for PC treatment.

1. Introduction

The development of the adhesive technique in dentistry made post and core (PC) dispensable for many clinical situation, but it can still be necessary for teeth with severe coronal defects when an endodontical treatment was needed [1,2]. Recent scientific dental literature proclaims that other than assumed by former studies [3], fitting of PC does not reinforce the tooth but increases the risk for root fracture because of the necessity of removing hard tissue during post space preparation [4,5]. Therefore, *Naumann* et al. proposed in a systematic review that PC should only be fitted in cases with insufficient adhesive surface for core reconstruction by filling, since they found no positive effect of post placement on survival [2]. Furthermore, they described that the most important aspect for survival of PC is the presence of a ferrule in which the covering restoration overlaps the margin of PC by at least 2 mm [2].

Even if PC is still a frequently used treatment option, there is still a lack of evidence in recent scientific literature how deep the post space preparation should be conducted. *Baraban* described in a treatment guide report from the 1970s that half of the root should be incorporated but care must be taken to prevent from root perforation [6]. *Perel and Muroff* claimed in their general companion for dentists which is also from the 1970s that the post must be long enough to prevent excessive internal stress on the root. Therefore, at least half of the root that is attached by bone should be included in the post space preparation [7].

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In particular, this rule is hard to follow in teeth with periodontal bone loss, since a remaining apical endodontic filling is obligate in order to prevent from reinfection [8–10]. That is why other authors described in more recent studies a preparation rule for post and core in which the post space preparation has to be conducted as long as possible leaving a minimum of 4 mm of apical seal [11–14]. However, in many cases the preparation depth is limited due to a curved root canal or root retractions [15]. Therefore, in former decades screw retained posts were common for treatment of severely destroyed teeth because of the high retention with short post space preparations [6,7,16]. Nevertheless, threaded posts lead to microcracks in dentin and are therefore no longer recommended in recently published studies [17]. Another recommendation for general post length which is frequently described in scientific dental literature is that the post must be at least as long as the clinical crown [18,19] However, this preparation rule is not applicable for every post material since *Zicari* et al. reported that shorting of post space preparation for fibre reinforced posts can improve the fracture modes compared to rigid materials and therefore can improve the therapy by lowering the perforation risk [20]. Santos-Filho et al. and Kaya et al. agreed to this and described in their in-vitro studies that post length did not influence the survival except for rigid posts in which shorter post space preparations led to a higher risk for root fracture [21,22].

To the best knowledge of the authors there is no recent clinical investigation including modern PC materials and treatment options which evaluates the required depth of post space preparation on the basis of a large cohort with long follow-ups. Therefore, this retrospective study of more than 1000 PC over an observation period up to 19 years aims to enlarge the knowledge about this frequently used but inconsistently described treatment option by evaluating the post length as well as the post-clinical crown ratio. In order to include all causes of failure also decementation of refitable PC was investigated but additionally these cases were analysed until possible extraction of the tooth.

2. Materials & methods

2.1. Data acquisition

The study was approved by the ethics committee of the Justus-Liebig University Giessen, Germany (Reg No. 164/11). The Data acquisition was conducted using a specialised treatment documentation software (Multizentrische Dokumentation, MZD) that was used in our clinic since 2004. Within the oberservation period of 2004 until 2023, all Patient files were digitally and automatically searched for treatment plans with PC. Primarily, 987 patients received a treatment plan for PC. These files were manually analysed for actual procession of the treatment plan, lack of data (especially no X-Ray or not fully imaged PC or covering prosthetic restoration on X-Ray), unstandardised workflows or treatments. Furthermore, patients suffering from illnesses possibly influencing the environmental factors of the oral cavity were excluded from this study.

Finally, 731 patients with overall 1026 PC fulfilled the inclusion criteria. Subsequently, the data acquisition was performed according to the following criteria, along with age and gender of the patient:

- Observation period (date of cementation / date of first decementation, extraction or final examination)
- In case of extraction: Reason for extraction
- Location of PC treated tooth (upper / lower jaw)
- Type of tooth (anterior / premolar / molar)
- Bone attachment (physiological: >75 % / pathological: <75 %)
- Type of covering prosthetic restoration (crown / bridge / RPD)
- Luting material used (conventional cement / adhesive cement)
- PC material (high-gold-content alloy / non-precious alloy / fibre reinforced)
- Therapist (dentist / student)
- Post-clinical crown ratio on X-Ray (post > crown / post = crown / post < crown)
- Post length on X-Ray (reaching coronal / middle / apical third of the root)

The data acquisition for post-clinical crown ratio and post length on the X-Ray was performed by using the measurement tool of an image software (VixWin Pro-VDDS, solution GmbH & Co. KG, Holzgerlingen, Germany) illustrated in Fig. 1.

