Clinical Study of Fibre-Reinforced Root Posts with a Ten-Year Observation Period: A Retrospective Study

Keywords

Cast Post
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ABSTRACT

Purpose: To analyze the survival rates and influential factors of in situ root posts from 2007 to 2017, identifying key parameters affecting their longevity. Methods: The study included all restorations treated at the Department of Prosthodontics, Center for Dentistry and Oral Medicine (Carolinum), Goethe-University, from 2007 to 2017, involving 1120 fibre-reinforced root posts with an 8.0% dropout rate and a significance level of alpha <5%. Results: Patients had a mean age of 61.1±14.37 years. The study found a survival rate of 60.71±14.70 years versus a loss at 64.58±10.45 years ($p<0.05$). The periodontal condition was the most significant factor affecting survival. Cytec Blanco and DT light post showed similar ten-year survival rates of 79.17% and 79.34%, respectively, without significant differences. Periodontal health was the most critical factor for root post loss. Conclusion: Root post loss is more influenced by patient's periodontal health and the indication for root canal treatment than by the structural characteristics of the fibre posts. Clinical relevance: This retrospective cohort study addresses the lack of long-term (>10 years) clinical research on fibre-reinforced root posts, focusing on various factors influencing their success or failure.

INTRODUCTION

Root posts are used in dentistry to provide an endodontically treated and extensively damaged tooth with enough retention surface for later restoration. A build-up filling is attached to a root post in the form of a core build-up. This should have the structural advantage of allowing the prosthetic restoration that follows the treatment to be more securely anchored to the tooth.[1]

In a large-scale study, Ferrari *et al*. show that teeth with a root post have a significantly higher probability of survival than those without a root post and that fractures of any kind occur less frequently.[2] The selection of different materials from which root posts are made ranges from metals and ceramics to fibre-reinforced composite root posts.[3,4] Metallic root posts no longer correspond to the lege artis treatment methods, as they show significantly lower survival rates compared to fibre-reinforced root posts.[5]

A fibre-reinforced root post is a material with an elastic modulus (modulus of elasticity) similar to dentin. If the material behaves in a tissue-compatible manner, the entire composite of tooth, root post and superstructure should

be able to bend under load in accordance with the dentin, in order to be clinically superior to the conventional metal root post.[6] The focus is on avoiding root fractures. These are more frequently observed in metal root posts due to their high modulus of elasticity.[6,7]

In the field of restorative dentistry, the gold standard for the definitive fixation of fibre-reinforced root posts is to use an adhesive system[8] to create a permanent adhesive connection.[9] In direct comparison to purely mechanical-retentive cements, a significantly lower decementation rate can be observed.[10,11]

In the case of a root post treatment, caries removal and root canal treatment are always required. Both these treatment steps and the choice of post size lead to the weakening of the tooth to be treated.[12]

During the later preparation for the superstructure, hard tooth structure may have to be sacrificed again in order to achieve the best possible ferrule effect, so that extra-axial loads are not only carried by the post core structure, but are evenly distributed over the tooth stump and the composite structure.[13] This shows that the treatment of a tooth with a root post depends on various parameters.

The aim of this study was to conduct an *in situ* survival time analysis of fibre-reinforced root posts that were inserted between 2007 and 2017. Furthermore, the possible influencing factors for survival and loss should be identified and compared with each other in order to determine which parameters have the greatest influence.

The null hypothesis was that due to the small differences between the fibre-reinforced root post systems in their material properties, no significant difference between them is expected in terms of their survival *in vivo*.

The second hypothesis was that the survival of the root post is influenced by the intraoral situation, such as periodontal disease or superstructure.

METHODS

This retrospective study is based on data collected from the Department of Prosthodontics, Center for Dentistry and Oral Medicine (Carolinum), Goethe-University. The root posts that were placed between January 2007 and December 2017 were examined. The data collected for the study comes exclusively from the documentation in the patient files.

Ethical approval was issued by the Committee of the University (file number: 329/2017). The study was carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki.[14]

The data were taken from the analogue patient files and collected in a pseudonymized form using an Excel master table. The following data to be evaluated was recorded from the patient file documentation.

DATA COLLECTION AND DATA ANALYSIS

Patient and root post related data as well as the adhesive system used were collected. Furthermore, success/loss rates were analysed as a function of tooth groups (front teeth, premolars, molars), superstructure and periodontal status on the basis of the periodontal screening index (PSI). The question to be investigated, statistically speaking, is which parameters have the greatest influence on the loss behaviour of fibre-reinforced root posts?

ROOT CANAL PREPARATION

The existing root filling material was removed at the canal entrance using a round drill. This was followed by the pilot drilling, in which the insertion depth should be at least 3 mm from the canal entrance and a maximum depth such that at least 4 mm of the remaining root filling material remains from the apical angle. The subsequent standard drilling serves to adjust the width of the drill shaft for the root post.

