A Review of Criteria for the Evaluation of Pulpotomy Outcomes in Mature Permanent Teeth

Marjorie Zanini, DD, MSc,*‡ Martine Hennequin, DCD, PhD, HDR,*§ and Pierre-Yves Cousson, DD, PhD*§

Abstract

Introduction: During the past decade, with a view to understanding pulp biology better and developing bioactive materials, pulpotomy has been reinvestigated as a definitive treatment in mature permanent teeth. Pulp chamber pulpotomy or coronal pulpotomy is widely used in deciduous and immature permanent teeth, and there is thus a need for trials to evaluate the outcome of pulpotomy as a therapeutic procedure on mature permanent teeth in accordance with Good Clinical Practice guidelines. This study aimed to review publications reporting the outcomes of pulpotomy when indicated as a definitive treatment in mature permanent teeth and to discuss the relevance of the criteria that could be used in clinical practice or research. Methods: A review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist was conducted on publications found by both PubMed and backward research. Results: Seven clinical trials, 9 cohort studies, and 15 cases reports have been included. Overall, goals, criteria for inclusion, and criteria for outcomes of pulpotomy varied among studies. The relevance and the reliability of the success or failure criteria of pulpotomy were discussed regarding the possible evolution of the radicular pulpal status that could be expected after pulpotomy. Finally, criteria for the evaluation of the outcome of pulpotomy are proposed. Conclusions: The use of standardized outcome criteria would facilitate further meta-analyses, aiming to assess whether pulpotomy should be considered as a true alternative therapy to root treatment. (J Endod 2016;42:1167–1174)

Key Words

Criteria, endodontics, outcomes, permanent Teeth, pulpotomy, review

Pulp amputation, or pulpotomy, is defined as a procedure in which part of an exposed vital pulp is removed, usually as a means of preserving the vitality and function of the remaining part (1). The rationale is to remove the portion of the pulp tissue that has undergone degenerative and irreversible changes and to leave behind healthy and vital tissue (2). Pulpotomy is essentially indicated as a treatment of normal pulp or reversible pulpitis associated with a carious lesion or after traumatic pulp exposure in primary teeth (3) and immature permanent teeth (4). In mature permanent teeth, full pulpotomy is actually only indicated as an emergency (routine) procedure before root canal treatment (RCT) (5, 6).

During the last decade, in relation with a better understanding of pulp biology and the development of bioactive materials, pulpotomy has been reinvestigated as a definitive treatment of mature permanent teeth. The advantages of maintaining pulp vitality are numerous; this strategy seeks to keep all the functions of pulp, especially the vascularization, innervation, immunocompetency, neurosensory, and proprioceptive functions of the tooth. The dentin-pulp complex would also continue to protect itself by stimulating the formation of tertiary dentin or a mineralized barrier against aggressions. Moreover, pulpotomy is technically less complicated, less time-consuming, and less expensive than RCT and could be indicated in difficult endodontic cases (7). If pulpotomy were considered an alternative to RCT, it would be necessary to define the outcome of pulpotomy and the criteria for evaluating the long-term results of pulpotomy in the same perspective as RCT.

This study aimed to review publications on pulpotomy as a definitive treatment in mature permanent teeth and to discuss the criteria that are necessary to evaluate the outcomes of pulpotomy for both clinical practice and further research.

Materials and Methods

A review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist was undertaken. The flow diagram of included records is shown in Figure 1. On November 16, 2015, 219 titles listed in PubMed from 1990 to 2015 were systematically selected using the following terms: [PULPOTOMY] AND [PERMANENT] AND [TEETH]. During screening of the abstracts, 2 investigators (M.Z. and M.H.) conducted the research on PubMed independently and for backward

<table>
<thead>
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<th>Significance</th>
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<tr>
<td>Pulpotomy in permanent teeth is a domain of interests in endodontics, but few studies have been conducted in clinical research. This review seeks to help clinicians and researchers to identify the numerous factors affecting the outcome of pulpotomy.</td>
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0099-2399/5 - see front matter

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http://dx.doi.org/10.1016/j.joen.2016.05.008
research. The criteria for exclusion were as follows: not in English; animal and \textit{in vitro} studies; reviews; comments; articles reporting pulpotomies on primary teeth, immature permanent teeth, traumatized teeth, or dens invaginatus; studies on vital pulp capping, partial excavation, or partial pulpotomy; articles related to general issues in pediatric dentistry; studies related to the use of formocresol; articles retracted by the journal’s editor; and trials in which the criteria for success or failure of pulpotomies were not reported. At the step of eligibility, all 3 authors agreed to exclude full-text articles that did not report which criteria were used to evaluate the outcomes of pulpotomy.

