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ORIGINAL ARTICLE

Long-term evaluation of direct pulp capping—treatment outcomes over an average period of 6.1 years

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Abstract To assess the treatment outcomes of direct pulp capping with calcium hydroxide, 248 teeth were examined 0.4–16.6 years (mean, 6.1±4.4) after pulp capping. Only teeth diagnosed to be clinical healthy or with spontaneous pain were capped. The treatment outcome was assessed by interviewing for signs or symptoms responsiveness and sensibility testing with CO_2. The overall survival rate was 76.3% after 13.3 years. Of the teeth, 80.2% were found to have a favourable treatment outcome. The pulps of 60-year-old patients showed a significant lower favourable treatment outcome when compared to patients younger than 40 years ($p<0.05$). The treatment outcome was significantly less favourable in teeth restored with glass ionomer cement compared to all other teeth ($p<0.01$). The likelihood to show an unfavourable treatment outcome after direct pulp capping was significantly higher for teeth with spontaneous pain than for teeth with clinically healthy pulps ($p<0.001$). In addition, the likelihood for a tooth to become non-vital after direct pulp capping was significantly higher within the first 5 years after treatment than after more than 5 years ($p<0.001$) after treatment.

Keywords Calcium hydroxide · Direct pulp capping · Long-term evaluation · Treatment outcome

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Introduction

Direct pulp capping is defined as wound dressing of exposed vital pulp tissue. The exposure can occur due to caries excavation or trauma. Usually, the pulp and dentine wound is treated with calcium hydroxide in order to protect the injured tissue, to induce the formation of reparative dentine, and to keep the tissue vital. The overall aim of direct pulp capping is pulp healing [1–3]. Several months after direct pulp capping, the following effects can be expected:

- Regular pulp tissue without signs of inflammation and with a constant layer of reparative dentine
- Chronically inflamed and infiltrated pulp tissue with a permeable layer of reparative dentine interspersed with tunnel defects
- Highly inflamed pulp tissue with an imperfect, incomplete or missing layer of reparative dentine or a dense collageneous scar tissue in the area of pulp perforation.

Only the first condition is regarded as successful pulp healing because only in this case the pulp tissue will survive, hold off and regenerate after prospective damages and irritations [4].

The advantage of a tooth with a directly capped and vital pulp is mainly the protective resistance to the force of mastication. A root canal treated tooth requires 2.5 times more load to register a proprioceptive response than a vital tooth [5]. Thus, the protection from hard tissue damage caused by mastication forces is superior in a tooth with a vital pulp when compared with a root-canal-filled tooth. Furthermore, direct pulp capping is a non-invasive, comparatively simple and inexpensive treatment, which does not require complex and costly restorations [6].

Since first published by Hermann around 1930 [7, 8], calcium hydroxide paste (aqueous suspension) and, since the 1960s, hard setting calcium hydroxide salicylate ester cements are used for direct pulp capping. However, the treatment outcome of direct pulp capping is still discussed controversially. One reason for reservations against direct pulp capping may be of historic origin. Based on animal experiments, Rebel stated in 1922: "The exposed pulp is a doomed organ". He did not believe that the exposed pulp has the capability to heal or that an injured odontoblastic layer can recover. Hard tissue formation seemed to him to be a degenerative process that cannot be influenced by dentists [9]. His statement was promoted by many authors, and Rebel's opinion became an incontrovertible paradigm for decades with consequences until today. Thus, efforts to use direct pulp capping techniques were discouraged, particularly in Europe [5]. However, Rebel did not use calcium hydroxide or comparable agents for pulp capping but cytotoxic antiseptics [10].