The drill channel was then etched with 36% phosphoric acid for 15 seconds. The fibreglass root post was degreased extraorally with ethanol and finally wetted with silane. The adhesive bond was created with RelyX Unicem, a self-adhesive, dual-curing resin cement. To accelerate and complete curing, the pin and the adhesive cement were illuminated with a polymerization lamp under light pressure. RelyX Unicem was then modelled onto the post to form the core and was completely cured. The root post was then shortened in the coronal portion using a diamond drill bit under water cooling to the desired occlusal height, so that the post was simultaneously covered with resin cement on all sides.

ABUTMENT PREPARATION

To ensure that the forces acting on the construction were transferred to the tooth and did not affect the transition of the core structure to the hard tooth substance, the ferrule design was used in the preparation of the tooth stump for a later prosthetic superstructure.[1]

INCLUSION AND EXCLUSION CRITERIA

All patients with complete documentation in the patient file of the Department of Prosthodontics, Center for Dentistry and Oral Medicine (Carolinum), Goethe-University who received therapy using a fibre-reinforced root post were integrated into the study.

The withdrawal of patients from the study was due to insufficient documentation, post insertion outside the University, production of the prosthetic superstructure outside the University, as well as different root post materials.

SUCCESS AND FAILURE CRITERIA

Success was realised if careful and evaluable documentation was available during the observation period and there were no complications of a root post. Failure was characterised by the loss of the post, fracture or decementation of the root post if the post could not be replaced and retained. The loss of a tooth due to various fracture patterns, periodontal inflammatory processes, caries, trauma and other indications also led to failure.

STATISTICS

For the statistical evaluation, the success rate and survival rate were evaluated using statistical time-to-event analysis (Kaplan-Meier, log-rank test and Cox regression). In addition to a univariate analysis, a multivariable Cox regression was conducted. As a sensitivity analysis, a multivariable Cox regression with a frailty approach was carried out to investigate whether dependencies within the patients were an important influence. All statistical tests were two-sided and performed with a significance level of alpha=5%.

In addition, further descriptive and statistical analyses were carried out to determine the frequencies (n), the proportion (percentage) of the total collective or subgroups and graphical representation using Excel (Microsoft Office 365/Windows 10).

The analytical statistical evaluation was conducted using the statistical software BiAS for Windows (program version 11 © epsilon-Verlag 1989-2019, Dr Hanns Ackermann, http://www.bias-online.de) and RStudio (version 1.1.463 - © 2009- 2018 RStudio, Inc.).

The sample size calculation was carried out by Professor Dr E Herrmann (Institute for Biostatistics and Mathematical Modeling, Johann Wolfgang Goethe - University of Frankfurt).

RESULTS

DESCRIPTIVE STATISTICS

In the manner described above, 1224 root post insertions were registered between January 2007 and December 2017. Fourteen different types of root posts, including two titanium posts, one radix anchor (partially assembled active metal post with thread and retentive core structure) and eleven laboratory-made individual root post core structures made of zirconium were not included in the study. Ninety patient files (drop-out rate of 8%) could not be sufficiently evaluated. Ultimately, 1120 root posts placed in 900 different patients were included in the evaluation. A descriptive survival rate of 89.8% and consequently a pin loss rate of 10.2% were determined, regardless of the time of observation.

As part of this study, 600 root posts were placed in men, of which 63 did not survive. In women, 520 root posts were inserted, of which 51 were lost. When directly comparing the gender-specific loss rates without depending on the duration of observation, no significant difference can be seen because the values of 10.5% and 9.8% are too close to draw conclusions.

NUMBER OF POST-STUMP ABUTMENTS PER PATIENT

Using a pivot table, a pseudonymous analysis was carried out to determine which patient had how many root posts placed during the examination period. The tabular list *(Table 1)* shows that 731 (81.2%) of all patients evaluated had only one root post placed during the examination period. Only in a very few cases have more than three root posts.

Table 1. Number of post-stump abutments per patient.

Root posts per patient	Number of patients
1	731
2	130
3	28
4	10
5	1
In total	1120 root posts

ROOT POST-RELATED DATA

The total number of individual root post systems means that only the two most frequently used post systems, Cytec Blanco (Hahnenkratt, n=908) and DT light post (VDW, n=169), can provide a valid evaluation for the later analysis, since the small number of cases of the others could cause possible inaccuracy. A direct comparison of the descriptive data between these two pin systems shows no significant difference in terms of loss values.

Ratio of insertion depth and length of the inserted root posts: the average length of the surviving root posts at approximately is 10 mm; by comparison, the average insertion depth is around 6 mm. The ratio of the two values was 0.6.

The values for the lost root posts are similar. Here the average total length is around 10 mm, the insertion depth is approximately 6 mm and the resulting ratio is just under 0.6.

There are, therefore, no significant differences in the relationship between the abovementioned ratio and possible loss.

Data on the adhesive systems used: The standard at the Department of Prosthodontics, Center for Dentistry and Oral Medicine (Carolinum), Goethe-University for root post restoration is the material RelyX Unicem (3M ESPE, Seefeld, Germany). Due to the fact that other materials were used in very small numbers (< 5%), these data are not suitable for analytical consideration, using, for example, a log-rank test to determine a significant influence or proof of survival or loss.

