REVIEW ARTICLE

Determining Factors in the Success of Direct Pulp Capping: A Systematic Review

Jose Francisco Gomez-Sosa[1], Mario Granone-Ricella[2], Marina Rosciano-Alvarez[3], Victor D Barrios-Rodriguez[4], Juan Goncalves-Pereira[5], Javier Caviedes-Bucheli[6]

Received on: 15 April 2024; *Accepted on:* 16 May 2024; *Published on:* 14 June 2024

Abstract

Aim: To elucidate the factors that determine the success of direct pulp capping (DPC) in permanent teeth with pulp exposure due to dental caries.

Materials and methods: A comprehensive electronic search from 1980 to 2023 across PubMed, Scopus, and ISI Web databases was conducted using specific keywords and MeSH terms in Q1 or Q2 journals. Only prospective/retrospective clinical studies in English on 15 or more human permanent teeth with carious pulpal exposure treated with DPC agents—mineral trioxide aggregate (MTA), Biodentine, or calcium hydroxide with a rubber dam and minimum 1-year follow-up, were considered. The factors retrieved and analyzed were based on study design, patient age, sample size, type of cavity, exposure size and location, pulp diagnosis, solutions to achieve hemostasis, hemostasis time, capping material, restoration type, follow-up period, methods of evaluation, and overall success.

Review results: Out of 680 articles, only 16 articles were selected for the present systematic review on application of the selection criteria. A wide age range of patients from 6 to 88 years were considered among these studies with sample sizes ranging from 15 to 245 teeth with reversible pulpitis being the predominant diagnosis of the cases. Mineral trioxide aggregate as a capping material was evaluated in 4 studies as a lone agent, while compared with other capping agents such as biodentine or calcium hydroxide in 7 studies. The follow-up period ranged from 9 days to nearly 80 months. While both clinical and radiographic evaluation was carried out in all studies, cold testing dominated the clinical tests while IOPR was the common radiograph considered. Mineral trioxide aggregate success rate was higher and similar to biodentine than calcium hydroxide.

Conclusion: Direct pulp capping has a high and predictable success rate in permanent teeth with carious exposure to reversible and irreversible pulpitis. Currently, mineral trioxide aggregate and biodentine have better long-term results in DPC than calcium hydroxide, hence, they should be used as an alternative to calcium hydroxide. Definitive restoration within a short period improves long-term prognosis.

Clinical significance: The significance of this review lies in its provision of evidence-based information on the effectiveness of DPC and the factors that influence its success. By considering these factors, clinicians can optimize treatment outcomes and improve the long-term prognosis of the treated teeth. This systematic review serves as a valuable resource for clinicians and researchers in the field of endodontics.

Keywords: Dental pulp, Direct pulp capping, Vital pulp therapy.

The Journal of Contemporary Dental Practice (2024): 10.5005/jp-journals-10024-3673

Introduction

Dental pulp can be compromised by cavities, trauma, or restorative procedures.[1] Vital pulp therapy (VPT) encompasses a series of procedures such as indirect pulp capping, direct pulp capping (DPC), and partial or complete pulpotomy.[1,2] Its objective is to preserve the health of the tooth through partial or complete preservation of the chamber and/or root pulp, ensuring its vitality and good blood supply, and promoting the formation of a dentinal bridge.[2,3]

Direct pulp capping is the treatment of exposed vital pulp by sealing the lesion with a material such as calcium hydroxide [$Ca(OH)_2$] or mineral trioxide aggregate (MTA) to facilitate the formation of reparative dentin and maintain pulp vitality. Direct pulp capping occurs when the capping dental material is placed directly on the mechanically or traumatically exposed vital pulp.[4]

Dentists often face a dilemma in the treatment of deep carious lesions in permanent teeth with closed apices and whether the dental pulp should be preserved to maintain its vitality or, if not, eliminate it and thus prevent infections, pulp necrosis, and apical periodontitis.[5]

However, over the years, with the scientific support provided by clinical studies, systematic reviews and meta-analyses, the

[1]Unidad de Terapia Celular-Laboratorio de Patología Celular y Molecular, Centro de Medicina Regenerativa, Instituto Venezolano de Investigaciones Científicas (IVIC), Caracas, Venezuela; Department of Endodontics, School of Dentistry, Universidad Santa Maria, Caracas, Venezuela

