Till Dammaschke, Kerstin Galler, Gabriel Krastl (in alphabetical order)

Current recommendations for vital pulp treatment

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Department for Periodontology and Operative Dentistry, Münster University Hospital, Albert-Schweitzer-Campus 1, Building W 30, 48149 Münster: Prof. Dr. Till Dammaschke
Department for Conservative Dentistry and Periodontology, Regensburg University Hospital, Franz-Josef-Strauß-Allee 11, 93053 Regensburg: Prof. Dr. Kerstin Galler
Department for Conservative Dentistry and Periodontology, Würzburg University Hospital, Pleicherwall 2, 97070 Würzburg: Prof. Dr. Gabriel Krastl
All authors contributed equally to this work and are listed in alphabetical order.
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Introduction

1.1. Definition and objectives of vital pulp treatment

In the last few years, clinicians and scientists in the dental field have become more aware of the importance of preserving pulp vitality. While excavating deep caries lesions (caries profunda), special attention should be given to the remaining dentin layer covering the pulp. While it has been taught over the years to excavate caries until reaching healthy, hard dentin (cri dentinaire), meanwhile it appears justifiable to selectively leave infected dentin close to the pulp in order to avoid exposure of the pulp tissue [19]. The traditional methods aiming to preserve the pulp, such as indirect or direct pulp capping and pulpotomies are also addressed. The standardized classification of reversible and irreversible pulpitis and the respective associated therapy decision of pulp preservation versus vital exstirpation is being questioned and it appears that the indications of pulpotomies are expanding. The present scientific work highlights the current state of knowledge on vital pulp treatment strategies and provides recommendations on how to proceed clinically. The collective term maintaining vitality sums up conservative treatments that protect exposed dentin and pulp areas from external stimuli, which prevents the progression of microorganisms (and components of filling materials). After a pulp capping material is applied, a bacteria-proof restoration follows. Key factors are the pulp status at the time of the procedure and the extent of the lesion or degree of dentin infection. Vital pulp treatment methods include the treatment of deep caries lesions (indirect pulp capping), direct pulp capping, partial and full pulpotomy.

The objective of all vital pulp treatment strategies is to create a state that enables the formation of a hard tissue barrier and the recovery of tissue, preserving the functionality and therefore ensuring that a vital tooth remains in the oral cavity long-term.

1.2. Function and loss of function of pulp tissue

The main functions of the dental pulp include dentin formation during tooth development and life span of the tooth, signal transmission through proprioreceptors and pain receptors, immune function towards invading bacteria and their metabolites, the formation of tertiary dentin as a defense mechanism towards external stimuli, and in the particular case of juvenile teeth, the completion of root formation.

If vital pulp therapies are not indicated, root canal treatment should be performed, where remaining pulp tissue is ideally completely removed, the root canals are enlarged, disinfected and finally obturated with a root canal filling material. Although success rates of over 90 % after 5 years could be achieved following a thorough approach after vital extirpation [42], this procedure goes along with the complete loss of function of pulp tissue and can carry disadvantages. The proprioceptive safeguard mechanism is partially lost. It has been described that a root canal treated tooth allows a occlusal load 2.5 times higher than a vital tooth before a proprioceptive reaction occurs [89]. Even though there is no evidence of this resulting in a higher risk of fracture, this may be the case. Furthermore, changes in root canal geometry (weakening of the root canal wall dentin through preparation), that are inevitable during root canal treatment, can lead to increased incidence of fractures [45, 67]. Additional problems that can possibly occur during treatment are tooth discolorations [62] and higher susceptibility to caries due to increased plaque formation and an altered microflora [77], or due to missing immune response of the pulp-dentin-complex and the lack of pain perception as a warning system. A root canal procedure can present itself as more complex than initially thought. Vital pulp therapies are conservative and cost effective measures [57, 98].