All patients ($n = 731$) were distributed to 392 (53.6 %) male and 339 (46.4 %) female. The average age of the patients at the time of PC cementation was 59.0 years with a range from 17 to 93 years. PC treatment was conducted by students in the Department of Prosthetic Dentistry under strict supervision of experienced dentists or by the dentists themselves following a standardised procedure [23].

2.2. Treatment

The inclusion criteria regarding the tooth were determined as absence of pain and clinical or radiological signs of inflammation. Moreover, the prosthetic viability of the tooth, degree of tooth movement, percussion and measurement of pocket depth was evaluated before including in this study [23–25]. The type of post system (cast PC (CPC) or fibre reinforced post and a composite core build-up (PFRP)) was chosen according to the size of the coronal defect and the remaining cavity walls [26,27].. PFRP had been fitted if there were ≥3 walls left providing sufficient adhesive surface for the composite core build-up ($N = 155/15.10$ %). In cases with ≤2 remaining cavity walls CPC had been fitted using non-precious ($N = 567/55.27$ %) or high-gold-content ($N = 304/29.63$ %) alloy matching to the covering prosthetic restoration. The depth of post space preparation was strived to the apical third of the root leaving a residual endodontic filling of at least 4 mm for apical seal. In teeth with a curved root canal or root retractions the post space preparation was conducted as deep as possible in order to prevent from perforation. Table 1 shows the distribution of the cases regarding post length on X-Ray reaching the coronal, middle and apical third of the root as well as the post-clinical crown ratio by means of post > crown, post = crown and post < crown.

The impression and the fabrication of CPC was performed according to a standardised procedure described in detail in a previously published study [23].

CPC were permanently fitted in a second appointment after try-in. Depending on the friction of CPC against pull out an adhesive or conventional cement was used, meaning that in the case of high friction a conventional cement ($N = 686/66.9$ %) was used while all other CPC and PFRP were fitted with a resin composites in combination with bonding agents ($N = 340/33.1$ %). Table 2 shows the distribution of PC regarding the type of tooth and the location (upper/lower jaw).

2.3. Covering prosthetic restoration

In every case included in this study the tooth that was treated with PC was prepared for a covering prosthetic restoration (crown, bridge or RPD) according to established preparation rules considering a ferrule of at least 1.5–2 mm [2,23]. Abutment teeth for cantilever bridges as well as single tooth retained RPDs were excluded from this study. All RPDs had parallel milled primary crowns made of non-precious or high-gold-content alloy and all patients participated in a strict aftercare program which is known to be a predominant factor for survival [28]. Therefore, all patients included in this study were asked for an appointment at least once a year. Table 3 illustrates the distribution of covering prosthetic restorations on the type of tooth.

2.4. Statistical analysis

Kaplan-Meier and cox regression analysis were used to assess the survival probability. In order to investigate significant differences between the groups, the log rank test was conducted and the significance