[2,4]School of Dentistry, Universidad Central de Venezuela, Caracas, Venezuela

[3]Periodontics Postgraduate Program, Universidad Central de Venezuela, Caracas, Venezuela

[5]Department of Endodontics, Universidad Central de Venezuela, Caracas, Venezuela

[6]Centro de Investigaciones Odontológicas (CIO) School of Dentistry, Pontificia Universidad Javeriana, Bogotá, Colombia

Corresponding Author: Jose Francisco Gomez-Sosa, Unidad de Terapia Celular-Laboratorio de Patología Celular y Molecular, Centro de Medicina Regenerativa, Instituto Venezolano de Investigaciones Científicas (IVIC), Caracas, Venezuela; Department of Endodontics, School of Dentistry, Universidad Santa Maria, Caracas, Venezuela, Phone: +58 4142805556, e-mail: josefgomezs@gmail.com

How to cite this article: Gomez-Sosa JF, Granone-Ricella M, Rosciano-Alvarez M, *et al.* Determining Factors in the Success of Direct Pulp Capping: A Systematic Review. J Contemp Dent Pract 2024;25(4):392–401.

treatment of dental caries has become less invasive to preserve as much dental tissue as possible and selective partial removal of these lesions is recommended in some cases.[6–8]

The same change is occurring in pulp treatment, the current approach is to avoid root canal treatments, since they are irreversible and sacrifice the hard and soft tissues of the tooth, making them vulnerable; therefore, whenever possible, it is preferable to use some VPT technique.[9]

Among the advantages of DPC, is the conservation of pulp vitality and dental tissue. Its success rate varies according to the literature, ranging from 70.49 to 100%.[3,10–24]

Direct pulp capping has different protocols depending on the study carried out, and the success rate of this treatment depends on a combination of factors, including the type of capping material used, the size and location of the pulp exposure, the degree of hemostasis achieved, the presence of infection or inflammation, and the quality of the restoration placed over the capped tooth. Careful patient selection and thorough diagnosis prior to performing DPC are crucial, as certain factors such as the age of the patient, the extent of the cavity, and the presence of systemic disease can also impact the success of the treatment. Therefore, it is important to consider more than one factor or combination of factors when gauging the success of DPC and to tailor the treatment approach to the individual patient's needs and circumstances.

Therefore, this systematic review aims to elucidate the factors that determine the success of DPC in permanent teeth with pulp exposure due to dental caries. Specifically, patient age, root maturation, pulp diagnosis, location and size of the exposure, control of hemostasis, capping material, and type of restoration were assessed.

Materials and Methods

The present systematic review was designed and conducted by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA: http://www.prisma-statement.org/). The research question was: What is the current evidence on the factors influencing the success of DPC in permanent teeth with pulp exposure due to dental caries? Been the PICO question: Population: Permanent teeth with pulp exposure due to dental caries, intervention: Direct pulp capping, comparison: None, outcome: Factors influencing the success of DPC, such as patient age, root maturation, pulp diagnosis, location and size of the exposure, control of hemostasis, capping material, and type of restoration.

Source of support: Nil
Conflict of interest: None

An electronic search of the literature was conducted from 01/01/1980 to 19/9/2023 (Fig. 1) using the following databases: PubMed, Scopus, and ISI Web; using the following keywords (MeSH terms in brackets): #1: (Pulpal diagnosis AND direct capping); #2: [(Dental pulp) AND (endodontics) AND (prognosis) AND (diagnosis)] AND [capping AND (pulp capping) AND direct pulp capping] NOT (animals) NOT primary teeth.

The articles included in this systematic review were selected according to the following inclusion criteria: Studies published in journals ranked Q1 or Q2, pulpal exposure by caries in human permanent teeth, *in vivo* studies in human teeth, prospective and retrospective clinical studies, studies that confirm the use of rubber dam during the procedure, studies with a sample of 15 teeth or more, studies with a minimum of 1-year follow-up, studies published in English, and studies that performed DPC with MTA, Biodentine, and calcium hydroxide. The exclusion criteria were articles regarding pulpal exposure in permanent human teeth due to mechanical exposure, trauma, or iatrogenic causes, as well as systematic reviews and meta-analyses.

The factors retrieved and analyzed in each article were based on study design, patient age, sample size, type of cavity, exposure size and location, pulp diagnosis, solutions to achieve hemostasis, hemostasis time, capping material, restoration type, follow-up period, methods of evaluation, and overall success.