Until today, the literature on the treatment outcomes of direct pulp capping with calcium hydroxide after iatrogenic pulp exposure is conflicting. While most authors reported favourable treatment outcome of about 70% to almost 98% (Table 1), Barthel et al. [11] found teeth with necrotic pulps,

Table 1 Treatment outcome of direct pulp capping in permanent teeth with calcium hydroxide given in literature

Authors	Year	Observation period	Cases	Favourable (%)	Type of calcium hydroxide	Rubberdam
Beerendonk [50]	1939	2–3 months	12	91.6	Paste form	No
Pajarola [51]	1940	3–9 months	94	88.0	Paste form	Not always
Fenner [52]	1944	3 months–5 years	91	95.6	Paste form	Yes
Tananbaum [53]	1951	1 months–1.5 years	54	90.7	Paste form	No
Castagnola [54]	1953	1–9 years	200	89.0	paste form	No
Patterson and van Huysen [32]	1954	1 month–2 years	56	90.9	Paste form	No
Ahlström and Krasse [41]	1956	8 months–4 years	118	72.0	Paste form	No
Mumaw and Cooper [55]	1957	1 year	164	96.9	Paste form	No
Pritz [56]	1957	1.5 months–4.5 years	135	89.6	Paste form	No
Nyborg [57]	1958	1 month–13 years	144	79.8	Paste form	Yes
Shankle and Brauer [21]	1962	2–12 months	70	74.3	Paste form	Yes
Sapone [58]	1962	6 months–1.5 years	540	74.4	Paste form	No
Armstrong and Hoffman [59]	1962	2–16 months	46	97.8	Paste form	No
Harndt and Schachtsiek [42]	1962	1 month–10 years	88	68.2	Paste form	Yes
Berk [33]	1963	3–10 years	300	94.0	Paste form	No
Künzel and Runkel [34]	1963	2 month–6 years	148	81.8	Paste form	No
Gülzow and Müller [35]	1966	1 year	132	72.8	Paste form	No
Jones and Gibb [60]	1969	1 month–6 years	207	93.7	Hard setting cement	Yes
Shovelton et al. [49]	1971	6 months + 1 year + 2 years	68	86.4 84.9 78.0	Paste form	No
Ahrends and Reuver [22]	1973	Mean 5.8±2.5 years	158	96.0	Hard setting cement	No
Haskell et al. [36]	1978	Mean 11.7 years	149	87.3	Paste form	Not always
Heyduck and Wegner [37]	1978	1–4 years	210	61.4	Paste form	No
Honegger et al. [38]	1979	Mean 4 years	110	83.0	Paste form	Yes
Hørsted et al. [31]	1985	5 years	510	81.8	Hard setting cement	Yes
Schreger et al. [30]	1988	6 months–5 years	143	69.2	Paste form	No
Beetke et al. [43]	1990	1 year	106	93.4	Paste form	No
Reuver [19]	1992	1 month–24 years	509	68.0	Hard setting cement	No
Attin et al. [39]	1993	4–6 years	77	75.3	Paste form	No
Matsuo et al. [13]	1996	3 months–2 years	44	81.8	Hard setting cement	Yes
Barthel et al. [11]	2000	5 years+ 10 years	123	37.0 13.0	Hard setting cement	Yes
Auschill et al. [16]	2003	1–8 years	359	61.0	Hard setting cement	No
Al-Hiyasat et al. [40]	2006	3–5 years	204	59.3	Hard setting cement	No

root canal fillings or extractions after 10 years in about 75% of the examined cases. In general, it can be assumed that most of the clinical studies show clinically acceptable results for direct pulp capping.

The aim of this retrospective study was to evaluate the treatment outcome of direct pulp capping in human teeth after iatrogenic pulp exposure treated at the Department of Operative Dentistry of the University of Münster, Germany. The hypothesis was that factors such as age, kind of tooth, type of coronal restoration and clinical status of the pulp tissue ("clinically healthy" or "spontaneous pain") have a significant influence on the results.

