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ORIGINAL ARTICLE

Radiographic examination of apical extrusion of root canal irrigants during cavitation induced by Er,Cr:YSGG laser irradiation: an in vivo study

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Abstract
Objectives The purpose of the present study was to test the hypothesis that apical extrusion of the irrigant occurs during laser-driven irrigation in vivo.
Materials and methods Three hundred human root canals, in 181 patients, were divided into two groups: the no lesion group (n=140) and the lesion group (n=160). All the root canals were enlarged using a crown down technique up to size 30–80 K-files, depending on the original condition of the root canal. For the final irrigation, the teeth were irrigated with a mixture of radiopaque contrast medium and NaOCl in solution. The solution was activated for 60 s in teeth with one canal or two canals and for 120 s in teeth with three or four canals.
Results Radiopaque contrast medium was absent from the periapical tissues of all samples.
Conclusions No contrast medium was observed radiographically in the periapical tissues. The hypothesis that apical extrusion of root canal irrigants occur during laser cavitation was rejected
Clinical relevance It appears that the power of the laser used at 1 W for 1–2 min can drive the irrigation solution to the tip of the canal without harming the apical tissues.

Keywords Apical extrusion · Cavitation · Contrast · Laser-driven irrigation

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Introduction

Large areas of the root canal wall, particularly in the apical third but also areas in ribbon-shaped and oval canals, cannot be cleaned mechanically. It has been shown that 35 % or more of the root canal system (RCS) is untouched by endodontic instruments, which means that microorganisms could survive in these untouched areas [1].

Although shaping of the root canal has been improved with advances in metal technology, cleaning of the canal still relies heavily on the adjunctive use of chemical rinsing and soaking solutions because of the anatomical complexity and irregularity of teeth [2]. This highlights the importance of root canal irrigation in the debridement and disinfection of the RCS [1]. Endodontic irrigants are used to remove pulp tissue, microorganisms, microbial by-products and debris from the RCS [3, 4].

For optimal effectiveness of irrigation, the preparation of the root canal should facilitate the insertion of the irrigation needle and agitation devices to 1–2 mm short of the working length (WL). In addition, the irrigation solution should make direct contact with all parts of the canal wall [5]; a flushing action is necessary for optimal cleaning of the root canal [6]. The problem with these techniques is that the depth of needle penetration depends on the size and morphology of the individual canal. Predictable delivery of irrigants to the WL with needle irrigation is rarely possible [7]. If too little positive pressure is used, the irrigants may not reach the WL. If too much positive pressure is used, the irrigants may be forced beyond the apical constriction, which can produce tissue damage, pain and swelling; this is commonly described as a sodium hypochlorite (NaOCl) accident [8–12]. To enhance the dispersal of the irrigant and to activate it, different agitation techniques have been investigated and developed. These include the use of hand files, gutta-percha cones, plastic instruments and sonic and ultrasonic techniques [13].

Since the introduction of the use of lasers in endodontics during the early 1970s, various types of laser have been developed in an attempt to increase the effectiveness of treatment, and the performance of lasers that are used in the field of dentistry has improved [14]. Recently, lasers have been used increasingly to provide an alternative approach to cleaning and disinfection [2]. Both ultrasound and pulsed middle-infrared lasers cause cavitation (the formation of bubbles) and the formation of pressure waves within the root canal space [15]. The use of lasers at different wavelengths has been proposed to supplement conventional endodontic cleaning procedures. However, a considerable limitation has been the unidirectional emission of the laser beam. In the conventional technique, the entire root canal wall must be exposed directly to the laser beam [16, 17]. The laser fibre must be moved repeatedly in a spiralling motion along the root canal wall and kept as close as possible to the apex in order to maximise the area exposed to the laser beam, but even this technique is not completely efficient. Ideally, the fibre should be inserted centrally in the pulp chamber without contact with the root canal wall and kept stationary during emission. The interaction between the laser and the root canal walls is based on absorption of the laser energy by the dentin, microorganisms and/or smear layer, on thermal effects such as evaporation and contraction of the smear layer and the thermal heating of microorganisms [16–19]. The undesirable side effects that occur with the use of lasers are moderate, and within limits, this technique is regarded to be safe [20–22]. Previous studies have revealed the side effects that can be caused by the use of lasers in the root canal. These include the creation of ledges up to a canal curvature of <10° [23], carbonization, cracks [14], collateral damage and apical extrusion of the solution [24].

