Which "band-aid" is appropriate for the dentin wound of permanent teeth?

Caries is the most common non-contagious disease worldwide. It has a higher prevalence in people of lower socioeconomic status [17, 34]. Deep carious lesions are defined as defects that extend radiologically into the inner third or quarter of dentin. This is where the pulp is at risk of exposure [15]. When the remaining dentin thickness decreases towards the pulp, the risk of pathogenic changes in the pulp increases [21]. In daily practice, however, it is often difficult to assess the remaining dentin thickness close to the pulp and to decide when and with which preparation a „dentin wound treatment" should be performed [21, 32]. For this reason, it is useful to consider pulp symptoms when making a diagnosis [33] and to leave some infected dentin behind near to the pulp if there is a risk of pulp exposure [3]. The primary aim of treating deep carious lesions is always to avoid exposing the pulp and to keep it healthy and vital. Thus, the purpose of dentin wound care is manifold; it is to protect the pulp from further exogenous noxae (such as residual monomers or thermal damage caused by light polymerization when using the adhesive technique), from toxins of microorganisms (such as lipopolysaccharides) [8], to eradicate bacteria, as well as to stimulate the formation of reactive dentin [1]. Furthermore, the outflow of dentinal fluid from the dentin tubules should be avoided.

Which conditions must be present to keep the pulp vital?

To date, the decision for further therapy is linked to whether the pulpitis is reversible or irreversible. If the clinical diagnosis reveals that an irreversible pulpitis has already developed, root canal treatment is indicated. This is because it must be assumed that, despite therapy, healing of the pulp tissue is no longer possible. It is currently being debated whether or not pulpotomy represents a sufficient treatment [8]. If a reversible pulpitis is present, vitality-preservation measures such as dentin wound treatment together with subsequent filling therapy are indicated (Table 1) [8].

What is the goal of caries treatment?

The goal is to adequately remove caries and to treat the pulp and dentin areas in a manner that protects the pulp from further irritation and microorganisms. The desired material properties for adequate dentin wound care include: the eradication of any potentially remaining microorganisms, the ability to neutralize acidic tissue, which is a metabolic by-product of carious lesions, to promote remineralization, to protect against infection and to stimulate tertiary dentin formation, which in addition to the formation of reactive dentin, also involves the dentinal tubules undergoing sclerosis [11].

Calcium hydroxide

Calcium hydroxide has been used in dentistry since the 1920s [13]. It is the most frequently applied material in dental treatment for dentin wound care [10, 24]. Due to its positive properties, it can be used for both direct and indirect pulp capping. Moreover, calcium hydroxide's very alkaline pH value of up to approximately 12.5 has a bactericidal effect, neutralizes lipopolysaccharides and supports the regeneration of the pulp tissue.

Soft calcium hydroxide preparations

Paste preparations which remain soft such as UltraCal XS (Ultradent Products GmbH, Cologne, Germany) or Calcicur (Voco GmbH, Cuxhaven, Germany) adhere poorly to dentin. Furthermore, resorption leads to a mechanical instability of the material [2, 19]. Thus, these preparations do not offer long-term protection against leaks (microleakage, tunnel effect) [4].

Self-hardening two-paste preparations

The most frequent examples from this group are calcium salicylate ester

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cements such as Dycal (Dentsply De Trey GmbH, Constance. Germany) or KerrLife (KerrHawe SA, Bioggio, Switzerland). Such preparations result in a lower pH value than aqueous suspensions, [27] and hence, have an accordingly weaker antimicrobial effect. Moreover, they also show continuous disintegration and are characterized by a very low modulus of elasticity as well as low compressive and tensile strength [4]. After the application of self-hardening cements, inflammatory changes in the pulp occur more frequently than when using aqueous suspensions [22]. In addition, these preparations exhibit a higher toxicity, which is attributable to additives such as zinc stearate (accelerator), barium sulfate (contrast agent used to make the cement appear opaquer in X-ray images), or pigments and stabilizers [20].

