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Effect of simulated intraosseous sinusoidal pressure on NaOCl extrusion

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ABSTRACT

Introduction: The present study examined the effects of irrigant flow rate and simulated intraosseous sinusoidal pressure on the rate of NaOCl extrusion from the apical terminus of a faux root canal.

Methods: An extrusion setup was designed to enable irrigant extrusion to be opposed by 30 mm Hg simulated intraosseous pressure. The faux canal apex was opposed by atmospheric + 30 mm Hg pressure (experimental) or atmospheric pressure only (control group). Using five irrigant delivery rates (15.6 8.0, 4.0, 3.4 or 3.0 mL/min), the extrusion rates of 2% NaOCl from the faux apex were measured in both groups (n = 16). Data were analysed with two-factor ANOVA and pairwise comparisons at $\alpha = 0.05$. Correlation between NaOCl delivery rates and extrusion rates in both groups were analysed with the Pearson product-moment procedure.

Result: Irrespective of the presence or absence of simulated sinusoidal pressure, NaOCl extrusion rates were positively-correlated with irrigant flow rates. For the factor "irrigant flow rates", significant differences in NaOCl extrusion rates were identified among all flow rates ($p < 0.05$), except for the pairwise comparison between 4.0 and 3.4 mL/min in the control. For all irrigant flow rates, NaOCl extrusion rate was significantly lower in the presence of 30 mm Hg simulated sinusoidal pressure than that obtained in the absence of opposing pressure ($p < 0.05$).

Conclusion: In the presence of 30 mm Hg simulated intraosseous pressure, NaOCl delivered via a side-vented needle inserted to 1 mm short of working length may be prevented from extrusion when its flow rate is ≤ 3.0 mL/min.

Clinical Significance: When opposed by intraosseous sinusoidal pressure, NaOCl delivered via a side-vented needle inserted to 1 mm short of working length may be prevented from extrusion when its flow rate is ≤ 3.0 mL/min.

1. Introduction

Debridement of root canals with sodium hypochlorite(NaOCl) carries the risk of periradicular extravasation of the extremely cytotoxic irrigant [1]. Following Becker's report of the sequela of accidental injection of NaOCl beyond the root apex [2], the literature is replete with case histories containing morbid photographs of NaOCl accidents [3–7]. All authors presage against using excessive delivery rates/pressure, or binding of irrigation needles to the canal space. However, the relationship between those anecdotal observations and the pathognomonic facial features associated with periradicular NaOCl extrusion has not been addressed.

Although intradermal injection of NaOCl may result in skin ulcerations [8], a recent report of a subject accidental infusion of NaOCl directly into the infraorbital tissues showed no signs of skin ulceration [9]. Surprisingly, the ecchymotic facial features [9] were virtually identical to those present in the 23 cases of root canal treatment-related NaOCl accidents compiled by Zhu et al. from the literature [10]. This serendipitous discovery prompted the authors to rationalise that NaOCl is ultimately drained into the anterior facial vein and its tributaries in a classical NaOCl accident [10]. Devastation of the superficial facial venous vasculature results in swelling and ecchymosis in the periorbital

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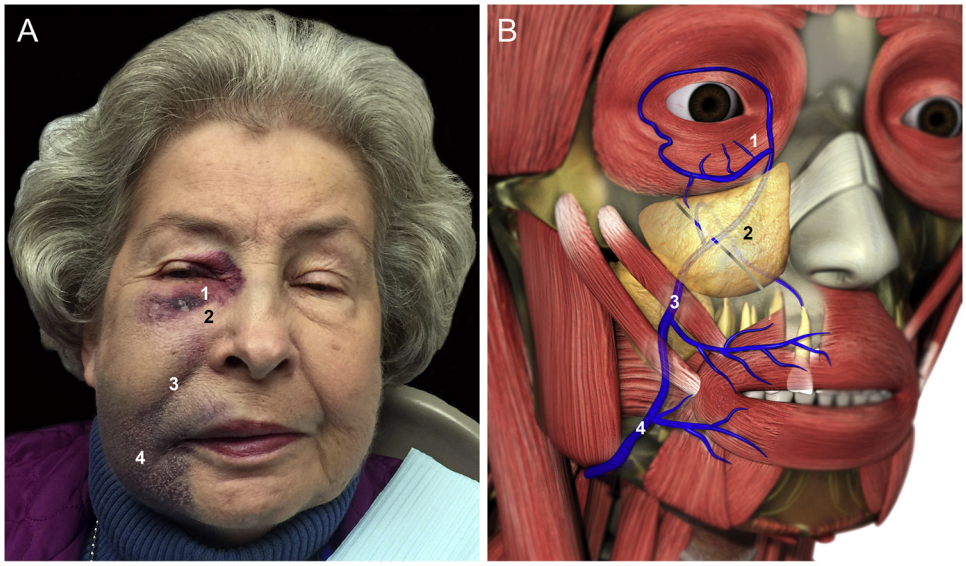