Three reviewers (M.G., M.R., and V.B.) independently reviewed the titles, abstracts, and full texts considering the established selection criteria, and in case of disagreement between the reviewers, decisions were made by consensus of all researchers.

The article evaluation was based on the Cochrane Collaboration's tool for assessing the risk of bias, which describes the following parameters: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome

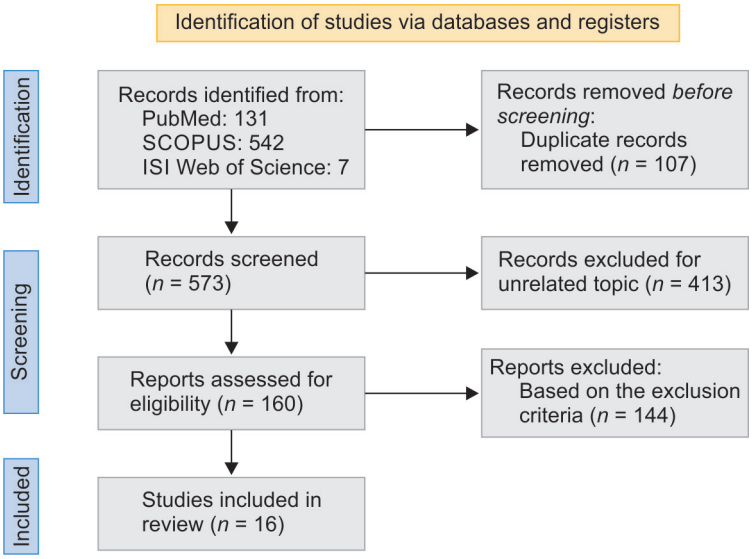

Fig. 1: Prisma flow diagram

assessment, incomplete outcome data, and selective reporting.[25] The performance bias (blinding of participants and personnel) was considered "Low" in all the studies. First, it is not possible to blind the clinician about the capping material that has been used because it has different characteristics, forms of use, and appearance. Second, the patient's knowledge of the procedure and material used does not have any repercussions in the future symptomatology. The incomplete data outcome was analyzed within 1 year because the articles had different follow-up protocols. A minimum 90% recall rate of the original sample was considered to classify the bias as "Low." The other three domains (selection, detection, and reporting) were evaluated using the Cochrane Collaboration's tool for assessing the risk of bias.

Results

In the PubMed database, 66 results were obtained with the use of keyword #1 and 65 for #2; in Scopus, a total of 502 articles were found for keyword #1 and 40 for #2; and in Web of Science, a total of 7 articles were obtained for keyword #1 and none for #2.

By unifying the PubMed, Scopus, and ISI Web data search and removing duplicates among them, a total of 573 articles were found. After application of the inclusion and exclusion criteria 557 articles were excluded: 413 for being unrelated to the topic and 144 by exclusion criteria. Sixteen studies were included in the systematic review (Table 1).

The analysis of the studies demonstrates several determining factors for the success of DPC, patient age is a controversial factor. The studies by Çalışkan M, Riccuci et al., Awawdeh et al., and Matsuo et al. consider it as a poorly predictive factor, while for Cho et al. and other authors it is a significant factor.[3,10,17,19–23] Direct pulp capping is a viable treatment in teeth with immature apexes, or with a diagnosis of irreversible pulpitis.[10,12–15]

The size of the pulp exposure treated ranged from less than 0.5 mm to greater than 2 mm, and its location was in the occlusal and axial areas of the tooth, according to the data from the selected studies.[3,13,16,17,19,21,22] The control of hemostasis within 5–10 minutes is an important factor in the outcome of direct pulp capping, as reported in the studies selected for this review.[3,10,12,13,20–22]

The capping material used is one of the most influential factors since calcium hydroxide reflects a higher failure rate than MTA at 1 year follow-up.[3,15,16] In a study by Cho et al., 30 of 105 cases coated with calcium hydroxide failed, compared to 7 of 70 in which MTA was used. This trend was similar in the follow-ups at 2 and 3 years.[3,17,18] However, Ricucci et al. reported success rates of 100 and 95% at 1 and 10 years of follow-up, respectively.[19]

Comparing MTA with biodentine, the study by Awawdeh et al. reported a success rate of 93.3% after 3 years, where the only failure was a tooth treated with white MTA (6.6%) in terms of DPC, however, they mentioned that all teeth treated with white MTA had a color change, unlike those treated with biodentine, which did not have a color change.[12,13,20] Parinyaprom evaluated results at 54 months, where MTA had a success rate of 92.6% and biodentine 96.4% in none, but again MTA showed a grayish color change in 55% of the teeth treated with said material, while BD had no changes. Katge et al. reported 100% success with both Biodentine and MTA after 1 year.

