Introduction

Among other parameters, pre-existing pulpal and periapical conditions are considered to affect the outcome of root canal treatment (RCT), being more favorable for vital teeth than for necrotic teeth, and for primary than for retreatment cases [1,2].

In order to evaluate treatment success or failure, clinical and radiographic follow-up is needed. Clinical absence of signs and/or symptoms of treated teeth is easily verifiable in the short term, and suggests a good prognosis. When a radiolucent lesion is present before treatment, the long-term healing process can be evaluated using periapical radiographic images [3,4]. As an aid to clinicians, tools such as the periapical index (PAI), based on patterns of radiographic features, can be used to evaluate the absence, presence and/or evolution of chronic periapical periodontitis [5,6].

The main objective of root canal treatment is elimination or maximum reduction of microbial infection inside root canals, at least at the subclinical level [7,8]. Conventional root canal treatment can only reduce the number of microorganisms, and it is estimating that around 40-60% of residual microorganisms can remain [9]. In an attempt to improve intracanal cleanliness, antibiotics and other products can be used, but this can lead to resistance, making it necessary to search for new antimicrobial alternatives [10,11].

Photodynamic therapy (PDT) is a technique first developed 100 years ago to fight microbial infections [12,13]. In the field of dentistry, it has been used for the treatment of caries, periodontal disease, periimplantitis and several oral infections [14]. It is an antimicrobial treatment based on the chemical interaction of a non-toxic photosensitive agent activated by a low-potency light source with a specific wavelength, in the presence of oxygen. The photosensitive agent reacts with oxygen, producing reactive oxygen species (ROS), oxygen ions and free radicals. These products are toxic for target tissues, but do not affect the guest’s cells [15,16]. The main advantages of PDT are absence of resistance to repeated use, absence of allergic reactions, and strictly local effect, thereby avoiding any damage to adjacent tissues [17,18].

In the field of endodontics, PDT has been implemented as a treatment associated with conventional chemical-mechanical cleaning. Classic instrumentation and irrigation prior to PDT increase intracanal oxygen availability, break up biofilms, and consequently increase the susceptibility of bacterial communities to the cytotoxic effect of PDT [18,19]. It should also be noted that the antimicrobial effect also depends on two other parameters: the light source and the concentration of the photosensitive agent [9,12].

Although PDT can be used as an alternative antimicrobial treatment, few clinical long-term follow-up studies have evaluated its success/failure when used as an adjunct to RCT [20,21].

The objective of the present study was to examine the effect of PDT as a complementary procedure to RCT by analyzing the time required for periapical lesion healing, the number of visits necessary to complete the treatment, and the number of times application of calcium hydroxide as an intracanal medicament was necessary, in the setting of both primary treatment and retreatment.

The working hypothesis was that PDT, as a supplement for RCT, would improve the clinical results of both primary treatment and retreatment in patients with periapical lesions.

Materials and Methods

In order to carry out this study, approval was obtained from the institutional ethics committee (HI485871857584) and informed consent for use of clinical data was obtained from all patients, in accordance with the Declaration of Helsinki.

The clinical histories of the patients were analyzed retrospectively. Teeth that satisfied the inclusion criteria were necrotic permanent teeth presenting with pain, abscess, sinus tract, a new periapical lesion and/or an increase in size of the original periapical lesion. Treatments were carried out by the same experienced clinician using magnification and the same procedural protocol for each group. Radiographic images were produced by the same digital capture system and radiographic positioner/parallelizer.

Two study groups were established: an RCT group of 100 teeth requiring conventional root canal treatment (43 necrotic teeth and 57 retreatments) without supplementary PDT, and an RCT + PDT group of 114 teeth requiring root canal treatment (61 necrotic teeth and 53 retreatments) along with supplementary PDT.

The procedural protocol for conventional RCT in both groups was performed under rubber dam isolation. Mechanical preparation was carried out using rotary files and irrigated with sodium hypochlorite (5.25%); sodium hypochlorite also served as a procedural medicament. The procedural protocol for conventional RCT in both groups was performed under rubber dam isolation. Mechanical preparation was carried

Conclusion:

In comparison with RCT alone, teeth receiving RCT + PDT showed less variation in the time need for periapical lesion healing, fewer cases required CaHy, and fewer cases required more than two visits to complete the treatment.

