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Restoration of teeth affected by molar-incisor hypomineralisation

A systematic review

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Molar-incisor hypomineralisation (MIH)
Hypersensitivity
Treatment
Survival rate

SUMMARY

The objective was to systematically analyse clinical studies on restorative procedures for teeth affected by molar-incisor hypomineralisation (MIH).
The databases PubMed, Embase, and Cochrane Library were searched. Only retrospective and prospective clinical studies dealing with sealing or restoration of MIH-affected teeth were included. The language was restricted to English and German.
Thirteen of 36 potentially eligible studies were included focusing on the following subjects: extension of enamel preparation, adhesive procedures prior to restoration, application of fissure sealants as well as restoration with conventional glass ionomer cements (GIC), resin-modified glass ionomer cements (RMGIC), resin composites, and indirect restorations. Seven clinical studies were controlled trials. However, only two included MIH-unaffected teeth as control. No meta-analysis was performed due to the heterogeneity of study designs (e.g., severity of MIH or the restorative materials investigated). Based on the present analysis, the annual failure rates were in average 21% for fissure sealants, 22% for GIC, 1–6% for RMGIC, 13–32% for resin composites, and 0–7% for indirect restorations. In summary, only few tendencies can be deduced from this review at a low level of evidence (number of studies): 1) preparation margins in sound enamel seem to be superior to preparations in hypomineralised enamel (1 study), 2) RMGIC seems to be superior to GIC (3 studies), 3) resin composites may be used for restoring all severities of MIH (7 studies) with self-etch and etch-and-rinse adhesive systems generally not performing differently (3 studies), and 4) in cases of severe MIH, indirect restorations showed a good clinical success (4 studies).

Introduction

The term molar-incisor hypomineralisation (MIH) was introduced by Weerheijm et al. in 2001 and is defined as "hypomineralisation of systemic origin of one to four permanent first molars, frequently associated with affected incisors" (Weerheijm et al. 2001). The defects range from white and/or brown spots to soft and porous enamel sometimes leading to a post-eruptive enamel breakdown of the affected teeth due to the reduced hardness of the enamel (Weerheijm et al. 2001). In some cases, MIH-like defects also occur in permanent second molars and permanent canines (Weerheijm et al. 2003) or in deciduous second molars, the latter case being described as "deciduous molar hypomineralisation" (Elfrink et al. 2012). The average prevalence of MIH worldwide is 14.2% (Zhao et al. 2018). More detailed information about prevalences is given in the other paper of our group in this issue (Dulla & Meyer-Lueckel 2021).

Apart from aesthetic problems (mainly if incisors are affected by hypomineralisation), patients mostly suffer from hypersensitivity, dentin exposure, and consequently also from a risk of pulp involvement, specifically of a chronic pulp inflammation (Rodd et al. 2007). The prevalence of hypersensitivity related to MIH has been described to be around 35%, with the hypersensitivity being dependent on the severity of the hypomineralisation (Raposo et al. 2019). The hypersensitivity, in turn, often leads to a reduced oral hygiene (e.g., fewer tooth brushing), which promotes plaque accumulation (Ghanim et al. 2017). Thus, in cases of soft and porous enamel, post-eruptive enamel breakdown is likely to occur (Fagrell et al. 2010), and patients with MIH generally suffer more often from caries in the permanent dentition (Grossi et al. 2017).

An early diagnosis, prophylaxis, and – if needed – an early restorative treatment of MIH seem to be important to reduce hypersensitivity, post-eruptive enamel breakdown, and caries. In cases of MIH with the need of sealing or restoring the affected teeth, restorative materials may be light curing fissure sealants, glass ionomer cements as sealants, or for restorations, resin composites as well as indirect composite, ceramic, or metal restorations such as onlays or partial crowns. Clinically, the restoration of hypomineralised teeth remains challenging: Structure and composition of hypomineralised enamel are different because of the lower mineral content, leaving 3 to 15 times more space for proteins (Almuallem & Busuttil-Naudi 2018). Consequently, surface hardness is markedly reduced and hypomineralised enamel shows a less distinct crystalline structure with indistinct prism borders and more interprismatic space (Elhennawy et al. 2017a). This may lead to high restoration failure, specifically repeated marginal breakdown of restorations.

Although information on the structural, mechanical, and chemical properties of MIH-affected teeth has been gained in recent years, restoring MIH-affected teeth remain a major challenge (Elhennawy et al. 2019), and several aspects regarding the restorative treatment of these teeth remain unclear. This raises the questions whether preparation of the tooth substance (e.g., complete removal of MIH-affected enamel) is needed, whether additional pretreatment of the tooth substance is required, and whether one of the above-mentioned restorative materials show a more advantageous longevity than another. Thus, we aimed to systematically search the literature for treatment options (i.e., preparation and pretreatment of the tooth substance as well as the choice of material) to restore teeth affected by different severities of MIH.

Materials and methods

Search strategy

Based on the search strategy listed in Table I, the databases PubMed, Embase, and Cochrane Library were systematically searched for studies mainly dealing with restorative treatment options of MIH-affected teeth. The review was conducted and reported according to the PRISMA statement (Moher et al. 2015). The PICOS model was used to define the in- and exclusion criteria and, thus, to structure the clinical research question (Miller & Forrest 2001).