Finally regarding to type of restoration, some studies have stated that the provisional material used and the time elapsed between the DPC and placement of the definitive restoration can influence the clinical outcome of the procedure.[15,18] The inadequate quality of definitive restoration and the presence of recurrent caries are the most relevant factors affecting long-term prognosis.[19]

Quality Assessment

All articles had a high risk of bias because, in at least one domain, the classification was "High." The results are shown in Figure 2 according to the parameters considered in the analysis.

Only four studies had a low selection bias; the performance bias was low in all articles because of the reasons explained in the methodology section of the present study. Only five articles blinded the examiners who evaluated the success or failure of the direct pulp cap procedure.[3,12,14,16,18,20,23,24]

Most of the articles have a high attrition bias because more than 10% of the patients did not come to their follow-up appointments. Finally, none of the studies used selective reporting, and all results fulfilled the article's purpose.[3,13,14,16,18–24]

Discussion

According to the results of the present study, the success of DPC procedures depends on some factors such as patient age, root maturation, pulp diagnosis, location and size of the exposure, control of hemostasis, capping material, and type of restoration.

These factors are crucial for the long-term success of DPC procedures. Previous studies have shown that DPC is an effective alternative for maintaining pulp vitality in certain cases.[3,12–23] However, its clinical application remains controversial owing to the complexity of diagnosis and the necessary therapeutic approach to achieve successful outcomes.[19]

For patient age and root maturation, various studies have reported that DPC has a higher success rate in young patients. This is due to the fact that the pulp tissue in these cases is more cellular, more vascularized, and with a larger apical foramen, which increases the possibility of repair and intensifies the maintenance of pulp vitality.[10,12,17,22,23] However, other studies have shown that the capacity for hard tissue formation within the pulp cavity is dependent on the angiogenic capacity of the tissue and that this capacity does not vary considerably between mature and immature teeth under normal physiological conditions.[26–28] These findings justify the results of Marques et al., who established from a clinical point of view that age is a poorly predictive factor for the success of DPC.[21] These results were supported by Matsuo et al., who divided their study groups into those over and under 40 years of age and did not find significant differences in success rate.[22] Other studies have also indicated that age or root maturation level is not determining factors for treatment success.[11,13]

Another critical factor is the pulp diagnosis, the correct diagnosis of the tooth to be treated is vital for the success of DPC.[15] Teeth that are commonly indicated for DPC are those with a diagnosis of reversible pulpitis and normal pulp, due to the belief that the outcome of DPC is more predictable.[3,10,11,13,16,18–21,23,24] However, it is challenging to accurately evaluate the difference between normal and altered pulps through clinical assessments, which also have a poor correlation with the histological status of the pulp.[10,12,15,22]

Parinyaprom et al. reported a high success rate in their study, despite including teeth with irreversible pulpitis, and the failures in the present study were evenly distributed among all groups with different pulp diagnoses.[12] In a study by Harms et al., all patients with spontaneous pain before treatment had good outcomes.[15] Matsuo et al. found no significant differences between patients who

