THE USE OF ULTRASOUND AND SODIUM HYPOCHLORITE AS ADJUNCTS TO THE CLEANSING OF ROOT CANALS.

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The work submitted for examination in this thesis is the original work of the candidate alone. This investigation was conducted within the Department of Operative Dentistry, University of Sydney. No portion of this work has been submitted by the candidate to any other University in part or full for the award of any other degree.

J. A. Cameron
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CHAPTER 1
INTRODUCTION

"What comes out of a root canal is as important as what goes into it" (anon).

Most endodontic texts subscribe to the concept that cleaning, shaping and sealing of the root canal system is the basis of clinical endodontics. While there have been changes in emphasis from one material or technique to another, this does not imply that either the instruments or materials used in endodontics have been radically altered in the last 50 years. Clinical reports and investigations have been directed towards the modification of long-standing clinical practice rather than the development of entirely new concepts, instruments or materials. The endodontic literature reflects prevailing endodontic practice in vogue at the time (Huer 1976).

It has been suggested that the current era of endodontics commenced in 1943 with the formation of the American Association of Endodontists (AAE). An overview of the literature reveals the change in emphasis from root canal therapeutics in 1943 to biomechanical preparation in 1988. One of the founder members of the AAE (Grossman 1950) stated "Root canal therapy may be divided arbitrarily into three phases: (1) mechanical preparation; (2) chemical preparation; (3) sterilization". Mechanical preparation of the canal was achieved with files used with a pull stroke, chemical preparation used 'double strength chlorinated soda solution' and sterilisation of the root canal utilised chemicals such as camphorated monochlorophenol.

In 1955 the University of Washington School of Dentistry sought an answer to the question, "How successful is endodontic therapy?" This study, and the 5 year recall period, became known as the 'The Washington Study'. 104 failures were recorded in the 1,229 cases reviewed. Incomplete obturation accounted for 59% of all failures; the next most common cause was root perforation in 10% of treatment failures. Such was the thinking of the day that a category 'Incomplete Debridement' was not provided.
Ingle (1965) wrote "Although an interest in preservation of the dental pulp has been generated, the majority of the recent endodontic literature has been directed towards the sterilization of the necrotic, infected root canal. The debate goes on unabated today, although very little true progress has been made in the field since Walkoff recommended chlorophenol in 1891."

Gutierrez and Garcia (1968) prepared root canals with either reamers, or reamers and files, and then injected rubber impression material into the prepared root canal. The rubber models demonstrated canal irregularities and fin formation. A similar experiment by Davis et al. (1972) showed that in many curved canals one wall of the canal was untouched by conventional instrumentation.

By 1974 instrumentation had been expanded to include the concepts of cleaning and shaping the canal. Terms such as 'biomechanical instrumentation' or 'chemomechanical instrumentation' were being used to convey different areas of emphasis as each modification was introduced. Histologic examination indicated that retained necrotic pulp tissue was present in many failed endodontic cases (Schilder 1974). Schilder considered cleaning and shaping of root canals to be the most important phase of endodontic treatment, and may be considered as an extension of the principles of coronal cavity preparation to the full length of the root canal system. The final shape of the root canal depended upon the properties of the root canal filling material and the obturation technique employed. Conventional Instrumentation, where all instruments were used to full working length, had been joined by Step-Back Instrumentation, where each consecutive instrument size larger than size #25 was used at a length 1mm shorter than its predecessor. Schilder suggested that serial reaming, filing and recapitulation would accomplish the continuously tapering funnel shape required to cleanse the root canal system. The benefits of serial, or step-back, preparation were confirmed by Coffae and Brilliant (1975).

One year later the literature forecast the end of the therapeutic era. 'It is no wonder that with superlative cleaning and shaping, endodontics can be practiced successfully with no intra-canal medication at all!' (Schilder 1976)
When the surfaces of debrided root canals were examined with the scanning electron microscope (SEM) (Baker et al. 1975, McComb and Smith 1975, Lester and Boyde 1977), the results indicated that most instrumentation techniques produced a canal wall that was smeared and packed with debris. None of the irrigating techniques was able to remove both the smeared layer and superficial debris.

If one compares the chapter 'Preparation of the Root Canal' in the Third and Tenth Editions of the textbook "Endodontic Practice" (Grossman 1950;1981) it would appear that the advances in canal instrumentation were more apparent than real. The Figure depicting root canal instruments is the same one in both editions. In that thirty year period instrument sizes had been standardised, the metallurgy improved and minor changes made to the design of the flutes on files, but the concepts outlined by Grossman were unchanged. "Biomechanical preparation of the root canal is the attainment of free access to the apical foramen through the root canal, by mechanical means, without injuring periapical tissue. The object of biomechanical preparation is to cleanse the pulp chamber and root canals of pulp remnants, foreign debris, infected or softened dentine in the pulp chamber or on the canal surface, etc; to remove obstructions; to enlarge the canal so as to receive the maximum amount of intracanal dressing; to smooth the canal wall in order to improve contact of the medicament with the infected surface; and also to prepare the canal wall so as to facilitate eventual obturation of the root canal."

A statement of basic aims was presented by Taylor (1984). Successful endodontic therapy requires removal of all degradable organic tissue from the root canal space and subsequent elimination of that space. If consulting engineers were asked how to achieve these two goals, it is unlikely they would recommend the use of reamers and files to produce a root canal shape dictated by the properties of gutta-percha, a filling material introduced in 1867. However, the use of a protein solvent activated by ultrasound to debride the canal, and an injection technique to obturate the canal space, might be recommended.
CHAPTER 2

ULTRASOUND

2.1 PHYSICAL PROPERTIES

Sound is a mechanical vibratory form of energy which can stimulate the human ear and brain to the sensation of hearing. The frequency range of these vibrations is from about 20 cycles per second (20Hz) to about 20,000 cycles per second (20kHz). Frequencies above 20kHz are called ultrasonic waves (Halliday 1966 p497). The simplest sources of sound are vibrating portions of solids, liquids and gases (Encyclopaedia Britannica 1961 <EB 1961>). All of these vibrating elements alternately compress the surrounding medium on a forward movement and rarely it on a backward movement. These disturbances are transmitted outwards from the source as a wave.

The essence of wave motion is the transfer of energy through space without a corresponding transfer of matter. Ultrasonic wave motion requires a supporting medium with the qualities of mass and elasticity. Elasticity denotes the ability to be deformed in proportion to the deforming force, and to recover the undeformed configuration when the force is removed. Propagation of the wave involves the displacement of successive particles of the medium. The motions of the displaced particles provides a means of classifying different kinds of waves; longitudinal waves are characterised by particle motion along the axis of propagation of the wave; shear or transverse waves have particle movement perpendicular to the propagation axis, and surface waves have particle movement restricted to a thin layer at the surface of the medium supporting the wave. The most common type of wave used in biomedical application is the longitudinal wave (Hussey 1975 p19).
2.2 SOURCES OF ULTRASOUND

The standard sources of ultrasound are piezoelectric and magnetostrictive oscillators. Both of these are electro-acoustic devices whose versatility depends on the possibility of designing oscillating electrical circuitry to almost any frequency and power specification.

2.2.1 The piezoelectric effect

Certain asymmetric crystals, like quartz and Rochelle salt, have electrical charges of opposite sign appear on opposite faces when they are subjected to mechanical stress. Conversely, if such a crystal is made the dielectric in a condenser subjected to an alternating electrical field, the crystal will vibrate with the frequency of the field. If a plate of quartz is cut with its faces parallel to the optic axis of the crystal the highest fundamental frequency is a function of the thickness of the plate. By making the thickness small enough, very high frequencies may be generated. Because there is a practical limit to the thickness of the plate, harmonics of the fundamental frequency are used to provide very high frequencies. Since the discovery of piezoelectricity in natural quartz crystal in 1880, many synthetic piezoelectric crystals have been grown from water solutions, including EDT ethylenediamine tartrate, ADP ammonium dihydrogen phosphate and Rochelle salt. At present most piezoelectric crystals, such as lithium tantalate and lithium niobate, are grown from high temperature melts. Another important class of piezoelectric materials are those that can be deposited as a thin film on various substrates. Frequencies of 100GHz (1GHz=1,000,000,000Hz) are obtainable with these devices (Ristic 1983 p117).

2.2.2 The magnetostrictive effect

A rod of magnetic material (iron, nickel or ferromagnetic alloy) changes length when the magnetic field to which it is exposed varies in magnitude. If an alternating current passes through a coil surrounding such a rod, the latter will vibrate lengthwise with a frequency double that of the current. If the frequency of the current coincides with one of the resonant modes of the rod, particularly large vibrations result, and sound of this frequency is radiated. A
nickel rod 10cm long emits a fundamental frequency of 24.3kHz. Magnetostrictive sources are less efficient than piezoelectric, largely because of the loss of energy due to the hysteresis (lagging of magnetic induction behind the magnetising force) in the magnetised rod. This effect can be reduced by using as a sender laminated nickel sheets fastened together (EB 1961).

2.3 PROPAGATION OF ULTRASOUND

Propagation of a sound wave involves the displacement of successive particles of the conducting medium. The passage of a wave is different in gases, liquids and solids. Gases have weak, short-range intermolecular cohesive forces which permit a random distribution of molecules. In liquids the higher cohesive forces result in the distribution of molecules radially about a particular molecule. In solids the forces are long range and the molecules are fixed relative to each other. The passage of an ultrasonic wave will display different characteristics in each state of matter. For instance, only solids can support shear waves. When fluids are subjected to shear waves they yield plastically rather than deform elastically. The increase in internal cohesion during the progression from gases to solids affects the density and the characteristic acoustic impedance of the medium. Each medium has its own characteristic acoustic impedance, which is a function of the density of the medium and the speed of ultrasonic propagation through that medium. Some propagation speeds and the acoustic impedance (kg/m²s x 10⁻⁶) at 20°C are:

<table>
<thead>
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<th>Material</th>
<th>Speed (m/s)</th>
<th>Impedance (kg/m²s x 10⁻⁶)</th>
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<tr>
<td>air</td>
<td>343</td>
<td>411.0</td>
</tr>
<tr>
<td>water</td>
<td>1430</td>
<td>1.5</td>
</tr>
<tr>
<td>dentine</td>
<td>3600</td>
<td>8.0</td>
</tr>
<tr>
<td>enamel</td>
<td>5800</td>
<td>17.1</td>
</tr>
<tr>
<td>steel</td>
<td>5950</td>
<td>46.6</td>
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(Ristic 1983:p.7)
The pattern of radiation from a transmitter rests on Huygens' principle, which states that the radiant energy at any point in the medium due to a complex source is equivalent to that due to a distribution of simple sources selected in their motion and distribution to represent the complex source. A vibrating rod is therefore equivalent to an array of point sources radiating into space (Hussey 1975 p28).

2.4 REFLECTION AND REFRACTION

When ultrasound is passed through a homogeneous medium, energy waves radiate outwards away from the source of ultrasonic energy. At the interface between two homogeneous media a longitudinal wave incident at an oblique angle to the interface generates two reflected waves. One is a longitudinal wave reflected at an angle equal to the angle of incidence, and the other is a shear wave reflected at a smaller angle. Two refracted waves are generated in the second medium (Ristic 1983 p9). This partitioning of the incident wave is dependent on the characteristic acoustic impedance of the two media. At the interface between two media a high level of acoustic complexity can develop. Medium #1 now has two longitudinal waves, an incident wave travelling forward and a reflected wave travelling backwards. Depending on the relative phases of the two waves the original wave can be reinforced or reduced. An increase in pressure is called a standing wave. Some scattering of the reflected wave does occur (Hussey 1975 p34). The part of the beam entering the second medium is refracted as it passes across the interface; some of the beam is transformed from longitudinal to shear wave formation, and some scattering of the beam occurs. If the second medium is not acoustically homogeneous some ultrasound is reflected out of the beam (scattered) and this leads to increased absorption of the beam.
2.5 ABSORPTION AND DISPERSION

In a purely elastic medium ultrasonic energy remains as potential and kinetic energy. All common media are visco elastic and contain mechanisms which transform mechanical energy to heat. This mechanism causes the deposition of heat in the medium and a loss of energy from the ultrasonic wave. The ultrasonic wave is attenuated, or absorbed, by the medium. Because the absorption occurs exponentially along the direction of propagation, a logarithmic scale is used to compare amplitudes and intensities along the wave path (Hussey 1975 p36). The existence of a gradient of energy density along an ultrasonic beam produces a force acting in the direction of decreasing energy density. This force can produce physical streaming of the medium; it is known as acoustic streaming (Hussey 1975 p43).

If the amplitude of the ultrasonic wave is increased from low intensity to medium intensity more heat per unit volume is deposited in the medium. With high intensity signals the medium becomes stressed to the limit, and rupture of the medium begins to occur. The most common version of this phenomenon is cavitation in liquids (Hussey 1975 p43). Ultrasonic cavitation is of two kinds. If a liquid contains dissolved air or other gases, the large and rapid changes in pressure produced by ultrasound cause the gas to come out of solution; this is called pseudo-cavitation. If a liquid is completely degassed, bubbles can still be formed if the pressure change is great enough to overcome the tensile strength of the liquid. This is called genuine cavitation (EB 1961). The onset of cavitation is marked by the appearance of bubbles in the path of the ultrasound. These bubbles remain stable in size and persist even when the ultrasound is removed. A further increase in intensity causes these bubbles to increase in size during the negative pressure phase of a small number of cycles and rapidly collapse during the positive phase. The collapse of the bubbles generates heat for a brief period, and shock waves are propagated. The pressure of these shock waves can exceed the pressure of the original ultrasonic wave (Hussey 1975 p43). The cavitation threshold of a liquid increases with its viscosity, and decreases with increased temperature.
2.6 ENDODONTIC IMPLICATIONS OF THE TRANSMISSION, REFLECTION, REFRACTION AND ABSORPTION OF ULTRASOUND.

In its endodontic application, ultrasonic energy is introduced into the root canal by an activated endodontic instrument such as a K file. The ultrasound waves radiate through the irrigant outwards away from the instrument in accordance with Huygens' principle. The radiation is more pronounced from the free end of the instrument than from the middle or the fixed end (Ahmad 1987a). At the interface between the irrigant and the root canal wall part of the incident wave is reflected and part refracted. The difference in specific acoustic impedance between a liquid irrigant and dentine (1.5 : 8.0 kg/m²s x 10^-6) results in more than half of the incident wave being reflected back into the irrigant. The incident longitudinal wave produces a reflected longitudinal wave and a reflected shear wave. The irrigant liquid cannot support a shear wave and yields plastically. Dental units generate ultrasound with a wavelength of about 5cm, so standing wave formation is not possible within a root canal. Acoustic streaming along the length of the file is possible. Ultrasound could accelerate the decomposition of the endodontic irrigant sodium hypochlorite and cause bubbles of oxygen to appear in the irrigant. Ultrasound waves hitting these bubbles would be reflected and refracted adding to the complexity of the wave movement.