Selection of studies

Title and abstract of potential studies were independently assessed by two reviewers (KRW and SF). In cases of a lack of consensus regarding study design or content, both authors initiated discussions until an agreement was reached. Only studies dealing with the application of fissure sealants or restoration of MIH-affected teeth using glass ionomer cements, resin composites as well as indirect composite, ceramic, or metal restorations were included. Studies with a follow-up time less than 12 months and studies with less than ten MIH-affected teeth were excluded. Studies dealing with other treatment options such as noninvasive therapies, desensitisation, and/or studies to solely improve aesthetics of MIH-affected teeth were also excluded. Retrospective and prospective clinical studies were included whereas in vitro studies, reviews, short communications, surveys, editorials, and letters to the editor were excluded. The language was restricted to English and German. The resulting studies of all three databases were then deduplicated, and the first reviewer (KRW) read the full text of the remaining, potentially eligible studies and decided about their inclusion or exclusion. After this first selection, the reference lists of the eligible studies were screened and an additional hand search was performed leading to the final selection of studies.

Calculation of annual failure rates and quality assessment

For each of the selected studies, calculation of annual failure rates (AFR) was performed. For this purpose, life tables were generated with the information given in the publications as

Tab. I Search strategy for each database (11.02.2021)

PubMed	(((hypomin* OR hypocalcifi* OR hypomatur*) OR (MIH OR molar-incisor hypominerali*)) OR (Dean's Index OR developmental defects of enamel)) AND (treatment OR therapy OR restoration* OR restorativ* OR bond* OR adhes*)	1145
Embase	1) (MIH OR molar-incisor hypominerali* OR (Dean's Index OR developmental defects of enamel)).af. 2) (treatment OR therapy OR restoration* OR restorativ* OR bond* OR adhes*).af. 3) 1 and 2	512
Cochrane Library	(hypomin* OR hypocalcifi* OR hypomatur*):ti,ab,kw OR (MIH OR molar-incisor hypominerali*):ti,ab,kw OR (Dean's Index OR developmental defects of enamel):ti,ab,kw AND (treatment or therapy OR restoration* OR restorativ* OR bond* OR adhes*):ti,ab,kw	98

previously described (Wierichs et al. 2017, 2020). For studies with insufficient or unclear information, no AFR was calculated.

Two reviewers (RJW and SF) independently assessed the risk of bias. In cases of a lack of consensus regarding study design or content, the two authors initiated a discussion until an agreement was reached. Risk of bias assessment was performed according to guidelines outlined by the Cochrane collaboration (Higgins & Green 2011).

Clinical and methodological heterogeneity were assessed by examining the characteristics of the studies, the similarity between the types of participants, the interventions, and the outcomes as specified in the inclusion criteria for considering studies for this review. Statistical heterogeneity would have been assessed using a Chi² test and the I^2 statistic, where I^2 values over 50% would have indicated substantial heterogeneity.

Results

Selected studies

The flowchart of study selection is depicted in Figure 1. Among the 36 potentially eligible studies (read in full text), 23 were excluded due to the following reasons: review/overview (Wong 2010; Kumar et al. 2012), no restorative treatment (Elhennawy et al. 2017b), no discrimination of therapy (Koch & García-Godoy 2000; Lygidakis et al. 2003; Jälevik & Klingberg 2012), follow-up time less than 12 months (Davidovich et al. 2020), less than ten