Keywords; calcium hydroxide, follow-up, number of visits, photodynamic therapy, retrospective study
out using the Reciproc system (VDW, Munich, Germany) until the working length was established by electronic apex localization and radiographic confirmation. Between files, patency was ensured using manual 06 or 08 K files. Irrigation was performed with 2.5% sodium hypochlorite solution followed by ultrasonic activation for 30 s per root canal (IRRI S25, VDW-Ultra, VDW, Munich, Germany), cleaning with saline solution, 17% EDTA solution with ultrasonic activation (30 s per root canal) and saline solution again; finishing involved drying the canals with paper points and cleaning with 2% chlorhexidine solution. After the root canals had been dried, they were filled with gutta-percha (2% K files. Irrigation was performed with 2.5% sodium hypochlorite solution, until EDTA Ultra, VDW, Munich, Germany), cleaning with saline solution, 17% sodium hypochlorite solution and λ = 630 nm, inserting the system’s endodontic point inside the root canal, as apically as possible, for 30 s per canal using protection goggles. This device vibrates during activation, thus helping to distribute the photoactivator. The photosensitizer was removed using saline solution followed by 2.5% sodium hypochlorite solution, until the pulp chamber appeared clean. The root canals were then cleaned with saline solution, dried with paper points and irrigated with 2% chlorhexidine solution, proceeding to root canal obturation thereafter.

In cases where a non-controllable purulent secretion was present, or when reactivation of the symptomatology occurred between visits, calcium hydroxide (Ultracal XS, Ultradent, South Jordan, UT, USA) was applied as a temporary medicament. A reduction in the PAI index score, but the presence or worsening of any previous associated signs or symptoms after RCT, was also considered as a failure. Data were analyzed using the Mann-Whitney test with a significance level of \( P < 0.05 \).

### Results

Among a total of 214 teeth evaluated from the clinical records, 29 (13.6%) did not present a periapical lesion prior to RCT. Fifteen teeth (7%) were lost due to periodontal reasons or fracture, and in 52 teeth (24.3%) periapical lesions were maintained or increased in size after RCT.

The success rate was 94.7% in the RCT group and 97.2% in the RCT + PDT group. To evaluate the months necessary for healing in each of the treatment groups, only teeth that exhibited periapical lesion healing were included (\( n = 118 \)). Periapical lesion healing was achieved in 20.35 ± 22.1 months (median 12 months) in the RCT group, and in 15 ± 9.33 months (median 13 months) in the RCT + PDT group (\( P = 0.97 \)). Analysis of the data in terms of apical lesion size is shown in Table 1. For teeth that had a periapical radiolucency of 1-3 mm on presentation, the healing time of the data in terms of apical lesion size is shown in Table 1. Periapical lesion healing was also analyzed separately for primary RCT (\( n = 59 \)) and for retreatment (\( n = 59 \)). For primary RCT, supplementation with PDT resulted in a shorter mean healing period (13.64 ± 9.82 months) than for RCT alone (23.18 ± 24.45 months), but the difference was not significant (\( P = 0.25 \)). For retreatment, supplementation with PDT also resulted in a shorter mean healing period (16.51 ± 8.65 months) than for RCT alone (23.18 ± 24.45 months), but the difference was not significant (\( P = 0.25 \)). For retreatment, supplementation with PDT also resulted in a shorter mean healing period (16.51 ± 8.65 months) than for
RCT alone (17.96 ± 10.10 months), but again the difference was not significant (P = 0.28). In the primary RCT group, the variation in periapical healing time was greater when PDT was not used (Table 2).

The number of cases for which application of calcium hydroxide as an intracanal medicament was necessary was determined for the total sample (214 teeth). For both primary and retreatment RCTs, the proportion of teeth for which calcium hydroxide had to be applied was significantly lower when PDT was used as a complementary procedure, compared to cases when it was not used (P < 0.01) (Fig. 1).

The number of visits necessary for completion of the treatment was also assessed for primary RCTs and retreatments separately. In retreatment cases, more than two visits were necessary for 64.9% of cases in the RCT group, compared with 49.1% of cases in the RCT + PDT group (P = 0.05). For primary cases, more than two visits were required in 18.6% of the cases in the RCT group, as opposed to 13.1% of those in the RCT + PDT group (P = 0.31) (Fig. 2).

Among the 52 teeth that showed no periapical lesion healing, 31 (52.5%) were subjected to RCT (7 primary [22.6%] and 24 retreatments [77.4%]). Among the remaining 21 teeth (40.38%) subjected to RCT + PDT, 10 (57.6%) were primary cases and 11 (52.5%) were retreatments. No significant association was found between the therapeutic procedure employed and the reason for the treatment (P = 0.05).

