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Management of pulp canal obliteration: systematic review of case reports

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ABSTRACT

Introduction: Pulp canal obliteration (PCO) is a sequel to dental trauma and usually affects the anterior teeth of young adults. In most cases, it goes undetected for at least one year after trauma. Discoloration of the crown is a frequent finding. Although pulp necrosis (PN) is a potential latter complication, it was an uncommon finding in several studies. Establishing a treatment plan for a tooth diagnosed with this condition is a difficult assignment. Considering that up to 24% of traumatized teeth develop some degree of canal obliteration, it is crucial that clinicians are aware of the treatment possibilities for these cases.

Aim: The aim of this systematic review of case reports was to determine what clinical approach should be implemented in traumatized teeth with PCO and to propose a new clinical decision-making algorithm.

Materials and Methods: An electronic search strategy was performed in Pubmed, EBSCOhost and LILACS. There was no restriction regarding the publication year. Only anterior permanent teeth with PCO due to dental trauma were included. Regarding the clinical approaches, only teeth managed with a “watchful waiting” approach, with tooth bleaching or with root canal treatment (RCT) were included. A qualitative analysis of the results was made.

Results: Twenty case reports were selected, resulting in a total of 27 patients. The number of traumatized teeth diagnosed with PCO was 33 (18 with PPCO and 15 with TPCO). The “watchful waiting” approach was the most implemented clinical strategy. The prevalence of PN in this sample was 36,36%. For teeth diagnosed with PN, non-surgical RCT was performed in 10 teeth and surgical RCT in one tooth. The guided endodontics technique was performed in 6 teeth and the conventional technique in the remaining 4. Prophylactic endodontic treatment was only performed in two teeth for aesthetic reasons. For the cases managed with external bleaching, the combined technique was the most common option.

Conclusion: Within the limitations of this review, a “watchful waiting” approach should be implemented in asymptomatic teeth with PCO without evidence of periapical pathology. In the presence of aesthetic concerns, external bleaching should be the first treatment option. If endodontic complications are detected, there are several endodontic strategies and imaging exams that can help clinicians treating calcified canals.

Keywords: Pulp Canal Obliteration, Tooth Injuries, Watchful Waiting, Tooth Bleaching, Root Canal Treatment

RESUMO

Introdução: A calcificação pulpar distrófica (CPD) é uma sequela pós-traumática que geralmente afeta os dentes anteriores de jovens adultos. Na maioria dos casos esta condição é detetada pelo menos 1 ano após o trauma. A descoloração dentária é um achado frequente. Apesar da necrose pulpar (NP) ser uma possível complicação tardia, esta mostrou ser pouco frequente em vários estudos. Estabelecer um plano de tratamento para um dente diagnosticado com esta condição não é uma tarefa fácil. Tendo em conta que até 24% dos dentes traumatizados desenvolvem algum grau de obliteração pulpar, é crucial que os médicos-dentistas estejam cientes das possibilidades de tratamento para estes casos.

Objetivo: O objetivo desta revisão sistemática de casos clínicos foi determinar qual a abordagem clínica que deve ser implementada em dentes com CPD após trauma e propor um novo algoritmo de decisão clínica.

Materiais e Métodos: Realizou-se uma pesquisa eletrónica nas bases de dados Pubmed, EBSCOhost e LILACS. Não houve restrição quanto ao ano de publicação. Apenas foram incluídos dentes permanentes anteriores com CPD devido a trauma dentário. Em relação às abordagens clínicas, apenas foram incluídos dentes tratados com uma conduta expectante, com branqueamento dentário ou com tratamento endodôntico. Foi realizada uma análise qualitativa dos resultados.

Resultados: Foram selecionados 20 relatos de casos clínicos resultando num total de 27 pacientes. O número de dentes traumatizados diagnosticados com CPD foi 33 (18 com calcificação parcial e 15 com total). A conduta expectante foi a abordagem clínica mais implementada. A prevalência de NP nesta amostra foi de 36,36%. Para os dentes diagnosticados com NP, o tratamento endodôntico não cirúrgico foi realizado em 10 dentes e o cirúrgico em apenas 1 dente. A técnica de endodontia guiada foi realizada em 6 dentes e a técnica convencional nos restantes 4 dentes. O tratamento endodôntico profilático foi apenas realizado em dois dentes por motivos estéticos. Para os casos tratados com branqueamento externo, a técnica combinada foi a opção mais comum.

Conclusão: Dentro das limitações desta revisão, uma conduta expectante deve ser implementada em dentes assintomáticos com CPD sem evidência de patologia periapical. No caso de haver preocupações estéticas, o branqueamento externo deve ser a primeira opção de tratamento. Caso sejam detetadas complicação endodônticas, existem várias estratégias endodônticas e exames imagiológicos que podem ser um bom auxílio para os médicos-dentistas tratarem canais calcificados.

Palavras-chave: Calcificação Pulpar Distrófica, Traumatismos Dentários, Conduta Expectante, Branqueamento Dentário, Tratamento Endodôntico

INTRODUCTION

Traumatic dental injuries (TDI) are a public health problem that requires an appropriate diagnosis, treatment planning and follow up to ensure a favourable outcome. Upper central and lateral incisors are the teeth most affected by trauma (1,2). After a TDI, different reactions of the dental pulp such as pulp necrosis, internal resorption or pulp canal obliteration can occur (3,4).

Pulp canal obliteration (PCO), also known as calcific metamorphosis, is a sequel to dental trauma and usually affects the anterior teeth of young adults (5). According to the American Association of Endodontists (6), calcific metamorphosis consists in a pulp response to trauma characterized by rapid deposition of hard tissue within the root canal and pulp chamber space**.** However, the exact mechanism of PCO is still unknown (7).

This condition may be noticed through tooth discolouration or as an incidental finding in routine radiographs (8,9). In most cases PCO is clinically recognized at least one year after the injury, in contrast with the 3 months for pulp necrosis (10)**.** Hence the importance of clinical and radiographic monitorization of traumatized teeth over time (11).

Frequently, the affected tooth shows a discolouration of the clinical crown that becomes darker than normal adjacent teeth**.** Yellow discolouration is more frequent, although the colour may also change to grey. This is a result of the increased dentine thickness, which leads to a reduced translucency of the crown (8,12)**.** The extent of calcification as well as the discolouration tend to get worse with time (3)**.** Several studies (8,12) have attempted to investigate the relation between grey discolouration of the tooth crown and pulp necrosis. The conclusion was that tooth discoloration has no diagnostic value regarding the assessment of the pulp condition (8,12)**.** Holcomb & Gregory (13) concluded that there seems to be no correlation between the amount of tooth discolouration and the degree of the obliteration.

It is generally accepted that sensibility tests of teeth with pulp obliteration are unreliable (8,12)**.** While some teeth with PCO show threshold values for electric pulp test (EPT) higher than teeth with a normal pulp, others give no response. This brings difficulties in pulp condition interpretation because a negative response to EPT does not automatically imply pulp necrosis (8).

Based on the results of the study of Oginni et al. (8)**,** teeth with complete pulp obliteration were more non-responsive to EPT than those teeth with partial pulp obliteration. Frequently, calcification of the pulp canal space develops in a coronoapical direction, first affecting the pulp chamber and then progressing to the root canal (7). Therefore, radiographically, the pulp canal space can be partially or totally obliterated (5). Several

histological studies came up with two important conclusions: the first one was that even when the entire canal space seems to be obliterated on radiographs it was possible to detect a portion of the remaining pulp space (14), and the second was that pulp from teeth with PCO were not able to demonstrate any inflammatory component indicative of a pathologic process when clinical and radiographic signs of pathology were absent (15).

It is generally accepted that the incidence of PCO is dependent on the type of luxation injury and the stage of root development (7). Andreasen et al. (10) concluded that the greater the damage to the pulp, the lower the chances are of the pulp surviving. After luxation injuries, PCO was found to be more common in immature teeth, while pulp necrosis was more prevalent in teeth with complete root formation (10). A study of Oginni et al. (3) tried to understand if there was any difference between the frequency of partial or total obliteration and the injury type and the result was not statistically significant.

Although pulp necrosis is considered a latter complication of PCO, it was an uncommon finding in several studies (7). The incidence of pulp necrosis in permanent teeth with PCO ranges from 1% to 16%, values that were computed by studies with an average observational period from 3.4 to 16 years (10,12,13). In a more recent study (8), the prevalence of pulp necrosis in 276 teeth with PCO was 27,2%. Robertson et al. (12) suggested that the risk of developing pulp necrosis in teeth with PCO increases over time while the accessibility for endodontic intervention decreases.