A first group of 28 articles was selected, and a backward search was performed from the references of these studies, which produced a group of 15 additional articles, 10 of which were eligible. Among the set of 38 eligible articles, the applied exclusion criteria were as follows: articles reporting short-term outcomes (8, 9), studies in which the numbers of immature or immature teeth could not be distinguished (10), \textit{in vitro} studies (11), duplicate reports (12), and 1 review (13). Two articles satisfying the inclusion criteria were published during the submission process of this article. One systematic review was excluded (14), and 1 prospective cohort study was included (15).

Finally, 31 articles were included: 15 case reports or case series (16–30), 9 cohort studies (15, 31–38), and 3 clinical trials and 4 randomized clinical trials (39–45).

**Results**

**Reported Outcomes of Pulpotomy**

This review included 7 observational cohort studies and 7 trials that provided the success rate for pulpotomy, which varied from 42%–100% (Table 1), whereas all 15 case series reported success. Meta-analysis was not undertaken because of the lack of common criteria to characterize the indications and outcomes of pulpotomy.

The problems questioned by the included studies differed greatly in terms of the initial pulpal diagnosis, material for pulp capping, interim restorative treatment, duration of the follow-up period, and the criteria for the outcome of pulpotomy (Table 1). In this situation, the formulation of a common answerable question (according to the Patient/Intervention/Comparator/Outcome statement) seems to be risky because only 2 studies were conducted under equivalent conditions (35, 37) but with small groups.

**Goals of the Studies**

Overall, the studies had 3 goals. In the first group, the outcomes after the use of different pulp capping materials were compared (18, 31, 39, 43), whereas other studies described the outcome of pulpotomy realized with a single material (16, 17, 22–24, 28, 30, 40, 44, 45). Different types of material were tested including bioactive materials such as calcium hydroxide with or without corticosteroid medications (18, 31, 32, 39, 40), materials such as calcium-enriched mixture cement (18, 23, 43, 44), mineral trioxide aggregate (16–18, 24, 30, 43), and Biodentine (Septodont, Saint-Maur-des-Fossés, France) (28). Certain authors tested a biological matrix platelet-rich fibrin membrane obtained after centrifugation of the patients’ own withdrawn blood (25, 29). Finally, the last group tested the impact of a new antiseptic material named \textit{Allium sativum} oil (19).

In a second group of studies, authors tested unusual clinical indications of pulp vitality therapy such as reversible pulpsitis associated with an apical radiolucency (20, 21, 33), both acute and chronic irreversible pathologies. In particular, studies investigated whether hyperplastic pulpsitis (32, 33), internal resorption (27), and osteosclerosis (33) could be treated with pulpotomy, whereas such diseases were indications for RCT.
The third group of publications gathered follow-up studies aiming to verify whether pulpotomy could be an alternative to RCT in a public health perspective (15, 34–38, 42–45).

Outcome Criteria for Pulpotomy

Generally, authors searched to ascertain whether pulpotomy led to the preservation of functionality of the tooth or pulp vitality. The methods and criteria to assess whether these objectives were achieved varied considerably among the studies (Tables 2 and 3). The terminology used to characterize the outcome of pulpotomy was binary, using the terms success or failure without any alternative. Moreover, in most of the cases, the authors made efforts to describe signs or symptoms that appeared after a pulpotomy, but these signs are not clearly categorized as evaluation criteria according to Good Clinical Practice in clinical research. Finally, it is generally agreed that a follow-up observation period is necessary to evaluate whether the outcome of pulpotomy has been reached. However, the follow-up duration varied among the studies, from 3 months to 29 years, and there was no agreement on the duration of the postoperative period that could be reliably related to a successful outcome of pulpotomy.