Discussion

For PDT, there are no established clinical protocols in terms of the photosensitive agents used, their concentrations, and activation time. The available literature regarding different color agents suggests that phenothiazine is used most often, i.e., methylene blue at concentrations of 60-25 μg/mL [16,23,24], and toluidine blue at concentrations of 15-0.1 mg/mL [17,25]. In the present series, toluidine blue was used at 0.1 mg/mL.

Discrepancies also exist with regard to the activation of the photosensitive agent, which has included the use of low-potency lasers [23,26] and low-potency LED lamps [10,26]. In the present series, the FotoSan LED light was used in view of its ergonomics and safety, as it does not thermally damage dental walls and periapical tissues [26,27].

Various prospective and retrospective studies have evaluated the success and outcome of RCT, but few studies have assessed the medium and long-term effectiveness of PDT as an adjunct to conventional RCT. In vivo studies of bacterial load have concluded that PDT as an adjunct to conventional RCT can achieve a major reduction [8,26], PDT is able to reduce the count of E. faecalis in root canal systems [28]. There are also reports of clinical cases that show complete remission of periapical lesions within 6 months. Similarly, Garcez et al. (2015), in a 3-year clinical follow-up study of periapical procedures with supplementary PDT, found a greater degree of bacterial reduction and a 78% reduction of periapical lesion area after PDT had been applied [13]. On the other hand, better resolution of periapical periodontitis with calcium hydroxide has been described in a recent canine study [29].

Evaluation of RCT healing is based on assessment of signs and/or symptoms related to treated teeth and comparative radiographic analysis, reserving the use of cone beam computed tomography or CBCT for situations in which there is insufficient information for clear assessment of standard criteria [30]. Some authors, such as Benenati et al. [4], Ng et al. [31] and Hoskinson et al. [1], have derived four categories for classifying the outcome of treated cases based on radiographic findings: success, acceptable, questionable, failure. On the other hand, Peak et al. [32] have suggested a classification comprising definite success, probable success and failure.

In the present study, absence or remission of periapical lesions and absence of symptoms with a clear reduction of the previous periapical lesion were considered to represent a successful outcome. Any other outcome than the above was considered a failure. On this basis, the success rate was 94.7% in the RCT group and 97.2% in the RCT + PDT group. Conventional treatments used in long-term studies have achieved a similar success rate [26,34,21]. suggesting that the effectiveness of conventional RCT and retreatment may be enhanced by the adjunctive use of PDT.

With regard to the period required for periapical lesion healing in the present study, the RCT + PDT group required a mean period of 15 ± 9.33 months and the RCT group 20.5 ± 22.1 months. These data fall within the range of values obtained in other studies: in a clinical follow-up study Estrela et al. [34] reported that teeth with primary infections healed within 10-36 months, while Weiger et al. [35] reported a period of 4 to 58 months for complete healing. In the present study, as the RCT + PDT group showed a lower standard deviation, a more uniform healing time was evident.

It has been suggested that PDT is a promising effective adjunct to standard antimicrobial intracanal cleaning and shaping for clinical treatment of periapical lesions, in particular for teeth requiring one-session endodontic treatment or retreatment [36]. In the present study, although the number of visits necessary to complete the treatment did not differ significantly between the groups in terms of primary RCT or retreatment, the retreatment group showed a substantially higher number of cases that necessitated more than two visits to complete the treatment for RCT alone (64.9% vs. 49.2%), which highlights the effect of PDT as a complementary modality. Although this study has also reported a lower number of visits necessary for completion of treatment in cases for which PDT was used, compared with cases for which only calcium hydroxide was used; postoperative pain was also reduced in patients which received PDT [37].

Calcium hydroxide dressing was required in a significantly lower number of cases for which PDT was applied as a complement to RCT. This could be explained by a reduction of intracanal biofilm after PDT, as has been confirmed by numerous in vitro studies [38]. A recent randomized controlled trial demonstrated that the use of complementary PDT provided better periapical healing at the 6-month follow-up point in comparison with the use of calcium hydroxide. However, the difference in intracanal microbial load between the groups was not statistically significant [21].

In the present study, the success rate in both the RCT and RCT + PDT groups was similar. In comparison to conventional RCT, the use PDT as an adjunct to RCT was shown to be advantageous in facilitating more homogeneous and predictable periapical lesion healing and reducing the need for application of calcium hydroxide as an intracanal medicament, as well as reducing the number of visits necessary for completion of treatment.

Conflict of interest

The authors have no conflicts of interest to declare.

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