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Factors promoting the tissue dissolving capability of sodium hypochlorite

W. R. MOORER, & P. R. WESSELINK, *Department of Cariology, Endodontology & Pedodontology, University of Amsterdam Dental School, Amsterdam, The Netherlands*

Introduction

It is an endodontic tenet that the chances of successful root canal treatment are greatly enhanced by using an irrigant that aids in the removal of pulpal and dentinal debris from the root canal system. Sodium hypochlorite (NaOCl) solutions are used as endodontic irrigants because of the combination of at least three important properties: tissue dissolving capability, microbicidal activity (Shih *et al.* 1970, Bloomfield & Miles 1979, Harrison & Hand 1980) and, when used in the intended manner, absence of 'clinical toxicity' (Harrison *et al.* 1978, Lamers *et al.* 1980).

Hand *et al.* (1978) dissolved pieces of necrotic tissue in NaOCl and observed that dilution of 5.25 per cent NaOCl greatly decreased the necrotic tissue dissolution properties of the solution. They also stated that 'the surface area of tissue exposed to the test solution is important because dissolution is a function of surface contact'. Yet, they did not offer experimental evidence to confirm this statement. Thé (1979) dissolved pieces of necrotic tissue in NaOCl and showed that contact time and the volume of the hypochlorite solution used were, in addition to the concentration of NaOCl, all important parameters to dissolve a certain amount of tissue.

Cunningham & Balekjian (1980) digested collagen by hypochlorite and observed that at 37°C, but not at 21°C, a 2.6 per cent NaOCl solution was as effective as a 5.25 per

cent solution. Koskinen *et al.* (1980b), dissolved small pieces of bovine pulp tissue and confirmed the efficacy of 5 per cent and 2.5 per cent, but not of 0.5 per cent NaOCl. However they stated that 3 ml of test solution was an excessive amount for dissolving 100 mg of tissue. Furthermore, they stressed the importance of good contact between tissue and irrigant, and suggested that their *in vitro* results with 0.5 per cent NaOCl indicated 'that 0.5 per cent was too weak, despite abundant and repeated application, for the dissolution of necrotic pulp tissue *in vivo*'.

Using pulp tissue of extracted molars, Senia *et al.* (1971) observed that 5 per cent NaOCl was effective in the debridement process except for the apical 3 mm of the root canal. They suggested that 'three factors: limited surface contact, volume of irrigant and exchange/refreshment, either individually or together may limit the effectiveness of NaOCl as a tissue solvent'. None of these factors were, however, investigated.

Trepagnier *et al.* (1977) recommended 5 per cent or 2.5 per cent NaOCl for clinical use. This was based on an experiment in which they applied, without mechanical agitation, NaOCl to previously instrumented root canals in teeth that were stored in 50 per cent alcohol at 4°C.

Rosenfeld *et al.* (1978) dissolved uninstrumented vital pulps in 5.25 per cent NaOCl. The authors concluded that NaOCl acted very effectively on non-confined vital pulp tissue and stressed that the solution had a limited ability to dissolve tissue in confined areas.

In their scanning electron microscope study, Baker *et al.* (1975) compared 24

Correspondence: W. R. Moorer, Department of Cariology, Endodontology & Pedodontology, University of Amsterdam Dental School, Louwesweg 1, 1066 EA Amsterdam, The Netherlands.