2. Indication for vital pulp treatment

The invasion of microorganisms and their metabolites initiates a stimulus that results in the development of an inflammatory reaction of the pulp. The immune response is mediated through cell receptors on odontoblasts, dendritic cells and pulp fibroblasts. Initially, this results in hyperemia and the developing inflammatory reaction is characterized by reduction in cell count, flattening of the odontoblasts as well as the immigration of lymphocytes and plasma cells [92]. This correlates clinically with the development of a reversible pulpitis, where it is assumed that the healing of the tissue could be enabled by therapeutic intervention. There are bacteria detectable in the pulp cavity following persisting stimulus, which results in micro abscesses and tissue necrosis that are lined with polymorphonuclear neutrophil granulocytes and inflammatory infiltrates in the peripheral region [92]. This stage is referred to as irreversible pulpitis.

Reversible pulpitis is characterized by a positive sensibility test and pain linked to a stimulus.

Irreversible pulpitis is diagnosed by (increased) positive sensibility, radiating pain that outlasts the stimulus or constant pain, pain after heat and possibly the patient's insufficient localizability of the tooth causing the pain.

Irreversible pulpitis can also progress asymptomatically [1]. Vital pulp treatment is indicated only when the clinical diagnosis of a reversible pulpitis is made. According to current scientific opinion, in case of an irreversible pulpitis, a healing of the tissue cannot be predictably achieved after removing the triggering stimulus. In this case, the diagnosis "irreversible pulpitis" requires the initiation of root canal treatment. Although there is some evidence that the histological observations described above correlate with the clinical diagnosis [92], it should be mentioned that the clinical classification of the symptoms yields little information about the regenerative capacity of the tissue. It solely eases decision-making of the practitioner in terms of therapeutic approach because a schematic approach is possible. The diagnosis and therapy regimen regarding the state

of the pulp and the resulting therapy are increasingly questioned. Because of this, the indication for a pulpotomy treatment of irreversible pulpitis is currently in flux and is investigated in clinical studies. According to current state of knowledge, measures maintaining vitality can only be conducted on teeth that do not exhibit a pronounced pain symptomatology (reversible pulpitis). Vital pulp treatment can not and should not be carried out when the tooth shows no reaction to a sensitivity test (here the pulp status must be verified after exposure of the pulp chamber), if the tooth is tender to percussion or occlusal load, exhibits spontaneous or persistent pain, as well as radiographic signs of a periapical osteolysis.

Further exclusion criteria after exposure of the pulp chamber include bleeding that cannot be stopped, a leakage of serous or purulent exudates, or necrotic tissue that is no longer supplied with blood. Teeth should be excluded if bacteria-proof sealing cannot be assured due to limited restorability. To avoid an infection of exposed pulp tissue during or after pulp capping, further conditions must be met. This includes the usage of sterile instruments, using rubber dam, full caries excavation as well as the possibility of immediate and definite bacteria-proof seal. If these conditions are not met unequivocally, root canal treatment (or extraction) is preferred.

Favorable conditions for maintaining vitality are given in a juvenile pulp without damage [109]. With increasing age, a reduced regenerative capacity is expected due to changes in terms of a reduced cell number and increased content of fibrous tissue [48, 80]. Nevertheless, the patient age plays a subordinate role with regard to treatment success [6, 30, 33, 37, 44, 59, 65, 70, 75, 107]. The same applies to factors such as the tooth position, size or location of pulp exposure [35].

In general, it must be noted that success rates of vital pulp treatment described in the literature vary significantly, especially for direct pulp capping after carious exposure. Prior clinical setbacks (within days or weeks) are multifactorial, but certainly correlate with improper diagnosis of the state of the pulp. This can result in underestimating the level of inflammation of the pulp, from which irreversible pulpitis and pulp necrosis can develop that can lead to postoperative pain.