PROSTHETIC INTEGRATION OF THE TEETH WITH ROOT POST ABUTMENTS

The graphic comparison of the absolute numbers related to the prosthetic integration of the root post restoration shows a very uneven distribution of the different prosthetic restorations *(Figure 1)*. The posterior crown, which is bordered on both sides by neighboring teeth, is most often treated with a root post abutment, followed by the anterior crown.

PERIODONTAL STATUS IN THE SAME SEXTANT OF THE ROOT POST RESTORATION

The periodontal screening index (PSI) values were also recorded for all root post restorations evaluated as part of the diagnosis. The following two pie charts show the periodontal situation as a function of loss and survival using the PSI values in the same sextant in which the root post was placed. By comparing the two pie charts *(Figure 2)*, it becomes clear that the root posts with failure within their group have a higher percentage of PSI Code 3 and 4 values, which indicates increased probing depths in the same sextant and thus a suspicion for periodontal damage.

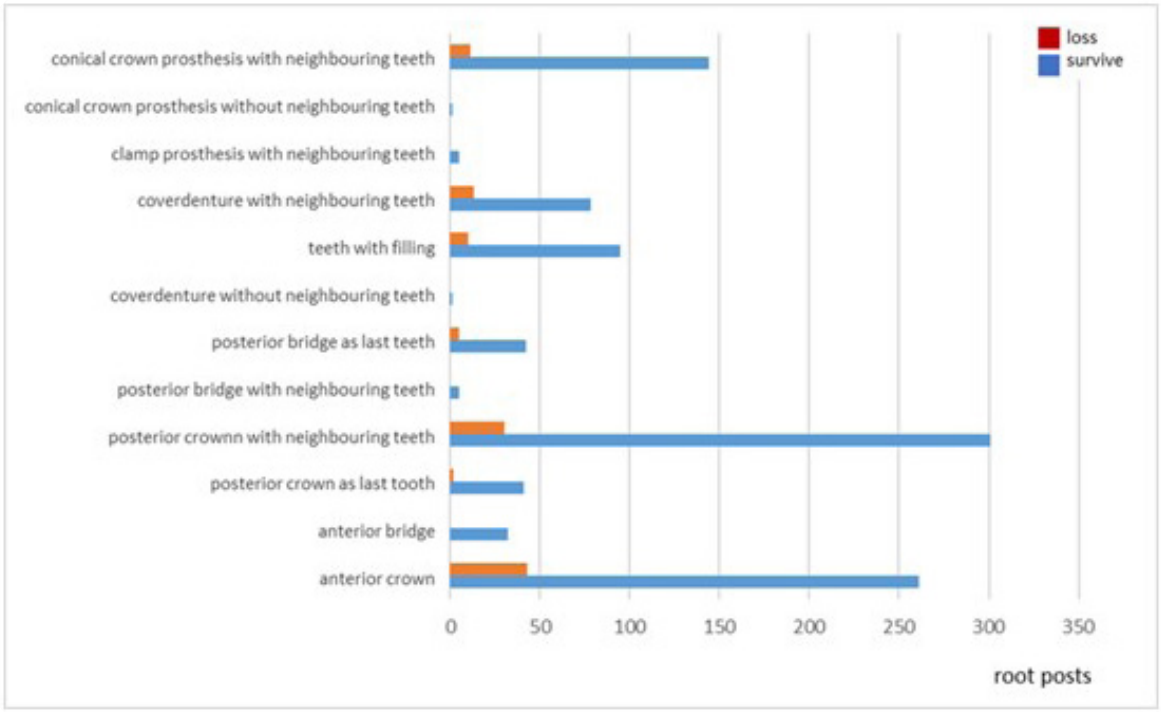

Figure 1: Prosthetic integration of the root post treatment compared with survival and loss.

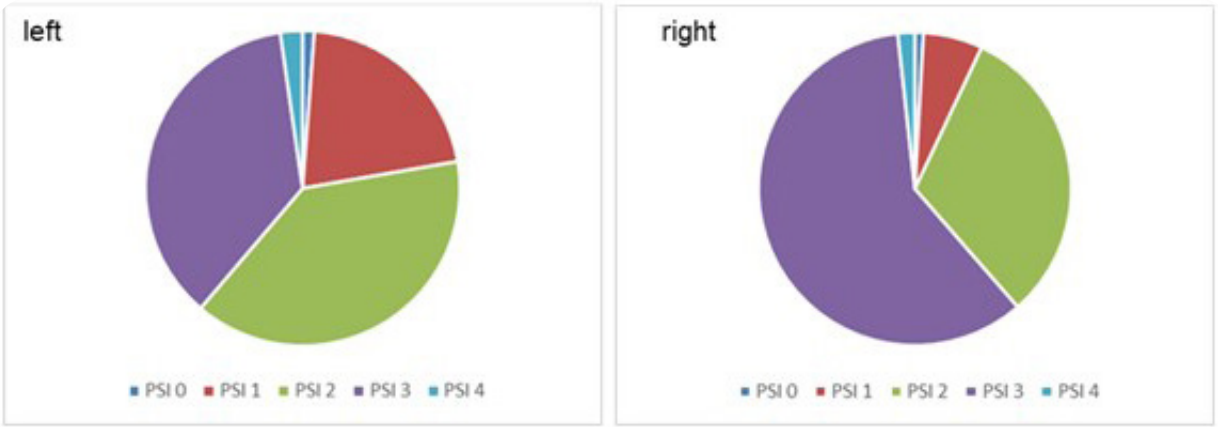

Figure 2: Distribution of PSI values in the same sextant of the root post restoration if the restoration survives (left). Distribution of PSI values in the same sextant of the root post supply in the event of loss (right).