In the present study, to avoid some of the side effects that are associated with the use of a laser, the laser-driven irrigation was performed by hovering the laser tip around the orifice of the RCS, instead of placing the tip within the canal itself. During laser irradiation, the root canal was irrigated continuously to maintain the hydration level. The pulp chamber served as a reservoir for the irrigant.

Using cinematic holography, Ebeling and Lauterborn observed shock waves that emanated from the collapsing bubbles that were generated by a laser pulse [25]. These laser-generated pressure waves moved at high speed and appeared to enhance the action of endodontic irrigants in the removal of the smear layer [26]. When pressure waves cause such movement of fluid, the possibility of accidental extrusion of the irrigant beyond the apical constriction must be considered. The consequences of this increase in pressure deserve attention. In particular, do the pressure waves that are generated by laser-driven irrigation within the root canal damage the periodontal tissues as the result of extrusion of irrigants?

The purpose of the study reported herein was to test the hypothesis that apical extrusion of the irrigant beyond the apical constriction occurs during laser-driven irrigation in vivo.

Materials and methods

Patient selection

The study sample comprised 181 patients with incisors, canines, premolars or molars that required routine endodontic therapy. A medical history was obtained, and a clinical examination was performed. All of the teeth, in people of both sexes, were diagnosed as having pulpal necrosis, and some of them had radiographically visible chronic periapical lesions. All teeth were asymptomatic and periodontal probing revealed no increased probing depth around any of the teeth. Patients were aged between 21 and 64 years (mean, 36.4 years). Five teeth were used as negative controls: the patients received routine endodontic therapy in which no intracanal radiopaque contrasting medium was used. All procedures were conducted with the approval of the ethical review board for studies on human subjects of Airlangga University, Surabaya, Indonesia. Written informed consent was obtained from patients who participated in the study. Patients who were allergic to any of the components of the formula and/or had teeth with sclerosis were excluded from the study. The study was performed by a single experienced endodontist.

Root canal treatment protocol

In each case, a periapical radiograph was taken to determine the presence of apical lesions, the canal morphology and the length and number of canals. In total, there were 300 root canals in the affected teeth. The patients were divided into two groups: the no lesion group ($n=140$) and the lesion group ($n=160$) (Tables 1 and 2). A routine procedure for endodontic therapy was performed on all root canals. Under rubber dam isolation, the pulp chamber was accessed using a diamond bur. Pulp remnants were extirpated, and the WL was estimated with the aid of an apex locator (Root ZX; J Morita, Irvine, CA). The root canal was instrumented using a crown down technique on the basis of its original shape and the size of the root canals. The final apical preparation was performed using K-files that ranged in size from 30 to 80 (Dentsply Maillefer, Ballaigues, Switzerland) (Tables 3). During instrumentation, the canal was irrigated copiously with 2.5 % NaOCl using a 28-gauge endodontic needle. The canals were further instrumented and irrigated with 3 mL of 17 % ethylenediaminetetraacetic acid, followed by final instrumentation. Blockages that occurred as a result of the presence of pulp remnants were cleared by renegotiating the canal with a 10 K-Flexofile to reach the WL. The final irrigation was accomplished with a mixture of 2.5 % NaOCl and contrast medium solution. Subsequently, the irrigant was

Table 1 Distribution of root canals without periapical lesion

No Lesion n=140 (%)