Discussion

Pulpotomy in permanent teeth is a domain of interests in endodontics, but few studies have been conducted in clinical research. This review stated that a meta-analysis would be premature. Gathering several studies with different inclusion criteria or outcomes would bias the interpretation of the resulting value for the weighted mean success rate, which could have negative effects. Reporting a high value for the weighted mean success rate could suggest that pulpotomy is an easy-to-apply procedure, whereas, in fact, many factors have to be controlled. Before considering pulpotomy among routine endodontic procedures, it is necessary to validate the indications for it and to validate the pertinent criteria that are necessary for evaluation of its outcome. Converging data from included studies suggested that pulpotomy could be recognized as one vital pulp therapy option in the near future. While awaiting more evidence-based studies, this review seeks to help clinicians and

<table>
<thead>
<tr>
<th>Questions</th>
<th>Study design</th>
<th>N</th>
<th>Follow-up duration</th>
<th>% success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Could teeth with carious pulp exposure and periapical radiolucency be treated by pulpotomy with calcium hydroxide in combination with corticosteroids? (31)</td>
<td>PC</td>
<td>30</td>
<td>Unknown</td>
<td>100</td>
</tr>
<tr>
<td>Could vital teeth with chronic partial pulpitis associated with deep painful carious lesions be treated by pulpotomy with calcium hydroxide alone or in combination with an antibiotic medicament? (39, 40)</td>
<td>CT</td>
<td>82</td>
<td>6 mo</td>
<td>71–76</td>
</tr>
<tr>
<td>Could teeth with hyperplastic pulpitis be treated by pulpotomy? (32)</td>
<td>PC</td>
<td>24</td>
<td>2 y</td>
<td>65</td>
</tr>
<tr>
<td>Could teeth with periapical involvement be treated by pulpotomy with calcium hydroxide? (33)</td>
<td>PC</td>
<td>26</td>
<td>6–9 mo</td>
<td>92</td>
</tr>
<tr>
<td>Is the outcome of pulpotomy on teeth with irreversible pulpitis affected by the interim restorative material? (41)</td>
<td>CT</td>
<td>18</td>
<td>6 mos</td>
<td>56</td>
</tr>
<tr>
<td>Could teeth that required root canal treatment be treated by pulpotomy with calcium hydroxide? (34)</td>
<td>RC</td>
<td>17</td>
<td>14–88 mo</td>
<td>94</td>
</tr>
<tr>
<td>Could teeth with irreversible pulpitis be treated by pulpotomy with MTA? (43)</td>
<td>RCT</td>
<td>179</td>
<td>1 y</td>
<td>95</td>
</tr>
<tr>
<td>Could vital teeth that required root canal treatment for deep caries or prosthetic reason be treated by pulpotomy with MTA? (35)</td>
<td>PC</td>
<td>32</td>
<td>1–24 mo</td>
<td>82</td>
</tr>
<tr>
<td>Could teeth with irreversible pulpitis be treated by pulpotomy with CEM? (42, 44, 45)</td>
<td>RCT</td>
<td>167</td>
<td>&gt;1 y</td>
<td>93</td>
</tr>
<tr>
<td>Could teeth with reversible pulpitis be treated with pulpotomy with MTA? (37)</td>
<td>PC</td>
<td>166</td>
<td>&gt;2 y</td>
<td>100</td>
</tr>
<tr>
<td>Could vital teeth that required root canal treatment be treated by pulpotomy with calcium hydroxide? (38)</td>
<td>PC</td>
<td>137</td>
<td>&gt;5 y</td>
<td>87</td>
</tr>
<tr>
<td>Could teeth with reversible or irreversible pulpitis with symptomatic deep caries be treated by pulpotomy with MTA? (15)</td>
<td>RC</td>
<td>273</td>
<td>&gt;2 y</td>
<td>93</td>
</tr>
</tbody>
</table>

GEM, calcium-enriched mixture; IRM, intermediate restorative material; MTA, mineral trioxide aggregate.