The ultrasound wave passing across the irrigant/dentine interface is refracted as a longitudinal wave or a shear wave. Dentine has organic and inorganic components, and so is not acoustically homogeneous; scattering and absorption of the ultrasound beam occurs. Because wave absorption occurs exponentially along the direction of propagation (Hussey 1975 p36) and dentine is a poor conductor of ultrasound (Lees 1971), much of the ultrasonic energy is absorbed and converted to heat energy on the irrigant side of the root canal wall.

It is possible that any ultrasonic energy reaching the cementum could stimulate repair in damaged tissue by increasing the blood flow to the area. (Bickford and Duff 1953, Dyson et al. 1970)
2.7 INTRA CANAL CELLULAR DISRUPTION

One of the main uses of ultrasound in biology has been to disintegrate cells such as bacteria. The aim in this application is irreversible disruption of the cell membrane. Cavitation (pseudo or genuine) appears to be the requisite mechanism (Hussey 1975 p140). Cell destruction seems to depend on ultrasonic intensity and duration of treatment. For high intensity signals a brief treatment time is needed to destroy the cells (Coakley 1971). Even in the absence of cavitation cell wall disruption is still possible. When the amplitude of vibration exceeds 8μm at 85kHz, the shear forces generated can cause erythrocyte cell membrane disruption (Hughes and Nyborg 1962). A rise in temperature from 40°C to 50°C lowered the membrane disruption stress threshold (Rooney 1972). Temperature and shear forces thus act synergistically in disrupting cell membranes. This could be because at elevated temperatures the effective "pore" size in the membrane is increased, and so the membrane is weakened.

2.8 REVIEW OF DENTAL LITERATURE

Richman (1957) was the first to report on the use of ultrasound for the endodontic treatment of pulpless teeth. He used a Cavitron Ultrasonic Dental Unit on 50 teeth to prepare the access cavity in the crown of the tooth, debride and shape the root canal and then obturate the prepared canal. The same ultrasound unit was used as an aid in endodontic surgery. Ultrasound plus an abrasive slurry cut through enamel and dentine with a minimum of vibration. As air turbines were not yet in general use, and profound anaesthesia was difficult to obtain, a vibration free cutting technique removed one source of patient discomfort. The cutting tool tip was then replaced with the root canal hub. This metal block screwed into a handpiece which contained the magnetostrictive stack. An endodontic instrument was passed through a hole in the block at right angles to the handpiece and held in place by a small hexagonal head set screw. The instrument was fixed so that the metal head could act as a working length stopper. Early ultrasonic units had to be tuned manually, so the vibrating length of the broach or file
was not dictated by the limitations of automatic tuning. A small barbed broach was placed at full working length, the ultrasound generator activated and the canal cleaned and shaped using a "gentle, massaging action". The canal was constantly flooded with sodium hypochlorite to dissolve tissue, flush out debris and prevent heat build up. The small barbed broach was replaced by larger broaches, then files from #1 to #6 and finally a rat-tail file to complete the enlargement of the canal. At the completion of instrumentation and irrigation the canal was flushed with alcohol and air dried. A small file was placed into the canal and the ultrasound activated at a slightly higher power setting. The heat generated completed the drying of the canal. The power setting was reduced and a fine tip used to circulate and pump a root canal sealer throughout the canal. A single gutta-percha point of correct size was then placed under pressure to complete the root filling. In the summary the author commented: "Much can be done in future research to augment the use of ultrasonics in dentistry."

Martin (1976) investigated the bacteriocidal efficiency of ultrasound, with or without a cidal agent, as an endodontic irrigation system against four test organisms. (Streptococcus faecalis, Streptococcus mitis, Staphylococcus aureus, and Escherichia coli.) The output of the laboratory ultrasound generator was approximately 25 watts with a tip displacement of 4μm at 23kHz. The author noted that the ultratip (the tip of the ultrasonic probe) was too large for clinical use. Instrumented, autoclaved molar teeth were inoculated with the test organism and the ultratip placed into the access cavity. It was concluded that ultrasound did have a bacteriocidal effect which peaked in 4-5 minutes. If 5.5% sodium hypochlorite or 2% potentiated acid 1,5 pentanedial was added to the pulp chamber before exposure to ultrasound the bacteriocidal effect was more pronounced. No controls without ultrasound were provided.

Takagi (1977) reported on the irrigating, bacteriocidal and clinical efficiency of ultrasound (15W at 28.5kHz). Irrigating efficiency was investigated in 80 extracted human teeth. The SEM study indicated that the use of ultrasound together with 10% sodium hypochlorite, 5% trypsin or 30% urea produced an excellent cleansing effect. It also improved the bacteriocidal effects of these cleansing agents. The ultrasonic bacteriocidal effect was more pronounced on
gram-negative anaerobic bacteria than on gram-positive cocci. Clinical use of ultrasound resulted in fewer patient visits.

The efficiency of the lateral condensation obturation technique was improved by using ultrasound to warm the condensing instrument (Moreno 1977). Conventional lateral condensation allowed leakage of radioactive isotopes into the canals of all 10 control specimens. The mean distance was 2mm. Eight out of ten specimens filled with thermomechanically softened gutta-percha showed no leakage. The mean leakage was 0.6mm.

Ultrasonic and hand-powered K type files were compared for their ability to remove dentine from a standardised canal prepared in a 4mm thick section of root dentine (Martin et al. 1980a). The ultrasound unit had a maximum output of 50 watts and frequency of 18kHz, just under the accepted limit of ultrasound. The energised file was found to remove a significantly greater amount of dentine than hand filing in a fixed time period. Martin et al. (1980b) then tested ultrasonically energised diamond files and found that they too were more efficient in removing dentine than hand held K files.

In 1982 the team of Cunningham and Martin reported on the effect of endosonics on the removal of debris from an instrumented root canal using light microscopy (Cunningham 1982a) or the SEM (Cunningham 1982b); the reduction of Bacillus subtilis spores in artificially contaminated teeth (Cunningham 1982c); the amount of debris extruded through the apex during instrumentation (Martin 1982a); the incidence of post operative pain following root canal therapy (Martin 1982b).

Cunningham, Martin and Forrest (1982a) paired recently extracted human teeth for hand or ultrasonic instrumentation. Three minutes was allowed for the preparation of each canal. Light microscopy was used to evaluate sections at levels 1mm, 3mm, and 5mm from the apex. For the eleven pairs of teeth evaluated at all three levels, ultrasound was found to be superior for canal cleansing in thirty two of the thirty three levels.
Cunningham (1982b) used the SEM to evaluate the debris removal capabilities of either ultrasonic or hand instrumentation of 7 pairs of teeth. Three minutes was allowed for sequential hand instrumentation with K files and copious irrigation with 2.5% sodium hypochlorite, or ultrasonic instrumentation with ultrasonic files #10 and #15 and a continuous flow of 2.5% sodium hypochlorite. Ultrasonic instrumentation was judged to present the cleaner specimen in all seven pairs. A smear layer was present in instrumented areas in all specimens. Specifications of the ultrasound generator were not stated.

*Bacillus subtilis* spores were introduced into the root canals of fifty sterilised anterior teeth. The teeth were instrumented by hand or ultrasound, with saline or sodium hypochlorite (concentration not stated), for a period of three minutes. Ultrasonic and hand instrumentation with sodium hypochlorite were equally effective at 99+%. Cunningham (1982c) felt that these results might not accurately reflect true clinical conditions, as the organisms might not have entered the remote areas of the root canal system. The ultrasound generator was not identified. Material extruded through the apex during instrumentation was evaluated for ultrasonic and hand instrumentation and for instrumentation beyond or 1mm within the apical foramen. Martin (1982a) concluded that ultrasonic instrumentation produced significantly less extruded material than push-pull hand instrumentation. Preparation past the apex produced significantly more extruded debris. The ultrasound generator was not identified.

A reduction in debris extruded through the apex was not significant in reducing post operative pain (Martin 1982b). Two groups, each of 164 patients, were treated with ultrasonic or hand instrumentation, with an average of 2.5 visits per patient. Ten patients requested more help than aspirin analgesia after hand instrumentation compared with six in the ultrasound group. This difference was not statistically significant. The ultrasound generator was not identified.

In a later article (Martin and Cunningham 1984), these authors summarised much of their earlier research work. They suggested that 2.5% sodium hypochlorite was a suitable irrigant for use in the recently developed Cavitron² system.
Weller et al. (1980) used simulated root canals in resin blocks and mandibular premolar teeth to compare the debridement efficiency of hand instrumentation, ultrasonication or hand instrumentation followed by ultrasonication. Canal spaces were filled with radioisotope-laden gelatin, and the loss of radioactivity was a measure of the technique efficiency. Serial preparation of the canals was carried out with 2ml of distilled water between each file size. Ultrasonic energy was introduced into the root canal by means of a #15 finger plugger spot welded onto a Cavitron scaler insert. The canal was filled with distilled water and the activated ultrasonic probe wiped against the canal walls over a 30 second period. In the third group hand instrumentation was followed by ultrasonication. All specimens received a final irrigation of 5ml distilled water. Hand instrumentation and ultrasonication were equally effective in removing gelatin from a root canal. Ultrasonication with distilled water reduced by half the residual debris left in the root canal after hand instrumentation. However in the resin blocks ultrasound alone was not as effective as hand instrumentation. The results of this experiment might have had greater clinical significance if the prototype endodontic insert had been manually tuned, a protein solvent irrigant had been used, and the simulated root canals had been irregular and fins were present.

Kielt and Montgomery (1987) measured the amount of root canal transportation after preparation using ultrasonic, sonic and hand instrumentation techniques in simulated curved canals in resin blocks. All techniques removed more canal wall on the inner aspect of the curve in the middle portion of the canal, and on the outer aspect of the curve in the apical portion of the canal. The MicroMega Sonic 30003 and Cavi-Endo transported the canal least in the apical section. The Cavi-Endo and Enac4 systems transported the canal most in the middle section of the root canal. These results were obtained after a file size #35 was passed to the apex. If ultrasound does permit a more conservative canal preparation, this mid-canal transportation might not be as pronounced when smaller, more flexible files are used.

Simulated root canals in clear plastic blocks were also used to compare the efficiency and safety of six automated devices for root canal preparation (Tronstad and Niemczyk 1986). These
authors rated a sonic device, the MicroMega Sonic 3000, as mediocre when used with conventional broaches and files, whereas combined with the newly designed RISPI-SONIC\textsuperscript{5} file its efficacy increased 3-fold. The ultrasonic Cavi-Endo was a disappointment, and it was felt that the manufacturers should consider developing a new root canal instrument for this device.

Reynolds \textit{et al.} (1987) compared by histological examination the effectiveness of four different methods of root canal instrumentation in small, curved canals. The instrumentation methods were step-back hand instrumentation, sonic instrumentation (Endostar \textsuperscript{56}) and ultrasonic instrumentation with the Cavi-Endo system or PZ-Ktec\textsuperscript{7} experimental system. 2.6\% sodium hypochlorite was the irrigant for the step-back and Cavi-Endo specimens, tap water was used for the Endostar and PZ-Ktec specimens. The authors concluded that “the step-back hand instrumentation technique was more effective than the sonic and ultrasonic systems for: a) increasing canal area; b) removing predentine and debris; and c) planing canal walls. The differences were noted primarily in the coronal and middle canal regions; the apical areas showed less contrast between techniques.” It is possible the benefits of the step-back technique were as a result of using a \#4 Gates-Glidden drill to flare the coronal part of the small canal.

Scott and Walton (1986) used scanning electron microscopy to examine the specially designed Cavitron endosonic files and diamond instruments after varying periods of usage. The files appeared to be well made with slightly rounded cutting edges. The diamond files were judged to be of good quality with uniform distribution of diamond chips. After 12 minutes clinical usage some gouge marks appeared in the cutting edges of the flutes but there was no evidence of untwisting of the stainless steel files. Some diamond chips were lost from the diamond files after 8 minutes. Overall, the surface of the instruments was damaged very little even after 20 minutes of clinical use. Metal fatigue, which could lead to instrument fracture, was not assessed in this study.

Langeland \textit{et al.} (1985) instrumented 65 freshly extracted human teeth with either hand instrumentation and 1\% sodium hypochlorite as the irrigant, a Cavi-Endo ultrasound unit and...
1% sodium hypochlorite, or two sonic units with water. Of these 65 teeth only 35 teeth had been histologically prepared and evaluated at the time of the report. One of the stated aims of the investigation was "to rank the devices according to their cleaning efficacy;", and yet the authors concluded the sample was too small for a rating of the procedures. The results table of canal cleanliness indicated a trend where hand instrumentation was superior to ultrasonic instrumentation, with the sonic devices least efficient. Two years later the full report had not been published.

Stamos et al. (1987) were able to rate the efficacy of hand, sonic and ultrasonic techniques after a histologic study of fifty human mandibular molars. Both ultrasonic units (ENAC and Cavi-Endo) produced cleaner canals at the apical 1mm level than the sonic or hand instrument techniques. The ultrasonic and sonic techniques were faster than hand instrumentation.

Crabb (1982) used a smooth broach activated by ultrasound to agitate a 5% sodium hypochlorite solution within an uninstrumented root canal. This SEM study indicated that it was possible to render root canals extremely clean using 5% sodium hypochlorite in conjunction with ultrasonic agitation. A minimum of instrumentation was required, beyond ensuring that the coronal restriction was removed to give clear access to the root canal.

Tauber et al. (1983) used a magnifying lens (x4) to study the topography of the dentine wall of extracted, single rooted teeth that had been instrumented with a standardised serial filing technique compared with teeth instrumented with the same technique using files activated by ultrasound. The files were held in a clip spot welded onto a scaler tip, the teeth had been stored in formalin and the irrigant used was 0.5% sodium hypochlorite. These three factors would all contribute to the inefficiency of the ultrasound technique used in this experiment. The authors still found a trend towards cleaner canals in the ultrasound group.

Cymerman et al. (1983) compared hand and ultrasonic instrumentation without regard to irrigating solution. The root canals of 12 freshly extracted teeth were either hand instrumented
or ultrasonically instrumented with a #30 K-file held in the Caviton insert PR30. Both groups were irrigated with normal saline. Both techniques produced a canal surface with irregularities and smeared with tissue debris.

Ahmad et al.(1987a) used the SEM to compare the efficacy of hand and ultrasonic instrumentation using either tap water or 2.5% sodium hypochlorite as the irrigant. Regardless of the technique used, less debris was present in canals irrigated with sodium hypochlorite. There was little difference in retained debris between the specimens of the hand and ultrasound group, but there was significantly less smear layer retained in the ultrasound group. These authors (Ahmad et al. 1987b) then compared the conventional ultrasonic instrumentation technique (power setting #1 on a scale of 3 + 2.5% sodium hypochlorite) with an ultrasonic instrumentation/ultrasonic irrigation technique. In the modified technique ultrasonic instrumentation at power setting #1 with 1% sodium hypochlorite was followed by five minutes of ultrasonic irrigation. A #15 ultrasonic file was placed to full working length, activated at power setting 2.5 for five minutes with a free flow of 1% sodium hypochlorite. Care was exercised to prevent physical contact of the vibrating file with the canal wall. The modified technique was particularly successful in removing the smear layer. The Cavi-Endo has a 10 click power range divided into Low Medium and High bands rather than settings of #1, #2, and #3. The modified technique as suggested used a very low irrigant flow rate of 20ml/min. After three minutes of instrumentation and five minutes of irrigation 160ml sodium hypochlorite would be used for each canals. The Cavi-Endo reservoir has a capacity of about 80ml.