Establishing a treatment plan for a tooth diagnosed with calcific metamorphosis is a difficult assignment (8). The question arises as to whether a more invasive approach should be implemented or a conservative one, based on watchful waiting, if the tooth is asymptomatic. The clinician is faced with two options: initiate a prophylactic root canal treatment (RCT) to prevent a difficult or barely impossible endodontic treatment, in case of pathology, or just control the tooth over time for the possibility of development of signs and symptoms (7,12). While some authors recommend endodontic treatment as soon as PCO is diagnosed radiographically, most of the literature supports that prophylactic endodontics as a routine treatment approach is not justified (7). Instead, it is recommended that these teeth should be monitored clinically and radiographically and that root canal treatment should only be initiated following the development of periapical disease or clinical symptoms (5,8). These considerations are based on the relatively low incidence of pulp necrosis and the overall success rate of nonsurgical RCT in teeth with PCO, which has been shown to be around 80% (16).

Regardless of this more common outcome, it is important to emphasize that the negotiation of severe calcified canals is a tremendous challenge for practitioners (9,17). If it becomes necessary, referral to a specialist endodontist is always an option (18). The key to

successfully solving cases of PCO is doing a proper diagnosis and a careful planning, using new technologies and appropriate instruments, sufficient knowledge of tooth anatomy and of radiographic techniques, coupled with patience (9,17). A surgical approach to the management of PCO has also been advocated but this strategy should only be implemented when conservative attempts to access the canal have failed or have been inefficient (18).

Considering that up to 24% of traumatized teeth develop some degree of canal obliteration and the inherent potential resulting discoloration, it is crucial that clinicians are aware of treatment possibilities for these cases (5,19). As PCO may lead to a decrease in translucency and a darker crown, these alterations can be a challenge in obtaining an aesthetic outcome in the anterior region (20). Just one discoloured tooth is enough to compromise the entire smile harmony and the professional may be faced with the difficulty to match colour to the adjacent teeth (21).

Regarding aesthetic concerns of teeth with PCO, the literature mentions four possible treatment options to manage discolouration: external or vital bleaching; prophylactic RCT followed by internal bleaching combined or not with external bleaching (inside-outside bleaching technique); internal and external bleaching without RCT and extracoronal full or partial coverage restorations (7). Considering the concept of maximum preservation of tooth structure, some authors prefer an external bleaching approach instead of alternatives such as prophylactic root canal therapy, veneer or crown (21,22). Despite that, the use of ceramic or resin composite veneers is considered a minimally invasive restorative procedure, when compared to the placement of a crown (23).

Overall, it is more common that teeth with PCO remain healthy and functional, with no clinical symptoms or changes at the periapical area (8,13). The discolouration of the clinical crown and pulp necrosis are the main sequels of PCO (12).

The aim of this systematic review of case reports was to determine what clinical approach should be implemented in traumatized teeth with PCO. Based on the results of this review and on the most recent literature, a new clinical decision-making algorithm was proposed.

MATERIALS AND METHODS

The present systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement.

Focused question

Initially, a PICO specialized framework was used to define the search strategy considering:

1. Population: Anterior permanent teeth with pulp canal obliteration as a sequel to dental trauma.

2. Interventions: "Watchful waiting" approach, conservative approach with tooth bleaching, surgical or non-surgical root canal treatment.

3. Comparison: Was not applicable in this study.

4. Outcomes: Aesthetics (tooth colour), signs and symptoms of pulp and periapical condition.

Other variables, such as stage of root development and apical closure and progression of the pulp calcification were also searched and, if present, described.

This review aimed to answer the following focused question: "What clinical approach should be adopted in teeth diagnosed with pulp canal obliteration after trauma?".

Search Strategy

For the identification of studies to be included in this review, an electronic search strategy was performed for MEDLINE via Pubmed, Dentistry and Oral Sources Database via EBSCOhost and LILACS via Virtual Health Library, up to May 2020. There was no restriction regarding the publication year.

Furthermore, additional records were identified by hand-searching through reference lists of the articles found in the primary search.

The following combinations of search terms, DeCS/Mesh terms and Boolean connectors was used:

Pubmed search until 2020.05.31: 639 records

(“tooth injuries”[MeSH Terms] OR tooth injury OR dental traumatology OR dental trauma OR dental injury OR tooth trauma) AND ("tooth calcification"[MeSH Terms] OR tooth calcification OR “dental pulp calcification”[MeSH Terms] OR dental calcification OR pulp canal obliteration OR pulp obliteration OR pulp calcification OR pulp canal calcification OR dystrophic calcification OR calcific metamorphosis OR “tooth discoloration”[MeSH Terms] OR tooth discoloration OR dental discoloration) AND (treatment OR therapy OR “treatment outcome”[MeSH Terms] OR management OR outcome OR prognosis OR “conservative treatment”[MeSH Terms] OR conservative treatment OR conservative approach OR watchful waiting[MeSH Terms] OR watchful waiting OR wait and see OR tooth bleaching[MeSH Terms] OR bleaching OR whitening OR endodontics OR endodontic treatment OR “root canal therapy”[MeSH Terms] OR root canal therapy OR root canal treatment) NOT ("in vitro techniques"[MeSH Terms] OR “in vitro”)

EBSCOhost search until 2020.05.31: 152 records

(tooth injury OR tooth trauma OR dental trauma OR dental injury OR dental traumatology) AND (tooth discoloration OR dental discoloration OR tooth calcification OR pulp canal obliteration OR pulp obliteration OR pulp calcification OR pulp canal calcification OR dystrophic calcification OR calcific metamorphosis) AND (treatment OR therapy OR management OR prognosis OR outcome OR conservative approach OR conservative treatment OR watchful waiting OR wait and see OR bleaching OR whitening OR endodontics OR endodontic treatment OR root canal treatment OR root canal therapy) NOT “in vitro”

Using the Boolean/phrase search mode expanded to related words and equivalent subjects.

Virtual Health Library search until 2020.05.31: 213 records

(mh:("tooth calcification") OR tw:(tooth calcification) OR mh:("dental pulp calcification") OR tw:(pulp canal obliteration) OR tw:(pulp obliteration) OR tw:(pulp calcification) OR tw:(pulp canal calcification) OR tw:(dystrophic calcification) OR tw:(calcific metamorphosis) OR mh:(“tooth discoloration”) OR tw:(tooth discoloration) OR tw:(dental discoloration)) AND (tw:(dental traumatology) OR mh:("tooth injuries") OR tw:(tooth injury) OR tw:(dental trauma) OR tw:(tooth trauma) OR tw:(dental injury) OR tw:(treatment) OR tw:(therapy) OR mh:(“treatment outcome”) OR tw:(management) OR tw:(outcome) OR tw:(prognosis) OR mh:(“conservative treatment”) OR tw:(conservative treatment) OR tw:(conservative approach) OR tw:(watchful waiting) OR tw:(wait and see) OR mh:("tooth bleaching") OR tw:(bleaching) OR tw:(whitening) OR tw:(endodontics) OR tw:(endodontic treatment) OR tw:(root canal therapy) OR tw:(root canal treatment)) AND NOT (mh:("in vitro techniques") OR tw:("in vitro"))

Eligibility Criteria

This systematic review considered as inclusion and exclusion criteria the following items:

Inclusion criteria

1- Clinical studies (randomized controlled trials, controlled clinical trials, prospective, retrospective or cross-sectional studies, case reports and case series) of patients without restriction of age, gender or sample size.
2- Anterior permanent teeth with pulp canal obliteration as a sequel to dental trauma.
3- Immature or mature teeth with open or closed apex.
4- The extent of the pulp obliteration was whether partial or complete.
5- Radiograph from the time of PCO diagnosis.
6- Teeth managed with a “watchful waiting” approach (no treatment implemented).
7- Teeth managed with a conservative approach with tooth bleaching, including pre and post treatment photographs.
8- Teeth treated with surgical or non-surgical root canal treatment.
9- Articles written in English, Portuguese or Spanish.

Exclusion criteria

1- In vitro studies, conference abstracts, editorials, commentaries or review articles.
2- Studies that dealt with primary teeth.
3- The reason of obliteration was not specified.
4- The cause of obliteration was other than trauma.
5- Patients submitted to orthodontic treatment before, during or after trauma.
6- Teeth with active or treated caries lesions.

Study Selection

The process of selection of the studies comprised several steps. At first, the duplicate studies were removed. Then, the titles and abstracts of all identified reports were independently screened by two review authors (CC, AV). When studies apparently met the inclusion criteria and when the abstract was not available or was insufficient to correctly assess validity, the full texts of this articles were obtained and independently analysed by two authors (CC, AV). Inclusion ambiguities were discussed and resolved by consensus between the same two authors. When agreement was not obtained, a third author (JR) was consulted. Finally, the studies that did not meet the inclusion criteria were excluded.

Data Collection and Analysis

Two authors (CC, AV) independently extracted data from the selected studies using standardized data extraction forms. Disagreements and technical uncertainties were resolved by discussion.