Discussion

Pulpotomy in permanent teeth is a domain of interests in endodontics, but few studies have been conducted in clinical research. This review stated that a meta-analysis would be premature. Gathering several studies with different inclusion criteria or outcomes would bias the interpretation of the resulting value for the weighted mean success rate, which could have negative effects. Reporting a high value for the weighted mean success rate could suggest that pulpotomy is an easy-to-apply procedure, whereas, in fact, many factors have to be controlled. Before considering pulpotomy among routine endodontic procedures, it is necessary to validate the indications for it and to validate the pertinent criteria that are necessary for evaluation of its outcome. Converging data from included studies suggested that pulpotomy could be recognized as one vital pulp therapy option in the near future. While awaiting more evidence-based studies, this review seeks to help clinicians and
TABLE 3. Methods of Evaluation and Assessment Criteria Used to Evaluate the Pulpal Vitality after Pulpotomy in Included Studies

<table>
<thead>
<tr>
<th>Method</th>
<th>Assessment criteria</th>
<th>Evaluation result</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical evaluation</td>
<td>Absence of clinical signs</td>
<td>Negative to percussion</td>
<td>16-18, 23, 24, 27, 29, 30, 33-38, 42-45</td>
</tr>
<tr>
<td>Pulp responsiveness to tests</td>
<td>Positive response to cold test</td>
<td>Positive response to pulp test after reintervention</td>
<td>20</td>
</tr>
<tr>
<td>Mineralization activity</td>
<td>Positive response after probing through the mineralized barrier</td>
<td>Presence of a mineral bridge tested by probing after intentional reintervention</td>
<td>32, 33</td>
</tr>
<tr>
<td>Radiologic evaluation</td>
<td>Periapical health</td>
<td>Absence of apical lucency</td>
<td>17, 23, 26, 29, 30, 32, 34-38, 41-45</td>
</tr>
<tr>
<td>Histologic evaluation</td>
<td>Lack of internal root resorption</td>
<td>Absence of canal obliteration</td>
<td>24, 25, 27, 33</td>
</tr>
<tr>
<td>Pulp tissue</td>
<td>Absence of inflammatory cells</td>
<td>Absence of necrosis tissue</td>
<td>16, 18</td>
</tr>
<tr>
<td>Internal resorption</td>
<td>Absence of granulation tissue</td>
<td>Absence of granulation tissue</td>
<td>19</td>
</tr>
<tr>
<td>Mineralization activity</td>
<td>Repairs or signs of repair of initial resorption</td>
<td>Presence of vacuole of osteoma</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Quality of mineral bridge: presence of cellular inclusions or tunnel defects</td>
<td>Presence of radio-opacity under pulp capping material</td>
<td>32-34, 37, 38</td>
</tr>
<tr>
<td></td>
<td>Complete or incomplete barrier</td>
<td>Disappearance of initial radiolucent area</td>
<td>20, 21, 25-27, 31, 33, 36, 42-45</td>
</tr>
<tr>
<td></td>
<td>Diffuse/focal calcifications</td>
<td>Disappearance of initial osteosclerosis</td>
<td>24, 27, 30, 32-34, 37, 38</td>
</tr>
<tr>
<td></td>
<td>Presence of a mineral bridge tested by probing through the mineralized barrier</td>
<td>Periapical health</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Mineralization activity</td>
<td>Mineralisation activity</td>
<td>32-34, 37, 38</td>
</tr>
</tbody>
</table>

*The types of the test used for pulp sensitivity were not detailed by the authors.

Researchers to identify the numerous factors affecting the outcome of pulpotomy in clinical practice.

Relevance of Inclusion Criteria

The evaluation of the efficacy of a treatment should be related to the diagnosis of a disease. However, several clinical trials evaluated the outcomes of pulpotomy in cases of carious pulpal exposure in vital teeth (21, 31, 34, 39). These criteria invite discussion. On the one hand, a carious lesion is not a diagnosis but rather a clinical sign. On the other hand, the term vital tooth includes different pulp diagnoses (reversible pulpitis and asymptomatic irreversible pulpitis), which differ greatly in terms of inflammation (46). Moreover, some authors consider that a “vital tooth” could be associated with periapical involvement (33), and others did not report the criteria they used to characterize a vital tooth (34). Finally, other authors prefer to exclude the non-vital teeth by controlling peroperatively the bleeding of the residual part of the pulp (36, 38). Such discrepancies among the inclusion criteria could bias the interstudy comparisons. Thus, it is of importance that further studies, aiming to evaluate the outcomes of pulpotomy, be designed to include cases using the diagnostic terminology approved by the American Association of Endodontists (46) in order to verify which diagnosis in mature permanent teeth can be treated by pulpotomy.

Relevance and Reliability of Criteria to Evaluate the Outcome of Pulpotomy

Functionality of the Tooth. The functionality of the permanent tooth was poorly defined among studies. There is general agreement to consider that a functional tooth is defined by clinical criteria, especially the presence of the tooth on the arch and the absence of pain (47).