Pedicord et al. (1986) compared the shape of the prepared root canal after hand or ultrasonic instrumentation. A step-back technique was used to instrument one of the canals in the mesial root of 63 lower molars; the other canal in the root was instrumented ultrasonically. The order of preferred shapes was round preferred to oval preferred to irregular. At the apex there was no difference between the two techniques. In the middle and coronal thirds hand instrumentation was significantly better in producing a preferred shape. This was not surprising, as the final instrument used in the step-back technique was a #3 Gates-Glidden drill. Hand instrumentation
was found to be faster than ultrasound in more than 86% of roots prepared. Part of this time difference was attributed to the operators' lack of experience with ultrasound. A second Cavi-Endo machine was obtained after the long instrumentation times were recorded. Machine #2 was significantly faster than machine #1, but still much slower than hand instrumentation. These observations about long instrumentation times are in keeping with my clinical experience. The first Cavi-Endo inserts #P105 to arrive in Australia were grossly under-powered and not suitable for clinical use. Inserts presented to me for evaluation could not cut a groove in my fingernail within 15 seconds when used at full power with the matching file. The manufacturer suggests the insert be used at power setting L (Low). While the power rating of the insert has been increased it still falls short of the output of its competitors such as ENAC or Spacesonic8.

Goodman et al. (1985) made a histological comparison of the efficacy of a step-back instrumentation technique with a step-back preparation/ultrasonic irrigation technique. The mesial root canals of human mandibular molar teeth were prepared using a step-back technique with a continuous flow of 2.6% sodium hypochlorite. Following hand instrumentation each canal was given either three minutes of continuous flow irrigation or three minutes of continuous flow irrigation activated by ultrasound. The ultrasound was transmitted to the sodium hypochlorite within the root canal by a finger plugger welded to a prophylaxis tip. The step-back/ultrasound technique produced significantly cleaner isthmuses at the 1mm and 3mm levels and cleaner canals at the 1mm level than the step-back preparation. In 31 of the 40 canals in which the ultrasonic tip did not negotiate to the full working length, complete tissue removal was shown at the 1mm level. Because of these results it was concluded that complete penetration of the ultratip to full working length might not be necessary to obtain ultrasonic cleaning of the apical levels. There was a significant difference in the operator's ability to clean the canals and isthmuses at the 1mm level using the step-back technique. This difference between operator #1 and #2 was not present using the step-back/ultrasound technique. The authors concluded that operation of the ultrasound instrument was more of a mechanical procedure, with the instrument doing the actual work.
Wilcox et al. (1987) examined the appearance of the root canal walls after gutta-percha and either AH26 or Roth's 801 sealer were removed by various methods. Eighty extracted human teeth were prepared using a step-back technique and obturated with gutta-percha and either AH26 or Roth's 801 sealer. The teeth were stored in a humidor for two weeks before one of four techniques was used to remove the gutta-percha and sealer. The removal techniques used heat, files, solvents and ultrasound in different combinations, none of which was efficient. The bulk of retained filling material was sealer, with the removal of AH26 causing more problems than Roth's 801. These authors used ultrasound as a final step in sealer and gutta-percha removal after softening the gutta-percha with a heated instrument. They did not take advantage of the heat generated by ultrasound to soften gutta-percha and create a pathway for solvents.

Ultrasound would seem to be a useful addition to the armamentarium used to retreat failed cases or to bypass an obstruction in a root canal. Gaffney et al. (1981) reported the successful use of an ultrasonic scaler for the removal of silver points, root canal posts and cemented endodontic instruments. Krell et al. (1984) used an ultrasonic scaler to loosen the bond between a silver point and the root canal sealer. If the scaler tip could not reach a sectional silver point the authors recommended screwing a Hedstrom file alongside the silver point and placing the scaler tip onto the file. Krell and Neo (1985) used ultrasound for one hour to remove a hard paste filling from the canals of a lower molar. Meidinger and Kabes (1985) used the Cavi-Endo unit to remove the head of a bur and amalgam particles from two teeth. Chennail and Tepitsky (1987) successfully removed broken files, the tip of a spreader, some silver points and a bur head from five teeth. Jeng and ElDeeb (1987) used ultrasound in two teeth to break down hard paste root canal fillings that had proved resistant to drilling and solvents.

Stamos et al. (1985) reported on a 10 month clinical evaluation of the Cavi-Endo unit at the Endodontic Department of Marquette University. The unit was used for preflaring, canal preparation, pathfinding and the removal of obstructions, silver cones and posts. The techniques described by the authors were those suggested in the instruction manual. The general consensus was that the endosonic unit was a very valuable endodontic tool with a multiplicity of uses.
Jahde et al. (1987) evaluated and compared the histological response associated with ultrasonic and conventional file overextension from root canals in the *Macaca fascicularis* monkey. All canals were instrumented 1mm beyond the radiographic apex with a size #25 file. Saline or 2.5% sodium hypochlorite was used as irrigating solution between each instrument size. 48 hours later the animals were sacrificed. No significant difference in inflammatory response was found between hand or ultrasonic instrumentation, or between specimens irrigated with saline and sodium hypochlorite. The authors could not understand why ultrasonic overinstrumentation was no more damaging to periapical tissues than hand overinstrumentation. They thought the apical constriction could act as a "damper".

The efficiency of ultrasonic, flow through irrigation was studied by Teplitsky et al. (1987). Acrylic moulds and extracted teeth were used to monitor radiographically the delivery of radio-opaque dye into a canal or the removal of the dye from the canal. Teplitsky commented that syringe irrigation to the working length of a canal is possible if the needle is able to penetrate close to the apex. This is difficult to achieve unless the canal is enlarged to at least file #30. Ultrasonic irrigation was found effective in any size canal, even canals prepared to file #10. The study demonstrated that apical penetration of irrigant was significantly greater with ultrasonics compared with syringe application.

Stock (1986) felt that if cavitation was a major factor in ultrasonic cleansing of root canals, then water would be a suitable irrigant. An initial study compared the ability of water, Solvidont\(^9\) and sodium hypochlorite to remove debris from the root canal using endosonics. Sodium hypochlorite was considerably better than the other two irrigants at removing debris. A second study showed that a 1% solution of sodium hypochlorite was more efficient at removing debris than a 0.5% or 0.25% solution. This abstract did not give details of sample size or methodology. While these studies did not resolve the controversy whether debridement is enhanced by ultrasound it did indicate that the choice of irrigant and its concentration could influence the efficiency of the ultrasound system.
The mode of action of ultrasound within a root canal has not been investigated. The early dental literature suggested that cavitation initiated a scrubbing action of the irrigant against the root canal wall (Martin 1982a). Later investigations suggested that the geometry of a vibrating endodontic file is such that it is unlikely that cavitation will occur to an extent where it will make a significant contribution to the ultrasonic cleaning process (Williams 1987; Ahmad 1987a). Acoustic streaming has been credited with the transport of irrigant along the file towards the apex. In theory, acoustic streaming will occur along a vibrating rod. Ahmad (1987a 1987b) demonstrated acoustic streaming along an activated file immersed in sodium hypochlorite in a container 50x30x10mm. The flow through irrigant delivery system, which delivers a flow of irrigant along the file at a rate of 30ml/min, was not activated. The flow of irrigant through the insert and along the file could be more significant than acoustic streaming. Whether acoustic streaming would occur in a container the size of a root canal is not known. The ultrasonic waves reflected from the canal wall could modify the streaming force along the file. Much of the work carried out on ultrasonic endodontics has not considered the basic science behind ultrasound as used in dentistry. Walmsley (1987) attempted to correct this deficiency. He noted that dental inserts vibrated in the long axis of the handpiece and this created transverse vibration in the file. This mode of vibration could be a source of file breakage in curved canals. Most ultrasound units use files designed for use with an up and down movement, so lateral vibration is not an efficient mode of movement. Walmsley's observation confirms the need for special instruments to be designed for ultrasonic canal preparation. Walmsley also subscribes to the concept that acoustic streaming could be responsible for many of the beneficial effects attributed to the use of ultrasound in endodontics. No mention was made of the shear waves generated at the surface of the smear layer or predentine when the ultrasound wave was reflected back into the irrigant at the irrigant/dentine interface.

Most issues of specialist endodontic journals contain an article on one aspect of ultrasonic endodontics, and as the base of researchers is expanded so is our understanding of the mechanisms involved.
CHAPTER 3

SODIUM HYPOCHLORITE AS AN ENDODONTIC IRRIGANT

3.1 DESIRABLE PROPERTIES OF AN ENDODONTIC IRRIGANT.

Successful endodontic therapy requires removal of all degradable organic tissue from the root canal space and subsequent elimination of that space (Taylor 1984). The sequence of procedures used to obtain these goals is sometimes called the endodontic triad; access, cleaning and shaping, and obturation. The use of an irrigant before, during, and after biomechanical instrumentation in the cleaning and shaping phase has become universally accepted (Teplitsky et al. 1987).

The ideal endodontic irrigant would have the following properties:

1) It would be bacteriocidal to the organisms commonly found in an infected root canal.
2) It would dissolve any tags of vital or necrotic pulp tissue remaining in the root canal.
3) It would not injure the periapical tissues (Harrison 1984).

Sodium hypochlorite is a powerful germicide and necrotic tissue solvent. It will dissolve vital tissue but at low concentration appears to have little effect on the periapical tissues.

3.2 MANUFACTURE AND STORAGE.

There is one major manufacturer of sodium hypochlorite in New South Wales\(^1\), and at the time of manufacture there are no different grades of sodium hypochlorite (Green 1983). The different commercial hypochlorite solutions are the stock solution diluted, buffered, stabilised and packaged by wholesale chemical companies.
Sodium hypochlorite is made in a continuous process by passing chlorine gas over a column of sodium hydroxide (caustic soda).

\[ 2\text{NaOH} + \text{Cl}_2 \rightarrow \text{NaCl} + \text{NaOCl} + \text{H}_2\text{O} \]

The stock solution has 12.5% available chlorine and from 0.1% to 0.5% sodium hydroxide carried over in solution. Sodium hydroxide increases the pH of the stock solution to pH12, and this high pH contributes to the stability of the solution. A 12.5% sodium hypochlorite solution at pH12 is more stable than a 12.5% neutral solution under the same storage conditions. Dilution of the solution reduces the concentration of sodium hydroxide and this leads to a decrease in the pH. If required, further reductions in the pH value can be obtained by buffering with sodium chloride solution (Green 1983). The water used for dilution should be demineralised as the presence of metallic ions, especially Nickel, Cobalt and Copper, adversely affects the stability of the solution. High storage temperatures and ultra violet light will also adversely affect the stability. The increase in stability at low concentrations has an exponential value. A 12% solution of sodium hypochlorite at room temperature has a shelf life (half life) of about one year, a 5% solution has a half life of about four years, and a 3% solution about ten years. A 5% solution seems to be a reasonable compromise between the stability of the solution and the cost to the consumer of packaging and transporting the added water. During the decomposition of sodium hypochlorite two reactions take place:

\[ 2\text{NaOCl} \rightarrow 2\text{NaCl} + \text{O}_2 \]

\[ 3\text{NaOCl} \rightarrow 2\text{NaCl} + \text{NaClO}_3 \]

The reaction in which \(\text{NaClO}_3\) is formed represents 85% of the decomposition reaction. The loss of oxygen from the concentrated stock solution necessitates the use of vented containers for its transportation.
3.3 MODE OF ACTION.

The mode of action of sodium hypochlorite as a bacteriocidal agent is not fully understood. It was thought that the chlorine oxidised the cell membrane. Recent experiments showed that less than the calculated amount of chlorine was used in the reaction. The present theory is that sodium hypochlorite dissociates to form hypochlorous acid which has a molecular structure very similar to that of water. This molecule can pass through the cell membrane and oxidise the cell body. Its effect on collagen is thought to be a straight oxidation process (Green 1983).

3.4 DAKIN TO GROSSMAN

Dakin (1915) is usually credited with being the first person to report on the use of sodium hypochlorite solution in the management of infected wounds. He commented upon the variable composition of the sodium hypochlorite solutions available at that time. The solutions could contain free alkali and free chlorine and could be irritating when applied to wounds. He suggested dissolving sodium carbonate in tap water and then adding chloride of lime. Half an hour later the clear liquid was filtered off and buffered with boric acid just before use. The solution contained 0.5% sodium hypochlorite with a shelf life of one week. Prior to 1915 it seems that most authors suggested the use of powdered chloride of lime and boric acid mixture. Dakin observed "To obtain the best results it is essential . . . . . . to bring fresh quantities of the antiseptic solution in contact with all the parts of the wound as frequently as possible."

Austin and Taylor (1918) studied the effect of Dakin's solution on radiation induced gangrene in the ears of rabbits. While the seven day time span of the experiment is outside the usual dental experience, their observations on sodium hypochlorite are valid today. They noted that the concentration of available chlorine in solution fell significantly during the dissolution of necrotic tissue, and they suggested frequent renewal of the solution. They also noted the irritating effect of sodium hypochlorite solution on rabbit skin.
The first dental application of sodium hypochlorite as an endodontic irrigation was suggested by Walker (1936). He found it to be a satisfactory collagen solvent and a powerful germicide, with no apparent ill effect on living tissue. Five years later Grossman (1941) confirmed that a 5% solution of sodium hypochlorite was capable of dissolving the pulps of freshly extracted teeth in less than one hour. Other caustic or acidic solutions tested by Grossman required one to three days to achieve a similar result.

3.5 SODIUM HYPOCHLORITE AND OXIDISING AGENTS.

Grossman (1943) suggested that sodium hypochlorite be used alternately with hydrogen peroxide as an aid in the cleansing of root canals. As well as reacting with sodium hypochlorite, hydrogen peroxide also reacted with blood and lost its antimicrobial properties. To overcome this problem of peroxide inactivation, Stewart (1961) suggested the use of urea peroxide in an anhydrous glycerine base. The urea peroxide was chosen for its antimicrobial properties, the glycerine base as a lubricant for reamers and files. Urea peroxide was more stable at room temperature than an aqueous peroxide solution, and retained its antimicrobial action in the presence of blood.

Stewart et al. (1969) later developed this preparation further and presented a compound of 15% EDTA and 10% urea peroxide. A base of polyethylene glycol was chosen to protect the EDTA from the oxidising effect of urea peroxide. This compound (RC Prep\textsuperscript{2}) was reacted with sodium hypochlorite to cleanse and bleach the canal.

McComb and Smith (1975) questioned the efficacy of using sodium hypochlorite in conjunction with a peroxide. In a SEM study (with small sample size), they found sodium hypochlorite and hydrogen peroxide to be no more effective than water as an irrigant, and less effective than sodium hypochlorite used as the sole irrigant. They found that RC Prep used in conjunction with 6% sodium hypochlorite resulted in a greater amount of retained debris than that resulting from instrumentation with water irrigation. These observations were confirmed by Baker et al.
(1975) in a similar SEM study. Rome et al. (1985) found there was no significant difference in smear layer formation between the use of sodium hypochlorite alone or in conjunction with Gly-Oxide, and that the use of 0.5ml Gly-Oxide between instruments did not affect smear layer build up.