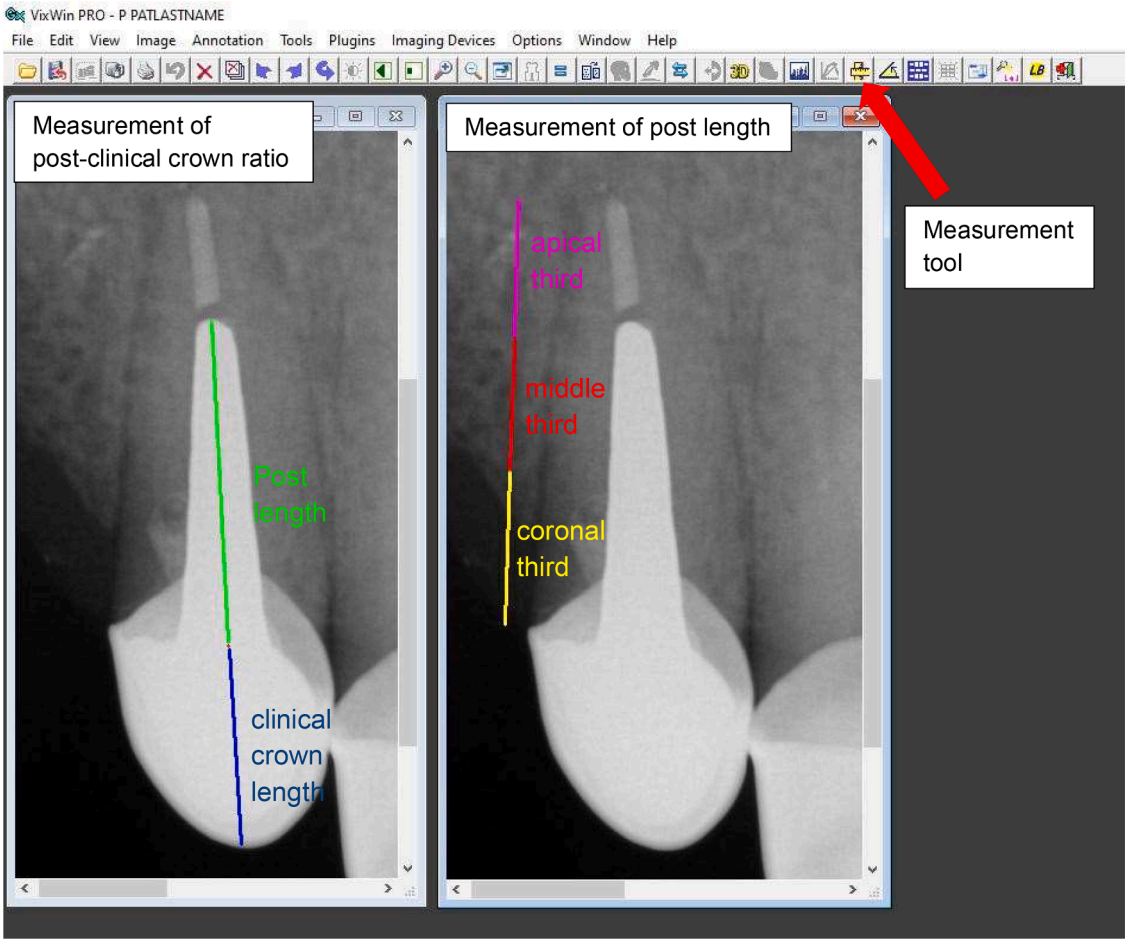

Fig. 1. Measurement of post-clinical crown ratio and post length on X-Ray using the measurement tool of an image software.

Table 1
Destribution of post length and post-clinical crown ratio.

post length on X-Ray	number of PC	percentage
Coronal third	86	8.4 %
Middle third	610	59.5 %
Apical third	330	32.1 %
post-clinical crown ratio	**number of PC**	**percentage**
post>crown	535	52.1 %
post=crown	388	37.8 %
post<crown	103	10.1 %

Table 2
Type of tooth and location of PC (number/percentage).

Type of tooth	Upper jaw	Lower jaw	Total
Anterior	340 / 33.1 %	129 / 12.6 %	469 / 45.7 %
Premolar	168 / 16.4 %	207 / 20.1 %	375 / 36.5 %
Molar	74 / 7.2 %	108 / 10.6 %	182 / 17.8 %
	576 / 56.1 %	450 / 43.9 %	1026 / 100 %

Table 3
Type of covering prosthetic restoration distributed to the type of tooth.

Type of tooth	Crown	Bridge	RPD	Total
Anterior	159 / 15.1 %	51 / 5.0 %	264 / 25.7 %	469 / 45.7 %
Premolar	206 / 20.1 %	65 / 6.3 %	101 / 9.8 %	375 / 36.5 %
Molar	117 / 11.8 %	57 / 5.6 %	6 / 0.6 %	182 / 17.8 %
	482 / 47.0 %	173 / 16.9 %	371 / 36.1 %	1026 / 100 %

was determined at $p < 0.05$. This statistic procedure is particularly suitable for considering unequal group sizes with varying observation periods between the cases and is therefore frequently used in comparable survival analyses as well [23,27,29,30]. Along with cofactors (location, type of tooth, bone attachment, covering prosthetic restoration, luting material, PC material and therapist) the post length on X-Ray as well as the post-clinical crown ratio on X-Ray were investigated for possible influences on the survival. The evaluation was conducted by forward stepwise logistic regression method based on the likelihood ratio, meaning that only cofactors that had significant influences (x^2: $p < 0.05$) on the failure probability were included in the analysis. Multiple PC in one patient was statistically considered using "shared frailty" [31].

3. Results

The mean observation period in the present study was 4.65 years (standard deviation = 4.32 years (SD)) regarding survival until extraction and 3.64 years (SD = 3.83) regarding survival until decementation. Fig. 2 illustrates the distribution of observation periods to the number of cases reagrding both target events for survival analyses (extraction: green diagram, decementation: blue diagram).