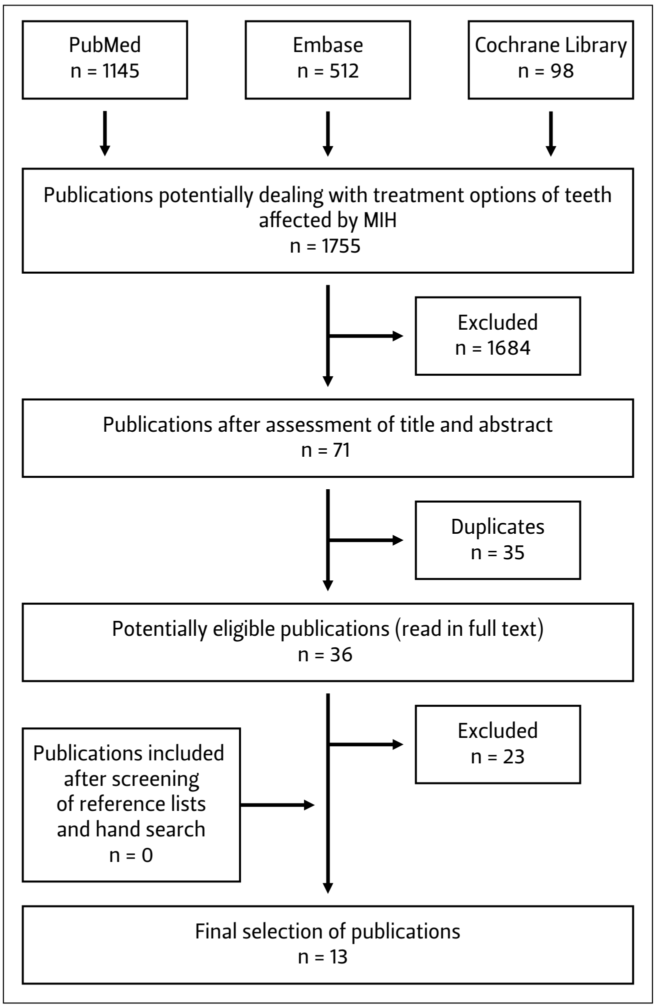

Fig. 1 Flowchart of study selection

MIH-affected teeth (Takahashi et al. 2009; Feierabend et al. 2012; Harika et al. 2016; Pessôa et al. 2018; Cavalheiro et al. 2020; Mendonça et al. 2020; Souza et al. 2020; Sundfeld et al. 2020; Trévia et al. 2020), no specification of the restoration process (Kotsanos et al. 2005; Mejàre et al. 2005), and no outcome reported (de Oliveira et al. 2015; Giannetti et al. 2018; Baroni et al. 2019; Vieira et al. 2019; Beretta et al. 2020). Thus, 13 studies were finally included.

Characteristics of selected studies

The characteristics of the selected studies are listed in Table II and III. Seven studies dealt with comparisons within one type of treatment, the latter being described as controlled trials (Tab. II). Of these, one study dealt with the extension of enamel preparation (Sönmez & Saat 2017), three with adhesive procedures before restoration with resin composite (i.e., self-etch versus etch-and-rinse adhesive systems; de Souza et al. 2017; Linner et al. 2020; Rolim et al. 2021), two with fissure sealants (Lygidakis et al. 2009; Fragelli et al. 2017), and one with indirect restorations (Dhareula et al. 2019). Among the other studies, no second group was included, or different types of treatments were compared and are hereby described as uncontrolled trials (Tab. III). Two of these studies dealt with a conventional glass ionomer cement (Fragelli et al. 2015; Linner et al. 2020), two with a resin-modified glass ionomer cement (Grossi et al. 2018; Durmus et al. 2021), one with resin composite (Gatón-Hernandéz et al. 2020), and three with indirect restorations (Gaardmand et al. 2013; Dhareula et al. 2018; Linner et al. 2020). The study of Linner et al. mainly dealt with adhesive procedures (i.e., self-etch versus etch-and-rinse adhesive systems; Tab. II), but also with investigations of conventional glass ionomer cements as well as indirect restorations (Tab. III) (Linner et al. 2020). The number of teeth affected by MIH included in the studies ranged from 10 to 281. Only two studies included a control group of teeth not affected by MIH (Tab. II) (Fragelli et al. 2017 [unaffected/sound molars]; Sönmez & Saat 2017 [carious molars]).

The AFR for fissure sealants ranged from 17% (Lygidakis et al. 2009) to 22% (Fragelli et al. 2017). The AFR for conventional glass ionomer cements was 22% (Fragelli et al. 2015), and ranged from 1% (Grossi et al. 2018) to 6% (Durmus et al. 2021) for resin-modified glass ionomer cements. Resin composites showed a wide variety of AFR from 13% (Sönmez & Saat 2017) to 32% (de Souza et al. 2017). Finally, indirect restorations showed AFR between 0% (Dhareula et al. 2018) and 7% (Dhareula et al. 2019).

The follow-up time varied from 12 to 48 months. For studies on fissure sealants, the follow-up time ranged from 18 (Fragelli et al. 2017) to 48 months (Lygidakis et al. 2009). The follow-up time for studies on conventional glass ionomer cements ranged from 12 (Fragelli et al. 2015) to 36 months (Linner et al. 2020) and for resin-modified glass ionomer cements from 12 (Grossi et al. 2020) to 24 months (Durmus et al. 2021). For studies on resin composite, the follow-up time ranged from 12 (Rolim et al. 2021) to 36 months (Linner et al. 2020). Finally, the follow-up time for studies on indirect restorations ranged from 35 (Dhareula et al. 2018) to 39 months (Gaarmand et al. 2013).

Risk of bias was assessed for controlled trials (Fig. 2) (Lygidakis et al. 2009; de Souza et al. 2017; Fragelli et al. 2017; Sönmez & Saat 2017; Dhareula et al. 2019; Linner et al. 2020; Rolim et al. 2021), and a low risk of bias could only be observed for three of these (Fig. 2) (Lygidakis et al. 2009; de Souza et al. 2017; Rolim et