Baumgartner and Ibay (1987) investigated the by-products formed when sodium hypochlorite was used in conjunction with hydrogen peroxide, EDTA or citric acid. The nett reaction between sodium hypochlorite and hydrogen peroxide was given as:

\[ \text{NaOCl} + \text{H}_2\text{O}_2 \rightarrow \text{NaCl} + \text{H}_2\text{O} + \text{O}_2 \uparrow \]

3.6 SODIUM HYPOCHLORITE + CITRIC ACID

Baumgartner et al. (1984) used 50% citric acid and 5.25% sodium hypochlorite, either alone or alternately, to remove superficial debris and the smeared layer. The distal root of lower molars, stored in formalin, were enlarged to file size #50 using a step-back technique. 3ml of irrigant was used between instrument sizes and a final flush brought the volume of irrigant used to 30ml per specimen. Sodium hypochlorite was significantly better than citric acid in removing superficial debris from the apical third of the canal while citric acid was more effective in removing the smeared layer.

Baumgartner et al. (1987) measured the chlorine gas liberated when 5.25% sodium hypochlorite was mixed with 50% citric acid. At 15 minute intervals, 15ml of each solution was added to a stainless steel container until a total volume of 240ml was obtained. The sodium hypochlorite/citric acid combination produced a vigorous effervescent reaction releasing chlorine gas measured at 3.5ppm at a distance of 6 inches from the container at the completion of the experiment. The air became foul smelling and caused eye and throat irritation. In clinical practice only the first few drops of the alternate irrigant would react with the irrigant remaining in the root canal. When sodium hypochlorite was combined with EDTA very little
chlorine gas was liberated. Baumgartner (1987) concluded that as the combination of sodium hypochlorite and EDTA seems to have all the capabilities of sodium hypochlorite and citric acid without the problem of chlorine gas liberation, sodium hypochlorite and EDTA would appear to be the combination of choice.

Sodium hypochlorite was a more effective antimicrobial agent against *Candida albicans* or *Streptococcus faecalis* than citric acid (Smith and Wayman 1986).

3.7 REACTION WITH CELLS AND TISSUES.

Spangberg *et al.* (1973) urged that the biologic effects of root canal irrigants and dressings be considered. They used $^{51}$Cr labelled L cells and HeLa cells in solution to test the cytotoxicity of sodium hypochlorite and other irrigants. Spangberg found a 0.02% available chlorine sodium hypochlorite solution caused complete lysis of the test cells in twenty-four hours, and that its cytotoxic effect was ten times greater than its antimicrobial effect. Even though an irrigating solution should not have this effect on living tissue they felt that 0.5% sodium hypochlorite was the irrigant of choice for the majority of cases. A 5% solution of sodium hypochlorite was considered to be considerably stronger than necessary to kill the bacteria commonly found in root canals. The toxic and irritating effect on the tissue may be a source of post operative problems.

Pashley *et al.* (1985) studied the problems of toxicity of sodium hypochlorite on a suspension of red blood cells, on rabbit eyes and after intradermal injection. Dilutions of 5% sodium hypochlorite as low as 1:1,000 caused complete lysis of the red blood cells. Undiluted and 1:10 dilutions produced moderate to severe irritation to rabbit eyes which healed after 24 to 48 hours. Intradermal injections of 1:1 and 1:4 dilutions produced skin ulceration. Pashley felt that the clinical efficacy of sodium hypochlorite was due to its ability to oxidise, to hydrolyse and osmotically draw fluids out of tissue.
If animal studies are used to assess the irritative effect of sodium hypochlorite the results are quite different from those obtained from cell cultures. Lamers et al. (1980) carried out vital pulpectomy and instrumentation on non-curious monkey teeth. They found that at all time intervals irrigation with a 1% sodium hypochlorite solution did not add to the trauma produced at the apex by the operative procedure. The hard tissue changes observed at day seven of the experiment were showing signs of repair by day forty two.

Thé et al. (1980) implanted a polyethylene tube containing a pad of the test solution into the backs of guinea pigs. The solutions tested were saline solution, sodium hypochlorite 0.9%, 2.1%, 4.1% and 8.4%, and formocresol. The saline solution and all concentrations of sodium hypochlorite caused a moderate reaction at the end of the tube after seven days, with less reaction after fourteen days. Severe reactions were present for formocresol after seven days and fourteen days. Thé felt that the seven day reaction was mainly the result of the operative procedure but that the fourteen day results were valid. They concluded that the optimum concentrations of a sodium hypochlorite solution for clinical use was mainly determined by its bacteriocidal and tissue dissolving action.

3.8 BACTERIOCIDAL EFFECTS

Many authors have tested the bacteriocidal effect of different concentrations of sodium hypochlorite against a vast array of organisms under varying conditions at room and body temperature. Harrison (1981) found that 5.25% sodium hypochlorite affected a complete kill on Streptococcus faecalis in less than forty-five seconds. The presence of human serum albumin did not interfere with the action of sodium hypochlorite, but dilution with water or hydrogen peroxide adversely affected its bacteriocidal effectiveness.

Cunningham and Joseph (1980) hypothesised that warming 2.6% sodium hypochlorite to body temperature should enhance its bacteriocidal action as well as its tissue dissolving properties. The organisms tested were Staphylococcus aureus, Streptococcus sanguis, Escherichia coli,
*Proteus vulgaris* and *Bacillus subtilis* spores. The hypothesis was supported by the experimental results when the overall difference in kill time between the two temperatures for the five test organisms was assessed as significant. *Staphylococcus aureus* showed a typical reduction in kill time from 180 seconds at 22°C to 90 seconds at 37°C.

Senia *et al.* (1975) and Linke and Chohayeb (1983) contaminated the surface of gutta-percha cones with gram-positive or gram-negative micro-organisms as well as fungi or yeasts. A 5.25% solution of sodium hypochlorite was found to be a rapid, effective sterilising agent for gutta-percha cones. Senia noted that this experimental technique allowed the bacteria to settle in a multilayered fashion. The settling effect afforded a natural physical barrier that protected the deeper layers of bacterial cells from the action of the hypochlorite solution.

Stabholz *et al.* (1987) contaminated gutta-percha cones with *Streptococcus mutans*, *Streptococcus sanguis* (oral flora), *Streptococcus faecalis*, *Escherichia coli* (intestinal flora), *Staphylococcus aureus* (skin flora) and *Bacillus subtilis* (air borne). Chlorhexidine (2%) and sodium hypochlorite (5.25%) showed complete decontamination of the cones after 10 minutes.

Bystrom and Sundqvist (1985) used 60 single-rooted teeth with necrotic pulps and radiographic evidence of periapical bone destruction to test the bacteriocidal efficacy of 0.5% sodium hypochlorite, 5% sodium hypochlorite, or a combination of 5% sodium hypochlorite with 15% EDTA. After biomechanical preparation using the selected irrigant the canals were sealed with no intracanal dressing in the canal. At the third appointment 80% of the strains obtained were anaerobic. The combination of 5% sodium hypochlorite and 15% EDTA was more effective than sodium hypochlorite alone. An important observation was that bacteria surviving instrumentation and irrigation rapidly increased in number in the 2-4 day period between appointments when no intracanal medicament was used.

Foley *et al.* (1983) found that the combined irrigation of root canals alternating Gly-Oxide and 5.25% sodium hypochlorite was no more effective at killing *Bacteroides melanogenicus* than sodium hypochlorite alone.
Studies by Buttler and Crawford (1982) into the action of sodium hypochlorite in the
detoxification of two different endotoxins gave conflicting results. The *in vitro* study showed
that 0.58% sodium hypochlorite was effective in detoxifying *Escherichia Coli* w or *Salmonella
Typhosa* w if the solution and toxin were combined for one hour. The *in vivo* tests were
inconclusive. Buttler noted that by killing the organisms a sodium hypochlorite solution was
effective in preventing the formation of exotoxins.

3.9 TISSUE DISSOLVING ABILITY

Senia *et al.* (1971) found that 5.25% sodium hypochlorite was not very effective in removing
pulp tissue which remained in the mesial root of lower first molar teeth after instrumentation.
He stated that there must be maximum contact with the tissue being treated. Without direct
contact with sodium hypochlorite, protected tissues sheltered in a fin or isthmus and were
dissolved more slowly and less completely. Because of this need for contact, sodium hypochlor-
- ite was more effective in canals with a large diameter than in the smaller apical constrictions.

Trepagnier *et al.* (1977) measured the hydroxyproline content of sodium hypochlorite to assess
the collagen containing tissues dissolved by that irrigant. After tests on 140 teeth with the
crown removed they found a 2.5% solution to be as effective as a 5% solution during a five minute
test period. The degradation of collagen with 5% sodium hypochlorite began rapidly, and one
minute after the reaction started half of the amount of collagen dissolved in an hour had been
dissolved. The 5% solution was 65% more effective than the 0.5% solution. Trepagnier
concluded that a 2.5% solution of sodium hypochlorite was the concentration of choice.

Hand *et al.* (1978) used 13mm diameter specimen of necrotic rat epithelial tissue to determine
the effect of dilution on the ability of sodium hypochlorite to dissolve necrotic tissue. After a
seven minute contact period the tissue specimen weight loss was -72% with a 5% solution, -26%
with a 2.5% solution and only -4% with a 1% solution. The weight loss with 0.5% solution was
negligible.
Thé (1979) studied the effect of different concentrations of sodium hypochlorite on relatively large pieces of fixed and unfixed necrotic rat connective tissue. He also investigated the effects of hydrogen peroxide on these systems. He found that a 3% solution of sodium hypochlorite was an efficient solvent of necrotic tissue, and that its action depended on the ratio of tissue to solvent. Fixing the tissue in parachlorophenol or formaldehyde made it more difficult to dissolve in sodium hypochlorite. The use of hydrogen peroxide tended to interfere with the solvent action of sodium hypochlorite.

Gordon et al. (1981) used 4mg pellets of vital and necrotic bovine pulp tissue to assess the tissue dissolving capabilities of different strengths of sodium hypochlorite over periods of two, five or ten minutes. They felt that a minimum concentration of 3% sodium hypochlorite used for five minutes was required for clinical conditions. This conclusion was reached in spite of results which showed that 75% of necrotic pulp was dissolved in two minutes, 90% in five or ten minutes. They noted the need for excess irrigant relative to tissue to be dissolved.

Moorer and Wesselink (1982) made an exhaustive study of the literature relating to the collagen dissolving ability of sodium hypochlorite solutions. They lamented the fact that "Although authors seem to appreciate the influence of factors such as concentration, volume, time, temperature, mechanical action, surface area of tissue on the tissue dissolving capability of sodium hypochlorite, only the influence of a few of these variables, particularly concentrations, have actually been investigated." They used a standardised water soluble protein hydrolysate (Peptone) as their protein matter. Moorer concluded that the concentrations of available chlorine rather than pH was the important variable in hypochlorite efficiency, and that the interaction is a function of the surface area of contact between tissue and fluid. The influence of even slow fluid flow on the system was striking, and the use of ultrasonic power an even more effective principle. Even though the effect of ultrasonic agitation was very impressive, Moorer felt that one should not attempt to use ultrasound clinically without careful consideration of possible side effects. These side effects included temperature rise, the possible forcing of debris through the apical foramen and the subsequent damage to the periapical tissues or even to hard tissues.
Cunningham and Balekjian (1980) investigated the ability of a 2.5% or a 5% solution of sodium hypochlorite to dissolve bovine tendon collagen at either room temperature or body temperature. This study demonstrated that the 2.5% concentration, when warmed to 37°C, was equally as effective in dissolving tissue as the 5% solution at either room temperature or body temperature. Titration of available chlorine showed that both solutions remained stable for up to four hours when maintained at 37°C. Twenty four hours of warming of the solutions did cause some deterioration. Cunningham agreed with other authors that most of the dissolving action took place in the first few minutes of contact between the tissue and the hypochlorite solution.

3.10 SCANNING ELECTRON MICROSCOPE STUDIES

Scanning electron microscopy was used to evaluate the effectiveness of sodium hypochlorite on the removal of the last traces of debris from the root canal system. L. Goldman et al. (1979) used a perforated needle to deliver 5% sodium hypochlorite to the uninstrumented root canal. They concluded that the perforated needle produced a much cleaner canal than a conventional needle. M.Goldman (1982) used a chelating agent during instrumentation as a means of removing the smear layer. A perforated needle was used to give the canals a final flush of 10ml REDTA followed by 10ml of 5% sodium hypochlorite. This combination in this order removed the smear layer, even in the apical third of the root. Soft tissue debris was not removed from an uninstrumented fin.

Yamada et al. (1983) compared the ability of several chelating solutions used after instrumentation to clean a root canal. 5.25% sodium hypochlorite was the irrigant used during instrumentation. A final flush of 10ml buffered 17% EDTA followed by 10ml 5.25% sodium hypochlorite was more effective than any other combination of EDTA, sodium hypochlorite or citric acid. The photomicrographs showing a clean canal free of soft tissue debris and smeared layer were of the middle of the canal.
Berg et al. (1986) removed the clinical crowns of 25 teeth with a single root canal and a straight root before instrumenting the canals to file size #70 at the apical foramen. The irrigants tested were Salvizol, sodium hypochlorite + Gly-Oxide, REDTA and sterile saline. Statistical analysis indicated that REDTA was the most efficient irrigant tested. The smear layer was removed at every level of the root canals leaving the dentinal tubules exposed. All photomicrographs used were of the middle and coronal thirds of the root canals.

3.11 SURFACE TENSION

To achieve its tissue solvent or bacteriocidal effect, sodium hypochlorite solution must come in contact with the tissue or the micro-organism. The intimacy of this contact depends on the wettability of the solution. In general, the wettability of a solution depends on its surface tension. Abou-Ras and Patonai (1982) suggested that the wettability of an endodontic irrigant was important to the penetration of the solution into the small spaces of the root canal. A reduction in surface tension may be accomplished by the use of heat or the addition of a surfactant. Abou-Ras used polysorbate 80 to reduce the surface tension of sodium hypochlorite because it had a pH of 7.0 and was used as an emulsifier and dispersing agent in medicine produced for internal use. The surface tension of 5.25% sodium hypochlorite was reduced from 79.1 dynes/cm to 69.8 dynes/cm. This reduction in surface tension resulted in a solution that penetrated further into the test root canal than did a standard solution.

Cunningham and Cole (1982) used alcohol to reduce the surface tension of sodium hypochlorite. Ethanol had a surface tension of only 24 dynes/cm and 5% added to a water-based solution will reduce the surface tension of the mixture to about 55 dynes/cm. The solution is not stable and must be used before the conversion of hypochlorite and ethanol into chloroform. A 30% ethanol/hypochlorite mixture had a useful working life of approximately fifteen minutes. It was suggested that even though the hypochlorite solution may be diluted by the ethanol the debridement and disinfection may be enhanced by the improved wettability. The formation of
chloroform would be a problem in canals with an open apex; but these canals would not require the use of a surface tension reducing agent.