Materials and methods

Between 1990 and 2006, 1,853 pulp cappings were performed at the Department of Operative Dentistry of the Westphalian Wilhelms-University in Münster, Germany. For this retrospective study, 248 teeth with iatrogenic pulp exposure of 186 patients were evaluated. The teeth were randomly selected concidering the criteria given in Table 2. The following clinical parameters were assessed as part of the pre-operative diagnosis before direct pulp capping was performed: sensibility test with CO_2, general pain, pain on percussion and pulp bleeding. A pulp was diagnosed to be "clinically healthy" if it reacted positive to sensibility testing, demonstrated no pain and showed no pain on percussion and pulp bleeding could easily be stopped. Teeth with "spontaneous pain" were defined as teeth where the sensibility testing was positive, discomfort before and/or subsequent to direct pulp capping was reported by the patient (spontaneously pain), no pain or uncertain pain on percussion and pulp bleeding could be stopped. Forty-nine out of 248 teeth showed "spontaneous pain," and 199 teeth were diagnosed to be "healthy". In all other cases, the teeth were diagnosed to have an "irreversible pulpitis" and were excluded from direct pulp capping.

All patients were treated under consistent and standardised conditions: use of rubber dam when reaching the dentine's inner third during excavation, cavity cleaning and hemostasis with H_2O_2 (3%) and caries-free dentine before direct pulp capping. The following parameters were used to assess caries-free status of the dentine: hardness on probing, dentine coloration and the unique sound of unaffected dentine on probing ("cri dentaire"). All pulps were capped with calcium hydroxide paste (Calxyl rot, Oco, Dirmstein, Germany). Zinc oxide phosphate cement (Harvard, Hoffmann Dental Manufaktur, Berlin, Germany) or glass ionomer cement (Ketac bond, 3M Espe, Seefeld, Germany) served as a subbase. The cavities were filled with amalgam or composite and, in some cases, with glass ionomer cement (Ketac Fil, 3M Espe, Seefeld, Germany). All pulp exposures were iatrogenic in non-carious dentine or after excavation of deep carious lesions (during probing) where the bulk of the central part of the dentine was clinical sound. No cappings of traumatically exposed pulps were included in this study. The cappings were performed by various dentists and undergraduate students of the dental school.

Directly after capping, 59.3% (n=147) of the teeth were restored with amalgam, 24.6% (n=61) with composite and 16.1% (n=40) with glass ionomer cement. Glass ionomer cement was placed usually because of lack in time during the treatment session.

In 2007, a total of 186 patients (248 teeth) who received direct pulp capping in the past 16 years were recalled for a

Table 2 Statistical comparison between all patients with direct pulp capping and the examination group **c**oncerning age, gender, arches, teeth and kind of coronal restoration

Criteria	Total (n)	Total (%)	Examination group (n)	Examination group (%)	p value
Direct pulp capping	1,853	100	248	13.4	–
Age (years)	30.8±11.9	–	29.3±10.3	–	0.0586
Gender: male	976	52.7	127	51.2	0.8622
Gender: female	877	47.3	121	48.8	0.8517
Maxilla	1,108	59.8	152	61.0	0.8730
Mandible	745	40.2	96	39.0	0.8204
Incisor	174	9.4	25	10.1	0.8486
Canine	28	1.5	1	0.4	0.2761
Premolar	571	30.8	70	28.2	0.5902
Molar	1080	58.3	152	61.3	0.6890
Amalgam	1030	55.6	147	59.0	0.6016
Composite	484	26.1	61	24.6	0.7536
Glass ionomer cement	339	18.3	40	16.1	0.5448

follow-up examination. The selected cases in this study were representative concerning age, gender, dental arches, teeth and type of coronal restoration when compared with all performed cappings after iatrogenic pulp exposure at the Department of Operative Dentistry (see Table 2). A questionnaire was completed by the dentist, with questions on the patients age and gender, type of affected tooth and restoration, spontaneous symptoms or during percussion and/or palpation, sensibility of the tooth, date of treatment and if the patient visited another dentist as well. The sensibility test was performed using CO_2. In addition, the oral cavity was inspected and the periodontal pocket depths measured. Teeth with periodontal probing depths of more than 3 mm were excluded from the study in order to avoid an interference from the periodontal and endodontic damage.

The treatment outcome was considered to be "favourable" when the following criterions were found: positive sensibility test to CO_2, no general pain, no pain on percussion or palpation and no swelling. These teeth were considered to be "clinical healthy". Teeth were considered to show an "unfavourable treatment outcome" if they did not respond to pulp sensibility test, pain on percussion or palpation and/or swelling was visible. Also teeth with root canal fillings and extracted teeth were asessed as "unfavourable treatment outcome".