3. Indirect pulp capping

In the German dental literature, indirect pulp capping refers to the treatment of a thin, caries-free layer of dentine close to the pulp [96]. Because this situation generally arises when a deep caries is excavated, indirect pulp capping is also referred to as treatment of profound caries. In English language literature the term "indirect pulp capping" is defined differently; it refers to the permanent capping of a thin layer of affected or infected dentin, where complete excavation during a second appointment is omitted [9, 40]. Since only a minimal dentin layer remains above the pulp tissue, there is a risk of irreversible inflammation of the pulp through the dentinal tubules: on one hand, this can occur through microorganisms remaining in or having penetrated the tissue, or through cytotoxic components of filling materials that diffuse through the remaining dentin. The capping material is expected to disinfect dentin close to the pulp, seal the pulp tissue and stimulate the formation of tertiary dentin [91]. This form of tertiary dentin is also referred to as reactionary dentin, which by definition is formed by surviving post-mitotic primary odontoblasts [101]. Therefore, indirect pulp capping protects the vital pulp, particularly after caries excavation. In the case of a reversible pulpitis, indirect pulp capping should create conditions for pulp healing. Despite comprehensive reasons that favor a separate treatment of dentin close to the pulp in the sense of direct pulp capping, it has to be noted that there is no evidence in favor of this therapy from clinical studies [19].

An indirect pulp capping should be performed under controlled isolation using rubber dam. To avoid cross-contamination, it is recommended to disinfect the clinical crown before excavation using sodium hypochlorite (NaOCl; 1–5 %) or chlorhexidine-gluconate (CHX; 2 %).

Microorganisms and spreading carious processes pose a threat to the pulp [93]. Therefore, the number of microorganisms in the cavity and close to the pulp should be reduced to a minimum. The issue of how much infected dentin can remain in order to enable healing of the pulp is not entirely resolved [19].

After successful excavation, the cavity is to be cleaned with NaOCl or CHX and water spray [18, 22]. There is no need to fear damage of the pulp tissue when applying NaOCl [95]. Materials used for indirect pulp capping are supposed to kill microorganisms close to the pulp, neutralize acidic tissue resulting from the carious defect, remineralize dentin and stimulate the pulp to form tertiary dentin [72]. Traditionally, calcium hydroxide has been recommended since the 1930s [55]. Because of the disadvantages of soluble calcium hydroxide suspensions, the usage of hydraulic calcium silicate-based cements today is possibly a better alternative for indirect pulp capping [3]. A definitive adhesive restoration is supposed to follow any kind of pulp capping material in the same session. After indirect pulp capping the formation of reactionary dentin can follow, however, depending on the odontoblasts' degree of damage the repair and deposition of an atubular hard tissue is more likely. Reactionary and reparative dentin can be found located right next to each other histologically [91].

4. Direct pulp capping

Direct pulp capping is defined as the treatment of an exposed pulp, which can be caused by caries, preparation measures or dental trauma. The indication is given when "reversible pulpitis" is diagnosed.

After clinical and radiological assessment, the tooth is isolated using rubber dam and the clinical crown is disinfected. It is important to use sterile instruments. The complete excavation of caries is carried out

with slowly rotating round burs and hand instruments from the peripheral to the central region, ideally using magnification (dental loupe, microscope). To reach hemostasis and disinfection, it is advised to use pellets soaked in sodium hypochlorite. This is followed by the application of a calcium hydroxide suspension or a hydraulic calcium silicate-based cement on the exposed pulp and the surrounding dentin, where a sufficiently broad seam must remain available for the adhesive restoration. To avoid unintentional removal of pulp capping material when sealing the cavity, it is advised to layer a hard-setting material. Subsequently, the dentin should be sprayed with water thoroughly to minimize negative impacts of disinfecting solution on the adhesive bond. The definitive adhesive restoration should follow in the same session. Because pulp exposure is associated with demise of the local odontoblasts, the hard tissue formation induced by the pulp capping procedure is regarded as a repair process in which a mineralization tissue develops, usually formed by fibroblasts [91].

5. Pulpotomy

Pulpotomy (pulp amputation) is a method to maintain vitality of the pulp after artificial exposure of the coronal pulp (iatrogenic, traumatic). The coronal pulp is partially amputated (partial pulpotomy) or amputated at the level of the root canal orifices (full or cervical pulpotomy) and treated similar to direct pulp capping after successful hemostasis [1, 63].