3.12 CORROSION OF METALS

Because iron constitutes more than 99% of the composition of a root canal file, corrosion of the carbon steel instrument is due to oxidation of the iron (Mueller 1982). In the presence of chloride ions corrosion of iron can be expected because of the breakdown of any protective oxides or hydroxides that might have formed. Iron chlorides offer little protection against corrosion because of their solubility. Callegos and Raymond (1981) found that the strength of carbon steel instruments was unaffected by less than eight hours exposure to a 2.5% sodium hypochlorite solution. Surface corrosion was detected after immersion times of fifteen minutes. The cutting ability of stainless steel instruments was adversely affected by a ten minute exposure of 5.2% sodium hypochlorite (Neal et al. 1983). The surface of these instruments showed a brown corrosion layer. Corrosion of carbon steel is no longer a problem with the root canal instruments currently in use. However the use of sodium hypochlorite as part of a continuous, flow-through irrigation system does mean that all metal parts of the equipment coming into contact with the irrigant must be corrosion resistant. To facilitate daily maintenance all surfaces should be well finished and all joins should be smooth.

3.13 SUMMARY

A 3% solution of sodium hypochlorite has been proven to possess potent collagen solvent and bacteriocidal properties. These properties are enhanced by heating a 3% solution to body temperature. Heating the solution also decreases the surface tension. Cytotoxic studies indicated that even at very low concentrations, sodium hypochlorite was injurious to living tissue. Because of this tissue toxicity, sodium hypochlorite must be confined within the root canal and not forced through the apical foramen.
The effectiveness of sodium hypochlorite as an endodontic irrigant depends upon the availability of chloride ions. It has been recommended that the supply of chloride ions be maintained by increasing the volume and flow of irrigant rather than by the use of a solution with a higher concentration of chloride ions.

Current research trends are leading towards the use of chelating agents, surface tension reducing agents or ultrasound as a means of improving the properties of this irrigating solution.
CHAPTER 4
AIMS OF THE INVESTIGATION

The aims of these investigations were:

1) To develop a clinical technique for the ultrasonic activation of the endodontic irrigant, sodium hypochlorite.

2) To investigate the duration of ultrasonic irrigation required to remove the smear layer from an instrumented root canal wall.

3) To determine the effect of sodium hypochlorite concentration on the effectiveness of ultrasonic irrigation.

4) To investigate the effectiveness of ultrasonic irrigation for the cleansing of uninstrumented, immature root canals.

5) To develop a stable sodium hypochlorite solution with a decreased surface tension.

6) To measure the temperature changes within the root canal and at the external root surface during ultrasonic irrigation.
CHAPTER 5

DEVELOPMENT OF A CLINICAL TECHNIQUE

5.1 INTRODUCTION

These studies were stimulated by observations made during the recovery of root canal filling models. When a tooth prepared to clinical standards was root filled and later split, the film of root canal sealer adhered preferentially to the gutta-percha rather than the root canal wall. If an instrumented tooth was placed into a bath of 3% sodium hypochlorite activated by ultrasound before being root filled, the sealer showed equal adhesion to gutta-percha or the root canal wall. The smear layer appeared to be acting as a "release layer" as is used in fibreglass moulding and to be preventing the sealer from adhering to the root canal wall. This effect could have clinical significance because the setting shrinkage of the sealer could pull it away from the root canal wall; a space between the gutta-percha and the sealer would be preferable. A smear-free wall could be more receptive to adhesive or chemically bonded sealers.

Some difficulty was experienced in transmitting ultrasound into a root canal. The clinical source of ultrasonic energy was a Cavitron Model 7000II. A prototype instrument was made by welding an endodontic file onto the tip of a prophylaxis insert. This modified insert was not very efficient in transmitting ultrasound into the canal and was prone to fracture. A new instrument had to be manufactured after each breakage. Dentsply (Australia) was able to supply an insert based on the model used by Richman in 1957 (Fig 5.1). This insert consisted of the same metal instrument retaining block but the magnetostrictive stack was now part of the insert instead of being fixed inside the handpiece. This insert was designed to accept conventional endodontic hand instruments with the handle removed. The file was retained in the head by a screw so that the long axis of the file was parallel to the long axis of the insert. Initially, either a size 10 K file or size 20 Hedstrom file was used in the insert, but instrument breakage was a problem,
especially if the file was bent to gain access to a posterior tooth. A "smooth broach without a spiral handle" was then used in the insert for the remaining teeth. The MicroMega brand of smooth broach was made of a relatively soft metal and did not fracture as easily as other more rigid broaches.

At the time of this study (1979), no commercially available endodontic instruments had been designed for use in conjunction with an ultrasound unit. Of the conventional instruments available, the smooth broach was the least troublesome in introducing ultrasonic energy into a sodium hypochlorite solution. The smooth broach was easily bent to improve access into the root canal and did not fracture in use; however, it did not seem to function as efficiently as a K file in transmitting ultrasonic energy to the sodium hypochlorite. Research is needed to produce a probe that can be easily bent, will not fracture in use, and is efficient in transmitting ultrasonic energy.

5.2 CLINICAL TECHNIQUE

After radiographic determination of the working length the apical funnel was enlarged by two instrument sizes using Hedstrom files. The appropriate size of Gates-Glidden drill was used to shape the middle and coronal thirds of the root canal. The canal was irrigated with 1-2ml of 3% NaOCl between instrument sizes, with a 5ml flush at the completion of instrumentation. The root canal and pulp chamber was left filled with NaOCl and the ultrasonic probe placed into the canal so that the tip (the ultratip) was in the middle third of the root canal. Care was taken to ensure that the ultratip did not touch the canal wall. The Cavitron was activated for one minute at setting #3 on a scale of 4. The probe was removed from the canal to permit an intermediate irrigation of 1ml of 3% NaOCl. The root canal and pulp chamber was left filled with NaOCl, the ultrasonic probe was replaced in the middle third of the canal, and the Cavitron unit activated for another one minute. The process of ultrasound followed by irrigation was continued until the irrigant was apparently free of debris. The canal was then dried with paper points and obturated with laterally condensed gutta-percha and a ZnO based sealer.
The technique was subsequently modified as follows:

1) The irrigant in the canal was replaced every 30 seconds instead of after 60 seconds. This maintained the potency and volume of irrigant within the root canal.

2) The 3% NaOCl purchased from a pharmacy was replaced with 4% NaOCl household bleach purchased at a supermarket.

5.3 DISCUSSION

The placement of the ultratip in the middle third of the root canal was arrived at empirically. When the ultratip was placed in the apical third of the canal, the probe touched the canal walls and the probe either fractured or gouged the canal wall. Reshaping of the canal wall was demonstrated by debris reappearing in the irrigant. Placing the ultratip in the coronal third of the canal produced a fine spray of NaOCl. This spray depleted the volume of solution within the canal and left the ultratip vibrating in air. With the ultratip placed in the middle third of the canal, the tendency for the probe to fracture was reduced, and spray formation at the access cavity was reduced significantly. It may not be necessary for the probe to extend to full working length to be effective because ultrasonic energy waves radiate through the irrigant, beyond the tip of the probe. For the energy to be transmitted it is essential that the canal be filled with irrigant and that the tip of the probe be surrounded by irrigant.

After the first minute of ultrasonic irrigation, the irrigant was turbid. The irrigations after the second and third minutes of ultrasound showed a progressive decrease in turbidity; after four minutes, the irrigant was clear. The clinical impression was that the bulk of the debris was removed during the first minute of ultrasound, and exposure beyond three minutes was not significant.

The debris released during the first minute of ultrasound was probably material forced into fins and crevices during instrumentation, or was material from the wall of the apical third of the canal where conventional irrigation is least effective. The debris could be part of the smear layer.
Some precautions need to be taken to protect the patient and equipment:

1) The metal instrument retaining block will be corroded by NaOCl unless it is protected by a spray of handpiece oil.

2) The metal instrument-retaining block heats up when the unit is activated. The heat generated is capable of burning a patient's lips even through a rubber dam.

3) A fine mist of irrigant is created by the ultrasonic activity. This mist could cause eye irritation unless suitable precautions are taken.

4) As the length of the probe that extends from the insert is increased, the amplitude of movement at the ultra tip is also increased. This can cause instrument breakage or accelerate the loss of irrigant by spray formation.

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This chapter is based on the paper:
The use of ultrasound in the cleaning of root canals: a clinical report.
CHAPTER 6
REMOVAL OF THE SMEAR LAYER
TIME FACTOR

6.1 INTRODUCTION

The chemomechanical phase of endodontic treatment is designed to remove debris and infected material from the root canal and to prepare a canal shape that facilitates the placement of the root canal filling. Scanning electron microscope studies have shown that debris containing bacteria, pulp remnants, necrotic tissue, or dentine chips is retained in root canals prepared to clinical standards. This debris collects and is most evident in the apical third of the canal. In areas where the canal wall has been instrumented, the presence of dentinal tubules is obscured by a "smear layer," which has been described as "translocated dentine" (Lester and Boyde 1977) or dentine plus necrotic and viable tissue (McComb and Smith 1975). The smear layer is loosely attached to the underlying surface and shows shrinkage cracks as a result of drying the specimens for SEM investigation. The presence of a smear layer could adversely affect attempts to obtain and maintain a satisfactory apical seal.

Removal of the smear layer under clinical conditions has presented some problems. Tidmarsh (1978) flooded the canal with 50% citric acid during instrumentation and the acid prevented the formation of a smear layer. However 60 ml of distilled water was required as a final irrigation to remove the crystals of calcium citrate from the canal wall. McComb and Smith (1975) found that even after 15 minutes exposure to REDTA the smear layer remained intact: if the REDTA was sealed into the canal for 24 hours the smear layer was completely removed.
Ram (1980), in his study of chelating agents, found that the use of RC Prep during instrumentation did not prevent the formation of a smear layer. Goldman et al. (1979) used 20ml of 5% NaOCl delivered through a perforated needle and were unable to remove the smear layer in instrumented sections of the root canal. Immersing an extracted, instrumented tooth in 5% NaOCl for three days removed the superficial smear layer but left plugs of debris in the openings to the dentinal tubules (Lester and Boyde 1977).

A SEM study was designed to investigate the efficiency of a 3% NaOCl solution activated by ultrasound as a means of removing the smear layer. Every effort was to be made to duplicate clinical conditions so that any conclusions would have chair-side significance.

6.2 MATERIALS AND METHODS

For this experiment, the 39 human teeth used were instrumented, irrigated and sectioned the day they were extracted. The sample included maxillary and mandibular incisor, canine, and premolar teeth extracted for prosthetic purposes. The canals were instrumented through a conventional access cavity to a length 1mm short of the visual apical foramen. The apical funnel was enlarged with Hedstrom files by a minimum of two instrument sizes and the remaining canal was shaped with the appropriate size Gates-Glidden instrument. An irrigation of 1ml of 3% NaOCl was used between each instrument size. The final irrigation was 5ml of 3% NaOCl and 5ml of 3% hydrogen peroxide, 1ml of each irrigant being used alternately. Any further protein solvent action of the NaOCl was minimised by irrigating the canals with a 2ml cartridge of anaesthetic solution. Ultrasonic energy was delivered to the root canal by a smooth broach held in the Cavitron insert #PR30. The length of the broach was adjusted so that the ultratip would reach the middle third of the root canal. Power setting #3 on a scale of 4 was used.
The teeth were divided into groups 1-4 on a random basis as follows:

6.2.1 Control

This group received no further irrigation and acted as control (4 teeth).

6.2.2 One minute ultrasound

These teeth received one minute of ultrasonic irrigation with 3% NaOCl followed by a final flush with a 2ml cartridge of anaesthetic solution (15 teeth).

6.2.3 Three minutes ultrasound

These teeth received a total of three minutes of ultrasonic irrigation with a flush of 1-2ml NaOCl between each minute of ultrasound. The final irrigation was 2ml anaesthetic solution (15 teeth).

6.2.4 Five minutes ultrasound

These teeth received a total of five minutes of ultrasonic irrigation with NaOCl in one minute increments. The final irrigation was 2ml anaesthetic solution (5 teeth).

In early experiments the roots of the teeth were grooved and split to expose the root canal surface, but the samples obtained were not always suitable for viewing in the electron microscope - the apical area had a tendency to split independent of the external grooves. The final specimens were prepared from the apical third of the root using a diamond wheel and a fine water-air mist. The specimens were dried, given a minimum thickness gold coating, and viewed in a Jeol\textsuperscript{1}JXA50A electron microscope. The image was recorded on Ilford\textsuperscript{2} HP5 negative film in a Mamiya\textsuperscript{3} roll film back.
6.3 RESULTS

The smear layer was thought to consist of two separate layers. One layer was superficial and adhered loosely to the underlying dentine, the other consisted of debris plugs in the openings of the dentinal tubules. When the four groups were assessed for the absence of either of these two layers, the specimens within each group were consistent, and the differences between groups 1, 2, and 3 were distinctive. The cleaner areas of specimens in group 3 were similar to the overall appearance of specimens in group 4. All groups had dentine chips on the canal wall. Figures 6.1 - 6.4 represent areas typical of each group at a level 3mm from the apical seal.

6.3.1 Control
The specimens in this control group had a typical smear layer appearance (Fig 6.1). The presence of dentinal tubules was obscured and dentine chips were present in all specimens.

6.3.2 One minute ultrasound
After one minute of ultrasound, the superficial smear layer had been removed; dentinal tubules were now seen (Fig 6.2). The debris plug in the mouth of these tubules was still present but showed signs of shrinkage during preparation of the specimen. An elevated ring of peritubular dentine was just evident. Dentine chips were present in all specimens.

6.3.3 Three minutes ultrasound
After three minutes of ultrasound, most of the smear layer had been removed (Fig 6.3). The dentinal tubules were now clearly seen and most had patent openings. Dentine chips were present in all specimens.

6.3.4 Five minutes ultrasound
After five minutes of ultrasound, removal of the smear layer was virtually complete (Fig 6.4A); little evidence of any debris in or around the dentinal tubules existed. The mouths of the dentinal tubules were now rounded over instead of square, and, overall, the surface appeared to
be less smooth. One specimen disclosed an uninstrumented hollow (Fig 6.4B), with no evidence of debris, predentin, or smear layer in this hollow. Dentine chips were still present.

6.4 DISCUSSION

This study confirmed that the smear layer consists of two separate layers, and supported the results of previous workers (Lester and Boyde 1977, McComb and Smith 1975). The appearance of the specimens receiving one minute or three minutes of ultrasound was consistent enough to suggest that the operator could remove the superficial smear layer and leave the tubules closed with a dentine plug, or increase the exposure to ultrasound and remove both components of the smear layer. This ability to selectively remove the superficial debris would satisfy clinicians who think that a dentine/debris plug is the most effective way of sealing dentinal tubules.

The presence of dentine chips on the canal wall in all specimens might be the result of the preparation of the specimens with a diamond wheel. Their number could not be regarded as significant.