Preservation of Pulp Vitality. Vitality in the radicular pulp is generally assessed by exploration of the nervous function of the coronal pulp, and the reliability of the electric and thermal tests was verified in teeth with a coronal segment. Whether thermal or electrical tests can be used to test the vitality of the root pulpal segments has not been shown (35). Moreover, the size of any coronal restoration and the depth of tertiary dentin could decrease the reliability of these tests. In some cases, thermal or electrical tests were applied on the radicular pulp segments through the dentinal bridge after a complete deposition of the material (22, 32, 33, 39, 40). There is no benefit from further intervention, and this procedure reduces the regenerative potential of the pulp and is not indicated in follow-up studies.

Because it is difficult to measure pulp vitality objectively, most of the studies used the presence of a periapical infection to assess pulp status; the signs may be clinical (tenderness to apical palpation and percussion, presence of a sinus tract, peripheral periodontal probing, swelling inspection, and palpation) or radiographic (periapical radiolucencies and radiographic signs of apical root resorption).
Consequently, postoperative pulp sensitivity testing is unreliable in pulpotomized teeth and could lead to an increased risk of false negatives. In clinical follow-up, it would be impossible to use objective criteria for pulp vitality, and the efficacy of the pulpotomy would be related more to the absence of signs of periapical inflammation or infection than the presence of vital radicular pulp tissue.

**Mineralization Activity.** It has generally been assumed that the mineralization activity of odontoblasts attests to the vitality of the pulp. Confronted with a chemical, physical, or thermal challenge, the odontoblast layer is locally destroyed, and new odontoblastlike cells are differentiated and secrete a new mineralized tissue (tertiary or reparative dentin forming a dentin bridge). This acts as a physical barrier against the challenge. These histologic mechanisms have been considered as repair reactions and are well described in the coronal part of the pulp (48, 49). The reactions of pulp repair have not been studied in the radicular section of the pulp; it has been assumed that the mineralization activity of odontoblasts was the same in the radicular section as in the coronal part. Two mineralization phenomena could be expected after pulpotomy. First, a mineral bridge is supposed to be formed under the section of the pulp. It can be detected clinically by inspection and probing after reintervention (32, 33, 39, 40), but drilling and material removal are harmful and are contraindicated in clinical follow-up studies. The quality of the observable mineral bridge after a pulpotomy is variable (50), and its radiographic detection is not reliable because of the low degree of mineralization or superposition of roots or restorative materials (32). Second, after a pulpotomy, obliteration of the canal lumen could reflect chronic pulpal inflammation. Canal obliteration has been sought in 6 studies (15, 25, 32–35, 43) but reported just twice (15, 25). Again, the radiographic evaluation of this activity is not reliable. As a result of this review, it can be stated that the presence of mineralization inside the canal could reflect either actual or past pulp vitality. However, the absence of radiographic signs is not a guarantee of the absence of vitality.

**Radiographic Evaluation.** It was generally assumed that the absence of pulpal infection could be related to the absence of periapical infection or external root resorption. External resorptions were reported in 2 studies (34, 43).

Absence of periapical infections was assumed when the clinical tests (axial percussion and periapical palpation and presence of a sinus tract) were negative and when there were no radiographic signs of apical infection (enlargements of periapical ligament and periapical osseous radiolucencies). For the assessment of the outcome of RCT, it was shown that the periapical status could be scored on 2-dimensional periapical radiographs from 0 to 4 with the periapical index developed by Ørstavik et al (51). However, in the set of included studies, the method of determining the size of the periapical lesion is not reported for some studies and differed widely among others. Some authors did not report any criteria for the presence of apical radiolucencies (17, 20, 21, 23–27, 29, 31–34, 37); others used subjective criteria (15, 23, 39, 41), and 1 study used a computerized densitometric ratio analysis (41). Moreover, among the studies using the periapical index (15, 30, 35, 36), few authors detailed the radiographic method (film radiography or digital radiography) for producing the images of the periapical area (35, 36).