Apical canal size	Incisors		Canines		Premolars		Molars		Total
	Maxillary	Mandibular	Maxillary	Mandibular	Maxillary	Mandibular	Maxillary	Mandibular	
Small	3 (2.14)	5 (3.57)	5 (3.57)	4 (2.85)	19 (13.57)	17 (12.14)	10 (7.14)	13 (9.28)	70 (50.00)
Medium	4 (2.85)	1 (0.71)	10 (7.14)	3 (2.14)	8 (5.71)	6 (4.28)	8 (5.71)	10 (7.14)	50 (35.71)
Large	2 (1.42)	NA	2 (1.42)	2 (1.42)	2 (1.42)	1 (0.71)	3 (2.14)	3 (2.14)	20 (14.29)

activated with an erbium chromium:yttrium–scandium–gallium–garnet (Er,Cr:YSGG) laser (60 s for teeth with one canal or two canals and 120 s for teeth with three or four canals). Radiography was performed to observe the presence or absence of contrast medium in the apical tissues. After the canal had been dried with sterile paper points, it was dressed with calcium hydroxide paste (Calxyl; VOCO, Cuxhaven, Germany) using a lentulo spiral instrument. Sterile cotton pellets were placed into the access cavities before they were sealed with a temporary filling (Cavit ESPE, Seefeld, Germany).

In each case, at the time of a second visit 2 weeks later, the teeth were asymptomatic. The canals were irrigated with 2.5 % NaOCl, and a CanalBrush (Coltene Whaledent Co. KG, Langenau, Germany) was used to remove the calcium hydroxide. Following this, each root canal was dried with sterile paper points and filled with gutta-percha (Diadent, Chongchong, Korea) and AH Plus sealer (Dentsply De Trey, Konstanz, Germany) using a lateral compaction technique. Glass ionomer cement (Ketac-Molar Easymix; 3M ESPE, Seefeld, Germany) was placed over the gutta-percha as an orifice plug, and restoration of each tooth was completed with a composite resin (Z250 3M ESPE, St. Paul, MN, USA). A post-operative radiograph was taken to check the quality of the filling.

Preparation of the radiopaque-NaOCl irrigation solution and procedure

A mixture of radiopaque contrast and NaOCl in solution was used as the contrasting medium to assess the presence or absence of radiopaque materials in the periapical tissues. A sterile intravascular contrast medium (Bracco SpA, Patheon, Italy) that contained iomeprol (0.81 g/mL) was mixed with 2.5 % NaOCl in the proportions 40:60 by volume to form the final irrigation solution. This mixture had a density and viscosity similar to those of pure NaOCl and permitted the flow of irrigant solution that contained the radiopaque medium to stain the canal wall thoroughly. The irrigant was mixed carefully by a chemist at the Department of Chemistry, Bandung Institute of Technology, Indonesia. Irrigation was performed at a rate of 2 mL/min.

Laser parameters and procedure

The Waterlase MD dental laser (Biolase, San Clemente, CA, USA) was used at panel settings of an average power of 1 W and 35 Hz and was focused through a plain fibre (quartz) tip (MZ4) with a diameter of 400 μm and length of 14 mm. The fibre tip was fixed in the hand piece of an Er,Cr:YSGG laser (Waterlase Millenium, Biolase, San Clemente, CA). The pulp chamber served as a reservoir for the irrigation solution. The tip was submerged in the solution and made to hover above the orifice in the cervical region, rather than inserting the tip into the canal. The co-axial water spray and air were switched off. In both groups (n=300), the solution was activated for 60 s in teeth with one canal or two canals and 120 s in teeth with three or four canals.