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CHAPTER 7

REMOVAL OF THE SMEAR LAYER

SODIUM HYPOCHLORITE CONCENTRATION

7.1 INTRODUCTION

The effectiveness of the ultrasound/sodium hypochlorite combination has been studied by several authors (Crabb 1982, Cunningham and Martin 1982, Cameron 1983, Tauber et al. 1983, Goodman et al. 1985, Langeland et al. 1985). These studies have used a variety of ultrasound generators, commercially available or prototype ultrasound inserts, and differing concentrations of sodium hypochlorite. The results have been assessed by low power magnifying glass, light microscopy, or scanning electron microscopy. The relationship between the concentration of sodium hypochlorite activated by ultrasound and the presence or absence of debris in the instrumented canal was a constant feature of the results. Sodium hypochlorite concentrations of 5% (Crabb 1982), 3% (Cameron 1983), and 2.5% (Cunningham and Martin 1982, Goodman et al. 1985) produced debris free canals; concentrations of 1.0% (Langeland et al. 1985) and 0.5% (Tauber et al. 1983) were not effective in removing debris. Martin (1984) claimed that a synergistic relationship exists between ultrasound and sodium hypochlorite when used in conjunction for the debridement of a root canal.

The purpose of this experiment was to investigate the effect of sodium hypochlorite concentration on the efficiency of ultrasonic irrigation and to determine if a synergistic relationship exists between sodium hypochlorite and ultrasound. Scanning electron micrographs were used to detect the presence or absence of a smear layer or surface debris on the instrumented, irrigated root canal walls.
7.2 MATERIALS AND METHODS

Twenty eight freshly extracted single rooted human teeth extracted for periodontal reasons were stored in water before being used in this experiment. To minimise variables between experimental groups, the teeth chosen all had straight roots, and were approximately 21mm long. Mature teeth were chosen so that a final file size in the range of #40 #45 or #50 would achieve instrumentation to clinical standards. After a conventional access cavity was prepared in the crown of the tooth, Hedstrom files were used with a twist-pull action to enlarge the apical portion of the root canal by 2 or 3 instrument sizes. Gates-Glidden drills were used to remove any gross irregularities from the coronal portion of the root canal. 1ml distilled water was used to flush the canal between each instrument size. While the use of water as an irrigant was a departure from clinical practice, it did ensure that the nature of the smear layer was constant for each group. Four instrumented teeth were allocated on a random basis to each of the six experimental groups;

7.2.1 4% sodium hypochlorite

The four teeth in this group were irrigated with 5ml 4% NaOCl¹ in 1ml increments over a three minute period. A final flush of 2ml distilled water was used to prevent any further soft tissue solvent activity of NaOCl. The other experimental groups received three minutes of ultrasonic irrigation with 5ml of NaOCl as follows:

7.2.2 4% sodium hypochlorite + ultrasound

7.2.3 2% sodium hypochlorite + ultrasound

7.2.4 1% sodium hypochlorite + ultrasound

7.2.5 0.5% sodium hypochlorite + ultrasound
7.2.6 Distilled water + ultrasound

7.2.7 Control

Four teeth received no further irrigation and acted as control.

Ultrasonic energy was introduced into the irrigant by a smooth broach held in an endodontic insert PR30 activated by a Cavi-Endo dental unit used in the prophylaxis mode. The root canal and access cavity was filled with the test irrigant, the broach placed into the canal so that the tip was in the middle third of the root canal, and the ultrasound unit activated for twenty seconds. Ten seconds was allowed to remove the broach from the canal, flush the canal with 1ml of the test irrigant and replace the broach into the canal, so that over the three minute (6 x 30 sec) period of ultrasonic irrigation, the ultrasound was activated for two minutes (6 x 20 sec). All specimens received a final flush of 2ml distilled water. The root was sectioned longitudinally using a diamond wheel under a fine air/water mist. The apical half of the root was mounted on a 10mm diameter brass stub, air dried, given a minimum thickness gold coating and viewed in a scanning electron microscope. The image obtained was recorded on negative film in a roll film back. All specimens were viewed from end to end at x500 magnification before photomicrographs were made of areas typical of the apical seat (1mm level), the apical funnel (4-5mm level), and the middle third area of the root (9mm level).

To minimise the effect of operator bias the following measures were introduced. All 4 control teeth were processed together. Six teeth, one from each of the 6 experimental groups, were processed and viewed together. Hand instrumentation of all 6 teeth was completed before an individual tooth was allocated to a numbered specimen container. The instrumented tooth was then given the appropriate irrigation and the SEM root section prepared. This specimen was then returned to its numbered container. A technical officer mounted the numbered specimen onto a coded brass stub for drying and gold coating. The areas selected as being typical of the 1mm, 4mm, and 9mm areas were chosen by the SEM director (G.W.) and a frame number was included in the SEM data line on the photographic negative. Areas of special dental interest such as fins
or lateral canals were chosen by the author. The negatives were printed and the photomicrographs assessed for presence or absence of smear layer. A field was classified 'smear free' if all dentinal tubules in the field were visible and most tubules were free from a debris plug. The negative number / stub number / specimen number / experimental group number process was then reversed to identify each photomicrograph.

Routine photomicrographs were taken at standardised magnifications of x500, x2,000 and x4,500. All photomicrographs in this paper are at x2,000 magnification and represent views typical of the retained smear layer and debris approximately 4mm from the instrumented apical seat.

7.3 RESULTS

7.3.1 4% sodium hypochlorite

A tightly adherent smear layer was present in all instrumented areas of the root canal. The surface of the smear layer was smooth and free from soft tissue debris (Fig 7.1).

7.3.2 4% sodium hypochlorite + ultrasound

All specimens in this group were free from surface smear. Debris plugs had been removed along the entire length of the specimens (Fig 7.2).

7.3.3 2% sodium hypochlorite + ultrasound

All specimens were free from surface smear but a debris plug was present in some dentine tubules (Fig 7.3).

7.3.4 1% sodium hypochlorite + ultrasound

A surface smear was present on all instrumented surfaces. There was evidence of the smear layer breaking up and lifting (Fig 7.4).
7.4.5 0.5% sodium hypochlorite + ultrasound

An intact smear layer was present on all instrumented areas of the root canal (Fig 7.5). All specimens receiving ultrasonic irrigation with sodium hypochlorite showed smear free uninstrumented areas.

7.4.6 Ultrasound + water

All specimens in this group were smeared from end to end with evidence of soft tissue-like debris on the surface (Fig 7.6).

7.4.7 Control

All specimens in this group were heavily smeared from end to end with soft tissue-like debris on the surface (Fig 7.7)

7.4 DISCUSSION

These results are in agreement with those obtained by previous workers (Crabb 1982, Cunningham and Martin 1982, Cameron 1983). If NaOCl with more that 2% available chlorine is used for ultrasonic irrigation, the smear layer is removed within three minutes. When solutions with less than 2% available chlorine are used, the smear layer is not removed. These results could explain the apparently contradictory results of different workers who have investigated ultrasonic instrumentation or ultrasonic irrigation, and who have limited their experiments to a single concentration of sodium hypochlorite.

The results would also confirm the claim that a synergistic relationship exists between sodium hypochlorite and ultrasound during ultrasonic irrigation. While either component used by itself was unable to remove the smear layer, the combination of ultrasound with NaOCl produced a debris free canal wall. The synergistic relationship became clinically significant with hypochlorite solutions containing more than 2% available chlorine. In the present experiment three minutes of ultrasonic irrigation with 2% NaOCl was able to achieve a cleaner
canal wall than three days immersion in a 5% NaOCl solution (Lester and Boyde 1977). The fluid flow created by ultrasound, together with replacement of the irrigant in the canal, increased the efficiency of NaOCl as an endodontic irrigant. It has been claimed that when ultrasonic energy passes through an irrigant it exerts a scrubbing effect on the root canal wall. In these experiments, the scrubbing effect of ultrasonic irrigation with water was not capable of removing the smear layer from an instrumented root canal wall within three minutes. This would indicate that the importance of the scrubbing action of ultrasound could have been over-estimated, and that the fluid flow within the NaOCl could be more important than this mechanical effect on the smear layer. However, it is possible that this scrubbing action could remove loosely attached material from a fin or from an uninstrumented area.

This chapter is based on the paper; The synergistic relationship between ultrasound and sodium hypochlorite: a scanning electron microscope evaluation. J Endodon 1987; 13:541-5.
CHAPTER 8
DEBRIDEMENT OF UNINSTRUMENTED IMMATURE ROOT CANALS

8.1 INTRODUCTION

Root canal preparation has two ultimate objectives; the mechanical debridement of the root canal space, and the preparation of that space for final obliteration. Fortunately, both goals are accomplished by the same procedure of instrumentation (Ingle 1965 p168).

Shaping and debridement is usually carried out using hand reamers and files, sometimes in conjunction with a motor driven Gates-Glidden drill. The ideal root canal preparation should have a uniform taper with an apical seat just short of the apical foramen (Schilder 1976). During the process of debridement and shaping, minor irregularities in the root canal wall are removed, and some thickness of the canal wall is lost. In teeth with a regular, mature root this loss of dentine from the root canal wall does not present a problem. However, there are instances when the irregularity is too large to be removed by instrumentation. In many cases of internal root resorption an attempt to remove the resorptive defect could mutilate the remaining root structure. Failure to instrument the wall of the defect could result in large quantities of debris being retained within the canal to the detriment of the long term prognosis for the tooth. A non-vital tooth with an immature root presents a different problem. While it is possible to instrument all areas of the canal wall, any loss of dentine could seriously weaken the remaining root structure. Failure to remove all infected pulp material could result in the failure of apexification treatment. The operator is then faced with the problem of a thin walled canal with a blunderbuss apical foramen instead of a hard tissue bridge as an apical seat. Replanted teeth with root resorption can present with an irregular root canal space and thin root canal walls.

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A protein solvent could be used to remove pulpal debris and the predentine layer to leave a clean, intact dentine surface.

The purpose of this experiment was to investigate the effectiveness of a 4% NaOCl irrigant, with or without ultrasonic activation, as a means of removing pulpal debris and predentine from an uninstrumented, immature root canal. The root canal was selected to mimic the canal found in an immature human upper incisor tooth. The effectiveness of the techniques was to be assessed using a scanning electron microscope.

8.2 MATERIALS AND METHOD.

Single rooted first bicuspid human teeth extracted for orthodontic treatment were used to provide a root with an immature apical foramen and a relatively wide root canal. To balance the wide range of root development encountered in the available teeth the following selection procedure was used. Upper bicuspid teeth with two roots were not used because the results obtained from these finer roots might not apply to the wide root canal of an upper incisor tooth. When four usable teeth were obtained from one patient, one tooth was allocated to each of the four experimental groups. Two teeth obtained from one patient were placed in separate groups. All specimens were irrigated and prepared within 8 hours of the tooth being extracted. If the prepared specimen could not be viewed within the next 24 hours it was stored in a formalin solution.

Twenty five freshly extracted single rooted human first bicuspid teeth were used for this experiment. A conventional access cavity was prepared in the occlusal surface, entry into the pulp chamber being refined with a #8 round bur in a slow speed handpiece. Two medium size barbed broaches were passed through the access cavity into the apical area of the root canal, twisted a full turn and the whole pulp removed in one piece. Any soft tissue still adhering to the root apex was left intact. The 25 teeth were divided into 5 groups each containing 5 teeth using the guidelines outlined previously.
To minimise the possibility of irrigant being lost from a wide open apical foramen, the root end was pressed lightly against a rubber dam stretched over a rubber dam frame. It was felt that the flexible rubber dam was clinically more significant than the solid wall that would be formed by dipping the apex in molten wax. In a pilot study some specimens were rendered useless by wax passing through the apical foramen onto the canal wall.

8.2.1 Control

Following extirpation of the pulp these teeth were irrigated with a 2.2ml cartridge of anaesthetic solution and acted as a control.

8.2.2 One minute 4% sodium hypochlorite

A plastic syringe with a 25 gauge needle was used to introduce approximately 1ml of 4% NaOCl solution into the apical area of the root canal. The needle was removed from the root canal and the process repeated in 30 seconds. After an elapsed time of one minute any further tissue solvent activity of the NaOCl was halted by irrigating the canal with a 2.2ml cartridge of anaesthetic solution.

8.2.3 Three minutes 4% sodium hypochlorite

The 5 teeth in this group received three minutes exposure to 4% NaOCl in 6 increments each of 30 seconds. This was followed by an irrigation of 2.2ml of anaesthetic solution.

8.2.4 One minute ultrasonic irrigation

The 5 teeth in this group were irrigated with 4% NaOCl activated by ultrasound for a period of one minute (2 x 30 seconds). Ultrasonic energy was supplied by a Cavitron Cavi-Endo unit set at maximum power in the normal (prophylaxis) mode. The technique of ultrasonic irrigation has been described previously (7.2). The time required to replenish the irrigant and replace the ultratip was standardised at 10 seconds, so that while the teeth in this group received a full minute of 4% NaOCl (2 x 30 seconds) they received only 40 seconds (2 x 20 seconds) of ultrasound. The final irrigation was 2.2ml of anaesthetic solution.
8.2.5 Three minutes ultrasonic irrigation

The 5 teeth received a total of three minutes exposure to 4% NaOCl in 6 irrigations of 30 seconds. During this time the ultrasound generator was activated for a total period of two minutes (6 x 20 seconds). Anaesthetic solution was used to prevent further solvent activity of the sodium hypochlorite.

The crown of each tooth was removed at the cemento-enamel junction and the root sectioned in a longitudinal plane using a diamond disk under a fine air/water mist. Any soft tissue adhering to the root apex was retained. The specimens were air dried, given a minimum thickness gold coating and viewed in a scanning electron microscope (JEOL JSM 840). The image so obtained was recorded on negative film (Ilford FP4) using a Mamiya roll film back. For photographic purposes, the relatively short, immature roots were assessed in coronal and apical halves, plus a developing apical area if applicable. An area typical of each half of the specimen was photographed at magnifications of x500, x2000, and x4500. All specimens were coded and the photomicrographs assessed as described previously (7.2).

8.3 RESULTS

8.3.1 Control

Teeth in this group received no irrigation after the pulp had been removed with barbed broaches. There was considerable variation between specimens and between apical and coronal areas of the same specimen. In the coronal area some specimens showed a membrane-like predentine surface free from any cellular debris (Fig.8.1a). The openings of the dentinal tubules were well defined and the surface of the collagen and associated ground substance was smooth. Closer to the apical foramen the predentine surface was covered with cellular debris which obscured some dentinal tubule openings (Fig.8.1b).
8.3.2 One minute sodium hypochlorite

Only one of the five specimens showed any cellular debris on the predentine surface. This debris was present along the whole length of the specimen and could have been as a result of the barbed broaches not engaging the pulp tissue securely. All other specimens were free from debris and showed some signs of disruption of the smooth surface of the predentine. This effect was more evident in the coronal area (Fig.8.2a) than the apical area (Fig.8.2b).

8.3.3 Three minutes sodium hypochlorite

Three minutes of NaOCl removed the predentine in the coronal area of all specimens to reveal the calcospherite structure of the dentine surface (Fig.8.3a). In two specimens this appearance continued into the apical area. In one specimen only the ground substance of the predentine had been removed to reveal connective tissue fibres (Fig.8.3b). The other two specimens showed areas of calcospherites together with areas of retained connective tissue fibres.