DURATION OF OBSERVATION FOR SURVIVAL

The average duration of observation for survival is almost four and one-half years. In the case of minimal observation, the patients no longer presented to the Department of Prosthodontics, Center for Dentistry and Oral Medicine (Carolinum), Goethe-University after root post insertion until the data were evaluated. The maximum observation period of over 11 years is due to the fact that the documentation was only evaluated from 2018 onwards. However, the first root post restorations were documented in 2007.

ANALYTICAL STATISTICS

Kaplan-Meier Survival Curve

The descriptive statistics showed that only the Cytec Blanco (Hahnenkratt) and DT light post (VDW) root posts were used in sufficient numbers, so meaningful graphs could be developed from them. The log-rank test, considering all previously evaluated root posts, did not show any significance. (Peto-Pike's $Chi^2 = 6.826$ with df = 5 and p = 0.23)

For this reason, only these two root post models were considered in the survival curve for the first time in analytical statistics *(Figure 3)*. The root posts have a very similar course, DT light post with 79.3% (CI 65.3%-93.3%) and Cytec Blanco with 79.1% (CI 71.6%-86.7%). The survival curve shows a steady decline up to around seven years of observation. After that, the probability of survival no longer changes.

The two root post systems, Cytec Blanco and DT light post, were not considered further separately due to the lack of significant differences in the survival analysis. Consequently, only the various parameters were examined for the significance of their influence.

Because of possible interactions and influence on the results of several root posts in one patient, the first root post placed was also evaluated analytically. The log-rank test of the root posts placed first in comparison with the remaining root posts also shows no significance; neither one group nor the other had a significantly higher probability of survival.

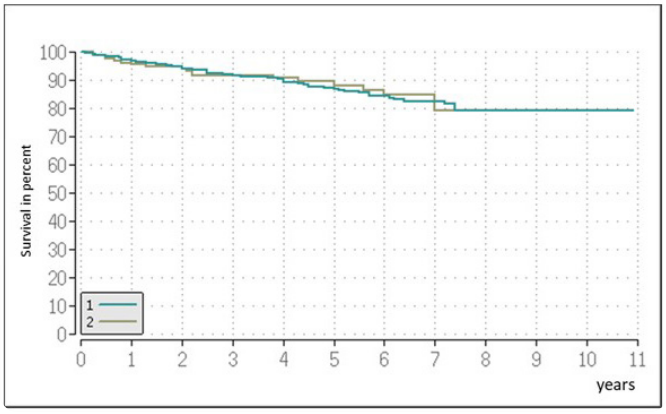

Figure 3: Kaplan-Meier estimator for Cytec Blanco and DT light post. Group 1- Cytec Blanco (Hahnenkratt) Group 2- DT light post (VDW).

Log-rank test for only the first root posts placed per patient:

Peto-Pike's $Chi^2 = 0.546$ with df = 1 and p = 0.459901

INFLUENCE OF PSI VALUES ON THE SURVIVAL OF THE ROOT POSTS

Log-rank test, univariate with respect to the PSI values, recorded in the same sextant of the root post.

Chi^2-tests:

PSI 1: $Chi^2 = 4.726$ approximated with df=1 und p = 0.029716

PSI 2: $Chi^2 = 1.616$ approximated with df=1 und p = 0.203685

PSI 3: $Chi^2 = 8.004$ approximated with df=1 und p = 0.004667

PSI 4: $Chi^2 = 0.000$ approximated with df=1 und p = 0.987910

PSI 0: $Chi^2 = 0.160$ approximated with df=1 und p = 0.689606

Log rank test:

Peto-Pike's $Chi^2 = 14.505$ with df = 4 and p = 0.005845

Periodontal health, as measured by the PSI value, has a very high significance for the survival of root post supply. Thus, the analysis confirms that the higher the PSI value in the same sextant in which the root post was placed, the higher the rate of loss. The evaluation of the influence of the PSI shows a clear significance for the PSI value 3. This significantly affects the event of the loss. However, the Kaplan-Meier estimator shows that the curves of the individual PSI values overlap depending on the survival of the root posts and that there is no uniform distribution. With a PSI value of 4, however, the p-value is not significant, as this almost always means the loss of the tooth due to excessive periodontal damage.