irrigants and combinations of irrigants as to their debris-removing properties and concluded that 'the removal of micro-organisms and debris seemed to be a function of the quantity rather than the type of irrigant'. Wayman *et al.* (1979) observed that, although NaOCl was superior in releasing hydroxyproline from the root canal system, much debris remained when the system was examined by the SEM. Bolanos & Jensen (1980) and McComb & Smith (1975) used SEM techniques to study the appearance of instrumented and irrigated root canals. In both studies, a smeared layer was observed on the dentinal walls after using either saline or NaOCl, Koskinen *et al.* (1980a), also using the SEM, observed that NaOCl dissolved predentine. They stressed the importance of mechanical treatment to clean and debride root canal walls. Brown & Doran (1975) tried to estimate the 'particle floating capability' of various irrigants; they felt that a great need existed 'for mechanical aids to remove debris which might otherwise block the apical portions of the root canal from contact with irrigating solutions'. It might be thought that a study on the tissue-dissolving capability of NaOCl would yield little new information. Yet, a review of the literature revealed that certain aspects of this subject did not receive adequate attention, that is, were either not recognized as important or were not dealt with in controlled experiments. Although authors seem to appreciate the influence of factors such as concentration, volume, time, temperature, mechanical action, surface area of tissue, and confinement of tissue on the tissue dissolving capability of NaOCl, only the influence of a few of these variables, particularly concentration, have actually been investigated. It is the purpose of this paper to describe some effects of fluid flow, pH and available surface area of tissue on the tissue dissolving capability of NaOCl in order to rediscuss the use, and to help the understanding of the usefulness of NaOCl in endodontics.

Materials and methods

Chemical interaction of NaOCl with organic matter in a homogenous system was investi-

gated using a standardized water-soluble protein hydrolysate (Peptone¹), freshly dissolved each day of experimentation. Dilutions of NaOCl² and solutions of peptone in distilled water were poured in a glass beaker and were magnetically stirred with a teflon-coated rod at approximately 5 Hz (300 revolutions per minute). Experimental combinations contained initial concentrations of 0.6, 1.2 or 3.0 per cent NaOCl and between 0.1 and 2.0 per cent (w/v) of peptone. The pH of the mixture was continuously monitored with the use of a combined pH-electrode.³ Every 2 or 4 minutes, samples of fluid were removed from the mixture and immediately added to 2 per cent potassium iodide in 10 per cent acetic acid solution. The liberated iodine was titrated with standard 0.1 N sodium thio-sulphate, using soluble starch as an indicator, to obtain the percentage of available (active) chlorine from:

$$1 \text{ ml } 0.1 \text{ N } \text{Na}_2\text{S}_2\text{O}_3 = 0.00355 \text{ g} \\ \text{of active chlorine (Vogel 1962).}$$

The hypochlorite stock dilutions were stable (less than 1 per cent loss of initial activity) for at least 1 month, provided that they were stored in brown glass bottles. The pH was between 11.9 and 12.2. When appropriate, it was adjusted to pH 10.0 using hydrochloric acid. Dilution of the stock solutions to 0.3 per cent (active chlorine) was required to obtain osmotic values isotonic with human serum, as measured by the freeze point depression principle.⁴ Considerable amounts of sodium chloride were, most likely, responsible for the high osmotic values of the hypochlorite solutions.

Non-homogenous systems

For investigation of non-homogenous systems and for tissue dissolution, rabbit liver was excised, the lobes were cut into pieces of approximately 100 mg or 10 mg and subsequently stored in a humid chamber at 4°C. The necrotic pieces of tissue were used

¹ Bacto-Peptone, DIFCO Laboratories, Detroit, USA.

² Natrium hypochloriet (Chloorbleekloog), Boom B.V., Meppel, The Netherlands.

³ EA 157, Metrohm, Herisau, Switzerland.

⁴ Halbmikro-Osmometer, Knauer, Berlin, Germany.