Table 4 shows the minimum and maximum values for the observation period as well as the first and latest recorded extraction and decementation.

The overall average survival times until extraction were 13.89 years (SD = 0.36) (95 % confidence interval of 13.19 – 14.58 (CI)) and until decementation 12.52 years (SD = 0.32) (CI = 11.93 – 12.16), showing that the cumulative survival probability in both analyses are almost matching. Therefore, one can assume that the conclusions of one

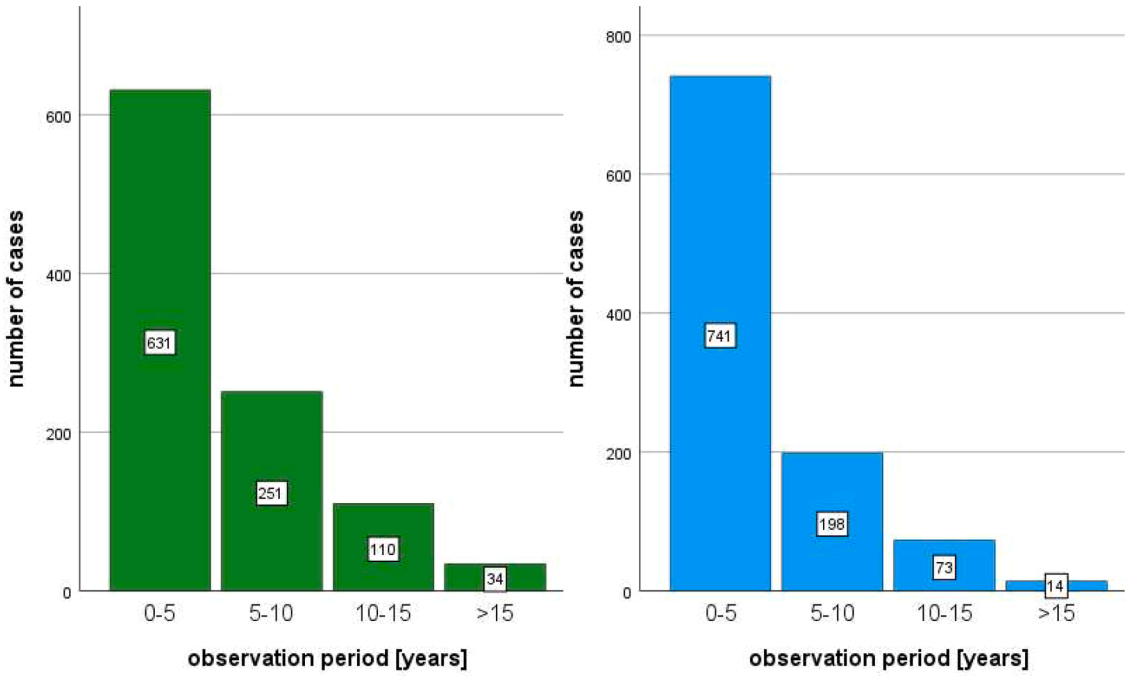

Fig. 2. Distribution of observation periods to the number of cases for survival until extraction (green diagram) and until decementation (blue diagram). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 4
Range of observation period for survival until extraction and survival until decementation [years].

	Survival until extraction	Survival until decementation
Minimum observation period	0.03	0.01
Maximum observation period	19.02	17.70
First recorded target event	0.03	0.01
Latest recorded target event	18.41	14.09

analysis is transferable to the other and the results can be discussed together.

During the observation period 241 of the 1026 investigated teeth had been extracted (23.5 %). The most common reason for extraction was root fracture (n = 86 / 35.7 %) followed by caries (n = 67 / 27.8 %), periodontal bone loss (n = 62 / 25.7 %) and periapical inflammation (n = 26 / 10.8 %). In Table 5 the reasons for extraction with the mean time of occurrence as well as the distribution of post length and post-clinical crown ratio are illustrated. It shows that root fracture occurs much earlier than periapical inflammation, periodontal bone loss and caries. Furthermore, root fracture was least recorded with posts reaching the middle third of the root (n = 6) while periapical inflammation was mainly associated with deep post space preparations reaching the apical third of the root (n = 21). Regarding the post-clinical crown ratio, root fracture was mostly recorded with shorter posts than the clinical crown (n = 76).

Table 5
Reasons for extraction with the mean time of occurrence as well distribution of post length and post-clinical crown ratio.