All dentists participating in the study were calibrated by one of the authors (TD). A radiological follow-up examination was not performed due to ethical reasons.

The data were statistically analysed using descriptive statistics including minimum and maximum values, standard error and mean values. The Kaplan–Meier statistics were used to calculate the survival rate. Cox regression, log-Rank-test, *t* test and chi-square test were performed to determine *p* values.

Results

The recall rate was 13.4% (248 pulp cappings out of 1,853). The follow-up period was 0.4–16.6 years after direct pulp capping with a mean period of 6.1 (±4.4) years. The age of the patients at the time of pulp capping was between 16.2 and 71.7 years with a mean of 29.3 (±10.5) years. For further analysis, the patients were grouped in five age cohorts (Table 3). The distribution between the sexes was balanced: 51.2% of the pulp cappings were performed in male patients ($n=127$) and 48.8% ($n=121$) in female patients. This difference was not significant ($p>0.05$). Sixty-one percent ($n=152$) of the treated teeth were in the maxillary arch and 39% ($n=96$) in the mandible arch. There was no statistically significant difference between the two arches ($p>0.05$). Of the capped teeth, 10.1% ($n=25$) were incisors, 0.4% ($n=1$) canines, 28.2% ($n=70$) premolar teeth and 61.3% ($n=152$) molar teeth. Table 4 shows a more detailed distribution of the teeth.

Table 3 Age cohorts in percent (at the time of direct pulp capping)

Age (years)	Number of teeth	Percent
16–20	14	5.7
20–30	165	66.5
30–40	43	17.3
40–60	15	6.0
60–72	11	4.4
Sum	248	100

At a subsequent visit, the type of restoration was recorded: 54.8% ($n=136$) of the teeth were restored with amalgam and 18.5% ($n=46$) with composite filling material. Meanwhile, 18.1% ($n=45$) of the teeth were restored with gold and 8.5% ($n=21$) still with glass ionomer cement (all these teeth had already been filled with glass ionomer cement directly after pulp capping).

After a mean follow-up period of 6.1 years, 199 of the 248 teeth showed a favourable treatment outcome (80.2%), and 49 teeth (19.8%) showed an unfavourable treatment outcome.

Out of the 49 teeth with an "unfavourable treatment outcome", 39 (79.6%) were teeth with "spontaneous pain". Only ten teeth out of 199 (5%), which were classified to be "clinical healthy" before direct pulp capping, showed an "unfavourable treatment outcome" after direct pulp capping. The likelihood to show an "unfavourable treatment outcome" after direct pulp capping was significantly higher in teeth with "spontaneous pain" than for teeth that were "clinical healthy" ($p<0.001$).

The cumulative survival rate of the pulp tissue was analysed with a Kaplan–Meier function (Fig. 1). This analysis demonstrated that over the first year after direct pulp capping, almost 10% and, after 5 years, nearly 20% of the teeth had an unfavourable treatment outcome. After 9 years until the end of the investigation period, the rate of teeth with a favourable treatment outcome remained at

Table 4 Distribution of treated teeth with regard to the arches

Teeth	Maxilla		Mandible	
	Number of teeth	Percent	Number of teeth	Percent
Molars	81	32.7	71	28.6
Premolars	46	18.5	24	9.7
Canine	1	0.4	0	0
Incisors	24	9.7	1	0.4
Sum	152	61.3	96	38.7

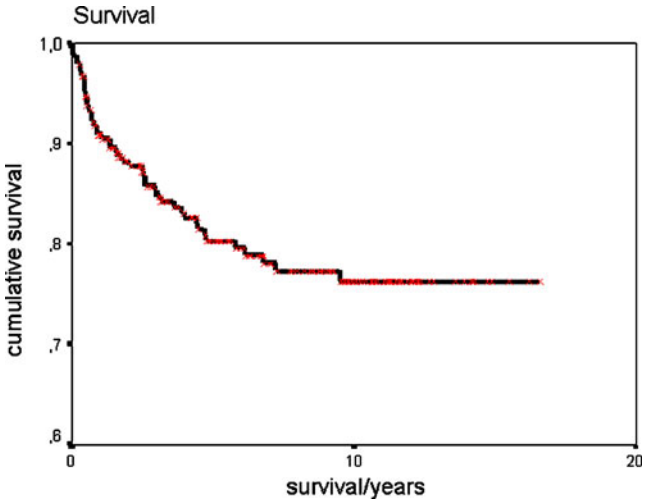

Fig. 1 Cumulative survival after direct pulp capping (Kaplan–Meier function)