5.1. Partial pulpotomy

During a partial pulpotomy the coronal pulp is reduced by 2 mm from the area of exposure to remove potentially inflamed irreversibly damaged parts of pulp tissue and maintain vitality of the remaining pulp [15]. Partial pulpotomy is preferably conducted using a small diamond bur [51] that removes the coronal 2 mm of the pulp in a high-speed manner, ideally with continuous rinsing using saline solution [40]. For practical reasons, pulp amputation is often conducted under water cooling using a handpiece [41]. There is no evidence that the use of cooling water from an accurately reconditioned and prepared handpiece will lead to lower success rates.

Similar to direct pulp capping, during partial pulpotomy the rinsing of the site of amputation with NaOCl is recommended until the bleeding is suspended. Provided that the formation of a blood clot is prevented, the same pulp repair mechanisms of direct pulp capping are to be expected [24, 33]. If the remaining pulp is healthy, the bleeding is expected to suspend within 5 minutes. If hemostasis has not taken place within this time, it may be concluded the pulp has not been reduced to a healthy level. In this case, the removal of the entire coronal pulp, a full pulpotomy, can be considered as the last possible measure to maintain vitality [63].

A calcium hydroxide suspension or hydraulic calcium silicate-based cement is applied to the artificially exposed pulp surface and covered with a thin layer of curing material [24].

Because more pulp capping material is used in partial pulpotomies than direct pulp capping, there would be a greater risk of tooth discoloration when using hydraulic calcium silicate-based cements [63]. The bacteria-proof restoration follows.

5.2. Full pulpotomy

Full pulpotomy is defined as the removal of the entire coronal pulp, whereas the radicular pulp that is to be preserved is capped at the height of the root canal orifices. Further steps take place according to a partial pulpotomy, followed by a definitive bacteria-proof restoration [63].

6. Pulp capping materials

6.1. Preparations containing calcium hydroxide

Calcium hydroxide is still commonly used as a pulp capping material today. In aqueous suspensions it has a high pH value, a bactericide effect, can neutralize bacterial acids and lipopolysaccharides in dentin and results in the release of dentin-bound growth factors [50]. Calcium hydroxide therefore supports formation of hard tissues and healing of the pulp [39, 102]. Disadvantages are the mechanical instability and the absorption of the material over time [10, 49]. After applying calcium hydroxide, porosities ("tunnel defects") in the reparative dentin are observed, which can act as an entry point for microorganisms [28]. The high pH value of aqueous calcium hydroxide suspensions results in liquefactive (or colliquative) necrosis if in direct tissue contact [103]. Calcium hydroxide is supposed to be applied sparingly in the area of exposed pulp and adjacent dentin [10, 103, 104]. Calcium hydroxide in aqueous suspensions would be preferable to other calcium hydroxide combinations (calcium salicylate cements, liners or putties). These exhibit a significantly lower release of hydroxyl ions [105], a continuous disintegration beneath the main filling [10], they induce a slower and less dense hard tissue formation [86] and a few additives, that cause the setting of the materials and possibly have a toxic effect on the pulp [69].

New light-curing liners and cements with calcium hydroxide or MTA-additives (product examples: Ultrablend Plus, Ultradent, South Jordan, USA; Calcimol LC, VOCO, Cuxhaven, Germany or TheraCal LC, Bisco, Schaumburg, USA) should be regarded as critical. These products are missing the specific calcium hydroxide effect that triggers bioactivity [21,106].

A cytotoxicity of these products is clearly verified and can be traced back to the monomer content [52]. According to current data, it is not advisable to perform pulp capping with light-curing materials containing calcium hydroxide or calcium silicates.

6.2. Dentin adhesives and composite resins

Two decades ago, the use of dentin adhesives has been propagated for pulp capping procedures [26, 27, 29], based on the idea that the bacte-

ria-proof seal is key for the success of maintaining vitality [3, 97]. However, dentin adhesives contain monomers that result in moisture-related incomplete polymerization and therefore have a toxic effect that largely remains close to the pulp [25, 36, 78]. It was proven that components of dentin adhesives inhibit the ability of pulp cells to form hard tissue [47]. Dentin adhesives and composite resins are not biocompatible [25] and therefore cannot be recommended as pulp capping materials [3].