	Root fracture (n = 86)	Periapical inflammation (n = 26)	Periodontal bone loss (n = 62)	Caries (n = 67)
Mean time of occurrence [years] (SD)	2.80 (0.27)	5.42 (0.73)	7.05 (0.49)	7.61 (0.48)
Post length:				
Coronal third	47	0	3	1
Middle third	6	5	20	26
Apical third	33	21	39	40
Post-clinical crown ratio:				
post>crown	1	14	34	38
post=crown	9	12	28	19
post<crown	76	0	0	10

Decementation of PC was recorded in 119 cases during the observation period (11.6 %). Table 6 shows the distribution of decementation on the post length and post-clinical crown ratio. It shows that the highest percentage of decementation was recorded with post space preparations reaching the coronal third of the root as well as when the clinical crown is longer than the post.

The pairwise comparisons of possibly influencing parameters for both, the survival until extraction as well as decementation, showed highly significant influences for the bone attachment, the covering prosthetic restoration, the post length as and the post-clinical crown ratio ($p < 0.001$). There was no significant influence ($p > 0.05$) of the other parameters investigated in this study. For reasons of clarity the significant influences in Table 7 were marked in bold and cursive letters. Best survival was recorded in cases in which the post was at least as long as the clinical crown and when the post space preparation reached the middle third of the root. Longer as well as shorter posts showed significantly lower survival probabilities. Figs. 3 and 4 illustrate the

Table 6
Distribution of decementation on post length and post-clinical crown ratio.

post length	number of decementation	percentage
Coronal third (n = 86)	20	23.3 %
Middle third (n = 610)	48	7.9 %
Apical third (n = 330)	51	15.5 %
post-clinical crown ratio	**number of decementation**	**percentage**
post>crown (n = 535)	43	8.0 %
post=crown (n = 388)	49	12.6 %
post<crown (n = 103)	27	26.2 %

Table 7
P-values of the pairwise comparisons (log- rank test) of survival analysis until extraction as well as decementation.

Parameters	Subgroups	P-values (a =Significant influence)	
		extraction	decementation
Location	Upper jaw Lower jaw	$p = 0.173$	$p = 0.240$
Type of tooth	Anteriors (A)	$p = 0.253$ (A/P)	$p = 0.348$ (A/P)
	Premolars (P)	$p = 0.442$ (P/M)	$p = 0.288$ (P/M)
	Molars (M)	$p = 0.332$ (M/A)	$p = 0.409$ (M/A)
Bone attachment	Physiological	***p<0.001[a]***	***p<0.001[a]***
	Pathological		
Covering	Crowns (C)	$p = 0.440$ (C/B)	$p = 0.208$ (C/B)
prosthetic	Bridges (B)	***p<0.001[a] (B/R)***	***p<0.001[a] (B/R)***
restoration	RPD (R)	***p<0.001[a] (R/C)***	***p<0.001[a] (R/C)***
Luting material	Conventional cement Adhesive cement	$p = 0.549$	$p = 0.205$
PC material	High-gold-content (G)	$p = 0.428$ (G/N)	$p = 0.388$ (G/N)
	Non-precious alloy (N)	$p = 0.136$ (N/F)	$p = 0.209$ (N/F)
	Fibre reinforced (F)	$p = 0.103$ (F/G)	$p = 0.172$ (F/G)
Therapist	Dentist Student	$p = 0.216$	$p = 0.655$
Post-clinical	post>crown (>)	$p = 0.070$ (>/=)	$p = 0.067$ (>/=)
crown ratio	post=crown (=)	***p<0.001[a] (=/<)***	***p<0.001[a] (=/<)***
	post<crown (<)	***p<0.001[a] (</>)***	***p<0.001[a] (</>)***
Post length	coronal third (C)	***p<0.001[a] (C/M)***	***p<0.001[a] (C/M)***
	middle third (M)	***p<0.001[a] (M/A)***	***p = 0.004[a] (M/A)***
	apical third (A)	***p<0.001[a] (A/C)***	***p<0.001[a] (A/C)***

corresponding Kaplan-Meier curves of post-clinical crown ratio and post length for survival until extraction and decementation in which one can see the statistically expected failure rate at a certain time after fitting of PC [29].

To investigate influences taking all investigated parameters into account a multifactorial cox regression analysis was processed. Confirming the results of the log rank test the bone attachment, the covering prosthetic restoration, the post-clinical crown ratio and the post length had a significant influence in the multifactorial analysis, too. These results were also concordant over the survival until extraction and decementation. All other investigated parameters did not have a significant influence on the risk for extraction or decementation in the cox regression analysis ($p > 0.05$). Table 8 illustrate the results of the Cox regression analysis. The missing subgroup in the table was chosen as reference variable for the analysis. For reasons of clarity the significant influences were marked in bold and cursive letters.