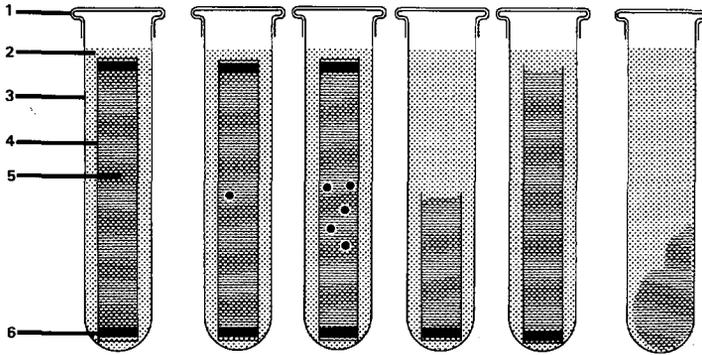


Fig. 1. Interaction of NaOCl with necrotic tissue in various states of confinement. Negative control (left) of completely enclosed tissue. Positive control (right) of free tissue. A–D are experimental tubes with enclosed tissue. (1) Parafilm seal, (2) NaOCl, (3) glass tube, (4) polyethylene tube, (5) enclosed tissue, (6) wax seal.

experimentally between the 2nd and 7th day after excision. One piece (100 mg wet weight) of tissue or about 10 small pieces (total wet weight 100 mg) were added to 5 ml of NaOCl solution in screw-capped glass reagent tubes (100 × 13 mm, net volume 9 ml). The filled tubes were clamped in a test tube rotator and were rotated end-over-end at various speed settings. Some control tubes remained stationary on the bench. At various time intervals, the pH was measured and small samples of fluid were taken in order to measure the residual available chlorine. At 15, 20 or 30 minutes, the remaining tissue was collected, lightly dried on a towel and subsequently weighed.

Interaction of enclosed or 'confined' tissue with NaOCl was investigated by placing 3 day old necrotic pieces of rabbit liver into polyethylene tubes (length 40 mm, diameter 3 mm). Some tubes (the negative controls) were closed at both ends with blue casting wax and contained approximately 450 mg of enclosed liver. Experimental tubes were closed at both ends but received:

- One small hole, diameter 0.3 mm in the middle part of its length to communicate the enclosed tissue with the outside.
- Ten small holes.
- Some of the tubes were reduced to half their length and left open.
- Other experimental tubes were closed at one end only.

In this way, various grades of confinement and various tissue/fluid interfaces were created (Fig. 1).

The polyethylene tubes containing the enclosed tissue were put into glass reagent tubes filled with 1.2 per cent NaOCl. Little lateral space remained for the polyethylene (tissue containing) tube, although it could move 'freely' in the NaOCl filled glass tube. An equivalent amount of 'free' necrotic tissue, not enclosed in polyethylene, was used as a positive control. Closure of the glass tubes was by means of Parafilm⁵ caps, after which the assembly was either rotated end-over-end or remained stationary on the laboratory bench. After 30 minutes, the fluid was assayed for remaining active chlorine and for pH. All experiments were carried out at approximately 22°C. In separate experiments ultrasonic power was delivered to the tissue/NaOCl system with a slender titanium probe, connected with the ultrasonic 25 kHz power supply unit.⁶ At the power control setting of 6, the sonic power output was approximately 100 Watts/cm², with a tip displacement of the probe of 100 μm. The probe was vertically immersed in the hypochlorite-containing reagent tube to a depth of 1 cm, and was

⁵ Parafilm, American Can Company, Dixie/Marathon, Greenwich, Connecticut, USA.

⁶ Kontes Micro Ultrasonic Cell Disruptor, Kontes Europe, Lancashire, England.

Table I. Inactivation of 3 per cent NaOCl reacting with protein hydrolysates

Amount of hydrolysate (weight/volume per cent)	Reaction time (minutes)			
	2	4	8	20
0.1	0.09* (12.0)†	0.13 (12.0)	0.13 (12.0)	0.14 (12.0)
0.2	0.24 (11.9)	0.25 (11.9)	0.28 (11.9)	0.30 (11.9)
0.4	0.52 (11.8)	0.57 (11.7)	0.59 (11.6)	0.76 (10.9)
1.0	1.48 (9.3)	1.66 (8.7)	1.84 (8.4)	2.09 (8.1)
2.0	1.96 (8.9)	2.00 (8.6)	2.06 (8.2)	2.11 (7.9)

* Per cent active chlorine consumed in the reaction (max. 3.0 per cent).