76.3%. The Kaplan–Meier function demonstrated a cumulative survival period of 13.3 years with a cumulative survival of 76.3% of the examined teeth.

In relation to age, the highest rate of a favourable treatment outcome was found in the cohort of 16–20-year-olds with a survival period of 14.7 (±1.7) years, followed by the cohort 30–40-year-olds with a survival period of 13.6 (±0.9) years, the cohort 20–30-year-olds with a survival period of 11.9 (±0.4) years and the cohort 40–60-year-olds with a survival period of 11.4 (±1.8) years. The lowest survival rate was found in patients over 60 years with a favourable treatment outcome of only 4.6 (±1.4) years after direct pulp capping. The two cohorts with patients younger than 40 years of age showed significant higher rate of favourable treatment outcomes than the group of patients over 60 years of age ($p<0.05$; Fig. 2).

Analysis of the type of restoration on the day of examination did not show any significant differences between amalgam, composite or gold restorations in teeth with "clinical healthy" pulps after direct pulp capping ($p>0.05$). However, teeth restored with glass ionomer cement as permanent filling material showed an unfavourable treatment outcome significantly more often than all other teeth ($p<0.01$; Fig. 3).

In the present study, 119 out of 248 teeth (48%) had a follow-up examination within the first 5 years after capping, and 129 teeth (52%) had a follow-up examination after 5 years or later. Teeth with a follow-up examination within 5 years showed significantly more often an unfavourable treatment outcome than teeth with a follow-up examination after 5 years ($p<0.01$). The likelihood for teeth to become non-vital was significantly higher in the first 5 years after direct pulp capping than in the following years. If a tooth showed a favourable treatment outcome 5 years after direct pulp capping, the likelihood that an unfavourable treatment outcome will occur at a later stage is less than 5% (Fig. 4).

The factors gender (female or male), jaw (mandible or maxilla arch) and kind of tooth (incisor, canine, premolar or molar teeth) had no significant influence on the results ($p>0.05$).

Discussion

It should be taken into consideration that the recall rate was low. This may have an influence on the results; for example, it can be assumed that some patients with pain after treatment did not return to the dental hospital but seek help from another dentist. Nevertheless, the examined