Table 1: Studies selected and variables analyzed

Author	*Study design*	*Age*	*Sample size*	*Type of cavity*	*Size of exposure*	*Location of exposure*	*Pulpal diagnosis*	*Solution to achieve hemostasis*	*Hemostasis time*	*Capping material*	*Restoration*	*Follow-up period*	*Method of evaluation*	*Overall success*
Çalışkan M and Güneri P 2017[3]	Retrospective study	14–55 years	172 Mature teeth	Class I, class II, MOD, class III, class IV or class	Up to 1 mm and 1 ≥ mm.	Occlusal and axial	RP	Saline-soaked cotton pellet	Up to 10 min.	MTA; 97 or CH: 75	Provisionally restored with ZOE cement. After 2–7 days, a layer of resin-modified glass ionomer and composite or amalgam.	24–72 months	Clinically: CT, SP, P, M, PPD, SEPT Radiographically: IOPR, PCT	MTA: 85.9% CH: 77.6%
Bogen G et al. 2008[10]	Observational Study	7–45 years	15 teeth with immature apexes.	Class I and II	0.25–2.50 mm in diameter	Not specified	RP	5.25 % or 6.00% NaOCl	Between 1 and 10 min.	MTA	Provisionally restored the tooth with unbonded ClearfiI Photocore. Final restoration 5–10 days with composite.	9 years	Clinically: CT; Radiographically: IOPR	97.96%
Farsi N et al. 2006[11]	Clinical study	9–12 years	22 immature, 8 closed apices	Not specified.	Not specified	Not specified	RP	Cotton pellet with sterile saline.	5–10 min.	MTA	Provisional with IRM. 2 weeks after replaced with composite.	24 months	Clinically: CT, SP, P; Radiographically: IOPR, PCT	93%
Parinyaprom N et al. 2018[12]	Randomized controlled Trial	6–18 years	Incomplete (27) Complete (28)	Class I (O.B or O-B) or Class II	Up to 2.5 mm.	Not specified	NP, RP or IP	2.5% NaOCl	Within 10 minutes.	Proroot MTA: 30 and biodentine: 29	Restored with resin composite, amalgam, or stainless-steel crown	6–54 months Median interquartile 15.0 months	Clinically: CT, SP, M; Radiographically; IOPR, PCT	Proroot MTA 92.6% Biodentine 96.4%
Katge F and Patil DP 2017[13]	A split-mouth study	7–9 years	58 permanent molars	Not specified.	Less than 1 mm.	Not specified.	Vital pulp	Sterile saline. If bleeding persisted, 3% NaOCl.	Not specified.	Biodentine; 29 and gray MTA: 29	Permanent restoration with composite.	12 months	Clinically: SEPT; Radiographically: IOPR, PCT	Biodentine: 100% MTA: 100%
Asgary S et al. 2018[14]	Randomized clinical trial	12–75 years.	73 Mature teeth	Occlusal or Interproximal.	Not specified.	Occlusal and interproximal	NP, RP or IP	Irrigation sterile saline and0.2% chlorhexidine for 5 minutes.	Not specified.	CEM cement	The cement was then covered with light-cured glass ionomer. Cavity restored with composite.	1 year	Clinically: CT, SEPT; Radiographically: IOPR	3 months: 98.4% 12 months: 94.7%
Harms C et al. 2019[15]	Retrospective study	10–88 years	245 teeth	Not specified.	Not specified.	Not specified.	RP and IP	NaOCl 3% with cotton pellets.	Within 5 minutes.	Biodentine	Self-etched adhesive and flowable composite.	2.3 years	Clinically: CT, SP, P.	86.0%

(Contd...)

Table 1: *(Contd...)*

Author	*Study design*	*Age*	*Sample size*	*Type of cavity*	*Size of exposure*	*Location of exposure*	*Pulpal diagnosis*	*Solution to achieve hemostasis*	*Hemostasis time*	*Capping material*	*Restoration*	*Follow-up period*	*Method of evaluation*	*Overall success*
Mente J et al. 2010[16]	Retrospective, single-center-case-control study	8–78 years.	122 teeth 69 MTA (experimental) and 53 CH group (control)	Occlusal or cervical	Not specified	Not specified.	RP	A sterile cotton pellet soaked in 0.12% chlorhexidine solution	Less than 5 minutes	MTA: 69 teeth (experimental) and CH: 53 teeth (control)	Temporary restoration: with resin modified glass ionomer and IRM Permanent: Composite or crown	12–80 months	Clinically: CT, SP, M, PPD; Radiographically: IOPR	MTA: 78% CH: 60%
Cho S et al. 2013[17]	Retrospective study	Two groups (< 40 and >40)	175 teeth	Occlusal or Axial	Not specified.	Occlusal and axial	RP	2.5% sodium hypochlorite	Within 10 minutes	CH cement: 75 or white MTA: 63	The cement was then covered with light-cured glass ionomer. Cavity restored with composite.	9 days to 3.7 years	Clinically: CT; Radiographically: IOPR	MTA: 1 year: 89.9% 3 years: 67.4% Dycal: 1 year: 73.9% 3 years: 52.5%
Mente J et al. 2014[18]	Retrospective, Prospective, single-center-case-control study	8–78 years	229 teeth 170 MTA (experimental) and 59 CH (control)	Occlusal or cervical	Not specified	Not specified	RP	A sterile cotton pellet soaked in 0.12% chlorhexidine solution	Less than 5 min	MTA: 170 (experimental and CH: 59 (control)	Temporary restoration: with resin modified glass ionomer and IRM. Permanent: Composite or crown.	24–123 months	Clinically: CT, SP, M, PPD; Radiographically: IOPR	MTA: 80.5% CH: 59.0%
Ricucci D et al. 2023[19]	Retrospective study	12–33 years	225 mature teeth	Not specified.	<1, =1, >1 mm	Not specified	RP	NaOCL 1% irrigation and cotton pellets	Within 10 minutes	CH and Dycal	Provisional: IRM Final: Composite, amalgam, Indirect restoration	Up to 35 years	Clinically: CT, SEPT, M, SP; Radiographically: IOPR, PCT, BWR	1 year: 100% 5 years: 95% 10 years: 95% 20 years: 86% 35 years: 89%