4. Discussion

4.1. Method

In order to analyse a large patient cohort over long observation periods a retrospective study is suitable and frequently used by other authors as well [23,24,30,32]. Since the data acquisition in this study was conducted digitally and according to a standardised protocol for a period of up to 19 years (2004–2023), one can assume that the results are representative and conclusive. Furthermore, by using the computer-assisted data search tool of the software, human mistakes could be avoided and data errors were minimalized. Nevertheless, it has to be stated that a prospective randomised controlled clinical trial would have been also suitable to investigate how deep a post space preparation has to be conducted. However, a sample size of more than 1000 cases with a comparably long follow-up as in the present study would have been hardly possible in a prospective study. Since the data acquisition is standardised to the highest possible level, one can assume that the results are comparable to these of other studies even if the data acquisition differed [8,33,34]. Nevertheless, one has to mention that in the present study not all pairwise comparisons had equally distributed group sizes and matching observation periods. Even if the statistical analysis of the present study is able to consider this kind of data and is commonly used in comparable survival analyses as well, this can still be a possible limitation related to the retrospective study design [23,24,27,29,30]. In particular the unequal distribution of CPC and PFRP related to the size of the defect has to be kept in mind when interpreting the results of the present study, since the amount of residual tooth structure is known to be one of the predominant factors for survival of PC [2].

There is a lack of clinical data concerning the necessary depth of post space preparation because to the best knowledge of the authors the only

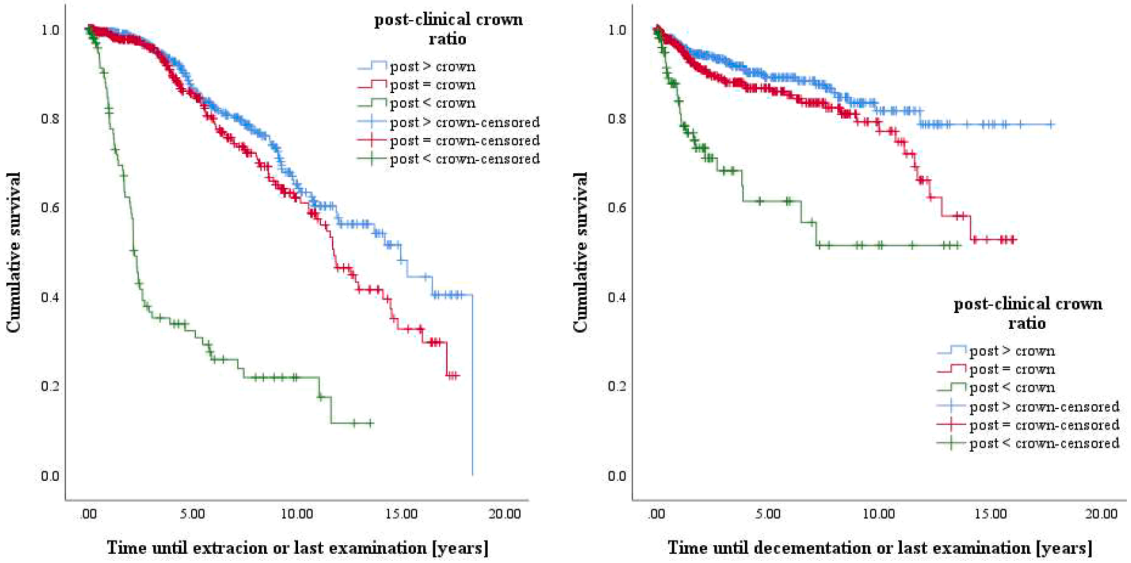

Fig. 3. Kaplan-Meier curves of post-clinical crown ratio for survival until extraction (left) and decementation (right). (post > crown (blue); post = crown (red) post < crown (green)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