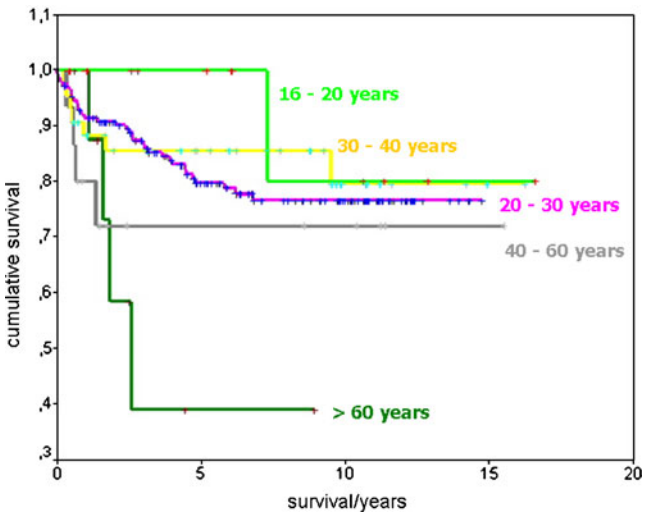

Fig. 2 Survival after direct pulp capping according to age

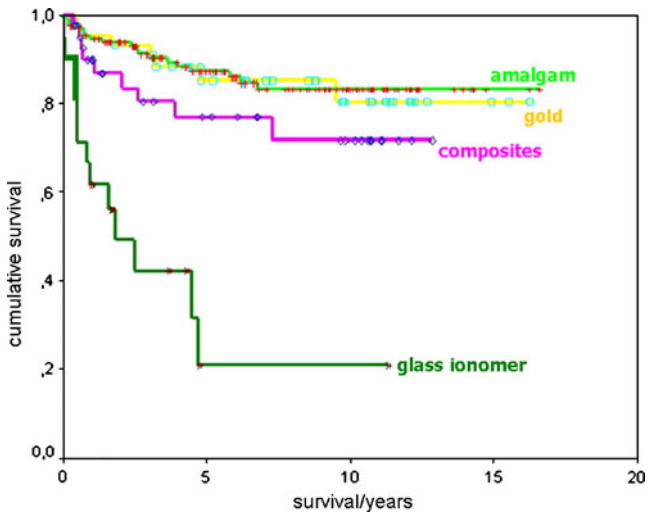

Fig. 3 Survival after direct pulp capping according to restoration

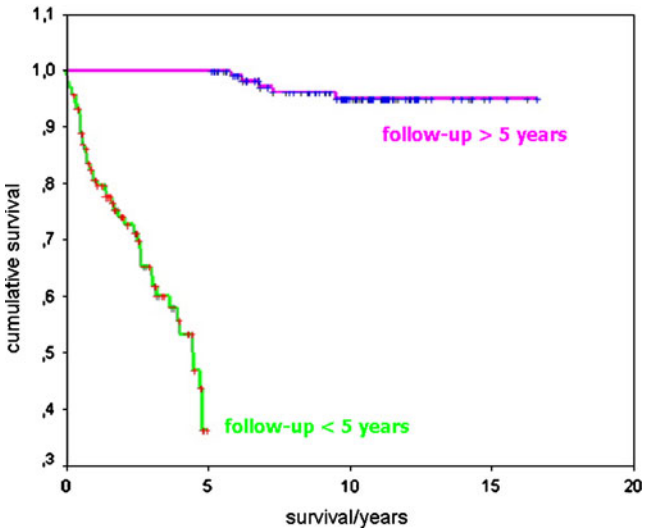

Fig. 4 Likelihood of survival after direct pulp capping according to follow-up

sample mirrors all patients treated with direct pulp capping at the Department of Operative Dentistry (Table 2).

Beside sensibility and pain testing, the bleeding of the exposed pulp tissue was used to evaluate the status of the pulp tissue as part of the pre-operative diagnosis. The degree of bleeding of the exposed pulp tissue may reflect the inflammatory level of the pulp. Excessive bleeding of the tissue usually indicates a pulp with little or no chance of recovery [12]. With increased bleeding on exposure, the possibility of inflammation of the pulp and irreversible pulpits will rise [13]. The inflammatory response extends deeper into the pulp tissue when an exposure with carious dentine present and bacteria penetrating the pulp compared to the superficial inflammation if the pulp is just mechanically exposed [14, 15].

Although the pre-operative diagnosis in this study tried to distinguish between teeth with healthy and with altered pulp tissue, it is clear that an accurate classification, whether the pulp tissue was damaged before pulp capping or not, can only be made with a histological examination. However, this method cannot be performed in clinical studies, like the present study, as pointed out by other authors [16].

Furthermore, discomfort or pain may be interpreted as a sign of altered pulp tissue. However, the presence of pain does not always indicate that a pulp injury is irreversible, although certain patterns and intensities of pain tend to suggest a greater likelihood of an irreversible change. The inflammatory status of the pulp tissue during exposure is a major factor that determines whether or not vital pulp therapy will be favourable but is extremely difficult to diagnose accurately [17].