The Kaplan-Meier analysis, related to the survival behavior of the root posts in univariate dependence on periodontal health, as measured by PSI, shows that a separate consideration of the individual PSI values using a univariate Cox model would not yield meaningful values, since the individual curves overlap and do not run uniformly according to the severity of the PSI *(Figure 4)*. Therefore, the influence of PSI was investigated in a multivariate Cox analysis *(Table 2)*. With each increase on the numerical scale of the Periodontal Screening Index, the risk of loss increases by about 76%. At the same time, the PSI collected before treatment in the same sextant of the root post supply has a very high significance with a p-value of 0.00012. This error value corresponds to a probability of 0.012%, so it can be concluded with a very high degree of certainty that the periodontal situation is an influence compared to the other parameters Table 2).

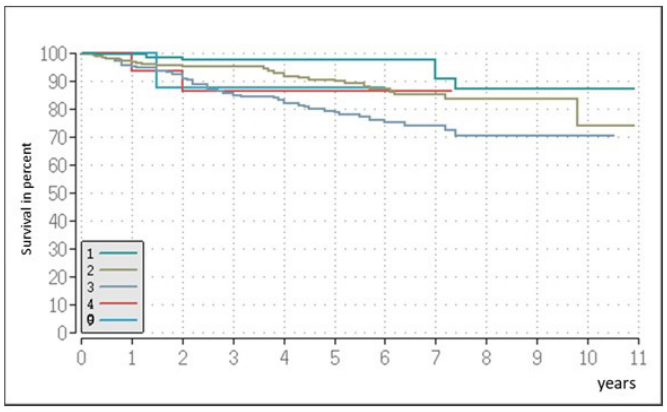

Figure 4: Kaplan-Meier estimator in terms of PSI values (0, 1, 2, 3, 4) in the same sextant of root post supply.

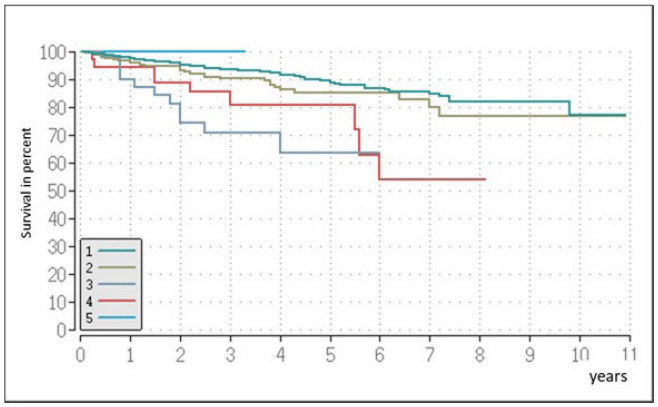

Figure 5: Kaplan-Meier estimator in relation to the indication - 1 = caries, 2 = fracture of the tooth, 3 = fracture of the tooth in combination with carious destruction, 4 = previuous loss of post, 5 = stabilisation of a tooth in a dentition that has suffered periodontal damage.

Table 2. Summary of multivariate Cox regression.

Variable	Hazard ratio	confidence interval 95%	P-value
PSI	1.760301	1.3194-2.349	0.00012
Indication fracture tooth	1.460142	0.9054-2.355	0.12000
Indication fracture tooth/caries	3.552998	1.7254-7.316	0.00058
Indication previous loss of post	1.866154	0.8289-4.201	0.13000

SENSITIVITY ANALYSISTOOTH GROUPS, UNIVARIATE COX REGRESSION WITH FRAILTY APPROACH

The results of our study show that maxillary molars have the highest (98%), whereas mandibular premolars have the lowest (52%) probability of survival over ten years of observation. These two groups differ greatly from the remaining groups. No significance could be shown when evaluating the individual teeth, which is why the abovementioned evaluation using groups of teeth seemed to make sense as a control function.

Figure 5 shows the ten-year survival probability in relation to the nominal indication after a meaningful increase in severity. The indication of previous post loss has the lowest probability of survival. The maximum observation time for this indication is around eight years, which is why the graph does not continue over the entire length of the x-axis. The indication for stabilizing a tooth in a dentition that has suffered periodontal damage has established that an observation period of approximately three years provides the best survival prognosis. Teeth were only included in this group of indications if no other indications listed were applicable. This applies to very few teeth compared to the other indication groups, as there were usually combined problems before the treatment decision was made.

COMPETING RISK ANALYSIS

The Competing Risk Analysis represents the risk of a specific loss depending on one or more variables. For the competing risk analysis, the characteristics of the various types of losses were summarized into just four plausible categories. The program was able to simplify it in order to provide a meaningfully interpretable overview and to make a statistically meaningful forecast by determining the respective risk.

The following categories were assigned to the 'tooth not worthy of preservation' group: PA loss of tooth, increased loosening and increased probing depth, iatrogenic loss (via falsa), secondary caries with suspected reinfection of the root canal with radiographic apical radiolucency, cause not clearly classifiable, and condition after unsuccessful endodontic procedures.

The grouping for 'fracture' was assigned the following categories: fracture (only) tooth horizontally, fracture (only) tooth vertically, combined fracture (only) tooth, fracture tooth and post horizontally, fracture tooth and post vertically, fracture tooth and post combined horizontally and vertically.

For the 'decementation' and 'new post possible' groups, only the two groups were used due to the clear description.