The extracted data included author(s), year of publication, country of origin of the study, study design, age and gender of the patient, tooth diagnosed with PCO, tooth in process of root development and apical closure, information about the trauma (type of injury and time elapsed between trauma and PCO diagnosis), associated symptoms and signs (including tooth colour, swelling and sinus tract), response to diagnostic tests (pulp sensibility and percussion tests), PCO classification, periapical diagnosis, clinical approach implemented, description of the treatment procedures, follow-up period and the assessed outcomes.

Owing to the heterogeneity of the case reports, the results could not be statistically assessed and, therefore, a meta-analysis was not attempted.

The outcomes varied across the studies. To summarize the main findings of the case reports, only the most common outcomes of each type of intervention were included in the analysis.

Quality Assessment

The methodological quality of the included studies was evaluated adapting the Joanna Briggs Institute Case Reports Critical Appraisal Tool (24). To synthesize the results of this evaluation, the tool proposed by Murad et al. (25) for evaluating the methodological quality of case reports and case series was assessed.

RESULTS

Study Selection

Electronic search resulted in a total of 1004 studies. Hand search identified 7 potentially relevant records. After removing duplicates, 897 articles remained. The titles and abstracts were screened and 833 irrelevant studies were excluded. 64 full texts were assessed for eligibility and 44 reports were excluded from the review at this stage. In the end, 20 articles were included. **Figure 1** describes the studies' selection process.

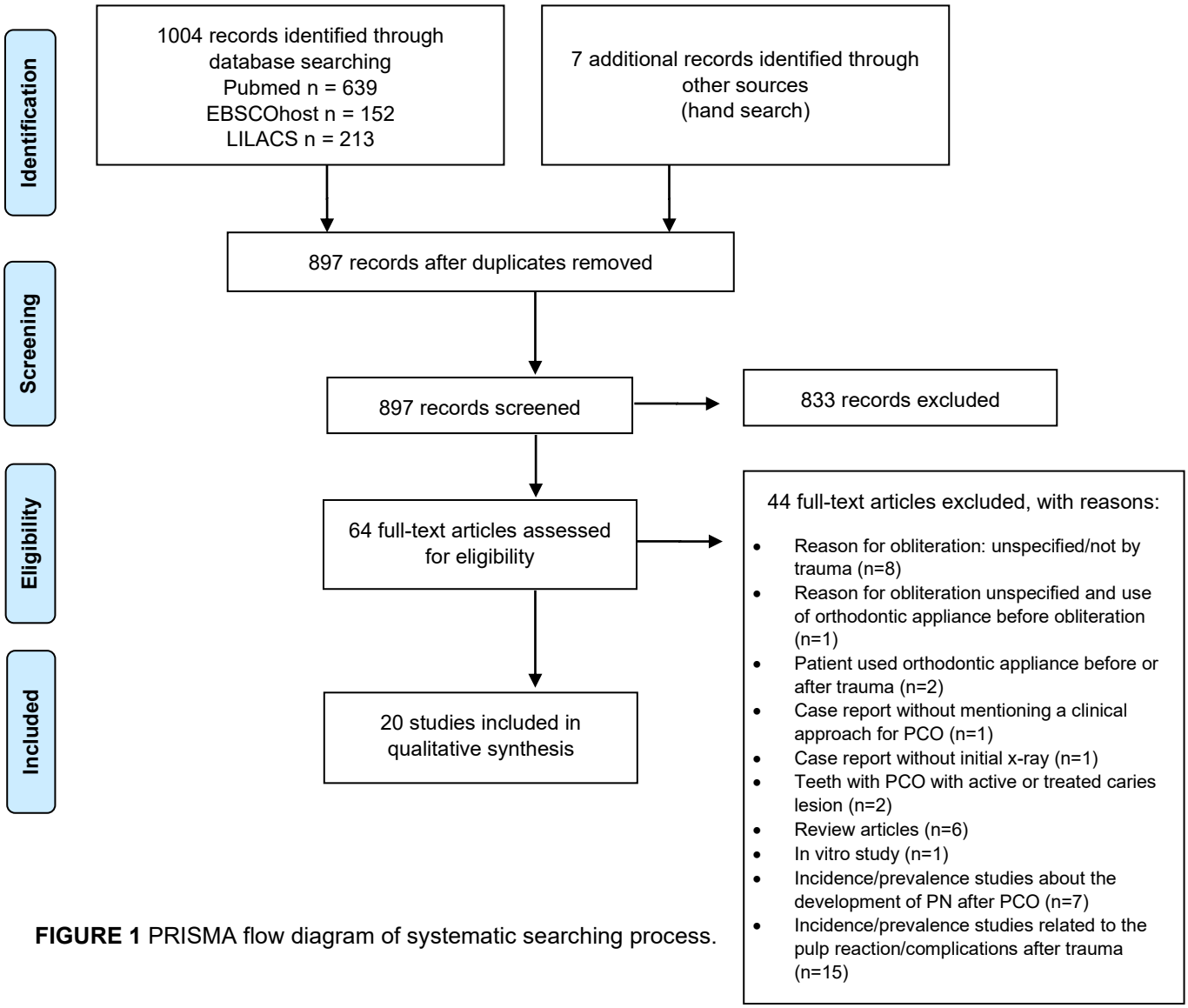

FIGURE 1 PRISMA flow diagram of systematic searching process.

Study characteristics

The 20 articles selected, which were all case reports, resulted in a total of 27 case studies. These reports were included because studies with a higher level of evidence that address treatment options for teeth diagnosed with PCO due to trauma that met the eligibility

criteria have not yet been conducted. For this reason, a systematic review of case reports was carried out.

The case reports were submitted to a methodological quality assessment, data extraction and analysis. The characteristics of the included studies, demographic data, clinical signs and symptoms and diagnostic tests are described in **Table 1.**

The articles selected were published between 1985 and 2019. Most of the studies were carried out in Brazil (n=8) and in the USA (n=4), followed by India (n=2) and Germany (n=2). The remaining ones were from Italy, Netherlands, Switzerland and Saudi Arabi.

Quality assessment

The methodological quality of each included study was assessed using the JBI Critical Appraisal Tool for Case Reports (24). This tool provides an approach to evaluate the quality of case reports based on eight leading explanatory questions. There are four possible responses: yes, no, unclear or not applicable. Considering that two of the leading questions of this tool are mostly relevant to cases of adverse drug events, an adaptation of these questions was made.

Thus, the quality of each case report was evaluated according to the following 8 parameters: patient's demographic characteristics, history of trauma, patient's current clinical condition, diagnostic tests or methods and the results, intervention(s) or treatment procedure(s), follow-up period, outcome and takeaway lessons.

To summarise the results of this appraisal, another methodological quality tool for case reports and case series were assessed (25). A score of 1 and 2 was attributed to each main question. The questions deemed most critical in the specific clinical scenario of this review received the higher score. If the case report clearly responded to the leading question, the respective parameter received a "yes" (total score); if the information provided was incomplete or not clear, the parameter received an "unclear" (half score); if it was not possible to find the information, the parameter received a "no" (a score of zero). After the judgement of each parameter, the scores were added and the studies were classified as: high quality (score=13); medium quality (score 11-12,5) and low quality (score ≤10,5).

Methodological quality assessment is summarized in **Table 2** and described in detail in **Appendix Table 1.** For the 20 case reports included, 2 was evaluated with high quality, 7 with medium quality and 11 with low quality. The studies scored particularly poorly on the following items: patient's demographic characteristics, history of trauma and diagnostic tests/methods and their results.