It can be concluded that infected pulps should not be capped because a favourable treatment outcome when capping an inflamed pulp is considerably lower when compared to non-inflamed pulps [18]. The occurrence of pre-treatment pain is decisive for the prognosis of direct pulp capping [19, 20]. Shankle and Brauer [21] reported that 50% of the teeth with pain before direct pulp capping did not respond to a sensibility test within 1 year. On the other hand, Matsuo et al. [13] found no significant relationship between spontaneous pain before treatment and a favourable outcome of direct pulp capping. Coincidentally, 49 teeth in this study were reported to show "spontaneous pain", and 49 teeth were found to demonstrate an "unfavourable treatment outcome". The results of the present study demonstrated that only 39 out of 49 teeth with "unfavourable treatment outcome" were teeth with "spontaneous pain". The other ten teeth with "unfavourable treatment outcome" were teeth that were considered to be "clinically healthy". This suggests that teeth that show "spontaneous pain" develop significantly more often an "unfavourable treatment outcome". It can be assumed that spontaneous pain may well be a sign of an irreversible process leading to pulp tissue necrosis. In all cases, it remains—under a histological viewpoint—unclear whether the pulp tissue was from the beginning "healthy" or if a pulpitis was reversible or irreversible. The results of this study suggests that pulp tissue that may be affected somehow should not be capped, e.g., teeth with discomfort before and/or subsequent to direct pulp capping.

A radiographic assessment was not performed in this study, which may be regarded as a disadvantage. However, besides ethical reasons, it must be kept in mind that information gained from radiographs (e.g., width of the periodontal ligament) may not correlate well with the status of the pulp tissue [22]. By contrast, Petersson et al. [23] showed that the positive outcome of a simple cold test indicates, with certainty of 90%, a vital pulp. Thus, the rate of clinically healthy teeth found in this study may include false positives in about 10% of the cases. However, the cold test can only give an indication on the pulp vitality because the vitality of a tooth is defined as sufficed blood circulation, whereas the sensibility is defined as reactive nerve supply of the pulp tissue. To keep pulp tissue vital, the blood supply is of more importance but cannot be determined clinically—not even with a radiograph. Hence, the use of CO_2 was presumed to be the most simple and reliable method for pulp testing [24]. An additional electrical sensibility testing was not performed because it cannot be used in teeth with crowns. Furthermore, this test is strongly influenced by subjective responsiveness as well as the vegetative response status of the patients and is not considered to be appropriate to evaluate inflammatory processes within the pulp tissue [25].

In addition, the clinical feedback from the patients and the diagnostic data may not correlate with the histological

findings [26–29]. Histologically, chronic inflammation, micro-abscesses, necrosis and an absence of bridge formation can occur in directly capped pulp tissue without any complains by the patients [29].

In the present study, significantly lower favourable treatment outcomes for direct pulp capping were found in the oldest age cohort (>60 years) when compared with patients younger than 40 years of age. Schreger et al. [30] found a significant influence of age on a favourable treatment outcome of direct pulp capping in patient over 60 years of age as well. Thus, the patients' age in patients younger than 60 years of age was no limiting factor concerning a favourable outcome of vital pulp therapy. Hørsted et al. [31] reported significant differences only between the youngest (10–29 years) and the oldest (50–79 years) patients. The observation that the outcome of treatment of direct pulp capping may be favourable not only in young patients is in accordance with several recent reports [11, 13, 21, 22, 32–40]. In contrast, some authors reported significantly more unfavourable treatment outcomes in older patients [16, 19, 31, 41, 42]. Nevertheless, the opinion that direct pulp capping should only be performed in younger patients before root formation is completed [43] cannot be supported by the results of these studies. The chronological age of a patient does not necessarily give an indication of the capacity of the pulp tissue to repair or heal [44].