The graph of the competing risk analysis (*Figure 6*) shows very clearly, that the risk of loss caused by a diagnosed non-preservability of the tooth has by far the greatest probability. The course of the graph also shows that even after a comparatively long period of insertion of the first root post, if it is lost, there is still about a 5% chance of removing the remaining root post fragment and stabilizing the tooth with a new, second, fibre-reinforced root post (*Figure 6*).

DISCUSSION

The aim of this retrospective study was to determine the clinical success of adhesively attached fibre-reinforced post abutments and to present it in the form of a survival time analysis and risk analysis in relation to the parameters examined.

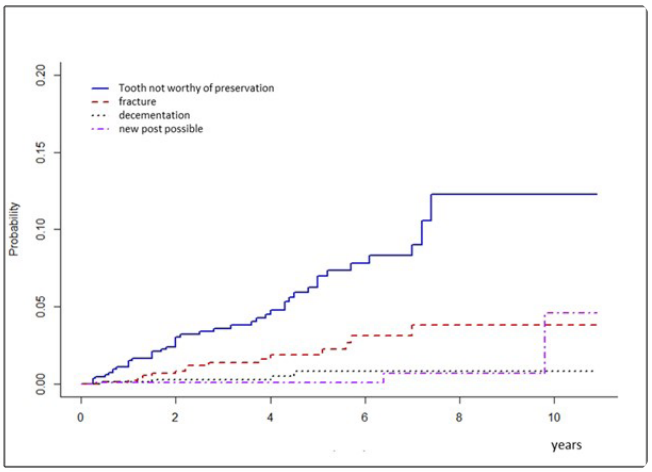

Figure 6: Competing risk analysis for the different types of loss.

The problem with any retrospective study is the availability of consistent data that can be analysed. A high loss-to-follow-up rate, typical for studies of this type, was also expected from the start.

Despite standardised treatment processes and a uniform approach to diagnosis, documentation and evaluation, incorrectly recorded data cannot be ruled out. The lack of x-rays for diagnostic verification of findings meant that the documentation in the patient file could not be checked and, therefore, its accuracy had to be assumed.

Of the total 900 patients, 81.2% had a root post placed during the observation period. The remaining patients received two or more posts.

Due to our large number of cases, a significant statement could be made about the influence on survival or failure of the parameters examined.

DEPENDENCE ON THE ROOT POST SYSTEM AND THE ADHESIVE SYSTEM

In the *in vitro* studies[10,16,17] only the adhesive system was evaluated, primarily in tensile tests. In still other laboratory studies[18,19,20], the influence of the root post system itself on survival was put to the test. Although material science tests showed clear differences between the individual root posts in other studies[18,20], this had no significant influence in our long-term clinical analysis. In our study, only the Cytec Blanco (Hahnenkratt) and DT light post (VDW) root posts were used for all further analyses, because they were used in a sufficiently large number.

The *in vitro* study by VDW showed that quartz fibre posts, such as the DT light post, have a slightly higher modulus of elasticity than posts made of glass fibre (Cytec Blanco).[20] However, this root post with a macroscopically smooth surface cannot compete with Cytec Blanco in test series such as the pull-out test, since the adhesion values are again below these standards.[18] A study by Babenhauserheide *et al.*[19] proved that DT light post SL (VDW) achieves approximately the same values in the pull-out test compared to the Cytec Blanco pins only at an insertion depth of 1.5 times. The adhesion strength values were 16 N/mm^2, which corresponds to 1.6 times that of DT light post.

Since a standardised protocol was used at the University of Frankfurt during the treatment period from 2007 to 2017[3] for the insertion of root posts, which, with a few exceptions, included the adhesive cement RelyX Unicem (3M ESPE) when choosing the fixation system, no significant values ($p<0.05$) could be evaluated in comparison to other materials.

Aleisa *et al.* showed in a direct comparison between RelyX Unicem and Variolink II and Paracore that the former luting cement achieved the best adhesion values in the *in vitro* tests. These highest load values were independent of the endodontic pretreatment and independent of the sealer used in the root canal filling.[16]

In this clinical study, the root post decemented only five times (4.4% of all losses) during the observation period. Therefore, it can be assumed that the surface design of the root post is not a significant parameter.

COMPARISON TO STUDIES WITH INSERTION DEPTH, RATIO

On average, in our study, the ratio of total length to insertion depth was approximately 60%. According to other studies, this also held true in terms of force distribution, as this ratio was similar to that of root length to crown height.[21,22]

In the literature on root posts there is no information on the topic of the ratio between post length and insertion depth. It is simply pointed out that the previously placed root filling should be left at least 4 mm long in the apical part of the root.[13,23] Potential retrograde reinfection of the root canal with too little apical gutta-percha would adversely affect the survival of the restoration through an apical lesion.[4] Chuang *et al.* showed in their series of tests when comparing fibre posts with a length of 5 mm and 10 mm that the longer root posts withstood less force in the event of a fracture. Furthermore, they had a tendency to cause disadvantageous root fractures, which directly led to total tooth loss. The decisive factor for success was the minimal weakening of the tooth due to dentin removal during the shaft drilling and the correct ratio of tooth length to root post length.[22,24]

Using a similar test method, Farina *et al.* demonstrated a higher significance of the dentin layer thickness in relation to the post length.[21]

Since the ratio of insertion depth to total length in the current study does not differ significantly from the information in comparative studies, it seems plausible that the results are comparable. It can, therefore, be assumed that the results are reproducible using a similar methodology.