TABLE 1 Characteristics of the included studies, demographic data, clinical signs and symptoms and diagnostic tests

Reference	Country Study design	Case No.	Age (Y) and gender of patient	Tooth (Stage of root development)	Trauma		Crown Discolouration (Shade)	Symptoms	Percussion tenderness	Pulp sensibility tests	
					Type of injury	Time of injury				Thermal	Electric
Kwon, 2019 (23)	USA Case report	1	NR	21	NR	NR	Yes (Cervical and Middle: D3 Incisal: A2)	NR	NR	NR	Pos
Aldaijy & Alsahaly, 2018 (26)	Saudi Arabia Case report	2	36 Female	11	NR	20 y ago	Yes (Cervical: A3.5 Middle: A2)	No	NR	NR	NR
Connert et al., 2018 (27)	Switzerland Case report	3	51 Male	31	NR	>30 y ago	Yes (Yellow)	Yes	Yes	Neg	Neg
				41	NR	>30 y ago	Yes (Yellow)	Yes	Yes	Neg	Neg
Lakinepally et al., 2018 (28)	India Case Report	4	35 Male	11	NR	3 m ago*	Yes (NR)	Yes	Yes	Neg	Neg
Lara-Mendes et al., 2018 (29)	Brazil Case report	5	26 NR	21	NR	13 y ago	NR	Yes	Yes	Neg	Neg
Mourad et al., 2018 (30)	Germany Case Report	6	8 Female	11 (Immature, open apex)	Concussion	1 y ago*	No	No	No	Cold: Pos	NR
Tavares et al., 2018 (31)	Brazil Case report	7	43 Female	11	NR	25 y ago	Yes (Yellow)	Yes	Yes	Neg	Neg
		8	24 Female	11	Luxation	>11 y ago	Yes (Yellow)	NR	Yes	NR	NR
				21	Luxation	>11 y ago	NR	No	NR	NR	NR
				22	Luxation	>11 y ago					

TABLE 1 *(Continued)*

Reference	Country Study design	Case No.	Age (Y) and gender of patient	Tooth (Stage of root development)	Trauma		Crown Discolouration (Shade)	Symptoms	Percussion tenderness	Pulp sensibility tests	
					Type of injury	Time of injury				Thermal	Electric
Krastl et al., 2016 (32)	Germany Case report	9	15 Male	11	NR	7 y ago	Yes (NR)	Yes	Yes	Cold: Neg	Neg
Raghuvanshi et al., 2015 (33)	India Case Report	10	26 Male	21	NR	5 y ago	Yes (NR)	Yes	No	Neg	Neg
		11	21 Male	11	NR	2 y ago	Yes (NR)	NR	No	Neg	Neg
Biagi, 2014 (34)	Italy Case report	12	9 Male	21 (Immature, open apex)	Avulsion	6 m ago	No	No	NR	Pos	
Lise et al., 2014 (19)	Brazil Case report	13	24 Female	11	NR	10 y ago	Yes (Yellow)	NR	NR	Neg	NR
		14	35 Male	21	NR	20 y ago	Yes (Yellow)	NR	NR	Neg	NR
		15	25 Female	11	NR	11 y ago	Yes (NR)	No	NR	Neg	NR
Gomes et al., 2013 (35)	Brazil Case Report	16	8 Male	11 (Immature, open apex)	Intrusion	7 m ago	NR	NR	NR	NR	NR
				21 (Immature, open apex)							
Ramos et al., 2013 (36)	Brazil Case report	17	33 Male	11	NR	>10 y ago	Yes (NR)	No	NR	Pos	Pos
Sacchetto et al., 2011 (37)	Brazil Case report	18	8 Female	21 (NR)	Intrusion	18 m ago	No	NR	NR	Cold: Neg Heat: Neg	NR

TABLE 1 *(Continued)*

Reference	Country Study design	Case No.	Age (y) and gender of patient	Tooth (Stage of root development)	Trauma		Crown Discolouration (Shade)	Symptoms	Percussion tenderness	Pulp sensibility tests	
					Type of injury	Time of injury				Thermal	Electric
Silva & Muniz, 2007 (38)	Brazil Case report	19	19 Female	21	NR	NR	Yes (Yellow)	No	NR	NR	NR
Muniz et al., 2005 (39)	Brazil Case report	20	48 Female	11	NR	≥12 y ago	Yes (Yellow)	No	NR	Neg	
Cleen, 2002 (40)	Netherlands Case report	21	34 Female	11	Uncomplicated crown fracture	25 y ago	Yes (NR)	NR	NR	NR	NR
Shuler et al., 1994 (41)	USA Case report	22	7 NR	11 (Immature, open apex)	Luxation and extrusion	10 m ago	No	Yes	Yes	Cold: Neg	Neg
Schindler & Gullickson, 1988 (42)	USA Case report	23	10 Female	11	Lateral luxation	6 m ago	NR	No	NR	Cold: Pos	Pos
				21							
		24	48 Male	11	NR	18 y ago	NR	Yes	Yes	Cold: Neg	Neg
		25	35 Male	21	NR	10 y ago	Yes (NR)	No	NR	Cold: Neg	Neg
Johnson et al., 1985 (43)	USA Case report	26	8 Male	11 (Immature, open apex)	Avulsion	1 y ago	NR	NR	NR	Neg	
				21 (Immature, open apex)	Intrusion	1 y ago	NR	NR	NR	Neg	
		27	8 Male	21 (Immature, open apex)	Avulsion	7 m ago	NR	NR	NR	Cold: Pos Heat: Neg	Neg

m, month(s); y, year(s); NR, not reported; Neg, Negative response; Pos, Positive response; *, second trauma

TABLE 2 Methodological quality assessment of the included studies.

Reference	1- Patient's demographic characteristics	2- Trauma history	3- Patient's current clinical condition	4- Diagnostic tests/methods and results	5- Intervention/ treatment procedure	6- Follow-up	7- Outcome	8- Takeaway lessons	Quality
Kwon, 2019	N	N	U	Y	Y	N	Y	U	Low
Aldaijy & Alsahaly, 2018	U	U	Y	U	Y	U	U	Y	Low
Connert et al., 2018	U	U	Y	Y	Y	N	Y	Y	Low
Lakinepally et al., 2018	U	U	Y	Y	Y	U	Y	Y	Medium
Lara-Mendes et al., 2018	U	U	U	Y	Y	Y	Y	Y	Medium
Mourad et al., 2018	Y	Y	Y	Y	Y	Y	Y	Y	High
Tavares et al., 2018	U	U	Y	Y	Y	U	U	Y	Low
Krastl et al., 2016	U	U	Y	Y	Y	Y	Y	Y	Medium
Raghuvanshi et al., 2015	U	U	Y	Y	U	N	U	Y	Low
Biagi, 2014	Y	Y	Y	Y	Y	Y	Y	Y	High
Lise et al., 2014	U	U	U	Y	Y	N	Y	Y	Low
Gomes et al., 2013	U	Y	N	U	Y	Y	Y	Y	Low
Ramos et al., 2013	Y	U	Y	Y	Y	Y	Y	Y	Medium
Sacchetto et al., 2011	U	Y	U	Y	Y	Y	Y	Y	Medium
Silva & Muniz, 2007	U	N	Y	U	Y	N	Y	Y	Low
Muniz et al., 2005	U	U	Y	Y	Y	Y	Y	Y	Medium
Cleen, 2002	U	Y	U	U	U	N	U	Y	Low
Shuler et al., 1994	U	Y	Y	Y	Y	Y	Y	Y	Medium
Schindler & Gullickson, 1988	U	U	U	U	Y	Y	Y	Y	Low
Johnson et al., 1985	U	Y	N	Y	Y	Y	Y	Y	Low

Y, Yes; N, No; U, Unclear

Patient demographics

The results of this review presented large heterogeneity. A total of 27 patients were selected. The age of the patients ranged from 7 to 51 years. 13 patients were male and 11 were female (no data on gender for three patients and on age for one patient).

The total number of teeth diagnosed with PCO included in this analysis was 33. Most of the teeth involved were maxillary incisors (n=31): 17 teeth were right central incisors, 13 were left central incisors and 1 tooth was a left lateral incisor. The other 2 were mandibular central incisors, one left and one right. At diagnosis, 8 teeth were still in the process of root development and apical closure. The majority of studies did not mention the type of injury. Two teeth had been exposed to a second dental trauma, ranging from 2 weeks (30) to 3 years (28) apart since the first trauma.

Signs and symptoms and diagnosis

Regarding the tooth discolouration observed at the time of the initial diagnosis, 18 teeth were discoloured and 4 teeth did not reveal any change of its colour. For the remaining teeth, this variable was not evaluated. For the teeth showing discolouration, the only colour observed was yellow (n=10). Only two studies assessed tooth colour using a shade guide (26) or a technology-based colour measuring device (23).

Table 3 describes the pulp and periapical diagnosis, clinical approach, follow-up period and assessed outcomes of the included studies. Periapical radiographs were the most used imaging exams for apical diagnosis. However, CBCT scan was performed on 4 patients to confirm the presence of apical periodontitis in 4 teeth with PCO (Cases No. 3, 5, 7, 9). Tenderness to palpation was only evaluated in 3 patients (Cases No. 8, 22, 24), which resulted in a positive response.

Based on the data provided by the articles, and through the analysis of the initial periapical radiograph of each tooth, the following criteria were used to establish the diagnosis of PCO, in order to standardize the results of this review: partial pulp canal obliteration (PPCO) was diagnosed when the pulp chamber or root canal was not recognizable or reduced in size; total pulp canal obliteration (TPCO) was diagnosed when both the pulp chamber and root canal were not recognizable radiographically. This evaluation was made by two authors (CC, AV) and, whenever a consensus was needed, a third author (JC) was consulted. For the 33 teeth with PCO, 18 had PPCO (54,5%) and 15 showed TPCO (45,5%).