(Contd...)

Table 1: *(Contd...)*

Author	*Study design*	*Age*	*Sample size*	*Type of cavity*	*Size of exposure*	*Location of exposure*	*Pulpal diagnosis*	*Solution to achieve hemostasis*	*Hemostasis time*	*Capping material*	*Restoration*	*Follow-up period*	*Method of evaluation*	*Overall success*
Awawdeh L et al. 2018[20]	Prospective longitudinal randomized controlled trial	16–59 years	68 mature teeth	Cavities involving 2 walls	Not specified	Not specified	RP	5 % NaOCl for 3 minutes	Within 6 minutes	White MTA: 34 or Biodentine: 34	Provisional; IRM Permanent restoration: Amalgam or resin composite	3 years	Clinically: CT, SP, M; Radiographically: IOPR	MTA: 6m: 93.5%; 1 year: 100%; 2 years: 100%; 3 years: 96% Biodentine: 6 months: 93.1%;1 year: 96%; 2 years: 100%; 3 years: 91.7%
Marques M et al. 2015[21]	Prospective study	Mean age of 36.1 years	64 teeth	Occlusal and proximal	Not specified	Not specified	RP	Water from a 2-way syringe of the dental unit and occasionally pressure applied with dry cotton pellets	Not specified	White MTA	Resin-modified glass ionomer liner on top of MTA, then total etch with phosphoric acid and composite as a filling	3.6 years	Clinically: CT, SP; Radiographically: IOPR, PCT	91.3%
Matsuo T et al. 1996[22]	Clinical study	20–69 years	44 teeth	Not specified.	< 0.5 mm 0.5–1 mm 1–2 mm, ≥2 mm	Not specified	RP	10% NaOCl and 3% H2O2	Not specified.	Calcium hydroxide-based cement	Temporarily restores with glass ionomer cement. Permanent restoration performed at least 3 months later	Up to 51 months	Clinically: CT, SEPT, SP; Radiographically: IOPR	81.8%
Lipski M et al. 2018[23]	Clinical study	11–79 years	112 teeth	Occlusal, Proximal or cervical	Not specified.	Occlusal and axial	RP	2% NaOCl, 2% CHX or sterile saline	Not specified	Biodentine	Final: Composite	Up to 1, 5 years	Clinically: CT, SEPT, SP; Radiographically: IOPR	82.6%
Ballal N et al. 2022[24]	Single-center randomized controlled trials	≥18 years	96 Mature teeth	Not specified.	Not specified.	Not specified	RP	Control group: Saline solution Experimental Group: 2.5% NaOCl	Not specified	MTA	Temporary restoration with resin modified glass ionomer and IRM. Composite or crown as soon as possible	Minimum 1 year	Clinically: CT, SEPT, SP, P; Radiographically: IOPR	NaOCl: 89% Saline: 55%

BWR, bitewing radiograph; CH, calcium hydroxide; CT, cold testing; IOPR, intraoral periapical radiograph; IP, irreversible pulpitis; M, mobility; NP, normal pulp; P, palpation; PCT, parallel; PPD, periodontal probing depth; RP, reversible pulpitis; SEPT, sensitivity to electrical pulp testing; SP, sensitivity to percussion

Articles	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome of assessment (detection bias)	Incomplete outcome data (attrition bias) (1 year)	Selective reporting (reporting bias)
Çalışkan M. et al. 2016.[3]						
Bogen G. et al. 2008.[10]						
Farsi N. et al. 2006.[11]						
Parinyaprom N. et al. 2018.[12]						
Katge F. et al. 2017.[13]						
Asgary S. et al. 2018.[14]						
Harms C. et al. 2019.[15]						
Mente J. et al. 2010.[16]						
Cho S. et al. 2013.[17]						
Mente J. et al. 2014.[18]						
Ricucci D. et al. 2023.[19]						
Awawdeh L. et al. 2018.[20]						
Marques M. et al. 2015.[21]						
Matsuo T. et al. 1996.[22]						
Lipski M. et al. 2018.[23]						
Ballal N. et al. 2022.[24]						