The present study showed that teeth filled with glass ionomer cement after direct pulp capping did not respond to the pulp sensibility test significantly more often than teeth that were restored with amalgam or composite. The significant effect of the restoration on healing and a favourable treatment outcome of direct pulp capping procedures have also been reported in other studies [11, 40]. The reason for this finding could be that amalgam and composite seal the margin between the restoration and the tooth structure more effectively than a glass ionomer cement, thus preventing or reducing the entry of bacteria that may occur at the restoration tooth tissue interface [40]. There is clear evidence that composite used with dentine adhesives have the ability to provide a bacteria tight seal with dentine, while glass ionomer cement may deteriorate over time. In addition, it is well known that amalgam and zinc oxide phosphate cement (applied as subbase) have an antibacterial effect, whereas the antibacterial potential of glass ionomer cement may be lower [11]. The adverse effect of microorganisms on the treatment outcome of pulp capping is well known. When pulp tissue is exposed in a germ-free environment, neither pulpal nor periapical inflammation will occur even if no further treatment like medication or a filling is performed [45]. Hence, the cavity should be restored immediately with a filling material providing a long-term clinical seal against the entry of bacteria in order to avoid a (re)infection of the pulp after direct pulp capping with calcium hydroxide [46, 47]. Microorganisms seem to be the key factor in the outcome of the direct pulp capping procedure. Unfavourable outcomes are caused by infection due to either remaining bacteri, or the exposure to new bacteria from penetrating filling margins [48]. Thus, beside the immediate placement of a bacteria-tight restoration, the use of rubber dam and aseptical treatment conditions are strongly recommended.

Various publications demonstrated that the survival rate of directly capped pulp tissue decreases over time when compared to short-term evaluations: Shovelton et al. [49] reported about a decrease of the survival rate from 84.9% after 6 months to 78.0% after 2 years and Hørsted et al. [31] from 96.7% after 1 year to 81.8% after 5 years. Barthel et al. [11] found a rate of unfavourable treatment outcome of 44.5% after 5 years and 79.7% after 10 years after direct pulp capping. It has been claimed in some of these studies that most unfavourable treatment outcomes occur within 1 year after treatment [34, 35, 37, 42]. Matsuo et al. reported that no tooth showed signs or symptoms 2 years after pulp capping. Thus, Matsuo et al. [13] suggested that the necessary interval for an adequate postoperative follow-up examination is 21 months. The present study showed that the likelihood for a tooth to become non-vital after direct pulp capping is significant higher in the first 5 years after treatment than after more than 5 years. The present results suggest that if direct pulp capping fails, this is most likely to happen within the first 5 years after direct pulp capping. It can be presumed that all pulp tissue alterations take place during the first years after direct pulp capping. However, there is no clear explanation for this fact and requires further investigation. If a tooth showed a favourable treatment outcome 5 years after direct pulp capping, the likelihood that it will stay vital in the following years is more than 95%. Hence, the time for an adequate postoperative follow-up examination of 1 to 2 years, as often recommended, may well be too short.

Some authors stated that anterior teeth had a higher unfavourable rate of treatment outcome than posterior teeth [31, 37, 39], whereas other authors reported about more favourable treatment outcome in anterior than in posterior teeth [16]. The present study demonstrated that the type of tooth (anterior or posterior) and location (mandible or maxillary arch) had no significant influence on the treatment outcome, which is in accordance with various other studies [11, 13, 30, 40].

A review of the literature revealed a controversy regarding the outcome of treatment of pulp capping procedures, with many methodological inconsistencies between the different studies. Hence, it may be difficult to compare the different studies because the status of the pulp tissue at the time of capping, capping techniques, observation

periods, examination methods and examination criteria may considerably differ [11, 16]. Although these studies vary in their research approach, most studies noted a favourable treatment outcome, which seems to conflict with the clinical viewpoint that the treatment outcome of pulp capping procedures is "dubious". The results of the present study confirm previously published data (Table 1). A mean survival rate of approximately 75% seems to be close to reality, confirmed even with long-running follow-up examinations.

Conclusions

The hypothesis that the factors type of coronal restoration and clinical status of the pulp tissue have a significant influence on the results could be confirmed in the present study, whereas for the factor kind of tooth, the hypothesis could not be confirmed. Age had only a significant influence in patients over 60 years of age compared to patient younger than 40 years of age.

In teeth with pain or discomfort, direct pulp capping should be avoided. The cavities should be restored with a bacteria-tight filling material immediately after direct pulp capping. Inlay, crowns or other costly restorations should not be inserted for at least 2 years after pulp capping. To evaluate the treatment outcome of direct pulp capping, a long-term prospective study is highly desirable.

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Conflict of interest The authors declare that they have no conflict of interest.

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