6.3. Calcium silicate-based hydraulic cements

With the introduction of hydraulic calcium silicate-based cements, such as mineral trioxide aggregate (MTA), aqueous calcium hydroxide suspensions are not seen as the first choice material for vital pulp treatment [3, 22]. Hydraulic calcium silicate-based cements are similar to Portland cement, which is well known in the construction industry. They are known as "hydraulic", because they set and are resistant in contact to air as well as under water [14]. Calcium silicate-based cements consist mainly of dicalcium or tricalcium silicates and are mixed with water. During the reaction and subsequent setting, calcium hydroxide is released over a longer period of time [14], which may explain the prolonged antibacterial properties [84].

Hydraulic calcium silicate-based cements are biocompatible and promote pulp cells to form hard tissue [111]. Mineral contents of the cement interact with the dentin [8], which results in a dentin adhesion similar to glass ionomer cements [60]. The advantage compared to calcium hydroxide products is the increased mechanical strength [34]. Even though more long-term clinical studies on vital pulp therapy with hydraulic calcium silicate-based cements would be preferable, they seem to be better suited for pulp capping than calcium hydroxide [3, 56, 64, 76].

Hydraulic calcium silicate-based cements may lead to tooth discoloration, which can be especially problematic in anterior teeth, for example after trauma [79]. This can be caused by the heavy metals included like bismuth oxide as radiopacifier [13, 38] or iron [99]. Oxidation of these metals after contact with sodium hypochlorite or the absorption of blood components play an important role [20, 66, 99]. In hydraulic calcium silicate-based cements that contain less or few heavy metals, the risk of discoloration is reduced. Calcium silicate-based cements, that contain zirconium oxide or tantalum oxide appear to be especially color-stable [79]. Lipski et al. (2018) did not detect any grayish discoloration in any case with such a cement 18 months after direct pulp capping. However, tooth discoloration has been proven in vitro for these materials in the presence of blood [99]. In vital pulp therapy after pulp exposure, contact between these capping materials and blood is inevitable. However, this seems unproblematic from an aesthetic viewpoint at least in posterior teeth [79].

7. Vital pulp treatment after trauma-induced pulp exposure

In most cases, pulp exposure caused by dental trauma offers an ideal setting for vital pulp treatment, particularly in sound teeth without any predamage of the pulp and provided that the procedures are carried out accurately. In order to simulate the conditions after dental trauma, coronal pulp exposure was induced in an earlier animal study in monkeys. Dental pulps were directly exposed to the oral cavity for 3 hours, 2 days and 7 days, and histologically examined afterwards. Inflammatory pulp changes were found depending on the duration of exposition, however, even after 7 days of exposure these were limited to the coronal 2 mm [32]. Heide und Mjör confirmed these results in 1983 and stated that a partial pulpotomy with removing 2 mm of coronal pulp tissue can be successful after several days of contact of the pulpal tissue with the oral cavity [54]. It must be taken into account that additional luxation injuries compromises the circulation and thus the healing capacity of the pulp [94].

8. Vital pulp treatment after carious pulp exposure

In comparison to teeth with trauma-induced pulp exposure, teeth with a carious exposure have inflamed pulps due to longer term contact with bacterial toxins or even bacterial invasion. Lesion size, bacterial spectrum and speed of progression impact pulpal status. When treating dentin in deep lesions in the sense of indirect pulp capping, the transition to direct pulp capping is fluent. Even the remaining dentin layer is affected by the cutting of odontoblast processes close to the pulp. When pulp tissue is exposed punctiform, it can go clinically unnoticed and a thorough inspection of the cavity using a dental loupe is advised.