Evaluation by radiography

The teeth were evaluated using digital radiography. X-rays were generated by a Nomad Pro machine (Arbitex, Utah, USA) operating at 60 kVP and 2.5 mA. The time exposure

Table 2 Distribution of root canals with periapical lesion

With lesion n=160 (%)

Apical canal size	Incisors		Canines		Premolars		Molars		Total
	Maxillary	Mandibular	Maxillary	Mandibular	Maxillary	Mandibular	Maxillary	Mandibular	
Small	1 (0.62)	5 (3.12)	3 (1.87)	6 (3.75)	14 (8.75)	12 (7.5)	20 (12.5)	13 (8.12)	74 (46.25)
Medium	19 (11.9)	1 (0.62)	5 (3.12)	4 (0.25)	3 (1.87)	3 (1.87)	9 (5.62)	6 (3.75)	50 (31.25)
Large	9 (5.62)	NA	10 (6.25)	5 (3.12)	2 (0.12)	NA	4 (0.25)	6 (3.75)	36 (22.5)

Table 3 Categorization of the final apical preparation

Root canal	Size (ISO)
Small	30
Medium	35–45
Large	50–80

was 0.13 s. Minimal focal spot is 0.4 mm. X-ray field size is at 20 cm. Radiographic images of the specimens were obtained by using a size #2 of intra oral Sopix CCD image receptor (Sopro; Acteon, La Cirotat Cedex, France). The digital images were saved in TIFF format for future evaluation. The images that were obtained following use of the irrigant that contained the radiopaque solution were investigated for the presence of apical extrusion of the irrigant in the periapical tissues. The outcome was recorded as either "no" (absence) if the radiopaque medium was not present in the periapical tissues or "yes" (presence) if radiopaque medium was present in the periapical tissues. Three calibrated and blinded endodontists determined the presence or absence of the radiopaque medium in the periapical tissue. In the case of differences among their assessments, the three examiners reached a consensus.

Statistical analysis

The presence or absence (yes/no) of apical extrusion of the contrast medium in the periapical tissues was investigated in the two groups. The results were analysed using the χ^2 test. Cohen's kappa analysis was used to analyse agreement among the three examiners.

Results

Value of kappa was 1.00. The weighted Cohen's kappa statistic showed excellent intra- and inter-examiner agreement. This suggests that there was excellent reliability and reproducibility among the examiners. Radiopaque images were completely absent in the negative controls. The data obtained from the study revealed that there was no apical extrusion of the irrigant beyond the apical constriction in teeth with any type of condition of the roots or periapical tissues during cavitation induced by the Er,Cr:YSGG laser.

Discussion

The key role of root canal irrigants is to clean the canal effectively during the enlargement and shaping process. One or more irrigants must be used for complete elimination of the smear layer and debris from the RCS [27]. Although syringe irrigation is the standard procedure, unfortunately, it is not effective in the apical third of the root canal [28–30].

In a recent study, evaluation by scanning electron microscopy revealed that a laser-driven irrigation system had the ability to remove the smear layer at the tip of the root [31]. This capacity was attributed to the ability of the laser-driven irrigation system to create cavitation. Cavitation is defined as the formation of vapour or a cavity that contains bubbles inside a fluid [32]. In water, the use of a laser at ablative settings can result in the formation of large elliptical bubbles. These vapour bubbles can cause expansion of the liquid to 1,600 times the original volume of the water [33]. This process can enable the irrigant to access the apical third of the canal more easily, which might assist in the cleaning of canals of irregular shape. In addition, cavitation bubbles expand, become unstable and then collapse, in a process called implosion [34]. The implosion will have an impact on the surfaces of the root canal, causing shear forces, surface deformation and the removal of surface material [35].

In light of the above, it should be considered whether implosion of the cavitation bubbles might generate pressure waves that result in accidental extrusion of the irrigant. The main aim of the present study was to test the hypothesis that apical extrusion of the irrigant occurs during laser-driven irrigation in vivo. Iomeprol solution was used as the radiographic contrast medium in the study because it belongs to a new generation of nonionic contrast agents that are water soluble, nontoxic, pyrogen-free and in sterile solution. It is used widely in disciplines such as neuroradiology, angiography and urography and as an enhancement agent in computerised axial tomography (CT) scanning; however, it is used rarely in dentistry. In the present case, it was combined with the use of 2.5 % NaOCl as the contrast medium to enable assessment by radiography of the presence or absence of contrast medium in the periapical tissues.