TABLE 3 Diagnosis, clinical approach, follow-up period and outcome

Reference	Case No.	Tooth	Diagnosis		Clinical approach	Treatment procedures	Follow-up	Outcome
			PCO Type	Apical diagnosis				
Kwon, 2019 (23)	1	21	Total	Normal apical tissues	External bleaching	**Single-tooth in-office bleaching:** 2 sessions with 1 week interval, 45min, 38% hydrogen peroxide gel, gingival resin barrier + **Single tooth at-home bleaching:** 2 weeks, carbamide peroxide gel	Immediate	Tooth 21 presented a successful colour matching to the adjacent teeth (In cervical region:B1, Midle: C1, Incisal:A1)
Aldaijy & Alsahaly, 2018 (26)	2	11	Total	Normal apical tissues	Internal bleaching without RCT	**Walking bleach technique:** rubber dam; access cavity; glass ionomer cement base at the CEJ; 3 applications with 1 week interval of 35% hydrogen peroxide gel	2 w	Tooth 11 presented a successful aesthetic result and no evidence of periapical changes
Connert et al., 2018 (27)	3	31	Partial	Radiolucency (CBCT): Apical periodontitis	Non-surgical RCT	**Guided Endodontics:** 2 sessions with 2 week interval; CBCT and intra-oral scan; template; drill Ø0.85mm; 1% NaOCl; reciprocating file; $Ca(HO)_2$ dressing; vertically condensed gutta-percha, epoxy sealer	Immediate	Teeth 31 and 41 showed an adequate RCT
		41	Partial	Radiolucency: Apical periodontitis				
Lakinepally et al., 2018 (28)	4	11	Total	PL space widening: Apical periodontitis	Non-surgical RCT	**Conventional RCT:** 1 session; US BUC 1 tips; DG 16 explorer; DOM; EAL; crown down technique; 17% EDTA gel; 5.25% NaOCl; K-file size 8, C+ file size 8, ProTaper Next rotatory files up to size X2; ProTaper Next X2 gutta-percha, resin based sealer	3 m	Tooth 11 was asymptomatic and showed periapical healing
Lara-Mendes et al., 2018 (29)	5	21	Total	Radiolucency (CBCT): Apical periodontitis	Non-surgical RCT	**Guided Endodontics:** 2 sessions with 14 days interval; CBCT and intra-oral scan; template; drill Ø1.3mm; 2,5% NaOCl; EAL; K-file size 10, WaveOne Gold Medium reciprocating; $Ca(HO)_2$ dressing; hydraulic compression technique with gutta-percha, epoxy sealer	1 y	Tooth 21 was asymptomatic and showed a small alteration in the PL space
Mourad et al., 2018 (30)	6	11	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	Every 6 m during the first 2 y 3 y	Tooth 11 was asymptomatic and showed complete apical closure, increased root development, almost complete root canal calcification without evidence of periapical changes or discolouration

TABLE 3 *(Continued)*

Reference	Case No.	Tooth	Diagnosis		Clinical approach	Treatment procedures	Follow-up	Outcome
			PCO Type	Apical diagnosis				
Tavares et al., 2018 (31)	7	11	Total	Radiolucency (CBCT): Apical periodontitis	Non-surgical RCT	**Guided Endodontics:** 1 session; CBCT and gypsum model scan; template; drill Ø1.3mm; 2.5% NaOCl; EAL; K-file size 15, 30.01 and 30.05 rotatory NiTi Logic System; Tagger's hybrid technique, resin-based sealer	15 d	Tooth 11 was asymptomatic
	8	11	Total	Radiolucency: Apical periodontitis	Non-surgical RCT	After 1 unsuccessful canal location attempt through conventional RCT, the guided endodontics technique was performed **Guided Endodontics:** 1 session; CBCT and gypsum model scan; 3D printed template; drill Ø1.3mm; 2.5% NaOCl; K-file size 10, 30.01, 25.06, 30.05 and 40.05 rotatory NiTi Logic System; Tagger's hybrid technique, resin-based sealer	30 d	Tooth 11 was asymptomatic
		21	Total	Normal apical tissues	Watchful waiting	**Periodic examination**	Immediate	Teeth 21 and 22 were asymptomatic and had no evidence of apical pathology
		22						
Krastl et al., 2016 (32)	9	11	Partial	Radiolucency (CBCT): Apical periodontitis	Non-surgical RCT	**Guided endodontics:** 2 sessions with 4 weeks interval; CBCT and intra-oral scan; template; drill Ø1.5mm; 1% NaOCl; K-file size 10; EAL; rotatory instrumentation system up to 50.04 file; $Ca(HO)_2$ dressing; vertically condensed gutta-percha, epoxy sealer	15 m	Tooth 11 showed no clinical or radiographic signs or symptoms of apical pathology
Raghuvanshi et al., 2015 (33)	10	21	Partial	Sinus tract	Non-surgical RCT	**Conventional RCT:** 1 session; 17% EDTA; 5.25% NaOCl; K-file size 6, C+ files size 6 and 8, rotatory Protaper files up to F2	Immediate	Tooth 21 showed an adequate RCT
	11	11	Partial	Normal apical tissues	Prophylactic non-surgical RCT	**Conventional RCT:** 1 session; EDTA gel; K-file size 10 to 25, C+ file size 6 and 8, rotatory Protaper files up to F2; F2 Protaper Gutta-Percha point, epoxy sealer	Immediate	Tooth 11 showed an adequate RCT
Biagi, 2014 (34)	12	21	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	Yearly during the first 5 y 7,5 y 9,5 y 12,5 y	During the follow-up period, tooth 21 revealed continued root canal calcification and root development. After 12,5 years, the tooth showed total PCO, slight yellow discolouration of the crown and no evidence of periapical changes

TABLE 3 *(Continued)*

Reference	Case No.	Tooth	Diagnosis		Clinical approach	Treatment procedures	Follow-up	Outcome
			PCO type	Apical diagnosis				
Lise et al., 2014 (19)	13	11	Partial	Normal apical tissues	External bleaching	**Single tooth at-home bleaching:** 3 weeks, 1h/day, 10% carbamide peroxide gel	Immediate	Tooth 11 presented a successful colour matching to the adjacent teeth
	14	21	Total	Normal apical tissues	External bleaching	**Single-tooth in-office bleaching:** 9 sessions, 1h, 3x/week, 37% carbamide peroxide gel without gingival barrier	Immediate	Tooth 21 presented a successful aesthetic result
	15	11	Total	Radiolucency: Apical periodontitis	External bleaching	**At-home bleaching:** 9 days, 1h/day, 37% carbamide peroxide gel	Immediate	Tooth 11 presented a successful colour matching to the adjacent teeth
Gomes et al., 2013 (35)	16	11 21	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	7,5 y 9,5 y	During the follow-up period, teeth 11 and 21 revealed complete root formation and continued root canal calcification. After 9,5 years, both teeth showed total PCO without clinical or radiographic signs or symptoms
Ramos et al., 2013 (36)	17	11	Total	Normal apical tissues	External bleaching	In a 1st phase, **single-tooth in-office bleaching:** 1 session, 35% hydrogen peroxide gel, gingival barrier + **Single-tooth at-home bleaching**: 4h/day, 20% carbamide peroxide gel In a 2nd phase, **single-tooth in-office bleaching:** 1 session, 2 applications of 15 min, 35% hydrogen peroxide gel, gingival barrier	2 m 5 y	2 months after the 1st in-office bleaching, a 2nd bleaching session was considering. 5 years after bleaching, tooth 11 presented a successful aesthetic result and no evidence of periapical changes
Sacchetto et al., 2011 (37)	18	21	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	6 m 18 m 30 m	Tooth 21 revealed no evidence of discolouration nor periapical changes
Silva & Muniz, 2007 (38)	19	21	Total	Normal apical tissues	External bleaching	In a 1st phase**, single-tooth at-home bleaching:** 30 days, 6-8h at night; 16% carbamide peroxide gel In a 2nd phase, **single-tooth in-office bleaching only in the cervical region:** 2 sessions, 3 applications of 12 min, activation with halogen light in the first 2min, 35% hydrogen peroxide gel, rubber dam	Immediate	After at-home bleaching, tooth 21 presented a successful colour matching to the adjacent tooth in incisal and middle region but a higher saturation in the cervical region. After in-office bleaching, the saturation problem in the cervical region was solved and a successful aesthetic result was obtained
Muniz et al., 2005 (39)	20	11	Total	Normal apical tissues	External bleaching	In a 1st phase**, single-tooth in-office bleaching:** 6 sessions, 3 applications of 10min, activation with LED in the first 2 min, 35% hydrogen peroxide gel, rubber dam In a 2nd phase, **single-tooth in-office bleaching:** 1 session, the same protocol	15 m 30 m	15 months after the 1st bleaching phase, a slight recurrence of yellowish colour in tooth 11 was observed. 30 months after the 1st phase, tooth 11 presented a successful aesthetic result and no evidence of periapical changes