SUPERSTRUCTURE

Currently, there are no comparable studies that differentiate between different superstructures in relation to the survival of fibre-reinforced root posts. The studies by Kim *et al*., Murali Mohan *et al*., and Scotti *et al*. only include patients with fixed single-tooth prosthetics in their studies.[25-27] Publications in which an investigation was made into removable dentures on post-stump abutments, which fall into the therapy pattern with fibre-reinforced root posts, could not be found during the time this study was carried out. In a few studies, this decision to filter the patient population was justified by hoping for more significant values if individual groups were excluded in advance.[26,27]

Although no statistical significance (p = 1.4e-02 - 1.0) could be determined in the study due to the influence of prosthetic integration, it can be said that anterior crowns are relatively more vulnerable. This was confirmed by the tooth-related evaluation, but does not provide any significant insight into the dependence on the prosthetic superstructure.

PERIODONTAL SCREENING INDEX (PSI)

By comparing the two pie charts, it becomes clear that the root posts with failure within their group have a higher percentage of PSI Code 3 and 4 values. This suggests increased probing depths in the same sextant and thus raises the suspicion of periodontal damage.

There are no comparable publications that show the periodontal condition in relation to the survival of the root post restoration, but this study provides meaningful significance values (p = 1.2e-04) that statistically confirm a significant influence of periodontal health on the probability of survival.

Critically, however, it must be noted here that PSI values refer to the periodontal condition of a tooth in a sextant. It is therefore possible that the higher PSI values in a sextant are not explicitly caused by the tooth provided with a root post. This is a disadvantage of this method of examination.

DISCUSSION OF ANALYTICAL STATISTICS

The studies used below for comparison purposes all have a similar research design with the same definition of failure.[28,29] In addition, all clinical analyses have a suitable cohort size, so that all statements made in the results analyses fall within a significance range of $p<0.05$.

Naumann *et al*. examined the survival of 105 fibre posts in 83 patients. The patient population was divided into two groups depending on the root posts used. Moreover, in this case, no significance (p=0.37) could be determined between the root posts themselves. With a loss rate of 3.8% in the first year and 12.8% after two years of observation, this is very similar to our results, at least in the first year.[30] The comparison of the Cytec Blanco and DT light post root posts showed no significance in our study (p=0.23). In the first year the loss rate was 3.4%; after two years it was 6.3%.

Xu *et al*. limited their test series to root posts of the DT light post (VDW) type, which achieved a success rate of 91.9% over the three-year observation period. This is consistent with the DT light post value of 91.6% at three years determined in our study. However, in the analysis by Xu *et al*., only front teeth and premolars were treated and fixed dentures were included.[31] Filtered in the same study design by excluding other root post models except DT light post and only including fixed restorations on anterior teeth and premolars (n=140), a survival probability of 89.89% at three years remains in our study.

To confirm the general validity of these results, the study by Mannocci *et al*. was used for comparison purposes. In the 2002 study, no premolar losses were observed during the first year.[32] In the continuation of this study from 2005 over an observation period of five years, a significant difference was found between different reasons for loss of premolars treated with root posts. The root fracture has a p-value of p=0.029 compared to secondary caries with p=0.047.[33] In our study, the probability of a fracture in relation to new caries cannot be fully understood. Caries and an unfavourable periodontal situation were summarised under the heading 'tooth not worth preserving'. This is due to the type of documentation within the patient files, as no distinction was made between the exact reasons.

In the study design of Signore *et al*. involving 192 patients and 526 root posts, the focus was solely on the success of the root post, so that failure was only caused by the actual failure of the root post itself due to, for example, fracture or decementation. In this way, survival values of 98.5% could be measured with an average observation period of 5.3 years.[34] Applying this definition of failure to our study results in a 96.1% survival at 5.3 years. Such a description of failure makes sense if one simply wants to describe the quality of a root post restoration, but, according to Juloski *et al*., this does not correspond to the actual success in everyday clinical practice, because in this case the survival of the root post is of dependent on other influencing factors.[35]

Cagidiaco *et al*. examined the differences in survival time between root canal-treated and crowned premolars with different intraradicular retention concepts. The premolars treated with DT light post achieved the best values with a survival rate of 90.9% based on 36 months of observation, whereas individual fibre sticks (Ever Stick Post) achieved 76.7% survival over the same period. Crowned premolars treated with root canals without a root post treatment had the worst survival rate at 62.5%. The authors concluded from the Cox regression that the more teeth that were destroyed before therapy, the worse the expected retention and, consequently, the worse the survival.[36]

Under the same inclusion conditions in the study, the survival rate of premolars treated with DT light post and single tooth crowns over a period of three years was 92.8%. However, this sorting only includes 51 data rows, each of which corresponds to a treated tooth. However, this value remains

valid once the individual inclusion criteria, such as tooth type, are highlighted. Then, for the same period of time with the same supply, the result is 90.5% for 115 data series with a very strong significance level of 1.2*10-9. This shows that these results can be reproduced very well even in different studies under different conditions.