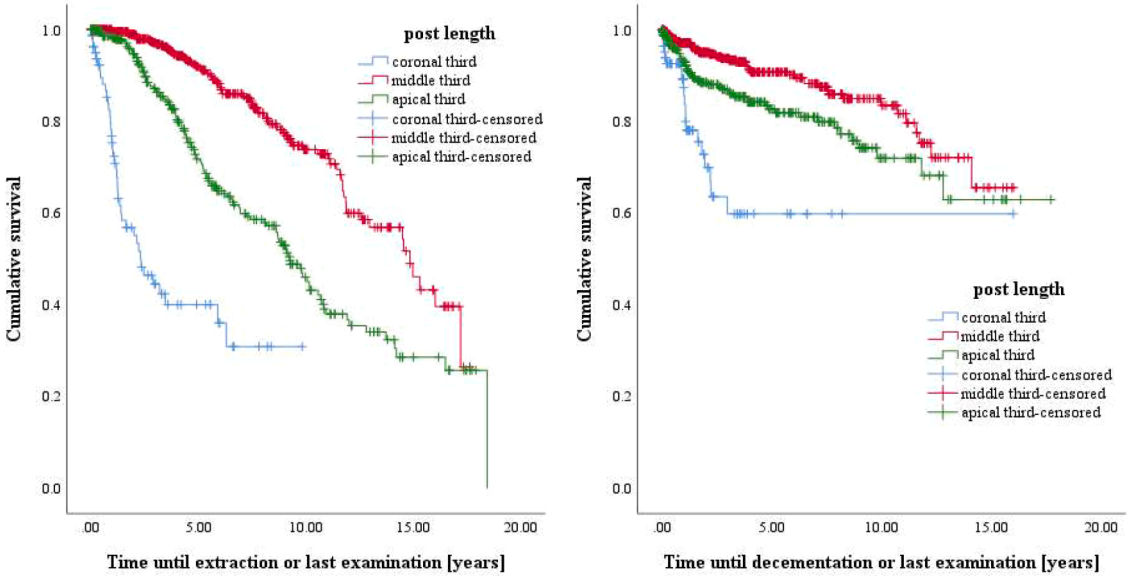

Fig. 4. Kaplan-Meier curves of post length for survival until extraction (left) and decementation (right). (coronal third (blue); middle third (red) apical third (green)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 8
Results of the Cox regression analysis for survival until extraction and decementation.

Parameters	B	p-value.	Exp (B)	95 %Confidence interval of Exp (B)	
				Lower	Upper
Survival until extraction:					
post=crown	0.635	0.104	1.886	1.346	2.644
post < crown	2.046	***<0.001***[a]	0.741	0.093	1.764
middle third	−1.718	***<0.001***[a]	0.179	0.115	0.280
apical third	−0.046	***0.031***[a]	0.626	0.400	0.982
Lower jaw	−0.157	0.310	0.855	0.632	1.157
Premolars	−0.119	0.485	0.888	0.636	1.239
Molars	0.043	0.873	1.044	0.620	1.756
Bone attachment (< 75 %)	0.684	***<0.001***[a]	1.982	1.461	2.690
Bridges	0.086	0.485	1.090	0.685	1.735
RPD	0.297	**<0.001**[a]	1.346	0.933	1.941
Adhesive cement	0.241	0.184	1.273	0.891	1.817
Non-precious alloy	0.090	0.596	0.864	0.297	1.524
Fibre reinforced	1.611	0.270	2.008	1.078	3.266
Dentist	−0.183	0.251	0.833	0.609	1.138
Survival until decementation:					
post=crown	−0.589	0.097	1.407	0.829	2.387
post < crown	0.341	***0.007***[a]	0.555	0.343	0.898
middle third	0.862	***0.005***[a]	2.368	1.295	4.331
apical third	1.507	***0.027***[a]	1.661	1.060	2.601
Lower jaw	0.125	0.531	1.133	0.767	1.675
Premolars	0.435	0.163	1.546	0.977	2.445
Molars	−1.337	0.197	0.263	0.035	1.999
Bone attachment (<75 %)	0.146	***0.016***[a]	1.157	0.762	1.757
Bridges	1.083	0.259	0.952	0.654	1.332
RPD	2.359	***0.001***[a]	1.577	0.252	2.281
Adhesive cement	−0.162	0.535	0.850	0.510	1.419
Non-precious alloy	0.043	0.856	1.044	0.659	1.652
Fibre reinforced	1.768	0.113	2.595	0.738	3.516
Dentist	0.085	0.690	1.089	0.717	1.757

B=coefficient; Exp(B)=hazard. Reference for the hazard is the respective missing subgroup.
[a] =Significant influence.

clinical evaluation dealing with this topic is almost 40 years old [11]. The recommendations given by the authors are obviously no longer up to date because of the advancements associated with new PC materials and the adhesive technique in dentistry. Indeed, there are some recent in-vitro studies investigating the post length [13,14,18,20,22], but those results are not fully transferable to the clinical situation because of the ideal ambient conditions in a laboratory [35]. Therefore, a renewal of guidelines concerning the required depth of post space preparation is of high clinical relevance for daily dental practice.