TABLE 3 *(Continued)*

Reference	Case No.	Tooth	Diagnosis		Clinical approach	Treatment procedures	Follow-up	Outcome
			PCO type	Apical diagnosis				
Cleen, 2002 (40)	21	11	Total	Normal apical tissues	Prophylactic non-surgical RCT and internal bleaching	**Conventional RCT** and then **walking-bleach technique**	Immediate	Tooth 11 revealed sub-obturation and a successful aesthetic result
Shuler et al., 1994 (41)	22	11	Partial	PL space widening and rarefaction: Apical periodontitis	Non-surgical RCT	**Conventional RCT:** 1 session; magnification and indirect fiberoptic lighting; EDTA gel; 2.5% NaOCl; K-files up to size 30; laterally condensed and warm gutta-percha, ZOE based sealer	6 m	Tooth 11 was asymptomatic, revealed complete root development and periapical healing
Schindler & Gullickson, 1988 (42)	23	11 21	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	1 y 2 y 3 y	Teeth 11 and 21 were asymptomatic and showed continued root canal calcification without evidence of periapical changes
	24	11	Total	Radiolucency: Apical periodontitis	Non-surgical RCT	**Conventional RCT:** 2 sessions with 1 week interval; K files; 5.25% NaOCl; laterally condensed gutta-percha, ZOE based sealer	6 m	Tooth 11 was asymptomatic and showed partial periapical healing
	25	21	Partial	Radiolucency: Apical periodontitis	Surgical RCT	After 2 unsuccessful canal location attempts, an apical surgery was performed. **Apical Surgery:** Triangular mucoperiosteal flap; retrofilling with amalgam; 4-0 silk sutures	1 y	Tooth 21 was asymptomatic and showed complete periapical healing
Johnson et al., 1985 (43)	26	11	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	6 m	Tooth 11 revealed continued root canal calcification, complete apical closure and no evidence of periapical changes
		21	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	6 m	Tooth 21 revealed further apical closure without evidence of periapical changes
	27	21	Partial	Normal apical tissues	Watchful waiting	**Periodic examination**	1 y 2 y	During the follow-up period, tooth 21 revealed continued root canal calcification and root development. After 2 years, the tooth showed complete apical closure, total PCO, slight yellow discolouration of the crown and no evidence of periapical changes

$Ca(HO)_2$, calcium hydroxide; CBCT, cone-beam computed tomography; CEJ, cementoenamel junction; DOM, dental operating microscopy; EAL, electronic apex locator; m, month(s); min, minute(s); NaOCl, sodium hypochlorite; PL, periodontal ligament; RCT, root canal treatment; US, ultrasonic; y, year(s); ZOE, Zinc Oxide Eugenol.

The reason for the detection of this condition varied across the studies: for 10 teeth, pulp obliteration was noticed because the patient's chief complaint was about the aesthetic appearance of the tooth; for 10 teeth, PCO was associated with pain; for the other 10, the diagnosis resulted from a periodic examination of the tooth since the trauma and for the remaining 3 it was an incidental finding during routine exams.

The pulp and periapical diagnosis, as well as the outcome assessment, were made considering the author's assumption and through the analyses of the diagnostic data provided by each case report (e.g. clinical signs and symptoms, response to tests, radiographs, photographs).This judgment was made by two authors (CC, AV) and, whenever needed, a third author (JR) was consulted.

Thereby, 12 teeth had PCO associated with pulp necrosis. Thus, the prevalence of PN in this sample was 36,36%. Only one tooth that developed PN had not been endodontically treated (Case No. 15). The prevalence of PN in PPCO and TPCO teeth is shown in **Table 4.** Overall, in 83,33% (n=10) of the referred teeth, the diagnosis of PN was based on the presence of apical periodontitis in a tooth non-responsive to sensibility testing.

TABLE 4 Prevalence of pulp necrosis (PN) in teeth with pulp canal obliteration (PCO)

PCO type	Number of teeth with PN (%)
PPCO (n =18)	6 (33,33%)
TPCO (n = 15)	6 (40,00%)
Total (n = 33)	12 (36,36%)

Clinical approach, follow-up period and outcome

The follow-up period of the studies ranged from immediate (right after the conclusion of the treatment or after PCO diagnosis) to 13 years. The clinical approaches implemented in the sample under study is summarized in **Table 5.**

TABLE 5 Summary of the clinical approaches implemented in teeth with PCO

Clinical approach	Number of teeth (%)
Watchful waiting	12 (36,36%)
External bleaching	7 (21,21%)
Internal bleaching without RCT	1 (3,03%)
Non-surgical RCT	10 (30,30%)
Prophylactic non-surgical RCT	2 (6,06%)
Surgical RCT	1 (3,03%)

Conservative management was adopted for 19 teeth, of which 12 underwent a “watchful waiting” approach and the other 7 underwent an external bleaching. The “watchful waiting” approach was the most implemented strategy. Non-surgical RCT was performed in 12 teeth. Two of them showed discolouration of the crown and were treated prophylactically by conventional access (Cases No. 11, 21) and the other 10 had symptoms or signs of periapical disease.

The number of sessions required to perform a non-surgical endodontic treatment in teeth with PN, based on the access technique and type of obliteration, are presented in **Table 6**. Additionally, in the referred teeth, the instrumentation was performed mainly with the association of K-files and rotatory instruments (60%).

TABLE 6 Number of treatment sessions related to type of PCO and access technique in teeth diagnosed with PN

Non-surgical RCT	Number of teeth	Type of PCO		Number of sessions	
		PPCO	TPCO	1 session	2 sessions
Conventional technique	4	2	2	3	1
Guided technique	6	3	3	2	4
Total	10	5	4	5	5

The outcomes varied across the studies **(Table 3),** but all teeth survived during the follow-up period.

Regarding the teeth managed with a “watchful waiting” approach for 6 months to 12,5 years (n=10), all diagnosed with PPCO, none of them showed evidence of periapical changes. Two revealed a slight yellow discolouration of the crown and 8 were going through a continued calcification of the root canal space. The stage of root development and apical closure at the time of PCO diagnosis is presented in **Table 1**. None of the 8 immature teeth with open apices developed pulp necrosis during the recall visits, of which 7 developed completely and one showed an almost complete apical closure (Case No. 26).

For the cases managed with external bleaching, the combined technique was the most common option **(Table 7).** The four patients who underwent external whitening with follow-up right after the conclusion of the treatment achieved a successful aesthetic result. In the two cases with a longer follow-up period, a second bleaching phase had to be performed. At the last recall visit, the aesthetic result was maintained (Cases No. 17, 20).

TABLE 7 External bleaching techniques performed in discoloured teeth with PCO

External bleaching technique	Number of teeth (%)
In-office bleaching	2 (28,57%)
At-home bleaching	2 (28,57%)
In-office + At-home bleaching	3 (42,86%)

All teeth submitted to non-surgical RCT (n=12) showed an adequate root canal treatment except for one that revealed a sub-obturation (Case No. 21).

For two of the cases, after unsuccessful attempts to locate the canal by using conventional RCT, the guided endodontics technique was chosen as the most appropriate treatment approach for one of the teeth (Case No. 24) and for the other an apical surgery was performed (Case No. 17).

DISCUSSION

As pulp canal obliteration is a frequent sequel of dental trauma, it is important to make informed evidence-based treatment decisions when managing teeth with this clinical condition. A systematic review of case reports about PCO after trauma was performed with the aim of determining what clinical approach should be adopted in these cases.

Several mechanisms other than dental trauma have been proposed as potential etiological factors of PCO, such as caries lesions, restorative procedures and orthodontic treatments (27)**.** For that reason, all cases involving these factors were excluded from this study.

The case reports that diagnosed TPCO or almost complete obliteration, and where a CBCT was performed, a pulp space was detected. These results supported the findings of previous studies (14), suggesting that a root canal showing complete radiograph obliteration does not mean that pulp space is absent. This fact is related to the low sensitivity of conventional radiographs. The utility of CBCT imaging was clearly borne out in this review. This tool was essential for the diagnosis of apical periodontitis in 4 teeth and for the treatment planning of all cases managed with the guided endodontics (27,29,31,32). However, CBCT must be used judiciously and should not always be requested in cases of PCO (9,44).

According to the findings of Abd-Elmeguid et al. (44), PCO may be clinically recognized as early as 3 months after trauma, but in most cases it goes undetected for at least 1 year (10). Although limited by the small number of observations of this current study, 10 teeth were routinely followed since the injury, with the first evidence of obliteration observed in 5 teeth between 6 (34) and 10 months (41) after trauma. For the remaining cases, PCO was undetected for 1 year or more.