8.3.4 One minute ultrasonic irrigation

Specimens in this group were similar to those in group 3. Coronal predentine had been removed and mature calcospherites were visible (Fig.8.4a). Closer to the apical foramen there were some areas of fine connective tissue fibres (Fig.8.4b), or areas of immature calcospherites (Fig.8.4c).

8.3.5 Three minutes ultrasonic irrigation

All specimens in this group were free from soft tissue except for the area immediately adjacent to the forming apex. The different stages of maturity of the dentine were visible in the coronal (Fig.8.5a) and apical areas (Fig.8.5b). Soft tissue was still evident in the specimens that had not lost the thin, partially calcified apical canal wall (Fig.8.5c).
8.4 DISCUSSION

Endodontic reamers and files have been designed for the specific purpose of cleaning and shaping mature root canals. The canal is enlarged by two or three instrument sizes, or until clean white fillings are removed by the instrument. The inefficiency of conventional instrumentation has been well documented (Gutierrez and Garcia 1968, McComb and Smith 1975, Moodnik et al. 1976, Lester and Boyde 1977, Svec and Harrison 1977, Ruban 1979, Goldman M 1982). The presence of necrotic debris in a root canal can lead to an inflammatory reaction in the apical tissues and create unfavourable conditions for connective tissue repair. It has been shown (Holland et al. 1979c) that the premolar teeth of dogs could develop an apical hard tissue barrier when treated with calcium hydroxide in the absence of debris. In the presence of debris the hard tissue barrier was partial, absent, or very irregular. In other experiments these authors found that instrumenting beyond the apical foramen (Holland et al. 1979b) or overfilling the canal with calcium hydroxide (Holland et al. 1979a) did not prevent the closure of the apical foramen even in cases where the pulp stump was destroyed.

This experiment was designed to demonstrate the presence or absence of uncalcified tissue within an uninstrumented, immature root canal after exposure to 4% NaOCl. Observations on the nature of retained soft tissue were not planned, so minor distortions produced by air drying the specimens were considered not significant. However, from the photomicrographs obtained, it was still possible to make some general observations and conclusions. Where soft tissue was retained, it was always more prevalent in the apical half of the root. This also applied to the control group, where only barbed broaches were used to remove the pulp in one piece. Uncalcified tissues were dissolved by sodium hypochlorite, and the different components seemed to be dissolved in a recognisable sequence. Pulpal remnants dissolved before the membrane-like surface of the predentine was disrupted; the ground substance dissolved to reveal the pattern of the collagen fibres; collagen fibres closer to the calcified dentine surface were the last structures removed, possibly because of early calcification of these fibres; the calcospherite surface was not affected by 4% sodium hypochlorite or the scrubbing action of
ultrasound. Ultrasound did not seem to alter the mode of action of sodium hypochlorite, but merely speeded up the reaction, so that one minute of sodium hypochlorite activated by ultrasound was as effective as three minutes of static sodium hypochlorite under the conditions of this experiment. Ultrasound and 4% sodium hypochlorite, used in the manner suggested, would appear to have little if any solvent or disruptive effect on calcified tissue. While it is important that all available root wall thickness be retained, it is also important that the clinician does not damage any new calcified tissue produced at the developing root end during apexification treatment. Sodium hypochlorite activated by ultrasound would appear to be a safe, efficient means of removing soft tissue from the root canal while maintaining the integrity of the developing calcified apical bridge.

Teeth with an immature apical foramen provide a large area of contact between the periapical tissues and the irrigant. Animal studies (Thé et al. 1980, Lamers et al. 1980) investigating the inflammatory response of connective tissue to sodium hypochlorite found that sodium hypochlorite, at concentrations up to 8%, did not contribute to the inflammatory response of the operative trauma. Rosenfeld et al. (1978) exposed pulpal tissue to 5.25% sodium hypochlorite for 15 minutes immediately prior to the teeth being extracted for orthodontic reasons. Sodium hypochlorite completely dissolved the predentine and exerted a non-specific non-coagulating digestive effect on vital pulp tissue. The tissue necrotising activity of sodium hypochlorite extended to a depth of three to five cells ahead of the digestive activity.

Ultrasonic energy waves travelling through an irrigant radiate equally in all directions away from their source. This radiating effect has two clinical implications:

1) If the ultratip does not extend apically beyond the middle third of the root canal, the force at the apex will be much lower than the force acting on the closer root canal walls. This theory was confirmed by the presence of soft tissue at the developing apex in group 5 specimens that exhibited canal walls completely free from predentine.

2) As the force radiates from the ultrasonic probe it exerts its scrubbing effect on all surfaces of the root canal in contact with the irrigant. This means that no surface of
the canal is "instrumented" more or less efficiently than any other surface. The presence of calcospherites in group 5 specimens indicates that this efficient debridement was achieved without the loss of dentine from the canal wall.

The clinical effectiveness of this technique has been demonstrated in a replanted tooth with severe inflammatory resorption (Chap 9) and teeth with incomplete root formation (Chap 10). The temperature changes associated with ultrasonic irrigation across an immature root canal wall have been investigated (Chap 12).

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This chapter is based on the paper; The use of 4 per cent sodium hypochlorite, with or without ultrasound, in cleansing of uninstrumented immature root canals; SEM study. Aust Dent J 1987; 32:204-13.
CHAPTER 9
ULTRASONIC IRRIGATION AND SEVERE ROOT RESORPTION

9.1 INTRODUCTION

The factors which influence the long-term retention of replanted avulsed teeth have been the subject of many investigations in recent years. Following extensive research and an exhaustive review of the literature, Andreasen (1981) suggested that the avulsed tooth should be replanted as soon as possible, preferably within 30 minutes. If the tooth can not be replanted immediately, it should not be allowed to dry out. The use of water, saline or milk has been suggested as a suitable transport medium. If drying has occurred the tooth should be moistened before replantation. The periodontal ligament should not be removed, nor should the socket be prepared in any way if possible. Splinting procedures should be functional and of short duration. Except for a tooth with an immature root end, the pulp should be extirpated and endodontic treatment initiated one to two weeks after replantation. Regular radiographic follow up is essential, particularly with immature teeth.

9.2 CASE REPORT

A 9-year-old girl fell onto a piece of furniture and avulsed the upper left central incisor. Acting on advice from the nearest hospital, the tooth was not washed but stored in a dry tissue during the next 40 minutes. At the hospital the tooth was then moistened in the patient's mouth for about five minutes prior to replantation. Temporary stabilisation was achieved with lead foil from an X-ray film packet and some periodontal dressing paste. Two days later an acrylic splint was cemented over the six upper anterior teeth and left in place for six weeks. When the splint was removed a radiograph revealed a small area of root resorption, but after a further four weeks approximately half of the root had been resorbed. At this time (ten weeks after the
trauma) the radiolucent area around the root had definite borders; four weeks later the borders were more clearly defined. During this last period of four weeks the rate of root resorption decreased. At week 14 the patient was seen for the first time by the author. On examination tooth #21 exhibited a degree of mobility and inflammation of the attached gingiva normally associated with a deciduous tooth just prior to exfoliation. The free gingiva above the tooth was inflamed so that it gave the appearance of an early acute infection. A radiograph (Fig 9.1) confirmed that the combination of root resorption and bone loss had left the remaining tooth with only soft tissue support. A fracture of the mesial incisal edge (Ellis class II) did not appear to have contributed to the problem. The adjacent teeth were firm and appeared normal.

Even though the prognosis for the tooth was unfavourable, the girl’s parent consented to conservative treatment. Under regional anaesthesia non-vital pulp tissue was removed from the coronal pulp chamber, while some vital tissue, which appeared hyperplastic, was removed from the apical part of the remaining root. A calcium hydroxide dressing¹ was sealed into place with a temporary filling material². At recall four weeks later (week 18) the gingivae appeared normal and the tooth, while still mobile, was comfortable. At week 24 the calcium hydroxide was replaced and a radiograph indicated some bone regeneration. At this appointment it was possible to observe almost all of the root canal through the access cavity. Perforations were present in both the mesial and distal walls of the canal. As the apex was not distinct instrumen-tation of the canal was limited to irrigation with 3% sodium hypochlorite prior to replacing the calcium hydroxide. The access cavity and crown defect were restored with a light cured composite resin using the acid-etch technique. By week 40 the tooth was firm, and did not appear ankylosed. The bone showed radiographic evidence of some lamina dura formation. The calcium hydroxide was replaced at this appointment. At week 54, even though the alveolar bone defect had filled in, the walls of the root canal were very thin, the lateral perforations were still visible, and the apical foramen, despite its radiographic appearance, was patent and irregular. Filing of the canal had not been attempted because of its irregular shape and thin walls. A recent technique for irrigating root canals using indirect ultrasound (Cameron 1982) was used to remove debris still on the canal walls. This technique has been described previously (5.2).
Ultrasonic irrigation was repeated one month later prior to canal obturation in July 1980. It was planned to use a custom-made gutta-percha point with excess sealer\(^3\) and vertical condensation to obturate the canal, but the paste extruded through the lateral perforations and the condensation could not be completed. Radiographs taken in November 1980 and June 1981 showed that whilst the condition of bone and root seemed stable the root filling paste was dissolving. In February 1982 the patient complained of hot and cold sensitivity which appeared to be associated with the root filled tooth. A radiograph (Fig 9.2) revealed that most of the sealer had disappeared from the root canal and so it was decided to retreat the tooth. When the root filling was removed from the tooth the remaining sealer was soft and discoloured. Indirect ultrasound applied for three minutes was used to complete the debridement of the canal. For refilling, a smear of AH26 was used followed by a heat-softened master cone formed by rolling together two size 110 gutta-percha points. As there was still no apical seat against which to condense, the coronal canal was filled initially with heat-softened gutta-percha, and vertical condensation used to move this material towards the apex. Again the root filling material moved laterally through the perforations rather than apically. A radiograph (Fig 9.3) taken in April 1983 indicated that the root of the replanted tooth, the root filling and the surrounding bone were all stable. The upper right central incisor had been root filled in October 1982 following an abscess.

9.3 DISCUSSION

When the patient was first seen at week 14, the prognosis for the tooth did not seem at all favourable because of mobility, root resorption and bone loss. As the tooth was still in place and prosthetic replacement in the mixed dentition could be difficult, it seemed worth attempting to retain the tooth as a space maintainer. Success in halting the root resorption and inducing repair of the bony defect was not anticipated, and this success created two problems, namely how to prepare the canal and how to fill it.
Ultrasonic irrigation with sodium hypochlorite was the method chosen to "prepare" the canal. The protein solvent ability of sodium hypochlorite is enhanced by fluid flow, and the scrubbing action of ultrasonic energy waves is exerted on all surfaces in contact with the irrigant.

The perforations in the mesial and distal walls of the root canal made obturation difficult. Because the canal walls were very thin it would have been impossible to place a retentive amalgam restoration in the defects. The thin walls, even without perforation, would have limited the force that could be used to condense the root filling. The use of an injectable root filling material, Poly Hema⁴, was considered, but rejected as the author was unfamiliar with its use. The loss of most of the original root canal sealer from the canal within eight months was unexpected and it is hoped that the AH26 paste will be more permanent.

Of the three major problems associated with the endodontic management of severe inflammatory resorption, only two were solved in this case. Removal of the non-vital pulp removed the irritation which caused the inflammatory resorption. The use of calcium hydroxide over an extended period of time induced the repair of the bony defect and the cleansing of the root canal by indirect ultrasound ensured the stability of the result. The canal walls were considered to be too thin to retain apical and lateral amalgam restorations, and the perforations were judged too extensive to allow conventional condensation techniques. The obturation technique used in this case, while clinically successful, was not considered ideal. Moisture within the canal and setting shrinkage could perhaps limit the alternative use of paste type filling materials.

A seven year follow-up radiograph taken in September 1987 showed a stable bone and root situation, with no apparent loss of sealer from the root canal.

This chapter is based on the paper:
CHAPTER 10
ULTRASONIC IRRIGATION AND ROOT END CLOSURE

10.1 INTRODUCTION

Necrosis of the dental pulp prior to root maturation can present the clinician with conditions unfavourable for a conservative or a surgical approach to root canal treatment. A wide open apical foramen does not present a seat for condensation of gutta-percha, and the thin canal walls can be too fragile to retain an amalgam retrofill. Frank (1966) described a technique which encouraged completion of root end growth or the formation of an apical hard tissue bridge. Emphasis was placed on the reduction of contaminants within the root canal by the use of hand instruments and generous irrigation with sodium hypochlorite. Holland et al. (1979c) confirmed that removal of debris was the most important phase of apexification treatment.

Conventional instrumentation of a mature root canal is designed to remove debris from the root canal, remove irregularities from the root canal wall, and to prepare a canal shape that will readily accept a root canal filling. In an immature root canal the loss of any wall thickness during instrumentation could prejudice the long term prognosis for the tooth, and the shape of the apical area is often the reverse of the ideal tapered apical seat. These factors would indicate that in an immature root canal the sole function of instrumentation is removal of necrotic debris, a function shared with the irrigation liquid. The clinical use of sodium hypochlorite activated by ultrasound as the sole instrumentation of a pulpless, immature root has not been previously reported. The two cases presented here were chosen because of their different clinical histories. The first case presented with a blunderbuss apex soon after the original trauma. The second case was seen for retreatment six years after the original treatment.
The patient, a 7 year old male, sought treatment from the author immediately following a fall at his home. On examination, the maxillary left central incisor had suffered a mesial oblique Class II Ellis fracture. The tooth did not seem displaced in the socket, and apart from some bleeding from the gingiva, there was no other soft tissue damage. A radiograph revealed absence of hard tissue damage; the immature state of root development was consistent with the age of the patient (Fig 10.1). Initial treatment was limited to covering all exposed dentine with carboxylate cement\(^1\). Five days later the tooth was comfortable but did appear a little cloudy to transillumination. This cloudy appearance was observed at appointments two weeks, one month and two months after the accident. Four months after the accident the patient presented with an alveolar abscess associated with the damaged tooth.

A routine access cavity into the crown of the tooth released a purulent discharge from the root canal. No conventional instrumentation was carried out. The canal was debrided using a 4% sodium hypochlorite solution\(^2\) activated by ultrasound. After receiving five minutes of ultrasonic irrigation with irrigant changes every minute, the canal was dried with paper points, filled with calcium hydroxide (Pulpdent) and the access cavity double sealed with Cavit and a silicate cement.

Three minutes of ultrasonic irrigation and calcium hydroxide replacement was carried out at regular intervals of approximately three months. A radiograph was taken at each of these appointments. By week 10 of calcium hydroxide treatment, the appearance of the periapical bone had returned to normal; at week 24 the first signs of apical barrier formation were observed; at week 40, apical barrier formation was confirmed. Fifty-two weeks after the commencement of endodontic treatment, a radiograph indicated that the apical barrier was complete. The apical area was not probed with an endodontic instrument to explore the extent of this barrier. All visible calcium hydroxide was removed from the canal after two minutes of ultrasonic irrigation, and the canal was dried using multiple paper points blunt end first. A
master cone was made by fusing three chloroform softened, size 100 gutta-percha points. This cone was coated with AH26 sealer and the canal space was obliterated using lateral condensation followed by vertical condensation.