An in vitro study conducted by Roy George and Laurence J. Walsh indicated that apical extrusion of root canal irrigants could occur following the use of Er:YAG and Er,Cr:YSGG lasers with optical fibres. In this earlier study, all canals were enlarged up to an F5 file [24]. However, of the 300 root canals treated in the current study, 56 root canals had large apices. Of these 56 root canals, 12 were categorised as having open apices. This type of apex could have increased the likelihood of apical extrusion of the irrigant beyond the apical constriction. However, there was no evidence of apical extrusion in these canals after the procedure has been completed (Fig. 1). This is probably because the root of a tooth is surrounded by the periodontal ligament and bone, and consequently the canal serves as a closed-end system [36].

Of the 160 root canals with apical lesions, 41were categorised as having large lesions (10–20 mm) (Fig. 2). However, the results of the current study revealed that even though the images of the large lesions showed the presence of radiolucent

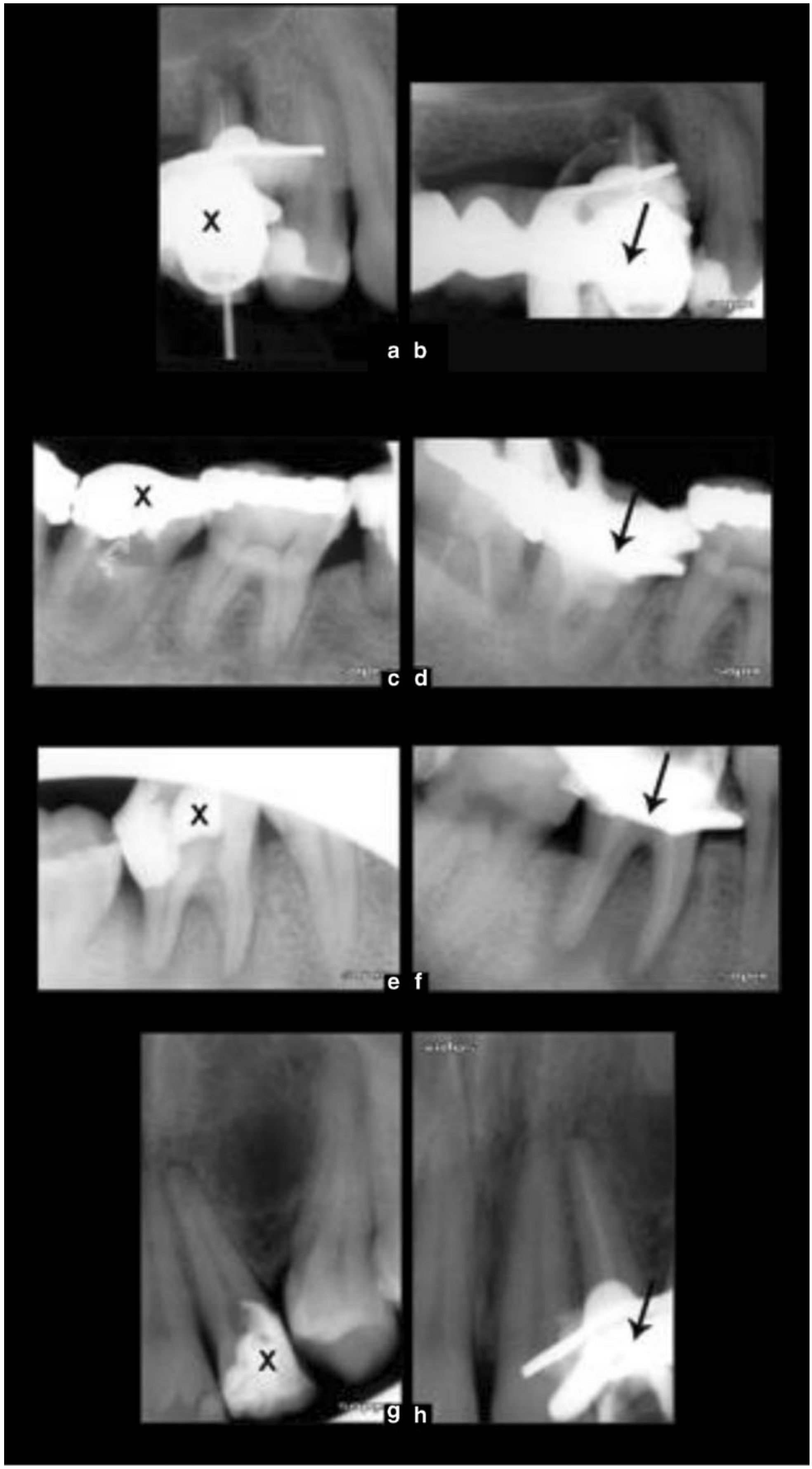

Fig. 1 Radiographs showing no evidence of radiopaque contrast medium in the periapical tissues of teeth with medium and large canals. **a**, **c**, **e** and **g**: before cavitation (indicated by *X*); **b**, **d**, **f** and **h**: after cavitation (indicated by *arrow*)