Several prospective studies aiming to determine the incidence of pulp necrosis after PCO have been published over time (10,12,13). Most of them do not support the prophylactic endodontic treatment because the frequency of endodontic complications is generally low.

One major finding of this study was that a significant proportion of teeth with PCO without periapical pathology was managed with a “watchful waiting” approach (36,36%) and all of them remained functional and healthy during the follow-up period that ranged from 6 months to 12,5 years. Since data about clinical signs and symptoms and response to diagnostic tests (i.e. percussion and pulp sensibility tests) was missing in several cases, the periapical condition seemed to be the most reliable criterion to diagnose PN. In fact, PN occurred in 36,36% of teeth. It is worth noting that almost all teeth showing this endodontic

complication was tender to percussion, non-responsive to sensibility tests and had symptoms of pain.

Most authors (5,8,12,45) proclaim that root canal treatment is only indicated in teeth with PN evidenced by periapical pathology and/or clinical symptoms. Only one case (19) involving a tooth showing a periapical lesion was not endodontically treated because the patient did not develop pain or any other discomfort since the trauma. However, according to the indications mentioned above and to the guidelines of the European Society of Endodontology (ESE), RCT should have been performed (46).

The study of Cvek et al. (16) was the only one that investigated the prognosis of non-surgical RCT in teeth with PCO post-trauma. The conclusion was that conventional endodontic treatment of teeth with PCO and periapical disease is associated with a success rate of 80% after 4 years, with a higher failure rate in lower incisors. However, we must analyse these results with caution because the obturation of these root canals was performed with resin-chloroform and gutta-percha and some teeth showed caries lesions before treatment.

In this current study, iatrogenic accidents such as deviations and perforations were not detected in any of the teeth treated with the conventional endodontics technique and, in general, the obtained results were favourable. Soares de Toubes et al. (9) suggest several safe and feasible clinical strategies to manage anterior teeth with PCO, such as the request of a CBCT scan when it is really needed, the use of digital radiography, magnification with microscopy and ultrasonic tips. Nevertheless, when conservative attempts to locate the canal are unsuccessful, two other treatment options have been advocated in the literature: RCT with guided access (31,32) and apical surgery (18,45).

Regarding the guided endodontics, this technique was performed in 4 maxillary and 2 mandibular incisors with PCO and apical pathology (27,29,31,32)**.** For the upper incisors, drills with a diameter of 1.3mm or 1.5mm were used; for the lower ones, a diameter of 0.85mm was used. The CBCT exam requested for these cases showed that the root canal was only visible in the apical third of the root.

These results showed that this approach can be helpful in gaining access to maxillary and mandibular incisors with pulp obliteration and straight roots, where the access via conventional RCT was not predictably or was unsuccessful. Tavares et al. (31) mentioned that apical surgery, although being a more invasive approach, can be considered in some cases, for example, in severely curved canals where the guided endodontics cannot be performed. The guidelines of the ESE (25) suggest that when it is impossible to treat the tooth from within the pulp chamber, surgical endodontics can be performed. This surgical

approach can be successfully completed as evidenced by one of the cases of Schindler & Gullickson (42).

Consistent with previous reports (16,17), this study presents several cases that highlight the difficulty of treating teeth with pulp obliteration, though most of them were managed via non-surgical RCT. Regarding conventional access, the difficulty to locate the canal (31,42) and the significant removal of tooth structure during the access opening (28,33,40) were the most mentioned obstacles. With regard to guided endodontics, its main downside was the wear of the incisal edge to enable a straight-line access, that could not be avoided in 3 of the teeth (27,32). According to several authors (18,20), if the identification of the canal becomes too difficult, referral to a specialist endodontist is recommended.

It should also be noted that more sessions were required to perform RCT with the conventional technique than with the guided one. This result may be attributed to the fact that the chair time for the RCT with guided access is considerably reduced because the majority of time is spent on digital laboratory work (47). Several authors (27,29,31,32) advocated that conventional endodontics, when compared to the guided one, would have been associated with a high risk of iatrogenic errors or at least major removal of coronal and radicular tooth structure. However, the quantitative loss of tooth substance associated with the access cavity preparation from conventional or guided endodontics in calcified teeth has not yet been evaluated. Therefore, further research about this aspect needs to be performed to conclude which is the most appropriate and conservative treatment option for endodontic management of teeth with PCO.

Although crown discolouration is a common finding in teeth with PCO (14), the tooth colour was not assessed in all the included studies, hence it was not possible to correlate this clinical sign to the implemented treatment and the assessed outcome in many cases. Even so, when the discolouration was mentioned, some case reports referred different solutions to solve this aesthetic problem. In only two of the case reports (33,40), teeth without periapical lesion were submitted to prophylactic non-surgical RCT. In both cases, the endodontic treatment acted as a basis for an internal bleaching of the discoloured central incisor. Several authors (20,21) defend that internal bleaching is recommended when there is an aesthetic concern and RCT is required. However, as there was no indication for endodontic treatment in these two clinical cases, an external bleaching should have been considered first. Only if the tooth does not respond successfully to external bleaching, a prophylactic RCT followed by internal bleaching may be considered as a viable option (48,49).

Internal and external bleaching without RCT is another bleaching protocol described in the literature. It consists in preparing an access cavity with the removal of coronal dentine

followed by placement of a base on the floor of the access cavity, without considering endodontic intervention (7). This treatment strategy is not strongly supported by other scholars (7), however an internal bleaching without endodontic treatment was performed in the study of Aldaijy & Alsahaly (26). This was the patient's choice to solve the tooth discolouration, due to financial reasons.

The findings from this systematic review have helped ascertaining different external bleaching strategies used to solve patients' aesthetic discomfort related to teeth with calcified canals. Hydrogen and carbamide peroxide gels were the only products used, though in different concentrations. The association of at-home bleaching with in-office procedure was a frequent approach, although several studies have shown that there is no difference in the bleaching effect when this combined technique is used (50,51). There is a high heterogeneity observed among the cases managed with external bleaching due to the different follow-up periods and bleaching protocols, the varied number of clinical sessions or daily time use, the different product concentrations and the use or not of a light-activated system. For that reason, conclusions about the most efficient protocol to bleach discoloured anterior teeth with PCO cannot be drawn in this review.

According to several authors, external bleaching should be considered as the first clinical option to manage aesthetic problems in teeth with PCO, as it is the most conservative approach, allowing tooth structure preservation (19,36). Besides, it is easy to perform and is more affordable than other restorative strategies (49). However, bleaching progress can be slow because of the lower permeability of the calcified tissue, which can require a longer treatment time (21). Discoloured teeth may demand a different whitening protocol soon after the first bleaching strategy, when the intended results are not achieved. This is shown in the cases of Ramos et al. (36) and Silva & Muniz (38). Due to an eventual regression of the colour, the bleaching treatment may need to be repeated in a medium term (21), as proved in the case of Muniz et al. (39), where the same bleaching protocol was repeated after 15 months. Nevertheless, if an unsuccessful outcome is obtained, there is always the possibility to undergo a more invasive intervention such as the placement of a direct or indirect resin composite or ceramic restoration (12,21). Despite the overall results showing a successful outcome immediately after bleaching, the efficacy of this treatment in teeth with PCO, in the long term, remains unclear. Therefore, studies with a longer follow-up period must be carried out to assess the maintenance of the aesthetic result.

Due to the nature of dental trauma, it is difficult to conduct studies with higher clinical evidence to determine the effectiveness of different clinical approaches and to properly assess the prognosis of traumatized teeth diagnosed with PCO. Thus, the results of this study were based only on case reports, which are uncontrolled observational studies. This

type of studies is associated with a high risk of bias, which can be difficult to assess because the authors usually do not report interventions that failed. Given the unavailability of higher level evidence that met the inclusion criteria of this study, and since clinicians still need to make treatment decisions for patients showing this condition, the evidence of case reports can be helpful to guide clinical practice. It must be recognized that the results hereby presented are very heterogeneous and many of them derived from low quality case reports. Due to the few available data and partly incomplete description of the circumstances of the trauma and the initial diagnosis, it was not possible to make well-defined associations. Furthermore, the immediate or short-term follow-up period of several studies was another limitation to assess the outcome of each intervention.

With the aim of achieving better quality studies, conducting prospective studies is the ideal option. Alternatively, the reports from future case reports or case series should be standardized using, for example, the CARE guidelines (52), and include longer follow-up periods.