Fig. 2: Assessment of ROB among the studies using Cochrane risk bias

reported a prolonged response to cold and those with a shorter response duration.[22] Similar results were reported by Asgary et al., who found no correlation between initial pulpal inflammation status and success at one-year follow-up.[14]

The size of pulp exposure is a critical factor in direct pulp capping, as it impacts the success rate of the treatment.[11,14,16,20,21,23] Most of the reviewed authors did not mention the size of pulp exposure in their protocols, but those who do recommend that DPC be performed in cases up to 1 mm in diameter to ensure success. Matsuo et al. concluded that, as the size of the exposure increased, the success rate decreased. Their results showed that groups with pulp exposure >1 mm and <2 mm had a success rate of 77.8%, which was lower than that of the groups with exposure of up to 0.5 mm and the group with exposure between 0.5 and 1 mm, with a success rate of 84.2 and 86.7%, respectively.[22] However, the difference was not statistically significant. Ricucci et al. stated that the failure in teeth with pulp exposures larger than 1 mm was 2.51 times higher than that of teeth with exposures smaller than 1 mm and 1.97 times higher than that of 1 mm exposures.[19] In contrast, Parinyaprom et al. found that DPC is possible in pulp exposures not greater than 2.5 mm, with a success rate of 94.5%, and failures occurring only in 0.5 mm diameter exposures.[12] Similarly, Caliskan did not find a significant difference in treatment success when comparing pulp exposures larger and smaller than 1 mm in diameter, but Bogen et al. observed that with multiple pulp exposures larger than 2 mm, reparative dentin exhibited a more aggressive formation pattern and there was increased calcification of the pulp chamber and root canal.[3,10]

The location of pulpal exposure is another factor that can influence treatment success.[16–18,21] This is because the proximal dentin of class II cavities is more permeable than the pulpal floor, making it difficult to achieve adequate isolation of the axial

exposure, complete removal of caries, placement of the covering material, and sealing of the cavity. Therefore, the prognosis of occlusal pulp exposure is more favorable.[16–18] However, no significant difference was found between proximal and occlusal exposures; that is, the location did not affect the success of the treatment as long as the affected tissue was completely removed.[3,23,29] Therefore, it is important to consider the location of pulp exposure when selecting the pulp-covering approach, but the most critical factor for treatment success is the complete removal of the affected tissue.[29]

Pulpal bleeding is a controversial topic in direct pulp capping, as its significance as an indicator of pulpal status and treatment success remains a matter of debate.[22] While some studies have suggested a correlation between increased bleeding and inflammation/infection, others have questioned its reliability and proposed alternative factors that may contribute to the success or failure of direct pulp capping.[27,30] Excessive bleeding from tissues is usually synonymous with pulp with poor or no recovery capacity, and uncontrolled pulpal bleeding is considered by most authors as indicative of irreversible pulpitis.[16,18,31–33] The clinical appearance and time for pulpal bleeding control are clinical characteristics of healthy pulp, but they do not correspond to histological characteristics and are therefore subjective.[10,12,13,16,18] The maximum time limit for hemostasis used in the selected studies was 10 minutes, although some authors recommend achieving hemostasis within 5 minutes.[3,10,12,17,34] The success rate of DPC was significantly lower in cases with profuse bleeding, but the degree of bleeding was not related to the size of the pulp exposure.[22] The presence of an extra pulpal clot between the exposure site and covering material can interfere with the repair process and increase inflammation and bacterial infection.[35] The use of disinfectants for pulp bleeding control in DPC has been questioned, as they may inhibit the attachment of the covering material and the differentiation of odontoblasts from dental pulp stem cells.[30,36]

However, the capping material used in the DPC is a determining factor for its success. According to Cho et al., MTA is more effective than calcium hydroxide because of its higher mechanical strength, better adhesion to dentin, and lower water.[16–18,36] In comparative studies, MTA demonstrated higher success rates than calcium hydroxide, as reported by Caliskan et al. (85.9 vs 77.6%) and Mente et al. (78 vs 60%).[3,16]