Tab. II Controlled trials

Study	Study design Number of teeth	Severity of MIH	Preparation	Pretreatment of teeth	Material	Criteria (visual-tactile) Outcome	Follow-up time	AFR
Enamel preparation								
Sönmez & Saat 2017	RCT 95 molars (MIH) 31 carious molars	PEB[a] associated with carious lesions	Group 1: invasive treatment (cavity margins in sound enamel) Group 2: noninvasive treatment Group 3: noninvasive treatment (both: reasonable resistance of enamel) Group 4: control (caries)	1) Phosphoric acid 2) Only group 3: NaOCl 3) Futurabond NR	Grandio	Modified USPHS Survival rate: Group 1: 81.3% Group 2: 58.1% Group 3: 78.1% Group 4: 87.1%	24 months	Group 1: 10.1% Group 2: 24.6% Group 3: 11.6% Group 4: 6.6% (Total: 12.9%)
Adhesive procedures								
Linner et al. 2020	NRCT 153 (unspecified)	Mild to severe	Group 1: no preparation Group 2: removal of carious tissue and unstable HE[b]	Group 1: SEA[c] (Scotchbond Universal) Group 2: E&RA[d] (Syntac Classic)	Group 1: Tetric EvoFlow Group 2: Tetric EvoCeram	EAPD, FDI CSP[e]: Group 1: 29.9% Group 2: 76.2%	36 months	n. a.
Rolim et al. 2021	RCT 64 molars	Moderate to severe	Removal of carious tissue and selective removal of HE[b]	Group 1: SEA[c] (Ambar Universal; self-etch mode) Group 2: E&RA[d] (Ambar Universal; total-etch mode)	Tetric N-Ceram Bulk Fill	Modified USPHS Survival rate: Group 1: 62.3% Group 2: 80.8%	12 months	Group 1: 42.2% Group 2: 20.5%
de Souza et al. 2017	NRCT 41 molars	PEB[a] or unsatisfactory atypical restoration with or without carious lesions	Removal of carious tissue	1) Duraphat 2) GIC[f] (Ketac Molar) After 2 months: Group 1: SEA[c] (Clearfil SE) Group 2: E&RA[d] (Adper Scotchbond Multi-Purpose)	Filtek Z350 XT	Modified USPHS Survival rate: Group 1: 68% Group 2: 54%	18 months	Group 1: 24.0% Group 2: 39.9% (Total: 31.95%)
Fissure sealants								
Fragelli et al. 2017	NRCT 25 molars 16 unaffected molars	Mild	–	Affected and unaffected teeth: fluoride varnish and phosphoric acid	Fissure sealant (FluoroShield)	EADP, modified USPHS Survival rate: Affected: 72% Unaffected: 62%	18 months	Affected: 22.4% Unaffected: 32.0% (Total: 26.0%)
Lygidakis et al. 2009	RCT 94 molars	Mild	Mechanical cleaning of fissures using a round bur	Group 1: phosphoric acid followed by adhesive system (Bisco ONE-STEP) twice Group 2: phosphoric acid only	Fissure sealant (Fissurit)	FDI Success rate: Group 1: 70.2% Group 2: 25.5%	48 months	Group 1: 8.6% Group 2: 29.4%

Indirect restorations

Study	Study design Number of teeth	Severity of MIH	Preparation/Pretreatment of teeth	Pretreatment of restorations	Cementation	Material	Criteria (visual-tactile) Outcome	Follow-up times	AFR
Dhareula et al. 2019	RCT 42 molars	Severe	Preparation margins in sound enamel, NaOCl, phosphoric acid followed by Adper Single Bond Plus	Sandblasted with 100 µm aluminum oxide particles, resin composite onlays: additionally hydrofluoric acid followed by silane	Dual-curing resin cement (RelyX Unicem 2 Clicker)	Cast metal onlays (cobalt chromium) and indirect composite onlays (SR ADORO)	Modified USPHS CCS[g]: 90% (metal) and 85.7% (composite) Survival rate: 85% (metal) and 100% (composite)	36 months	Metal: 7.1% Composite: 7.0% (Total: 7.0%)

AFR: calculated annual failure rate, RCT: randomized controlled trial, NRCT: non-randomized controlled trial; a = post-eruptive enamel breakdown, b = hypomineralised enamel, c = self-etch adhesive system, d = etch-and-rinse adhesive system, e = cumulative survival probability, f = glass ionomer cement, g = calculated clinical success; n. a. = not applicable

Tab. III Uncontrolled trials

Study	Number of teeth	Severity of MIH	Preparation	Pretreatment of teeth	Material	Criteria (visual-tactile) / Outcome	Follow-up time	AFR
Conventional glass ionomer cements								
Linner et al. 2020	28 (unspecified)	Mild to medium	No preparation	No pretreatment	Ketac Molar	EAPD, FDI CSP[a]: 7%	36 months	n. a.
Fragelli et al. 2015	48 molars	Unsatisfactory atypical restorations or PEB[b] associated with or without carious lesions	No complete removal of MIH-affected area, removal of carious tissue	Duraphat (3–4 weeks before restoration; once per week)	Ketac Molar	Modified USPHS, DMFT, EAPD Survival rate: 91.7% after 6 months 78.7% after 12 months	12 months	21.7%
Resin-modified glass ionomer cements								
Durmus et al. 2021	134 molars	Cavitated with moderate to deep carious lesions	Selective carious tissue removal	–	Equia Forte and Equia Coat	Modified USPHS CSP[a]: 87.5%	24 months	6.4%
Grossi et al. 2018	60 molars	Severe	ART[c], margins of the restoration in sound or MIH-affected enamel	Cavity conditioner (polyacrylic acid and aluminum chloride hexahydrate)	Equia Forte	Nyvad criteria, EAPD Success rate: 98.3%	12 months	1.3%
Resin composites								
Gatón-Hernandéz et al. 2020	281 molars	Severe	Selective removal of carious tissue, margins in sound enamel	1) NaOCl 2) GIC[d] (Equia) After 6 months: 3) Scotchbond Multi-Purpose	Filtek Supreme XTE	Own criteria Success rate: 96.8%	24 months	1.6%