Based on the results of this current review and other studies (7,20), the following clinical decision-making algorithm is proposed, which could become a valuable tool to aid dental clinicians in making the proper treatment decision in cases of PCO. Treatment suggestions were made according to clinical and radiographic signs and symptoms, including signs of discolouration, as illustrated on **Figure 2.**

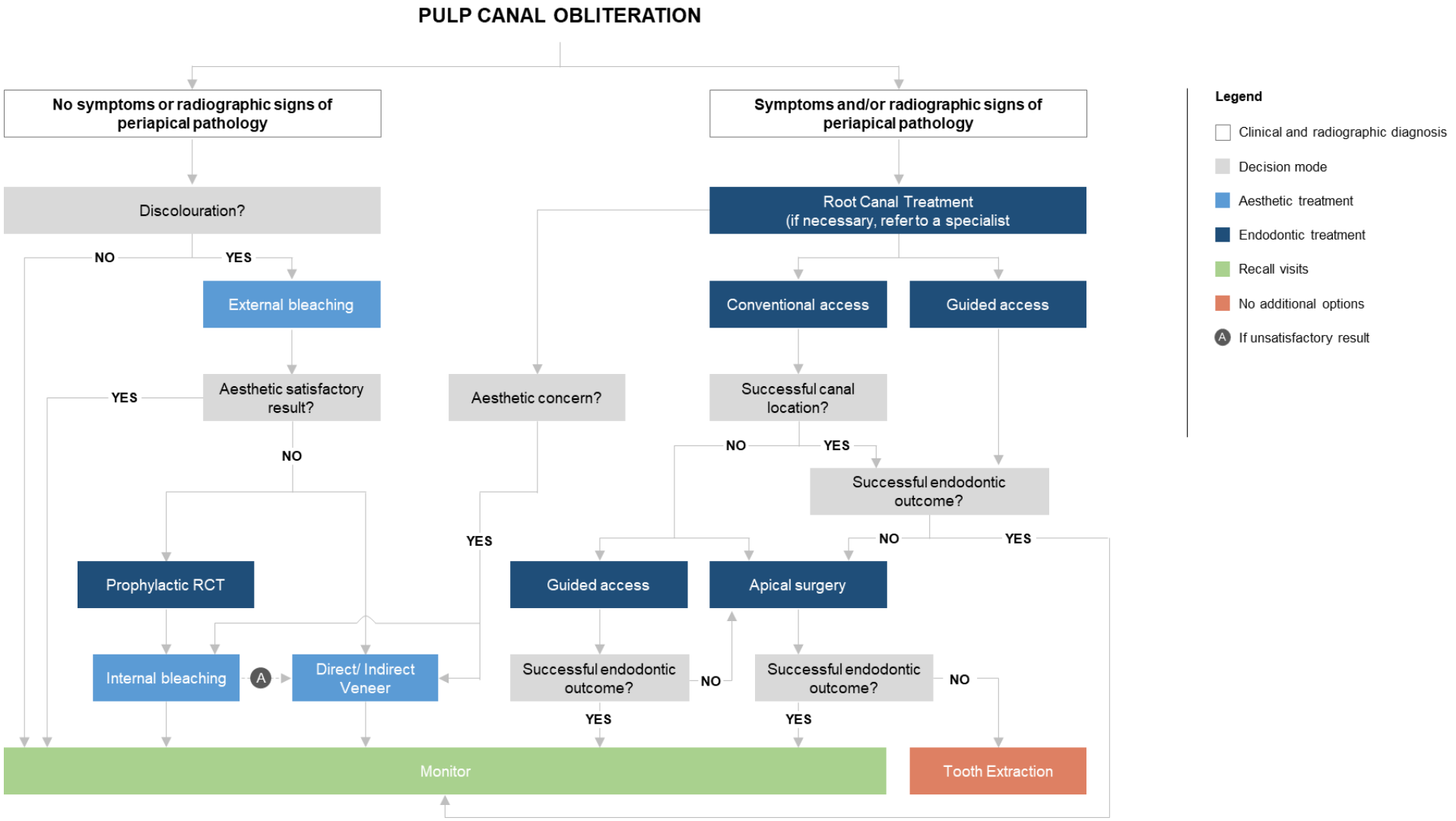

FIGURE 2: Clinical decision-making algorithm for teeth diagnosed with PCO.

CONCLUSION

This systematic review of case reports highlights the inherent limitations of data about the management of traumatized teeth with PCO, which could be useful to enhance future clinical studies.

The findings of this study suggest that prophylactic RCT approach should not be faced as a preventive intervention or as a first line of action to allow the treatment of discoloured healthy teeth. “Watchful waiting” was the most frequent clinical approach implemented. For all teeth diagnosed with pulp necrosis submitted to surgical or non-surgical RCT, treatment without iatrogenic errors was possible.

Hence, to manage asymptomatic teeth with PCO without evidence of periapical pathology, a conservative approach is advocated. For that purpose, periodic recall appointments are required. In the presence of aesthetic concerns, external bleaching should be the first strategy to be adopted. However, if endodontic complications are detected, there are several endodontic strategies (e.g. guided access) and CBCT scan views that can help clinicians treating calcified canals.

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APPENDIX

TABLE 1 Methodological quality assessment of the included studies.

	1- Patient's demographic characteristics	2- Trauma history	3- Patient's current clinical condition	4- Diagnostic tests/methods and results	5- Intervention(s)/ treatment procedure(s)	6- Follow-up	7- Outcome	8- Takeaway lessons	Total score	Quality
Description	Patient's age, sex and medical history	Information about the dental trauma: type and time of injury	Clinical signs (namely crown discolouration) and symptoms	Diagnostic tests or methods used (imaging exams, pulp sensibility tests and/or percussion tests)	Description of the intervention or treatment protocol in detail	Follow-up period	Assessed outcomes related to the aesthetic result and/or pulp and periapical condition	Key lessons learned from the case		
Score	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**1**	**13**	
Kwon, 2019	N 0	N 0	U 1	Y 2	Y 2	N 0	Y 2	U 0,5	7,5	Low
Aldaijy and Alsahaly, 2018	U 0,5	U 0,5	Y 2	U 1	Y 2	U 1	U 1	Y 1	9	Low
Connert et al., 2018	U 0,5	U 0,5	Y 2	Y 2	Y 2	N 0	Y 2	Y 1	10	Low
Lakinepally et al., 2018	U 0,5	U 0,5	Y 2	Y 2	Y 2	U 1	Y 2	Y 1	11	Medium
Lara-Mendes et al., 2018	U 0,5	U 0,5	U 1	Y 2	Y 2	Y 2	Y 2	Y 1	11	Medium
Mourad et al., 2018	Y 1	Y 1	Y 2	Y 2	Y 2	Y 2	Y 2	Y 1	13	High
Tavares et al., 2018	U 0,5	U 0,5	Y 2	Y 2	Y 2	U 1	U 1	Y 1	10	Low
Krastl et al., 2016	U 0,5	U 0,5	Y 2	Y 2	Y 2	Y 2	Y 2	Y 1	12	Medium
Raghuvanshi et al., 2015	U 0,5	U 0,5	Y 2	Y 2	U 1	N 0	U 1	Y 1	8	Low

TABLE 1 *(Continued)*

	1- Patient's demographic characteristics	2- Trauma history	3- Patient's current clinical condition	4- Diagnostic tests/methods and results	5- Intervention(s)/ treatment procedure(s)	6- Follow-up	7- Outcome	8- Takeaway lessons	Total score	Quality
Biagi, 2014	Y 1	Y 1	Y 2	Y 2	Y 2	Y 2	Y 2	Y 1	13	High
Lise et al., 2014	U 0,5	U 0,5	U 1	Y 2	Y 2	N 0	Y 2	Y 1	9	Low
Gomes et al., 2013	U 0,5	Y 1	N 0	U 1	Y 2	Y 2	Y 2	Y 1	9,5	Low
Ramos et al., 2013	Y 1	U 0,5	Y 2	Y 2	Y 2	Y 2	Y 2	Y 1	12,5	Medium
Sacchetto et al., 2011	U 0,5	Y 1	U 1	Y 2	Y 2	Y 2	Y 2	Y 1	11,5	Medium
Silva and Muniz, 2007	U 0,5	N 0	Y 2	U 1	Y 2	N 0	Y 2	Y 1	8,5	Low
Muniz et al., 2005	U 0,5	U 0,5	Y 2	Y 2	Y 2	Y 2	Y 2	Y 1	12	Medium
Cleen, 2002	U 0,5	Y 1	U 1	U 1	U 1	N 0	U 1	Y 1	6,5	Low
Shuler et al., 1994	U 0,5	Y 1	Y 2	Y 2	Y 2	Y 2	Y 2	U 0,5	12	Medium
Schindler and Gullickson, 1988	U 0,5	U 0,5	U 1	U 1	Y 2	Y 2	Y 2	Y 1	10	Low
Johnson et al., 1985	U 0,5	Y 1	N 0	Y 2	Y 2	Y 2	Y 2	Y 1	10,5	Low

Y, Yes; N, No; U, Unclear