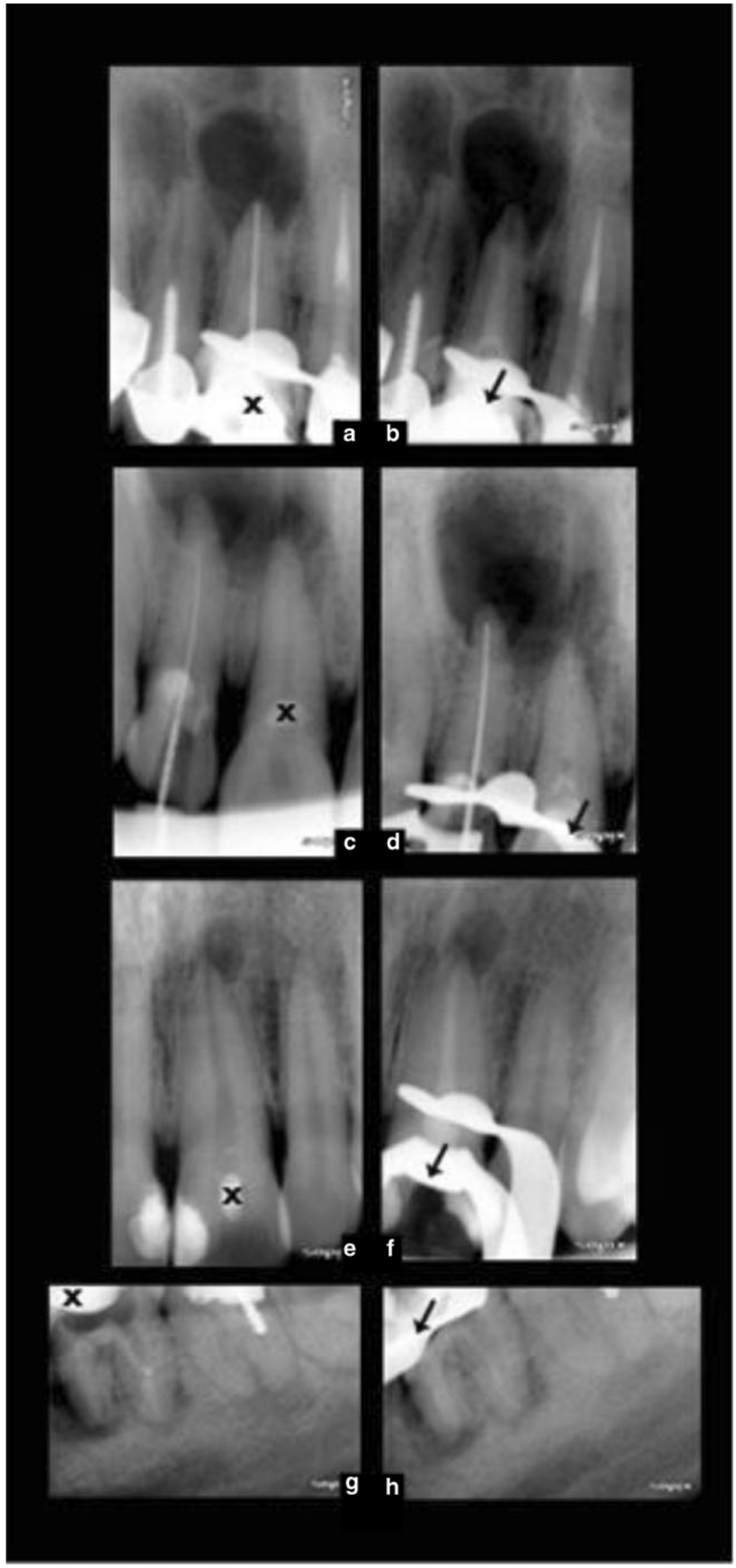

Fig. 2 No apical extrusion of contrast medium beyond the apical constriction of teeth with large lesions. **a**, **c**, **e** and **g**: before cavitation (indicated by *X*); **b**, **d**, **f** and **h**: after cavitation (indicated by *arrow*)

spaces in the periapical tissues, there was no evidence of extrusion of the irrigant beyond the apical constriction. We assumed that the absence of contrast medium in the periapical tissues indicated that these tissues remained intact. Another explanation for the lack of extrusion could be the influence of the intracystic pressure of the large lesions [37]. It is reasonable to assume that intracystic pressure would prevent extrusion of the irrigant beyond the apical constriction.

Notwithstanding the fact that the results of the present study showed no apical extrusion of the irrigant in the periapical tissues during laser-driven irrigation, a wise clinician should follow the highest standards for clinical procedures to avoid iatrogenic accidents. Of the 181 patients treated in the present study, 11 reported feelings of discomfort and pain, and even bleeding, which were caused by the unintentionally increased pressure in the periapical tissues. However, there was no evidence of apical extrusion of the irrigant beyond the apical constriction, as confirmed radiographically. In clinical practice, it is difficult to control all circumstances, such as sudden movement of the patient or an awkward positioning of a tooth that could alter the distance from the tip of the laser to the WL. In the authors view, care must be taken during laser cavitation because an unintentional increase in pressure in the periapical