† pH value of the reaction mixture (in brackets).

Table II. Inactivation of 1.2 per cent NaOCl reacting with protein hydrolysates

Amount of hydrolysate (weight/volume per cent)	Reaction time (minutes)			
	2	4	8	20
0.1	0.05* (11.9)†	0.08 (11.8)	0.12 (11.7)	0.12 (11.6)
0.2	0.15 (11.9)	0.17 (11.7)	0.20 (11.5)	0.33 (10.3)
0.4	0.38 (11.0)	0.47 (10.0)	0.63 (9.4)	0.75 (8.8)
1.0	0.80 (9.6)	0.83 (9.3)	0.86 (8.6)	0.91 (8.0)
2.0	0.82 (9.6)	0.84 (9.3)	0.87 (8.5)	0.92 (8.0)

* Per cent active chlorine consumed in the reaction (max. 1.2 per cent).

† pH value of the reaction mixture (in brackets).

Table III. Inactivation of 0.6 per cent NaOCl reacting with protein hydrolysates

Amount of hydrolysate (weight/volume per cent)	Reaction time (minutes)			
	2	4	8	20
0.1	0.05* (11.7)†	0.06 (11.7)	0.07 (11.5)	0.10 (11.1)
0.2	0.15 (11.4)	0.15 (11.3)	0.18 (10.5)	0.24 (9.5)
0.4	0.22 (10.3)	0.29 (9.5)	0.35 (9.1)	0.38 (8.6)
1.0	0.25 (9.7)	0.36 (9.3)	0.36 (9.0)	0.37 (8.5)
2.0	0.33 (-)	0.36 (-)	0.37 (-)	0.39 (-)

* Per cent active chlorine consumed in the reaction (max. 0.6 per cent).

† pH value of the reaction mixture (in brackets).

subsequently tuned to optimum power output. The tissue was enclosed in the C-type tube.

Results

Interaction in homogeneous solution

The interaction of sodium hypochlorite with protein hydrolysate involves a simultaneous inactivation of NaOCl, which was monitored by measurement of the active chlorine that is consumed in the process, and by assessment of the pH of the reaction mixture. Tables I, II and III list the results

obtained with several concentrations of peptone and 3.0, 1.2 and 0.6 per cent NaOCl respectively. It was observed that, at each hypochlorite/peptone ratio, the loss of most of the active chlorine occurred within 2 minutes of mixing, indicating a relatively fast initial reaction. The tables demonstrate the importance of the ratio of NaOCl and peptone in the reaction process. In cases of excess NaOCl, only a small proportion of its activity is lost. However, an excess of organic matter rapidly depletes the activity of NaOCl and also lowers the pH drastically during the first moments of the reaction.

Table IV. Efficacy of NaOCl expressed in TA 50

Protein hydrolysate (weight/volume per cent)	Sodium hypochlorite solution (per cent)					
	3.0		1.2		0.6	
	pH 12	pH 10	pH 12	pH 10	pH 12	pH 10
0.1	≥20	≥20	≥20	≥20	≥20	>20
0.2	≥20	≥20	>20	>20	>20	20
0.4	≥20	>20	7	12	4	4
1.0	2	<4	<2	<4	3	4
2.0	<2	<4	<2	—	<2	—

Table V. Dissolution of tissue. Effect of amount and surface area

Pieces of tissue	Sodium hypochlorite solution (per cent)						
	3.0		1.2		0.6		Saline
	pH 12	pH 10	pH 12	pH 10	pH 12	pH 10	
1 × 10 mg	100†	100	100	100	100	95	0
10 × 10 mg	100	100	96*	88*	68*	69*	0
1 × 100 mg	85	86	81*	73*	44*	53*	0

* An asterisk denotes associated TA 50 values shorter than 20 minutes, indicating too rapid depletion of active chlorine.