Alternatives to the classic calcium hydroxide preparations

Resin-modified calcium hydroxide preparations

These include:

1. liners and cements with added calcium hydroxide, e.g. Calcimol LC (Voco, Cuxhaven, Germany), Calcident LC (Willman und Pein GmbH, Barmstedt, Germany), Prisma VLC Dycal (Dentsply Sirona, York, USA), Kent Calciumhydroxide LC (Kent Dental, Instanbul, Turkey)
2. liners and cements with added calcium silicate, e.g. TheraCal LC (Bisco, Schaumburg, USA)

Only a few resin-modified preparations, e.g. Prisma VLC Dycal (Dentsply Sirona, York, USA) and TheraCal LC (Bisco, Schaumburg, USA) are approved for direct pulp capping in the treatment of profound caries. They possess several advantages due to their resin modification. Curing occurs very quickly by means of light polymerization. They also have better physical properties, are less soluble in water and show no signs of dissolution [4]. However, resin-modified pulp capping materials contain and release organic materials [18]. Thus, released residual monomers can damage the pulp, as they display a cytotoxic effect [12]. Also, the polymerization itself causes problems, as it is negatively influenced by the moist dentin surface [18]. The leakage of dentinal fluid and the resulting poorer adhesion may lead to the formation of micro/nanoleakage. Additionally, due to the depth of the cavity, thermal damage to the pulp as a result of light polymerization is possible. Soares et al. investigated the influence of light polymerization of light-curing pulp capping materials and adhesives in the area close to the pulp; they could show that a temperature increase of 3.8–6.4 °C can occur with a residual dentin thickness of 1 mm [26]. Since the remaining thickness of the dentin layer is often only approximately 0.2 mm in the treatment of profound caries, an even higher temperature increase in the area of the pulp is to be expected. If the temperature rises above 42 °C, tissue damage occurs. Moreover, a deformation in the area of the pulp chamber roof is produced [26]. Therefore, capping of the pulp with resin-modified calcium hydroxide preparations is not recommended [8].

Reversible Pulpitis	Irreversible Pulpitis
– Positive response to sensitivity test – Pain does not persist after the stimulus ends	– Strong response to sensitivity test – Pain clearly persists after stimulus ends or is permanently present – Pain radiates and can be triggered by warmth – *Also asymptomatic progression is possible*
Vitality-preservation measures	**Root canal treatment**

Table 1 The currently recommended diagnosis and therapy scheme for reversible and irreversible pulpitis

Calcium silicate cements

The best-known calcium silicate cement used in dentistry is MTA (mineral trioxide aggregate [di- and tricalcium silicate + water]). It has a higher strength and a lower solubility than conventional calcium hydroxide preparations [7]. Moreover, MTA has a high biocompatibility and it releases calcium hydroxide and silicon during the hardening phase [27, 29]. During the setting process, the pH value of MTA increases to a value of 12.5, which is comparable to the pH value of a calcium hydroxide preparation [14, 28]. The disadvantages of MTA in daily practice are the material's high cost and the long setting time [16]. In order to be able to perform an adhesive closure, a cover is necessary due to the long setting time of calcium silicate. Vural et al. conducted a clinical study over the course of 24 months, which compared MTA and calcium hydroxide in the treatment of profound caries [30]. Both preparations showed an equally good clinical success. No significant differences were found [30].

Summary

The treatment of dentin wounds should be considered in the context of the current consensus recommendation for caries excavation [25]. This recommendation states that complete caries excavation should be avoided in areas close to the pulp in order to avoid possible pulp exposure. In areas distant from the pulp, complete removal of the caries is mandatory for ensuring the stability of the subsequent restoration [25]. However, there is currently no precise guideline on how much carious dentin close to the pulp can be left [3]. Overall, based on studies, there is very little evidence to support the use or need of calcium hydroxide preparations in profound caries treatment [9, 10, 24, 31]. Even in the case of gradual or selective caries excavation, no influence on clinical success has been found [9].

However, a study from 2013 showed that a large proportion (about 70 %) of practicing dentists in northern Germany tries to completely excavate caries during treatment because they fear that the re-

maining caries could damage the pulp [23]. The age, gender and professional environment of the dentist were not significant variables in the clinical procedure [23]. If this procedure is chosen for the treatment of profound caries, the area near the pulp should to be covered. Based on its positive properties, MTA is the most suitable material. However, if handling, setting time and high costs are taken into account, calcium hydroxide would be the more reasonable alternative. In any case, an adhesive restoration is recommended so as to avoid recontamination with microorganisms [13]; adequate sealing plays a more important role for the success of the treatment than the material used for the capping [5, 6].

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