The purpose of radiographic evaluation is to identify possible changes of the periapical status between 2 dates. This evaluation may be undertaken by 1 or several investigators, with the possibility of intra- and interexaminer variability. Consequently, the number of the investigators involved in the evaluation of the periapical index scores should be reported, and the internal and external reliability of the measure should also be described. Among the included studies, the number of investigators who performed the periapical radiographic evaluation was reported in 9 studies (15, 34, 36–38, 42–45). Five of them mentioned a calibration process (36, 42–45), and 2 reported a kappa value for intraobserver reliability (15, 36).

**Expected Evolution of Pulpal Status after a Pulpotomy**

Pulpotomy is an aggressive procedure that consists of sectioning and removing the coronal pulp tissue at the radicular canal openings. The postoperative reactions depend on the reparative potential of the residual radicular pulp and the hygienic conditions of the technical procedure. Theoretically, the expected complications of pulpotomy could be caused either by an inflammatory process or a bacterial infection.

The development of irreversible inflammation of the radicular parts of the pulp could occur either as an acute or chronic process. Irreversible acute radicular pulps could occur during the postoperative 2 months and would constitute an immediate adverse event. It would be characterized by the occurrence of spontaneous, intense, continuous, or intermittent pain (35, 41). Chronic radicular irreversible pulpitis constitutes a late adverse event. During a period of several months or years, the tooth remains totally asymptomatic or intermittently lightly sensitive. There are no clinical signs that can be objectively related to chronic irreversible pulpitis, but chronic inflammation could induce radiographic images of condensing apical periodontitis, canal obliteration (15, 25, 34), or internal root resorptions. The relevance of radiographic signs of internal root resorptions is open to discussion. According to certain authors, internal resorptions may be closely associated with the pulp capping material, especially calcium hydroxide, and such resorption can occur up to a year after the procedure (52). Internal radicular resorptions have been described in deciduous teeth (53, 54) but were not observed in permanent mature teeth (15, 24, 27, 30, 32–34, 37, 38).

After either acute or chronic pulp inflammation, bacterial contamination can lead to either acute or chronic infectious disease. Bacterial contamination can occur through the marginal gap of the coronal restoration, via the capping material, or through an accessory canal related to a periodontal pocket (Fig. 2). These adverse events may or may not be related to the pulpotomy procedure depending on the clinical case and the latency of their occurrence. The presence of external root resorption is the single, but not pathognomonic, sign of pulp infection that can be used after pulpotomy (34, 43). Other signs for the absence of pulpal vitality are related to periapical complications including tenderness to percussion and periapical palpation or the presence of a sinus tract. It is not known whether the evolution of pulp disease is the same in the radicular pulp as in the coronal chamber. Bacterial contamination could lead to either acute or chronic infectious disease, and by analogy with the reactions of the coronal pulp, 4 infectious disease conditions could be expected: acute or chronic apical periodontitis and acute or chronic apical abscesses.

The possible evolution of the pulpal status expected after pulpotomy and its treatment is represented in Figure 3. This figure highlights the paradox between the clinical and the biological points of view when considering evaluation of the outcome of pulpotomy. Biologically, after pulpotomy, the 3 outcome possibilities are healthy pulp, necrobiosis, and septic necrosis, and they must be treated differently. No signs or symptoms exist that can distinguish them clinically without invasive re-intervention with subsequent histologic analysis. Reintervention would affect the prognosis of the treatment or the future of the tooth and cannot be considered in follow-up studies aiming to evaluate the outcome of pulpotomy. Consequently, these 3 histologic entities should be fused into a single clinical one and that involves the risk/benefit ratio for the patient. For this reason, regular monitoring of any pulpotomized asymptomatic tooth is necessary.
Figure 2. Schematic representations of 2 ways for bacterial contamination after pulpotomy on a permanent tooth. R, restoration; PC, pulp capping material; RP, radicular pulp; PL, periodontal ligament; G, gingiva; AB, alveolar bone; AC, accessory canal. (A) A healthy tooth postoperatively. (B) Fracture of the restoration or a recurrent carious process led to the contamination of the marginal gap of the coronal restoration or of the capping material. (C) The presence of a periodontal pocket leading to exposure of the root dentin and to an accessory canal.