† Per cent of tissue dissolved in 20 minutes in 5 ml. Rotation at 0.1 Hz.

For any hypochlorite-containing closed system the time span needed to deplete the system of half of the original concentration of active chlorine can be defined as a TA 50 (time of 50 per cent residual activity, or active chlorine remaining). The TA 50, expressed in minutes, is interpreted as a measure of interaction or efficacy of NaOCl. The longer the TA 50 the more efficient interaction in the system under consideration, the hypochlorite being in an excess. The shorter the TA 50 the more insufficient the interaction. Table IV summarizes the TA 50 values, obtained from the data of Tables I–III. In addition, it compares these figures with those obtained from analogous experiments (data not presented) but using NaOCl dilutions adjusted to pH 10.0 instead of the 'normal' pH of about 12. Only minor differences in the magnitudes of the TA 50 values obtained with the two sets of NaOCl dilutions were noted.

Interaction in non-homogenous systems

Small (10 mg wet weight) and large (100 mg) pieces of necrotic rabbit liver tissue dissolved

in a NaOCl solution. The effects of surface area, initial tissue weight and the initial pH of the NaOCl dilutions are set out in Table V, which lists the mean weight percentages of tissue dissolved after 20 minutes of contact with NaOCl.

An asterisk denotes a short TA 50, indicating inefficient interaction between NaOCl and the amount of tissue. In all cases with short TA 50's, the pH of the system after 20 minutes fell by more than 1.5. This is in contrast with the minor pH-drop (less than 0.5) observed in the efficient systems.

Introduction of mechanical agitation or fluid flow as a variable in the tissue dissolving capability of NaOCl led to the data summarized in Table VI. Table VII indicates that ultrasonic power may serve as a very effective means of dissolving tissue rapidly in NaOCl.

The effect of confinement could not be measured directly by weighing undissolved tissue. However, with an excess of tissue relative to the amount of hypochlorite, the consumed active chlorine is a measure of interaction (and thus of dissolution) of

Table VI. Influence of mechanical agitation on tissue dissolution

Frequency of rotation		Reaction time (minutes)	
Hz	(rev/min)	15	30
0.0	(0)	—	34 (32–39)
0.017	(1)	60 (54–67)*	78 (72–85)
0.10	(6)	73 (71–76)	89 (80–93)
0.33	(20)	100	100

* Mean weight per cent of tissue (range), one piece of 100 mg at $t = 0$ minute, dissolved in 5 ml of 1.2 per cent NaOCl. In physiological saline no tissue loss was observed.

Table VII. Effect of ultrasonic power on the speed of tissue dissolution

Mode of tissue* treatment	<i>n</i>	Minutes needed for complete dissolution, mean (range)
still	4	>30
rotated at 0.33 Hz	6	10 (7–15)
ultrasonically agitated† ‡	6	2 (1–4)

* One piece of tissue (100 mg) in reagent tube with 5 ml of 1.2 per cent NaOCl.

† Ultrasonic probe tip immersed 1 cm in the hypochlorite fluid.

‡ No appreciable loss of tissue in physiological saline activated by ultrasound, although fragments of tissue broke loose from the main block of tissue.

Table VIII. Interaction* of enclosed tissue with NaOCl. Effect of mechanical agitation (fluid flow) and ultrasonic power

State of confinement of tissue†	<i>n</i> ‡	At 0.17 Hz (10 rev/min)	Still
completely enclosed (negative control)	6	9 (3–14)*	—
one small orifice (A)	10	13 (6–18)	6 (1–10)
ten small orifices (B)	4	17 (8–25)	—
open at one tube-end (D)	10	29 (20–38)	11 (6–21)
open but halved tube (C)	4	40 (28–52)	13 (6–20)
free tissue (positive control)	4	89 (86–92)	56 (51–61)
ultrasonic oscillation			
as C (but with probe tip present)§	10	97 (95–98)	

* Per cent of active chlorine consumed (range) at high tissue/NaCl ratio, see text for details.