Fig. 1. A. Clinical photograph illustrating the pathognomonic manifestations of a NaOCl accident involving facial swelling and ecchymosis, and **B.** graphic dissection of the superficial venous vasculature along the course of the anterior facial vein and its tributaries. Damage to the anterior facial vein involves the superficial palpebral complex of the eyelids (area 1) that connects to the facial vein as it descends deep under the malar fat pad (area 2). The anterior facial and then arises superficial again at the level of the zygomatic muscles where it unites with the superior (area 3) and inferior (area 4) labial veins. The anterior facial vein continues superficially as it goes under the mandible and unites with the jugular vein. The superficial/deep spatial relationship of the facial venous system coincides exactly with the archetypical appearance of the subject who suffered from NaOCl extrusion during root canal treatment.

area, beneath the malar pad of fat that masks the ecchymosis, and at the angle of the mouth where ecchymosis reappears (Fig. 1). Although the most common course of venous drainage of teeth is the pterygoid plexus, a rare anatomical venous by-pass may cause the extruded NaOCl to be drained into the anterior facial vein [11]. The necessity for the presence of a venous by-pass explains why NaOCl accidents are rare [12,13], and that the facial ecchymosis resulting from extravasation NaOCl from the periapex is almost identical from case to case, irrespective of the tooth location [10].

Despite the presence of extensive facial swelling and ecchymosis, it remains elusive why contusion of the capillaries in the soft tissues around the root apex is never observed in all reported NaOCl accidents. Davies and Campbell asserted that the sinusoids in medullary bone is part of the non-collapsible component of the venous system, which may result in fatal air embolism when air is inadvertently introduced during surgical manipulation of the medullary bone [14]. This is in consonance with earlier reports that the intraosseous space is a non-collapsible vein [15]. Sinusoidal veins rapidly absorb fluids infused into the medullary areas because the sinusoidal blood pressure is only ~30 mm Hg [16,17]. Bone marrow injection is often used as a medium for administration of fluid directly to the venous system [18]. This physiologic background [10] accounts for the rapid onset of facial swelling/ecchymosis when NaOCl is expressed from the apical terminus into the central venous system.

For NaOCl to enter the sinusoids, the irrigant must have direct access to the sinusoids and be pressurised higher than 30 mm Hg to oppose the intraosseous sinusoidal pressure. A tooth surrounded by a healthy periodontal ligament prevents fluids from escaping the root canal system even if the apically-direct pressure is higher than 30 mm Hg. This combination of conditions, including the aforementioned rare venous by-pass, makes the NaOCl accident very rare. Although the likelihood of exacerbation of NaOCl has been examined for various clinically-relevant root canal instrumentation and irrigation parameters [19–28], no study to date has considered the effects of opposing intraosseous sinusoidal pressure on NaOCl extrusion from the root canal space.

When NaOCl extrusion was examined in a closed periradicular system versus an open system where there was no resistance to flow, the investigators opined that failure to consider partial apical resistance could have led to overestimation of NaOCl extrusion [29–31]. Accordingly, the objective of the present study was to examine the extrusion rate of 2% NaOCl when its delivery was opposed by simulated venous blood pressure in human sinusoids (~30 mm Hg). The null hypotheses tested were: 1) irrigant flow rate has no effect on the rate of NaOCl extrusion from the apical terminus, and 2) intraosseous sinusoidal pressure has no effect on reducing the extrusion of NaOCl delivered at different clinically-relevant flow rates.

2. Materials and methods

2.1. Model construction

A testing apparatus was designed with the objective of enabling irrigant extrusion to be opposed by 30 mm Hg to simulate the average intraosseous sinusoidal pressure. The set-up consisted of a single-rooted faux canal created within a polycarbonate block (McMaster-Carr, Santa Fe Springs, CA, USA). A 0.3 mm-diameter hole was drilled into the block to a depth of 19 mm. The final shape of the faux canal was completed by instrumenting the entire length with a size 30, 0.04 taper hand file. A 2 mm-diameter horizontal irrigant extrusion channel was drilled perpendicular to the faux canal, connecting the faux apical termination to a custom-made glass Extrusion Measurement Tube (EMT; Fig. 2A).

The faux canal was infused with 2% NaOCl, via a programmable precision pump (Legato 100; World Precision Instruments, Sarasota, FL, USA), through a 30-gauge Max-i-Probe side-vented needle (Dentsply Sirona, York, PA, USA) positioned 1 mm coronal to the canal's apical termination. Extruded NaOCl was directed into the left side of the EMT. Excess NaOCl was aspirated from the coronal access via an 18-gauge blunt needle attached to a dental operatory high vacuum unit (HiVac; Fig. 2A).

The EMT (~4.75 mm internal diameter with Luer fittings at both ends) was completely filled with water and an air bubble was used to isolate the extruded NaOCl coming from the left against the pressurised water on the right. The bubble also served as marker to record the volume of extruded NaOCl. The EMT was pressurised via a 3-way valve that could select either atmospheric pressure or a combination of atmospheric pressure and 30 mm Hg. Atmospheric pressure was realised by filling the open beaker with water and connecting it to the 3-way valve via a flexible tube.

A water column regulator was connected to a sealed reservoir (all components to the right of the 3-way valve; Fig. 2B) to achieve constant, precise 30 mm Hg pressure. A mechanical pressure regulator, attached to a compressed air cylinder, was used to deliver air at 5 psi. The air-flow rate was just strong enough to create constant bubbles at the bottom of a glass tube extending 406.4 mm (16 in.) into a column of water, enabling a stable, exact pressure of 30 mm Hg to be generated. The tubing was extended to the sealed reservoir to pressurize the water