Indirect restorations

Study	Number of teeth	Severity of MIH	Preparation/Pretreatment of teeth	Pretreatment of restorations	Cementation	Material	Criteria (visual-tactile) / Outcome	Follow-up time	AFR
Linner et al. 2020	23 (unspecified)	Severe	Removal of HE[e]/ E&RA[f] (Syntac Classic)	–	Dual-curing resin cement	CAD/CAM ceramic restorations (Celtra Duo)	EAPD, FDI CSP[a]: 100%	36 months	n. a.
Dhareula et al. 2018	10 molars	5 moderate and 5 severe	Final preparation margins in sound enamel/ phosphoric acid followed by Adper Single Bond Plus	Sandblasted with 100 µm aluminum oxide particles followed by hydrofluoric acid followed by silane	Dual-curing resin cement (RelyX Unicem 2 Clicker)	Indirect composite onlays (SR ADORO)	Modified USPHS Survival rate: 100% Success rate: 90%	Mean: 34.8 months	0%
Gaardmand et al. 2013	57 molars	FPMs[g] with PEB[b]	Entire margins in sound enamel without opacities	Surface roughening ("sugar crystal method")	Resin cement (Twinlock)	Cast-adhesive gold copings (onlays/ partial crowns)	No information Four lost, one recemented after three months, caries in two	Mean: 38.5 months	n. a.

AFR: calculated annual failure rate; a = cumulative survival probability, b = post-eruptive enamel breakdown, c = atraumatic restorative treatment, d = glass ionomer cement, e = hypomineralised enamel, f = etch-and-rinse adhesive system, g = first permanent molars; n. a. = not applicable

Authors	Random sequence generation	Allocation concealment	Blinding of participants and personnel detection bias	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Ideal pre-specification	**Overall bias**
Linner et al. 2020	Low risk	Low risk	Low risk	Unclear risk	Unclear risk	High risk	Low risk	a
Rolim et al. 2021	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Dhareula et al. 2019	Low risk	Low risk	High risk	High risk	Low risk	High risk	Low risk	High risk
de Souza et al. 2017	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Fragelli et al. 2017	High risk	Low risk	Low risk	Unclear risk	Low risk	High risk	Low risk	b
Sönmez & Saat 2017	Unclear risk	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Low risk	Unclear risk
Lygidakis et al. 2009	Low risk	Unclear risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk

● Low risk ● Unclear risk ● High risk
a Moderate risk b Moderate to serious risk

Fig. 2 Risk of bias for controlled trials

al. 2021). Due to the heterogeneity of investigated focuses and study designs (e.g., severity of MIH or the restorative materials investigated), no meta-analysis was performed, and only few tendencies could be deduced at a low level of evidence. Preparation margins in sound enamel seem to be superior to those in hypomineralised enamel (Sönmez & Saat 2017), RMGIC seems to be superior to GIC (Fragelli et al. 2015; Grossi et al. 2018; Durmus et al. 2021). Several studies indicate that resin composite can be used for restoring all severities of MIH (Lygidakis et al. 2009; de Souza et al. 2017; Fragelli et al. 2017; Sönmez & Saat 2017; Gatón-Hernandéz et al. 2020; Linner et al. 2020; Rolim et al. 2021). Self-etch and etch-and-rinse adhesive systems do not seem to perform differently (de Souza et al. 2017; Rolim et al. 2021). In cases of severe MIH, indirect restorations showed a good clinical success over a fairly long observation time (Gaarmand et al. 2013; Dhareula et al. 2018, 2019; Linner et al. 2020).

Discussion

The present review aimed to systematically search the literature for treatment options to restore teeth affected by MIH. The included studies showed that there is quite a heterogeneous range of treatment options regarding preparation and pretreatment of the tooth substance as well as the choice of restorative material.

A microinvasive treatment option of MIH-affected teeth is the application of a fissure sealant (corresponding to therapy "B2" of the Würzburg MIH concept [Part 2]; Bekes et al. 2016). In the present review, two studies investigated the longevity of fissure sealants (Lygidakis et al. 2009; Fragelli et al. 2017). In the first study, the application of an adhesive system after phosphoric acid etching significantly increased the clinical success rate of the fissure sealant compared to application of the fissure sealant after phosphoric acid etching alone (Lygidakis et al. 2009). This is in agreement with the results of a clinical study on first permanent molars not being affected by MIH but by caries, in which a flowable resin composite was applied as fissure sealant after phosphoric acid etching and application of an adhesive (Kucukyilmaz & Savas 2015). In the second study on fissure sealants in MIH-affected teeth, the calculated annual failure rate after a follow-up time of 18 months was slightly higher for unaffected teeth (32%) compared to teeth affected by MIH (22%) (Fragelli et al. 2017). It must be noted that this study was the only one in the present review that used sound and MIH-unaffected teeth as a control. However, a study of fissure sealants in sound molars showed a higher cumulative survival rate of 81% after a follow-up time of four years (Zhang et al. 2017). Overall, the study design and the focus of the studies by Kucukyilmaz & Savas and Fragelli et al. are entirely different and, consequently, the level of evidence is very low, and clinical implications can hardly be given for fissure sealants in combination with MIH-affected teeth.