† Fig. 1.

‡ Number of determinations.

§ Tip diameter 2.4 mm.

tissue with NaOCl. Table VIII contains data obtained with enclosed tissue in different states of confinement (see Fig. 1). The influence of even slow mechanical agitation (fluid flow) of such hypochlorite/tissue systems on the dissolution of tissue is striking. Ultrasonic power is an even more effective principle. It agitates the fluid violently, it releases pieces of tissue from confinement and ruptures the tissue, thus causing rapid dispersion and dissolution in,

and inactivation of, NaOCl. In our system, the temperature of the fluid rose to approximately 45°C. (When less fluid, i.e. 0.5 ml instead of 5 ml, is treated ultrasonically, the temperature may reach values as high as 70°C within minutes).

Discussion

The active principle of NaOCl solutions is the amount of undissociated HOCl molecules. This is responsible for the strong

chlorinating and oxidizing action on organic materials such as textiles, tissues, microorganisms, wood, etc. A hypochlorite solution forms HOCl from NaOCl and H₂O as the HOCl is consumed in the interaction with organic matter. The 'available chlorine' in any hypochlorite system is the sum of the HOCl and OCl⁻ concentrations (Bloomfield & Miles 1979) in the system. As all types of organic matter interact strongly with hypochlorite, it is possible to quantify this interaction by measurement of the available chlorine that remains at the end of, or is present at any time during, the interaction. The tabulated data from Tables I-III exemplify two important aspects of the interaction.

First, the course of the reaction is governed by the ratio of hypochlorite/organic matter and secondly, a relatively fast initial reaction is followed by a slow, second phase. In fact, the initial reaction proceeds much faster than can be followed by sampling the reaction mixture; 2 minutes of elapsed time may well mean reaction within seconds. An excess of organic matter depletes the system of most of its activity (the remaining iodometrically measured available chlorine may not even represent useful available chlorine but rather reversibly bound chlorine that is detected by the iodometric technique) and causes a large drop of the pH value within minutes. For hypochlorite solution to be effective, it should act quickly and be in an excess in relation to the amount of organic material that is to be digested (i.e. chlorinated, oxidized, broken down, dissolved). The TA 50 value may be used to identify the effectiveness of the hypochlorite, thus simplifying the necessary quantitative considerations of amounts, time and other circumstances that influence efficacy. For hypochlorite solution to be effective as a root canal irrigant it should have TA 50 values larger than about 10 or 20. Considering the approximate amount of organic matter within the root canal system and the small volume of applicable NaOCl solution, the way to accomplish this is by frequent application of fresh irrigant, and/or the use of high percentages of active chlorine.

Hypochlorite solutions, chlorinated lime and household bleach have pH values of

about 12 due to an excess of NaOH, as the shelf life of the product is optimal at this pH. It has been argued that lowering the pH value and concentration of a hypochlorite dilution results in a less harmful and less hypertonic fluid, better adapted to everyday use because it is less toxic if it comes in contact with the eyes, skin or with textiles. Indeed 'Dakin's solution', which is used as a wound irrigant, consists of 0.5 per cent NaOCl, 'neutralized' with carbonate to pH 10. In cases of accidental injection of NaOCl into the periapical tissues (Becker *et al.* 1974), the acute symptoms will probably be less severe when low concentration and low pH hypochlorite solutions are used. Furthermore, hypochlorites at low pH possess an even better anti-microbial activity (Bloomfield & Miles 1979). Tables IV and V indicate that the concentration of available chlorine rather than pH is the important variable in hypochlorite efficacy although, theoretically, the higher the pH, the better the dissolution of tissue ground substance and protein. In non-homogenous tissue/fluid systems, the interaction is a function of the surface area of contact between tissue and fluid. Several workers have already observed and deduced that the surface area or surface contact is important (Shih *et al.* 1970, Senia *et al.* 1971, Brown & Doran 1975, Hand *et al.* 1978, Koskinen *et al.* 1980b).