Even after full caries excavation and thorough disinfection, microorganisms can still be left behind. It is therefore recommended to apply capping material not only to the area of the pulp exposure, but also the surrounding dentin to treat bacteria effectively. This increases the success rate of pulp capping especially in teeth with deep caries [18]. For calcium hydroxide, it should be noted that extensive application can lead to disintegration and mechanic instability [10, 49]. Furthermore, after pulp exposure in carious dentin a contamination of tissue with infected dentin chips is possible. When the exposure of the pulp can be anticipated, it is recommended to use a new, sterile round bur. Because the capping of pulp tissue is only indicated after full caries excavation, a pulpotomy can be considered when pulp tissue is exposed to cariously infected dentin after excavation. Infected dentin chips that have already been transported into the pulp and damaged tissue parts can be removed and the conditions for pulp healing can be improved.

9. Follow-up and success rates

The failure of vital pulp treatment may be caused by an infection that can be attributed to remaining microorganisms or the intrusion of new bacteria along a gap between tooth and filling material in defective restorations [82]. In the process, pulp ne-

crosis and formation of periapical inflammation can occur unnoticed. This is why the sensibility after vital pulp treatment should be tested regularly, after 3, 6, and 12 months and annually thereafter. A thermal sensibility test is suitable using refrigerant spray or CO_2 dry ice. A reduced reaction is to be expected after partial and especially cervical pulpotomy, and is not to be seen as a criteria for failure. A radiographic examination is only recommended in the case of a negative sensibility test [61]. It should be noted that a possible formation of new hard tissue around the point of exposure, or rather the site of amputation, cannot be clearly judged radiologically. Also a minor widening of the periodontal ligament space must not necessarily have any pathological meaning [2].

A clinical treatment success after vital pulp treatment is when the teeth can be classified as "asymptomatic", which means when they react to a sensibility test, there is no spontaneous pain, no pain on palpation or percussion, and no swelling present. Radiographic changes such as a periapical lesion must not be visible. If a tooth does not react to a sensibility test, or is tender to percussion and/or palpation, or presents a periapical radiolucency it can be assumed that the treatment was a failure. Teeth, where a root canal treatment or an extraction is indicated after pulp capping, represent a failure of treatment [35].

The studies available suggest, that after partial pulpotomy there is no increased risk for pulp canal obliteration [11, 59, 74, 88]. In comparison, the long-term risk for obliterations is higher after a full pulpotomy. While the risk is considered very low during the first 2 years [5, 46, 100], partial obliterations occur in 30 % of the cases after a mean observation period of 3 years [70] and occur in nearly 40 % of the cases after a mean observation period of 4,8 years.

Vital pulp treatment after trauma offers high success rates if the pulp was not previously damaged or the circulation compromised due to luxation injury. The prognosis for direct pulp capping using calcium hydroxide is 54 %–90 % [43, 53, 90]. Partial pulpotomy using the same material exhibits higher success rates of 86 %–100 % [4, 30, 31, 33, 37, 53, 109] and is therefore favored. It remains to be seen if the success rates achieved with calcium hydroxide suspensions in partial pulpotomies after trauma-induced pulp exposure can be increased by a clinically relevant amount when hydraulic calcium silicate-based cements are used instead [63].

Although the conditions for vital pulp therapies after carious pulp exposure appear unfavorable compared to trauma-induced exposure, decent success rates are still possible. These rates lie at 62 % and 98 % after 3 to 10 years in indirect pulp capping using calcium hydroxide preparations [3, 58]. There are only few studies in the literature regarding hydraulic calcium silicate-based cements and indirect pulp capping, so that further investigations concerning this appear necessary [85]. Clinically and radiographically, teeth treated with indirect pulp capping using MTA show higher success rates after 3 months compared to using a setting calcium salicylate cement (Dycal, Dentsply Sirona, Konstanz, Germany). After 6 months, this result is put into perspective [68].

The listed success rates in the literature for direct pulp capping during caries excavation vary substantially [12, 56, 76]. Under the premise of correct indication and technical implementation, direct pulp capping using calcium hydroxide can reach success rates of nearly 60 % after 10 years [76, 110]. Success rates after using hydraulic calcium silicate-based cements such as mineral trioxide aggregate (MTA) are even higher at 80 % [56, 64, 71, 76].

For partial pulpotomy after carious pulp exposure using hydraulic calcium silicate-based cements the success rates are 85 %-97 % after 2 years and 94 % after 4 years [74].