In the prospective study by Monticelli *et al.*, the patient population was randomly divided into three groups, each provided with a different fibre pin system. No significant differences in survival properties could be found between the DT light post, Aesthetic Plus and FRC Postec root posts.[37] This result is consistent with those from this study.

In their comparative cohort study, Ferrari *et al.* were able to carry out a direct comparison between fibreglass root posts and those made of carbon fibre. The size of the Composipost (n=985), Aesthtetic Post (n=160) and Aesthetic Plus Post (n=210) cohorts increases the significance of the values determined. Composipost (10.2 years mean observation period, 95.6% survival), Aesthetic Post (7.5 years, 91.9%) and Aesthetic Post Plus (7.2 years, 81.3%) provide results that are similar to all other studies comparable level of significance.[38] In our study, all root posts cumulatively achieved a survival probability of 75.3% over an observation period of ten years. Composipost (n=22) has a survival probability of 40.7% with an observation period of ten years. However, due to the small number of cases, no statistically meaningful comparison can be made.

COMPETING RISK ANALYSIS

To date, no risk analysis has been published for therapy with fibre-reinforced root posts in which the probability of a specific event leading to the immediate loss of the treated tooth is predicted. However, this could be stated with sufficient significance (p=0.019) by the competing risk analysis. However, since this only applies to the cohort examined and has not yet been examined in another study setting, no general reproducibility can be assumed from this, but rather it serves as a guide.

This analysis method is suitable for providing an approach to clinical guidance on how to increase root post survival. The problem for failure lies largely in the indication. Teeth that have previously been damaged and are considered questionable for preservation have too often had root posts placed. A stricter indication could lead to a higher success rate.

From a clinical point of view, the indication is to be judged more significantly in the application than determined mathematically here, as this would lead to a significant improvement in the results if there were a clear demarcation. For later treatments, an indication for root post insertion in periodontally damaged teeth is to be viewed as critical.[4]

The results show that in the event of failure, there is a high probability that the root post was lost due to the tooth not being worth preserving.

The cumulative probability of this event is approximately 15% in the event of a loss event from an observation period of seven years or more. This analysis method can be used to statistically determine the factors most unfavourable for a root post. In clinical implementation it is then important to reduce this as much as possible in order to maximise the chances of success.

The study design used here, including all cases treated at the Department of Prosthodontics, Center for Dentistry and Oral Medicine, (Carolinum), Goethe-University, has a negative impact on the statistics compared to other clinical studies. Other studies excluded in advance certain patient groups or explicit types of superstructure care or individual groups of teeth.

ANSWERING THE QUESTION AND HYPOTHESIS

The null hypothesis that no significant differences were to be expected with regard to the survival time analysis due to the assumed similarity in the material properties between the different root post systems was confirmed. To illustrate this, the analyses were carried out using the Kaplan-Meier estimator, which showed no significant difference between the different models with a p-value of p = 0.23. The root post itself, therefore, had no influence on survival and loss in relation to the other recorded values of various parameters.

The second hypothesis that the patient's intraoral situation would have a significant influence on the survival of the treatment was proven by Cox regression. Accordingly, the periodontal condition of the respective patient, as measured by the periodontal screening index, has the greatest influence on success among all other factors surveyed (p = 0.00012).

CONCLUSIONS

The success of root post treatment can be influenced by various factors. In our study, the indication for root post therapy and periodontal health measured by the PSI at the time of insertion resulted in significant values (p<0.05). The most common reason for failure was tooth loss due to periodontal lesions.

In clinical use, however, it can be assumed that a summation of unfavourable factors can significantly reduce the survival of a root post. In order to generally increase the probability of survival of root posts in daily practice, the practitioner should make a realistic assessment of tooth preservation before therapy, thus narrowing the range of indications.

In order to support the universality of the conclusion reached in the study, it is recommended that similar studies be carried out with other patient groups. The results of this retrospective cohort study also have no claim to general validity.

AVAILABILITY OF DATA AND MATERIALS

The original datasets analysed in the current study are available on reasonable request from Dr Maximilian Justus Dobbertin.

COMPETING INTERESTS

ARK, MJD, HCL, LS and AP hereby declare that they have no conflict of interests.

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AUTHORS' CONTRIBUTIONS

ARK's contributions included the preparation of the original draft as well as to the revision and approval of the final version of the manuscript. MJD's contributions included the study conception and methodology, supervision of participants, data acquisition and preparation, and preparation of the original draft, including revisions and approval of the final version of the manuscript. HCL contributed substantially to statistical evaluation, revised and approved the final version of the manuscript, and contributed to project planning and supervision, data curation and statistical evaluation. LS and AP made substantial contributions in the methodology, revision and approval of the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE:

The study was carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki. (14) The study was registered at the University of Frankfurt/Main . Ethical approval was issued by the Committee of the University of Frankfurt/Main (file number: 329/2017).

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