Figure 3. Possible evolutions of radicular pulpal status that could be expected after pulpotomy; signs and symptoms of each condition and therapeutic decisions (in frames).
Duration of the Follow-up Period

The observed latency for the appearance of complications in a tooth treated with pulpotomy would permit a pre- or postoperative inflammation or infectious process to be associated with the pulpotomy procedure. The duration of the follow-up period depends on the kinetics of adverse events. However, the initial result of pulpotomy could be engaged in the long-term if contamination were to occur because of the clinical or biological conditions of the tooth (root exposure, restorative fracture, and so on). Consequently, long-term follow-up studies should include criteria that would allow adverse events, possibly because of long-term postoperative contamination, to be distinguished from those directly related to a failure of the treatment.

Overall, a 6-month follow-up seems adequate for evaluation of the results of the treatment (32). For longer duration observation periods, the nature of the bacterial pathways needs to be described, with the use of criteria for marginal leakage of the restoration or root exposure.

Criteria for the Evaluation of the Outcome of Pulpotomy

If the outcome of pulpotomy is to be compared with that of a root canal filling, the criteria for evaluation of both treatments should be comparable. The debate on the categorization of the outcomes of endodontic treatment is still open (55, 56) and could be correlated with pulpotomy. The current concerns are, first, the use of a classification based on the dynamic nature of the apical condition and, second, to choose a follow-up period long enough to identify a need for retreatment for the benefit of the patient. There is no consensus on the terminology to be used for the evaluation of the outcome of RCTs. Some authors use terminology such as healing/healed/disease based on the disease status (47), whereas others refer to classifications like the categorizations success/failure or effective/uncertain/ineffective (55) that are related to the efficacy of treatment. This review reported that the outcome of pulpotomy could not be described with a binary categorization such as success/failure. The potential complications of pulpotomy can occur after the postoperative period. During this latency, the final outcome cannot be clearly assessed, and the term uncertain would be necessary to characterize treatments too recent to be assessed as success or failure or treatments for which all the diagnostic criteria could not be verified (inaccurate or indefinite outcome of pulp or periapical tests). Moreover, the healing/healed/disease classification cannot be used because pulpotomy would be indicated on vital teeth. Considering the previous list of criteria for the expected pulpal status after pulpotomy, we propose an adaptation of the terminology defined by Wu et al (55) to allow the outcome of RCT and pulpotomy to be described in similar terms (Table 4).

Limitations of the Study

The main limitation of this study is that only 1 research database was searched. However, the backward search that provided 15 additional records’ abstracts improved the exhaustiveness of the research. The inclusion of case reports and case series is the second limitation. All case reports were reporting success of pulpotomy, whereas none described failure, which clearly shows the existence of publication bias related to the authors’ positive expectations of the outcome of pulpotomy. Contradictory cases could enrich the scientific questions when they provide new arguments leading to understanding the reasons for failure.

TABLE 4. Proposed Criteria for the Evaluation of the Outcome of Pulpotomy

<table>
<thead>
<tr>
<th>Outcome of pulpotomy</th>
<th>Clinical criteria</th>
<th>Radiographic criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Success, effective pulpotomy</strong></td>
<td>Lack of pain declaration and Presence of the tooth and Sealing properties of the restoration</td>
<td>Absence of spontaneous pain and Absence of pain on chewing and Lack of swelling and Lack of swelling and sinus tract and Negative response to axial percussion test and Negative response to apical palpation test and Periodontal probing &lt;2 mm Absence of spontaneous pain and Absence of pain at chewing and Lack of swelling and Lack of swelling and sinus tract and Negative response to Apical palpation test and Periodontal probing &lt;2 mm Absence of spontaneous pain and/or Absence of pain at chewing and/or Lack of swelling and Lack of swelling and sinus tract and/or Negative response to axial percussion test and/or Negative response to Apical palpation test and/or Periodontal probing &lt;2 mm</td>
</tr>
<tr>
<td><strong>Uncertain outcome</strong></td>
<td>Lack of pain declaration and Presence of the tooth and Sealing properties of the restoration</td>
<td></td>
</tr>
<tr>
<td><strong>Failure, ineffective pulpotomy</strong></td>
<td>Lack of pain declaration and/or Presence of the tooth and/or Sealing properties of the restoration</td>
<td></td>
</tr>
</tbody>
</table>

PAI, periapical index; $T_0$, date of the treatment; $T_1$, date at the follow-up control.

Acknowledgments

The authors thank Professor Paul Riordan for corrections of the English language assistance.

The authors deny any conflicts of interest related to this study.

References