4.2. Results

In the present study the survival until extraction and until first decementation was evaluated separately, since loss of retention has been described as the most common cause of failure in studies investigating the survival time of PC [23,24,26,36,37]. However, PC in some cases is refitable without any additional effort [38–41], thus decementation does not necessarily include extraction of the tooth. Therefore, *Kramer et al.* distinguished between 'success' and 'survival' of PC [40], but these terms are inconsistently defined in literature, since survival can mean extraction of the tooth or renewal of PC [23]. For Kaplan-Meier survival analysis only two dates (date of fitting PC / date of last recall appointment or target event) can be taken into the account. That is why we determined "decementation" as the first loss of retention of PC. Even if PC was refitted, the case was excluded from further investigation regarding decementation in order to prevent from bias by evaluating on PC repeatedly. In order to ensure clarity for the reader and since the results of the survival until extraction and decementation are comparable and almost matching, the discussion in the following refers to both survival analyses. In the present study the survival was significantly lower when PC was fitted in teeth with pathological bone attachment and teeth that were used as abutments for RPD. Indeed, clinical evidence for the influence of bone attachment on survival of PC is scarce, *Martino* et al. confirmed to the findings presented in this article [30]. Also the result of bad survival of PC in connection with RPD is in line with other investigations published in scientific dental literature [23,25,42]. One reason for this may be because of the extra axial forces resulting on the tooth when the RPD is removed and inserted incorrectly or when the denture saddle does not fit the edentulous jaw [23].

Regarding the post length and post-clinical crown ratio in the present study, a root fracture was least recorded with posts reaching the middle third of the root while periapical inflammation was mainly recorded in deep post space preparations (apical third). Furthermore, root fracture occurred mainly in shorter posts than the clinical crown (post < crown). One reason for this may be that in cases with a longer clinical crown than

the post the leverage effect increases the forces on the tooth favouring root fracture. This effect is even bigger in teeth used as abutments for RPD because of the extra axial forces. In cases with deep post space preparations the increase of periapical inflammations might be because of an insufficient apical seal after preparation [11–14]. Even if a residual endodontic filling of at least 4 mm is shown on the X-Ray, it cannot be excluded that a reinfection occurs through a side canal in the apical root causing a periapical inflammation. The result of the present study that root fracture occurs much earlier than periapical inflammation, periodontal bone loss and caries can be explained accordingly: Other than root fracture the other reasons for extraction follow a biological and chronical progression leading to a delayed failure [43,44].

Summarising these results one can recommend for PC treatment guidelines that the post space preparation should not be extended over the middle third of the root but has to be deep enough to ensure that the post is at least as long as the clinical crown. This recommendation is supported by the results of the pairwise comparisons because there was no significant difference between “post > crown” and “post = crown” but significant differences were detected between all other investigation groups for post length and post-clinical crown ratio. Concurrently, the highest survival rate was recorded for posts reaching the middle third of the root.

The results of the present study are comparable to the findings of *Baraban, Perel and Muroff* from the 1970s which is remarkable, because it emphasizes that their outdated recommendations are still valid to present PC treatment options with modern materials and adhesive techniques. Other authors recommended that post space preparation should be conducted as deep as possible, but they performed mechanical behaviour studies with extracted teeth under laboratory conditions [12–14]. These findings are not transferable to the clinical situation, because they did not include biological failures such as periapical inflammation.

5. Conclusion

This retrospective survival analysis investigated a large patient cohort with more than 1000 PC over a mean observation period of 4.65 years (SD = 4.32 years) and a maximum follow-up of 19 years. Therefore, the results are suitable to give general recommendations regarding how long a post has to be in order to ensure the best survival probability of PC treatment. Summarising the results, the post space preparation should not be extended over the middle third of the root, but has to be deep enough to ensure that the post is at least as long as the clinical crown. Moreover, clinicians should critically review PC treatment in teeth with pathological bone attachment and teeth which are used as abutments for RPD because of the bad survival probabilities.

Ethical approval

Processing data of patient files (Reg. No. 164/11).

Informed consent

For this type of study, formal consent is not required.

CRediT authorship contribution statement

Sarah Marie Reich: Data curation, Investigation. **Kay-Arne Walther:** Writing – review & editing, Visualization. **Bernd Wöstmann:** Resources, Methodology. **Peter Rehmann:** Project administration, Methodology, Conceptualization. **Jonas Adrian Helmut Vogler:** Writing – original draft, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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