Success rates of full pulpotomies using hydraulic calcium silicate-based cements are at 74 %–100 % after 1 to 5 years [5–7, 46, 70, 81, 87, 100, 107]. It is worth mentioning that the cited studies concerning full pulpotomies also included teeth that were diagnosed with irreversible pulpitis. If further studies confirm the data over a longer period of time, the indications for vital pulp tretment could be extended to teeth diagnosed with irreversibly damaged pulp areas (irreversible pulpitis). During a partial or full pulpotomy, these areas can be targeted and removed selectively, in order to preserve vitality of the remaining pulp.

Despite the overall favorable success rates for vital pulp treatment after carious exposure, the selective or step-wise excavation method is another treatment alternative with comparable success rates. These approaches have demonstrated 5-year success rates ranging between 56 % (step-wise excavation) and 80 % (selective excavation) [73]. A clinically relevant difference regarding the success rates of a pulp capping or pulpotomy compared to the selective or step-wise caries excavation cannot be verified.

Only one clinical investigation exists that compares both treatment strategies directly and published data after 1 and 5 years [16, 17]. In this study, the prognoses of the step-wise excavation and full excavation with subsequent direct capping were compared. After stepwise caries excavation, preservation of pulp vitality after 5 years was possible in 60 % of the cases. In contrast, the prognosis after direct pulp capping and partial pulpotomy during the same observation period was 6 % and 11 %, respectively [16]. These success rates are considerably lower than those of other clinical trials. The highly unfavorable results in that study may be attributed to the fact that the cavity was restored only with a temporary filling for 8–10 weeks after pulp capping or partial pulpotomy instead of an immediate definite restoration [16]. Furthermore, the lack of disinfection after pulp exposure, as well as the choice of pulp capping material (Dycal), are considered unfavorable. These factors might have contributed to the low success rates in the study. The data does not match the remaining literature, which attests a favorable prognosis for vital pulp treatment after carious pulp exposure if properly performed.

10. Final evaluation of vital pulp treatment strategies

The improved understanding of the interaction between microorganisms and tissue response led to increased use of minimally invasive, tissue conserving treatment concepts in conservative dentistry in the last few years. With this in mind, vital pulp treatment strategies can preserve functional endogenous pulp tissue and avoid its replacement with synthetic materials.

Maintaining pulp vitality should always be aspired to when the indication is given.

According to the current state of knowledge, the evaluation that measures maintaining vitality are considered uncertain is obsolete. Provided that a careful assessment and adequate implementation of all required treatment steps took place, the prognosis of vital pulp treatment can be considered to be very good, thus improving conditions for long-term tooth conservation.

It is not possible to prove higher success rates for the currently propagated selective or stepwise caries excavation methods as opposed to vital pulp treatment after complete excavation and pulp exposure.

It is the responsibility of well-designed, future clinical studies to find out which approach offers better long-term conditions for maintaining pulp vitality. For teeth diagnosed with irreversible pulpitis, future trials need to evaluate whether pulp vitality can be maintained on long-term if irreversibly damaged pulp areas are removed.

Conflict of interest:

Till Dammaschke has received fees from Septodont for lectures.
Kerstin Galler and Gabriel Krastl declare that there is no conflict of interest within the meaning of the guidelines of the International Committee of Medical Journal Editors.

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(Photos: private)

PROF. DR. TILL DAMMASCHKE
Department of Periodontology and Operative Dentistry
University Hospital Münster
Albert-Schweitzer-Campus 1,
Building W 30
48149 Münster, Germany
tillda@uni-muenster.de

PROF. DR. KERSTIN GALLER
Department for Conservative Dentistry and Periodontology
Regensburg University Hospital
Franz-Josef-Strauß-Allee 11
93053 Regensburg, Germany
Kerstin.Galler@klinik.uni-regensburg.de

PROF. DR. GABRIEL KRASTL
Department for Conservative Dentistry and Periodontology
Würzburg University Hospital
Pleicherwall 2
97070 Würzburg, Germany
Krastl_G@ukw.de