At a fixed surface area, the higher concentration of NaOCl is the most effective, a fact upon which there is general agreement. However, it is important to realize that this is a valid concept only in cases of relatively large amounts of tissue. When only small amounts of tissue are present (in an excess of hypochlorite fluid), this need not be true. In fact, large TA 50 values are obtained, in these cases, even with hypochlorite concentrations as low as 0.6 per cent (Table V), indicating efficient hypochlorite action. It is possible to compare Table IV (protein hydrolysate/NaOCl) with Table V (liver tissue/NaOCl) by calculation of the total organic matter in an amount of liver (20 per cent) and in peptone (81 per cent). Thus, about 80 mg of wet weight of liver in 5 ml of NaOCl contains the same amount of organic matter as 0.4 per cent of

protein hydrolysate. A good correlation between the tabulated data of both tables is now evident in so far as the efficacy of the hypochlorite action is concerned.

It came as a surprise to find that the influences of mechanical agitation on the tissue dissolving ability of NaOCl proved to be so important (Tables VI–VIII). It may be concluded that fluid flow is a more important variable than the initial percentage of available chlorine in the tissue-dissolving action of NaOCl. This phenomenon may explain the variability in results of different workers. Thé (1979) agitated his tissue/NaOCl system once in 10 minutes, Hand *et al.* (1978) 'stirred' the tissue in a beaker, Koskinen *et al.* (1980b) used 'continuous agitation' to dissolve pulp tissue, Rosenfeld *et al.* (1978) applied NaOCl statically on uninstrumented vital pulp tissue *in situ*, while other authors used or simulated clinical techniques of mechanical action (Svec & Harrison 1977, Trepagnier *et al.* 1977, Senia *et al.* 1971, Shih *et al.* 1970, Bence *et al.* 1973, McComb & Smith 1975, Baker *et al.* 1975, Wayman *et al.* 1979, Bolanos & Jensen 1980, Koskinen *et al.* 1980a). It may seem strange that mechanical fluid flow is such an important factor in a system with hypochlorite solution of a similar viscosity to water: it would appear that diffusion and an occasional stirring action would suffice to accomplish dissolution. Unknown factors like shearing forces on the tissue and limited local diffusion may well be responsible for the quantitative important effect of fluid flow.

Ultrasonic oscillation is an extremely effective means of detaching, suspending or dissolving solid matter. The resulting cavitation effect produces large shearing forces on solid matter suspended in fluids as well as involving violent agitation of the whole fluid phase. It was not surprising to find the very strong effect of ultrasonic power on the speed of tissue dissolution in NaOCl. Enclosed tissue is 'pulled' out of its confinement and is ruptured under the forces of the ultrasonic probe. The magnitude of the effect of ultrasonic agitation cannot be compared with classical means of agitation. Although the effect is very impressive, it is felt that one should not attempt to use this method

clinically without careful consideration of undesirable ill-effects, such as temperature rise, the possible forcing of debris through the apical foramen, and the resultant damage to the periapical tissues or even to the hard tissues. It should be stressed that the magnitude of any supposed side-effects will depend on the amount of ultrasonic power (and of the frequency, tip displacement and geometric configuration) that is delivered to the pulp. However, our laboratory micro-ultrasonic cell disruptor as well as that of Martin (1976) may well be much more powerful than the ultrasonic devices generally used in practice, i.e. Cavitron.⁷ Quantitative considerations on the effects of ultrasound on living tissue should precede clinical use of any ultrasonic device.