In cases of partially erupted molars showing caries and/or post-eruptive enamel breakdown in combination with an insufficient compliance of the patient, the use of conventional glass ionomer cements has been recommended (Lygidakis et al. 2010; Linner et al. 2020). The use of conventional glass ionomer cements corresponds to therapy "C1" of the Würzburg MIH concept (Part 2) (Bekes et al. 2016) and is generally regarded as a rather provisional restoration (Lygidakis et al. 2010; Bekes et al. 2016). Two studies investigated conventional glass ionomer cements as restorative materials for MIH-affected teeth (Fragelli et al. 2015; Linner et al. 2020). Whereas the first study recommended to remove the entire carious tissue but to leave the MIH-affected enamel intact (Fragelli et al. 2015), the second study used a noninvasive approach without any cavity preparation before restoration (Linner et al. 2020). In either case, conventional glass ionomer cements are supposed to bind to calcium of enamel. The mineral concentration of hypomineralised enamel is lower (Almuallem & Busuttil-Naudi 2018), and bonding to this type of enamel seems reduced compared to sound enamel. Consequently, it may be that a frequent application of fluoride promotes a remineralisation of hypomineralised enamel, which then could improve the bond of conventional glass ionomer cements. Thus, Fragelli et al. applied a fluoride varnish (Duraphat) for three to four weeks (once per week) as a pretreatment prior to restoration with a conventional glass ionomer cement (Fragelli et al. 2015). The authors speculated that conventional glass ionomer cements might then be able to further promote remineralisation of enamel and may reduce the development of caries and hypersensitivity. The efficacy of these effects, however, remains unclear.

Two of the included studies investigated resin-modified glass ionomer cements as restorative materials for MIH-affected teeth. In both studies, a similar preparation of the tooth substance as described for conventional glass ionomer cements has been used (Grossi et al. 2018; Durmus et al. 2021). Advantages over conventional glass ionomer cements are that light curing of these cements enables a timely hardening and that the mechanical properties of resin-modified glass ionomer cements are superior to those of conventional glass ionomer cements. However, a "bulk-fill technique" is not recommended for resin-modified glass ionomer cements, and additional pretreatment with a cavity conditioner of the tooth substance resulted in a rather low AFR of approximately 2% (Grossi et al. 2018).

When indirectly comparing the 12-month success rates of conventional glass ionomer cements with the one of resin-modified glass ionomer cements, a clinical study investigating a resin-modified glass ionomer cement showed a success rate of 98.3% (Grossi et al. 2018), whereas a clinical study investigating a conventional glass ionomer cement showed a survival rate of 78.7% (Fragelli et al. 2015). However, it must be noted that the two studies were designed and conducted differently regarding severity of hypomineralisation and pretreatment of the teeth.

Restoration of MIH-affected teeth with resin composite corresponds to therapy "E1" of the Würzburg MIH concept (Part 2) and is regarded as a definitive restoration (Bekes et al. 2016). The studies that investigated resin composites for restoration of MIH-affected teeth suggest that these materials can be used for restoring all severities of MIH (Lygidakis et al. 2009; de Souza et al. 2017; Fragelli et al. 2017; Sönmez & Saat 2017; Gatón-Hernandéz et al. 2020; Linner et al. 2020; Rolim et al. 2021). However, the use of resin composites requires a good compliance of the patient during the treatment, at best with application of a rubber dam. Regarding preparation of the tooth substance, a higher survival rate of composites was shown after complete removal of the MIH-affected enamel (Sönmez & Saat 2017; Linner et al. 2020). However, patients with MIH usually suffer from hypersensitivity, which may complicate profound local anaesthesia and the subsequent (invasive) preparation of the respective teeth. In cases of MIH-affected enamel with partial preparation of the tooth substance and remaining hypomineralised enamel, one study indicated that the survival rates might be increased if enamel had been pretreated with sodium hypochlorite (5% NaOCl) before application of the adhesive system (Sönmez & Saat 2017). Considering that an adhesive system is needed when using resin composites as restorative materials, information about which type of adhesive system/procedure to use is rather sparse. Two studies showed no significant differences between a self-etch and an etch-and-rinse adhesive procedure (Clearfil SE versus Adper Scotchbond Multi-Purpose [de Souza et al. 2017] and Ambar Universal in the self-etch versus total-etch mode [Rolim et al. 2021]). The adhesive procedures of both studies were carried out on tooth substance of which all carious tissue had previously been removed, leading to the assumption that most of the restoration area was primarily in sound dentin. From a clinical perspective, more or less invasive removal of larger areas of less mineralised enamel (or tooth substance in general) has to be weighed against the stability of the resulting restoration, but no guidelines on a higher level of evidence can be given at present.