Biodentine, another calcium trisilicate-based material, has shown similar results to MTA in terms of DPC success.[12,13,20] The studies by Parinyaprom et al., and Katge et al. and Awawdeh et al., have reported success rates ranging from 92 to 100% for both materials.[12,13,20] Biodentine offers advantages in terms of easy manipulation, better sealing, and faster hardening, as well as superior physical-mechanical properties, with greater resistance to compressive forces that simulate dentin.[12,36] Mineral trioxide aggregate and biodentine are alkaline materials that prevent the growth of microorganisms and promote reparative dentin formation. Additionally, they stimulate the release of transforming growth factor-beta 1 (TGF-b1), which promotes odontoblastic differentiation.[31] In general, most failures in DPC occur in the first few months and the trend stabilizes in subsequent months.[12,13,20]

The type of restorative material used can influence the success of the DPC. Harms et al. used amalgam, composite resin, and glass ionomers and highlighted that the latter had the lowest success rate when used as a restorative material for prolonged periods.[15] Ricucci et al. stated that the failure of VPT in the groups that used varnish for amalgam was 2.86 and 4.06 times higher than that in the groups that used glass ionomer and IRM, respectively.[19] Mente et al. considered the time elapsed for the placement of a definitive restoration to be an important factor in the prognosis of DPC.[18] As the waiting time increases, the success rate decreases. This decrease has also been reported by Barthel et al. and Al-Hiyasat. This may be due to the lower protection against microleakage offered by a temporary material or contamination during replacement with a definitive restoration.[37]

However, Matsuo et al. recommended waiting 3 months after DPC to have a presumptive prognosis of the treatment and perform the final restoration in successful cases, as in their study, the results between 3 and 18 months of follow-up were similar.[22] In general, most failures in DPC occur in the first few months and the trend stabilizes in subsequent months.[12,13,20]

Regarding performance bias, the blinding of participants and personnel was consistently considered low across all studies, highlighting the importance of considering contextual factors and practical limitations when assessing biases in clinical studies. However, the high risk of bias identified in most of the included studies, with at least one domain classified as high, indicates the potential limitations of the study design or implementation, which could affect the validity and reliability of the findings. For instance, most studies exhibited high attrition bias, indicating that a substantial proportion of patients did not attend their follow-up appointments, which could have introduced bias and affected the generalizability of the results. The present study has a limited number of large randomized controlled trials that met the selection criteria, which could render the present study unrepresentative of the entirety of the available research on direct pulp capping, thereby limiting the generalizability of the results to clinical practice. Overall, the analysis of the risk of bias underscores the need for careful interpretation of the study findings and consideration of the potential limitations. Future studies should aim to address the identified biases and employ strategies to minimize their impact on the results while adhering to rigorous methodological standards to enhance the credibility and applicability of scientific research.

Further studies are required to confirm the findings of this review, but these studies must improve their methodologies to reduce bias and obtain robust results. To avoid omitting important information for future analyses, it is necessary to include more details of the procedures performed, such as the use of rubber dams, specification of apical formation, size and location of the exposure, reason for exposure, method of carious lesion removal, cavity disinfection, hemostasis time and method, time of restoration, type of material used, and pulp diagnosis. These factors are crucial for interpreting the results. Moreover, future studies on DPC should consider all the aforementioned criteria with longer follow-up periods and a larger sample size to evaluate their long-term effectiveness, especially with calcium trisilicate-based materials.

Limitations

Regarding the limitations of the study, the present study has a limited number of large randomized controlled trials that met the selection criteria, which could render the present study unrepresentative of the entirety of the available research on direct pulp capping, thereby limiting the generalizability of the results to clinical practice. Finally, the review only included studies published

in English, which may have excluded relevant studies published in other languages.

Conclusion

The evidence presented in this review suggests that DPC has a high and predictable success rate in permanent teeth with carious exposure to reversible and irreversible pulpitis. Currently, MTA and Biodentine have better long-term results in DPC than in $Ca(OH)_2$, which is why they should be used instead of $Ca(OH)_2$. Definitive restoration within a short period improves long-term prognosis.

Authors Contribution

JFGS: conceptualization, methodology, supervision, project administration, writing original; MGR: validation, investigation, resources, writing and editing; MRA and VDBR: validation, investigation, resources; JGP: methodology, validation, writing; JCB: conceptualization, data curation, validation, visualization.

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