tissues may cause pain. We recommend that: (1) before the procedure, all patients should be informed that if any uncomfortable feeling occurs, they should give a signal to the operator, and the operator should stop the procedure; (2) the tip of the laser should not be introduced into the canal, but be made to hover above the orifice or the cervical region of the tooth; (3) because continuously driven laser irrigation is used, a rubber dam should be compulsory, and suction should be applied at all times; (4) the power of the laser should not be increased above 2 W. In a pilot study with a limited number of samples, a laser power of 2 W was found to be safe. However, additional caution should be applied when using lasers in combination with irrigants such as NaOCl.

This is the first reported clinical study to examine apical extrusion of root canal irrigants during cavitation induced by Er,Cr:YSGG laser in routine endodontic therapy. It is likely that results from the long-term clinical and radiographic follow-up of the patients in this study will likely provide more insight into the efficacy of laser-driven irrigation. Studies are in progress to determine the optimal laser settings for the safe dispersal of irrigant into the apical portion of a RCS.

Conclusions

On the basis of the results of the present investigation, it appears that the power of the laser used at 1 W for 1–2 min can drive the irrigation solution to the tip of the canal without harming the apical tissues. The hypothesis that apical extrusion of the irrigant occurs during laser-driven irrigation in vivo was rejected.

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

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