Finally, the studies that investigated indirect restorations for MIH-affected teeth generally indicated promising survival rates, especially for indirect composite and ceramic onlays (Gaardmand et al. 2013; Dhareula et al. 2018, 2019; Linner et al. 2020). Resin composite onlays showed a sufficient marginal adaptation and were considered as fairly attractive aesthetic restorations (Dhareula et al. 2019). For all indirect restorations, preparation of MIH-affected teeth was performed with the margins being located in sound enamel. In analogy to unaffected teeth, preparation for a restoration such as an onlay resulted in a rather invasive treatment of the affected teeth to ensure an adequate thickness of the restorative material. This considerably more invasive treatment option should be confined to severe stages of MIH. Restoration of MIH-affected teeth with indirect restorations corresponds to therapy "E2" of the Würzburg MIH concept (Part 2). This is the last category of therapy before "F", which then includes a possible extraction of the affected tooth/teeth (Bekes et al. 2016). However, the state of eruption of the teeth, the age of the patient, his/her compliance, and potentially increased financial aspects compared to the aforementioned restorative materials must be taken into account.

In summary, the following conclusions result from the present review:

- Clinical studies about the restoration of teeth affected by MIH are very heterogeneous regarding the investigated factors (e.g., the severity of MIH of the included teeth, preparation and pretreatment procedures, or the restorative materials investigated). Thus, recommendations based on best clinical practice can rather be given than conclusions on a higher level of evidence regarding restorative treatment of MIH-affected teeth.
- Preparation margins in sound enamel seem to be superior compared to those in hypomineralised enamel. However, the benefit of an improved stability of the restoration must be weighed against the greater loss of tooth substance.
- Resin-modified glass ionomer cements seem to be superior to conventional glass ionomer cements.
- Resin composites are expected to be suitable for restoring all severities of MIH.
- Both self-etch and etch-and-rinse adhesive systems seem to perform similarly, but a generally lower adhesion to MIH-affected enamel can be expected compared to sound enamel.
- Indirect restorations (i.e., onlays or partial crowns) show a good long-term clinical success, but they should be restricted mainly to severe cases of MIH.

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Conflicts of interest
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Zusammenfassung
Einleitung
Der Begriff Molaren-Inzisiven-Hypomineralisation (MIH) wurde 2001 von Weerheijm et al. eingeführt und ist definiert als «Hypomineralisation systemischen Ursprungs von ein bis vier permanenten ersten Molaren, häufig mit betroffenen Schneidezähnen kombiniert». Die durchschnittliche Prävalenz der MIH liegt weltweit bei 14,2%. Eine frühzeitige Diagnose, Prophylaxe und – falls erforderlich – frühzeitige restaurative Behandlung der MIH sind wichtig, um Überempfindlichkeit, posteruptiven Schmelzverlust und Karies zu reduzieren. Klinisch bleibt die Versorgung von hypomineralisierten Zähnen aufgrund der veränderten Struktur und Zusammensetzung des Schmelzes eine Herausforderung. Daher stellt sich die Frage, ob eine Präparation der Zahnsubstanz (z.B. vollständige Entfernung des von MIH betroffenen Schmelzes) erforderlich ist, ob eine zusätzliche Vorbehandlung der Zahnsubstanz notwendig ist und ob ein Restaurationsmaterial vorteilhafter als ein anderes ist. Unser Ziel war es, die Literatur nach erfolgsversprechenden Behandlungsmöglichkeiten (d.h. die Vorbereitung und Vorbehandlung der Zahnsubstanz sowie die Wahl des Restaurationsmaterials) zur Versorgung der von MIH betroffenen Zähne zu durchsuchen.

Material und Methoden
Die Datenbanken PubMed, Embase und Cochrane Library wurden systematisch nach Studien durchsucht, die sich potenziell mit Möglichkeiten zur restaurativen Behandlung von MIH-betroffenen Zähnen befassten. Es wurden nur Studien berücksichtigt, die sich mit der Restauration von MIH-betroffenen Zähnen mittels konventionellen und kunststoffmodifizierten Glasionomerzementen, Kompositmaterialien (Fissurenversieglern und regulären Kompositen) und indirekten Komposit-, Keramik- oder Metallrestaurationen befassten.

Resultate
13 von 36 potenziell infrage kommende Studien wurden in die Endauswahl aufgenommen. Unter den kontrollierten Studien befasste sich eine mit der Ausdehnung der Präparation im Schmelz, drei mit adhäsiven Verfahren vor der Restauration mit Komposit und eine mit indirekten Restaurationen. Zwei der unkontrollierten Studien befassten sich mit einem konventionellen Glasionomerzement, zwei mit einem kunststoffmodifizierten Glasionomerzement, eine mit Komposit und drei mit indirekten Restaurationen.

Diskussion
Die eingeschlossenen Studien zeigen, dass es ein recht heterogenes Spektrum an Behandlungsmöglichkeiten hinsichtlich Präparation und Vorbehandlung der Zahnsubstanz sowie der Wahl des Restaurationsmaterials gibt. Bei MIH-betroffenen Zähnen mit Restaurationsbedarf (z.B. bei posteruptivem Schmelzeinbruch) kann nicht nur der hypomineralisierte Schmelz die Restauration beeinflussen, sondern auch der Durchbruchszustand der Zähne, das Alter der Patientin oder des Patienten oder deren oder dessen Compliance.