Apart from being an effective tissue solvent, NaOCl is a very powerful antimicrobial agent. As is the case with tissue dissolution, the amount of available chlorine in a hypochlorite system is important, not the mere initial 'strength' of the hypochlorite solution. Bactericidal hypochlorite concentrations as low as a few parts per million are widely used to sanitize public water supplies and swimming pools. The presence of substantial amounts of organic matter, however, dictates the use of much higher concentrations of hypochlorite for general disinfection purposes (Cousins 1976, Bloomfield & Miles 1979) or for endodontic use (Shih *et al.* 1970, Bence *et al.* 1973, Senia *et al.* 1975, Martin 1975, 1976, Ellerbruch & Murphy 1977, Harrison & Hand 1980). The recommended strength of antibacterial NaOCl is totally dependent on the amount of organic substances that are present. It can be safely stated that any hypochlorite solution that is able to dissolve tissue (i.e. is not depleted of most of its available chlorine) is, at the same time, a powerful disinfectant. In endodontics, re-infection rather than inadequate disinfection by hypochlorite seems to be a problem (Bence *et al.* 1973). Similarly, the amount of hypochlorite or its frequency of application seem, because of the organic matter present, more important than the strength of

⁷ Amalgamated Dental Ltd, London, UK.

the NaOCl, as may also be concluded from the work of Shih *et al.* (1970).

Interaction of NaOCl with tissue or organic matter results in inactivation of the hypochlorite. The breakdown products of hypochlorite are simple sodium and chloride ions, totally innocuous for living organisms. This important property of NaOCl does distinguish it from most endodontic medications or irrigants, except physiological saline and iodine-potassium iodide solution (as well as the infrequently used citric or lactic acids). The very toxic effects of NaOCl in tissue cultures (Spangberg *et al.* 1973, Koskinen *et al.* 1981) and the acute toxicity in cases of accidents (Becker *et al.* 1974) stand in sharp contrast to the histological absence of toxic or irritant effects in the subcutaneous placement of NaOCl in guinea-pigs (Thé *et al.* 1980), or in the teeth of monkeys (Lamers *et al.* 1980), or to the clinical absence of pain in endodontic patients (Harrison *et al.* 1978). As the much used commercial household bleaches such as Clorox⁸ contain approximately 5 per cent NaOCl and, in addition, 4 per cent NaCl, 0.2 per cent Na₂CO₃ and 0.015 per cent NaOH, it should be realized that undiluted Clorox will possess an osmotic value of approximately eight times the physiological value. Thus, it will, at least theoretically, cause irritation of living tissues (in tissue culture, but also of periapical tissues and the remnants of tubular pulp tissue) by its very hypertonic nature. A NaOCl solution with the same osmolarity as human serum may be prepared by dilution with distilled water.

Conclusions

The tissue-dissolving power of NaOCl solutions appears to be strongly dependent on

- (1) the amount of organic matter in the hypochlorite/tissue system,
- (2) the frequency and intensity of mechanical agitation (fluid flow), and
- (3) the available surface area of free or enclosed tissue.

⁸ Clorox, Clorox Corp., Oakland, California, USA.

Careful consideration of the magnitude of these three effects in clinical situations should encourage an endodontic chemo-mechanical debridement technique based on NaOCl application with continuous and intensive mechanical debridement of the canal system and repeated refreshment of the sodium hypochlorite in accordance with present knowledge.

Review of the literature and essential aspects of the present *in vitro* results confirm that the unique set of anti-bacterial, tissue-dissolving and non-toxic properties of NaOCl are satisfactory and therefore the material is fit for endodontic use.

Although any concentration of NaOCl between 0.3 per cent and 5.0 per cent may be used successfully in clinical endodontics, it is stressed that the mechanical aspects of the technique appear to be more important than the initial hypochlorite concentration. It is felt that with a better mechanical debridement technique, and with more frequent changes of hypochlorite, a lower concentration of irrigant may be used for safe and thorough debridement and disinfection of the root canal system. It is recommended that a solution between 0.5 and 2 per cent be used in clinical practice.

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