Insgesamt können lediglich Empfehlungen auf einem tiefen Evidenzniveau gegeben werden. Präparationsränder in gesundem Schmelz scheinen im Vergleich zu Präparationsrändern in hypomineralisiertem Schmelz überlegen zu sein, wobei die Schichtstärke und die Stabilität der Restauration gegen den Zahnsubstanzverlust abgewogen werden müssen. Hinsichtlich Restaurationsmaterialien scheinen kunststoffmodifizierte Glasionomerzemente den konventionellen Glasionomerzementen überlegen zu sein. Komposite können generell bei allen Schweregraden von MIH verwendet werden. Bei Kompositen kann bezüglich der Vorbehandlung der Zahnsubstanz mit Adhäsivsystemen kein direkter Vergleich gezogen werden. Sowohl «self-etch»- als auch «etch-and-rinse»-Adhäsivsysteme scheinen geeignet zu sein, wobei generell eine geringere Haftung zu MIH-betroffenem Schmelz im Vergleich zu gesundem Schmelz zu erwarten ist. Indirekte Restaurationen (d.h. Onlays oder Teilkronen) zeigen einen guten klinischen Langzeiterfolg. Die Indikation indirekter Restaurationen sollte aber hauptsächlich auf schwere Fälle von MIH beschränkt werden.

Résumé
Introduction
Le terme «Hypominéralisation Molaire Incisive» (HMI), introduit en 2001 par Weerheijm et al., est défini comme « une hypominéralisation, d'origine systémique, d'une à quatre des premières molaires permanentes, souvent combinée avec une affection des incisives ». La prévalence moyenne de la HMI dans le monde est de 14,2 %. Un diagnostic précoce, une prophylaxie et, si nécessaire, un traitement restaurateur précoce des HMI sont importants pour réduire l'hypersensibilité, la perte d'émail posteruptive ainsi que l'apparition de caries. Sur le plan clinique, la restauration des dents hypominéralisées reste un défi en raison de la structure et de la composition altérée de l'émail. Par conséquent, il est important de savoir si une préparation de la substance dentaire (par exemple, l'élimination complète de l'émail affecté par la HMI) est nécessaire, si un prétraitement supplémentaire de la substance dentaire est nécessaire et si un matériau de restauration serait plus avantageux qu'un autre. Notre objectif était de passer en revue la littérature pour trouver des options de traitement (c'est-à-dire la préparation et le prétraitement de la substance dentaire et le choix du matériau de restauration) prometteuses pour la restauration des dents affectées par la HMI.

Matériel et méthodes
Les bases de données PubMed, Embase et Cochrane Library ont été consultées pour trouver des publications potentiellement liées aux options de traitement des dents affectées par la HMI. Seules les publications traitant la restauration des dents HMI à l'aide de ciments verre ionomère conventionnels et modifiés à la résine, de composites (produits de scellement de sillons et composites ordinaires) et de restaurations en céramique ou en métal ont été incluses.

Résultats
Treize des 36 publications potentiellement éligibles ont été incluses dans la sélection finale. Parmi les études contrôlées, une portait sur l'extension de la préparation dans l'émail, trois sur les procédures adhésives avant la restauration au composite et une étude portait sur les restaurations indirectes. Deux des études non contrôlées portaient sur un ciment verre ionomère conventionnel, deux sur un ciment verre ionomère modifié à la résine, une sur le composite et trois sur des restaurations indirectes.

Discussion
Les études incluses montrent qu'il existe un spectre relativement hétérogène d'options de traitement concernant la préparation, le prétraitement de la structure dentaire et ainsi que le choix du matériau de restauration. En ce qui concerne les dents affectées par la HIM nécessitant une restauration (par exemple, lors de défaut d'émail postéruptif), non seulement l'émail hypominéralisé influencera la restauration, mais aussi le stade d'éruption des dents, l'âge du patient ou encore sa compliance.

Dans l'ensemble, seules des recommandations à faible niveau de preuve peuvent être données. Les marges de préparation dans de l'émail sain semblent être supérieures aux marges de préparation dans de l'émail hypominéralisé, bien que l'épaisseur de la couche et la stabilité de la restauration doivent être mises en balance avec la perte de structure de la dent. Concernant les matériaux de restauration, les ciments verre ionomère modifiés à la résine semblent être supérieurs aux ciments verre ionomère conventionnels. Les composites peuvent généralement être utilisés pour tous les degrés de HMI. Dans le cas des composites, aucune comparaison directe ne peut être faite en ce qui concerne le prétraitement de la structure de la dent avec des systèmes adhésifs. Les systèmes adhésifs « self-etch » et « etch-and-rinse » semblent tous deux convenir, à noter toutefois une adhérence généralement plus faible à l'émail affecté par la HMI par rapport à l'émail sain. Les restaurations indirectes (onlays ou couronnes partielles) présentent un bon succès clinique à long terme. Toutefois, l'indication de restaurations indirectes devrait principalement se limiter aux cas graves de HMI.

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