As the patient has returned to the author every 6 months for routine preventive dentistry, it has been possible to monitor the stability of the result for a further 6 years. Figure 10.2 shows the root filling and apical bridge at 4 years after the root filling.

10.3 CASE REPORT #2.

The patient, a 13 year old male, was referred to the author by a fellow general practitioner for diagnosis and treatment. As a result of trauma some 6 years previously, the maxillary right central incisor had become pulpless, had been root filled, and a gold post with an acrylic crown had been constructed. The patient was concerned with the puffy state of the gingiva and an associated foul taste from the area. On examination the fixed gingiva was hypertrophic, the free gingiva inflamed, and a deep periodontal pocket was present on the labial root surface. Radiographic examination revealed a short post, inadequate root filling, an incompletely formed root apex and periapical pathology (Fig 10.3). Possible causes of the inflammatory response were, root perforation, split root, periapical pathology or a combination of these factors. At this first appointment an exploratory flap was raised which showed the gold post perforating the root surface. The gold post was shortened and the root defect repaired with a dentine bonded composite resin\(^3\). Composite resin was used in an attempt to eliminate the discolouration often produced in soft tissues covering a root perforation repaired with amalgam. After freshening up the root and soft tissue surfaces the flap was sutured back into place. At suture removal one week later the condition of the fixed gingiva had improved and the gingival pocket no longer extend beyond the site of root perforation. One month later the soft tissues had responded well to the perforation repair, so retreatment of the root canal was scheduled. Following removal of the post crown, the internal defect in the coronal half of the root canal caused by the post preparation was repaired with composite resin. This created a conventional
root canal shape and full thickness of the canal wall. When the single point root canal filling was removed a purulent exudate flowed from the periapical tissues. Cleaning of the canal was achieved by two minutes of ultrasonic irrigation. The apical half of the root canal was filled with calcium hydroxide (Pulpdent) and a temporary post crown cemented. Three months later the periapical radiolucency seemed less profound. In a further 6 weeks the temporary crown was dislodged and, at the parent’s request, the crown was recemented by the referring dentist. Within one week the tooth was mobile and uncomfortable. When seen by the author the temporary crown was in traumatic occlusion, so the crown was removed. A purulent exudate was present, and the apical half of the root canal contained unidentified matter, possibly food debris, rather than calcium hydroxide. After this debris was removed with ultrasonic irrigation, a calcium hydroxide dressing was inserted and the temporary crown recemented. Two months later (7 months of calcium hydroxide) the tooth was comfortable, the canal was dry and an apical stop was evident on a radiograph. As the patient was available for treatment only during school vacation the root filling was carried out at this appointment. Using a chloroform softened master cone, an impression of the apical seat was obtained prior to coating the canal with sealer. This custom cone was coated with AH26 and the canal space obliterated with lateral and then vertical condensation. A temporary crown was cemented until a permanent cast post and core restoration could be constructed during the next vacation, 5 months later. Radiographs taken 5 months and 12 months (Fig 10.4) after placement of the root filling indicated that a stable result had been achieved. At routine recall (February 1988), three years after treatment, the patient reported the tooth to be comfortable. Radiographic examination, however, revealed that the periapical bone pathology had not healed, so surgical curettage of the area was carried out.

10.4 DISCUSSION

The use of calcium hydroxide is now an accepted method of inducing root end closure in a pulpless tooth with an immature root. When Holland et al. (1979c) examined the factors influencing the success of this technique, they found that the presence of debris could inhibit the
formation of a calcific bridge. Even though the debridement and shaping of mature and immature root canals presents different problems, the same instruments and techniques have been used for both groups of teeth. Conventional endodontic hand instruments were designed for use in mature root canals free from major irregularities in the canal wall. Their function is to:

1) remove soft tissue debris
2) remove minor irregularities from the canal wall
3) prepare an apical seat
4) prepare a canal shape dictated by the filling material to be used for canal obturation.

These goals are achieved by enlarging the apical portion of the canal by two instrument sizes and by flaring the middle and coronal thirds of the canal. In an immature canal it is not possible to create an apical seat, it is not necessary to enlarge the canal space, and it is not desirable to remove dentine from the thin walls of the canal. It is possible that the soft tissue debris could be removed more efficiently by the use of an irrigation solution with protein solvent properties.

Richman (1957) was the first to describe the use of ultrasound in endodontics but since 1957 very little clinical data has been published. Most authors have concentrated on the efficiency of instruments activated by ultrasound or the lack of debris on the canal walls. There is no information available on the ultrasonic forces within a canal that might tend to force irrigant or debris through the apical foramen.

Rosenfeld et al. (1978) removed all but the apical 5mm of the pulp from vital human premolar teeth. After 15 minutes of intermittent exposure to 5.25% sodium hypochlorite only the surface of the pulp stump had been affected. Because the tissue solvent and necrotising activities of sodium hypochlorite are non-specific and non-coagulating, tissue denatured by sodium hypochlorite is then dissolved, so that no gross cellular debris remains.

It has been shown (Ch.8) that three minutes of ultrasonic irrigation removed all pulpal debris and predentine from the wall of an uninstrumented, immature root canal, but that soft tissue
associated with the developing apex was not completely removed. It was possible that these
tissues had started to calcify, or that the volume of tissue to be dissolved was too great for the
volume of tissue solvent. The magnitude of the ultrasonic energy tending to force irrigant
through the apical foramen is not known. With the ultratip in the middle third of the canal,
the distance from ultratip to apical foramen is greater than from the ultratip to canal wall, so
the force acting at the apical foramen is less than the force acting on the canal wall in the
coronal and middle thirds of the canal. Because of the width of an immature canal, the smooth
broach cannot act as a plunger or prevent the release of intracanal pressure through the coronal
access cavity. Therefore, it seems that the forces tending to push irrigant or debris through the
apical foramen are not clinically significant. Should a small amount of sodium hypochlorite
pass through the apical foramen it would be acting on a small surface area of a large volume of
tissue and the available chlorine would soon be exhausted.

The use of ultrasonic irrigation would appear to have some advantages over conventional
instrumentation as a means of debriding necrotic immature root canals. With ultrasonic
irrigation the ultratip does not enter the apical half of the canal, so the risk of forcing necrotic
debris through the apical foramen is minimised. Debridement of the root canal is achieved
without any loss of root canal wall thickness. It is not necessary to know the exact length of the
root canal to achieve complete debridement. Conventional instrumentation produces a smeared
canal wall, while ultrasonic irrigation leaves a debris-free wall.

In one of the cases presented, entry of debris into the root canal during apexification treatment
caused an acute inflammatory reaction in the periapical tissues. When this debris was removed
with ultrasonic irrigation the acute phase subsided. This episode tends to confirm that
degradation products originating within the root canal can have an adverse effect on the
periapical tissues.

From the cases presented here, it would appear that if any damage is caused in the periapical
tissues by the short exposure to sodium hypochlorite or ultrasound, then this damage is better
tolerated by those tissues than the damage caused by continuous exposure to the toxins and protein degradation products found in a necrotic root canal.

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This chapter is based on the paper:
CHAPTER 11

SODIUM HYPOCHLORITE AND A FLUOROCARBON SURFACTANT

11.1 INTRODUCTION

Root canal therapy has been divided into three phases; diagnosis, biomechanical preparation of the root canal, and obturation of the root canal space. Biomechanical preparation can be divided into instrumentation, irrigation and medication. The prime function of the irrigant is to remove any debris loosened, but not removed, by the instrumentation. Some irrigants also offer chelating, tissue solvent or bacteriocidal properties.

The efficiency of an endodontic irrigant could be improved by reducing its surface tension, or by increasing fluid flow over the debris on the root canal wall. An irrigant could extend its protein solvent capability, or perform the bacteriocidal function of a medicament, if the irrigant could penetrate the uninstrumented areas of the root canal system. A reduction in surface tension could allow the irrigant to flow into these remote areas.

Surface tension is the force between molecules which produces a tendency for the surface area of a liquid to decrease. The diminution takes place not by a contraction of the liquid, but by a passage of the surface molecules into the body of the liquid. This force tends to inhibit the spread of a liquid over a surface, or to limit its ability to penetrate a capillary tube. Surface tension diminishes with an increase in temperature until it reaches zero when the liquid turns to vapour (E.B. 1961). Surface tension can also be reduced by the use of chemicals known as surfactants.

Abou-Ras and Patonai (1982) used polysorbate 80 to reduce the surface tension of sodium hypochlorite 5.25% from 79.6 to 69.8 dynes/cm, sodium hypochlorite 2.6% from 76.7 to 67.2 dynes/cm and an EDTA solution from 39.7 to 33.7 dynes/cm.
Cunningham et al. (1982d) mixed equal volumes of sodium hypochlorite with reagent grade ethanol and measured its movement into a glass capillary tube. While the movement of this solution into the capillary tubes indicated a lower surface tension than sodium hypochlorite alone, other experiments indicated that the solution was not stable, and lost most of its available chlorine within 15 minutes.

The purpose of this investigation was to evaluate the effectiveness of a fluorocarbon surfactant, Fluorad FC991/sodium hypochlorite solution in four separate areas related to its use as an endodontic irrigant:

1) surface tension
2) stability of available chlorine
3) tissue solvent ability
4) presence of chemical residue on root canal walls.

11.2 MATERIALS AND METHOD

The sodium hypochlorite used was a household bleach (Zixo) with a stated 4% concentration of available chlorine. Each litre of solution provided two 500ml samples; one received 0.5ml surfactant, the other acted as control.

11.2.1 Surface tension

Surface tension readings of experimental and control solutions were obtained using a Du Noy tensionmeter2. The readings were measured at the time zero, one hour, one day, one week and one month. All readings were made in triplicate, corrected for temperature, and recorded in dynes/cm.

11.2.2 Available Chlorine

The concentration of available chlorine in the test and control solutions was determined by titration for free Iodine using the Sodium Thiosulphate, Potassium Iodide technique. Samples
were analysed at weekly intervals over a period of two months. The solutions were stored in a cool, stable environment protected from direct light.

11.2.3 Tissue Solubility

Both test and control solutions used were prepared two months before the experiments were conducted. Ten ml of the test or control solution was placed in a screw topped 12ml capacity glass container. The pulp was removed in one piece from a freshly extracted, unfixed human single rooted tooth using a barbed broach; only complete pulps were used. One pulp was added to each of the two containers. After replacing the cap, the container was shaken briefly then allowed to stand until the pulp dissolved. Six pulps were added to each container over a one hour period, the time taken for each pulp to dissolve being measured.

11.2.4 Chemical Residue

Four freshly extracted unfixed human teeth were instrumented to clinical standard through a conventional access cavity. One ml of 4% sodium hypochlorite 0.1% FC99 solution was used as irrigant between each instrument size. Two of these teeth were given a conventional irrigation with 2ml of the test solution, the other two were given one minute of ultrasonic irrigation with the test solution. Both groups received 2ml of anaesthetic solution as the final irrigant to prevent any further tissue solvent action of the sodium hypochlorite. The specimens were prepared for the scanning electron microscope using a diamond wheel under a fine air/water spray, dried, and given a minimum thickness gold coating. They were viewed in a scanning electron microscope JEOL JSM840 and the image recorded on Ilford FP4 negative film using a Mamiya roll film back.

11.3 RESULTS

11.3.1 Surface Tension

The surfactant reduced the surface tension of 4% sodium hypochlorite from 70 dynes/cm to 27 dynes/cm, and this level was maintained without change for a period of one month. Full details are presented in Table 11.1.
11.3.2 Available Chlorine

The test solution showed a stability far superior to previous combinations, losing less than 5% available chlorine in the first month and 26% of the available chlorine in the two month test period. Full details are given in Table 11.2. At the completion of these tests the sample containing FC99 was showing some signs of instability:

1) a colour change from clear light yellow to a dull brown tinge
2) a brown deposit had settled at the base of the container
3) gas in solution gave it a spritzig effect
4) gas liberated from solution had pressurised the container

11.3.3 Tissue Solvent Capability

Under the conditions of this experiment it was not possible to determine accurately when the pulp tissue had completely dissolved. For all twelve samples some tissue was visible after five minutes in the test or control solutions, and all the tissue had dissolved by nine minutes. No difference was noted between the time taken to dissolve the first or sixth specimen in each container, and no difference was noted between the test or control solution.

11.3.4 Chemical Residue

Magnifications of up to x4,500 did not reveal any evidence of chemical crystals or unusual smear layer derived from the test irrigant. One specimen presented a well defined fin leading off the instrumented main canal. All pulpal tissue and predentine had been removed from the fin, revealing the calcosphere structure of the dentine surface (Fig 11.1). The instrumented surface of the main canal showed a tightly adherent smear layer with a debris-free surface. Specimens receiving the ultrasound activated final irrigation showed clean uninstrumented root surfaces, and evidence of removal or loosening of the smear layer from instrumented areas.
11.4 DISCUSSION

With the introduction of ultrasound into endodontics the distinction between instrumentation, irrigation and medication is not distinct. It is possible that future emphasis will be more on irrigation activated by ultrasound rather than shaping the canal with hand instruments. Even without a reduced surface tension, a combination of sodium hypochlorite and ultrasound can remove debris from areas inaccessible to hand instruments and conventional irrigation (Goodman et al. 1985). It is possible that with a reduced surface tension sodium hypochlorite would be able to exert its tissue solvent action in the fins and interconnecting lacework of the root canal system. Previous attempts to reduce the surface tension of sodium hypochlorite have produced reductions of doubtful clinical significance, or solutions with an available chlorine stability measured in minutes.

Fluorad FC99 is a 25% active solution of amine perfluoroalkyl sulfonates in water. It has a pH of 6 - 7 as supplied, is considered mildly irritating in conjunctival tests and practically non-toxic on an acute dermal basis. In these experiments FC99 was used at a concentration of 1ml per litre of 4% sodium hypochlorite, so it is unlikely that it would add to the toxic effects of sodium hypochlorite. FC99 was chosen as the test surfactant because of its proven ability to withstand aggressive oxidising or reducing media. Its efficiency as a surfactant in low concentrations ensures minimum dilution of the host solution. Cunningham et al. (1982d) used ethanol and sodium hypochlorite in equal volumes to produce an irrigant with a reduced surface tension and a concentration of available chlorine diluted from 5.2% in the host solution to 2.6% in the test solution. The FC99 reduced the surface tension of sodium hypochlorite to that of ethanol alone, without diluting the concentration of available chlorine in the host solution. After two months more than 70% of the original chlorine concentration had been retained. Mixing sodium hypochlorite with ethanol produced an immediate drop of 50% in the concentration of chlorine, because of dilution, and further loss of chlorine because of the unstable nature of the mixture. The loss of chlorine from the proposed irrigant could have been caused by the relatively high concentration of FC99 used in the experiment, or by the introduction of contaminants during the
test period. The concentration of FC99 used in this experiment, 0.1%, is relatively high as the manufacturers recommend concentrations as low as 0.04% to produce significant reductions in surface tension.

Some materials introduced into the root canal have left a residue that has proved difficult to remove. Citric acid produced crystals that required large volumes of water for their removal, and the smear layer associated with RC Prep was resistant to the usual endodontic irrigants. This experiment would indicate that the FC99/sodium hypochlorite combination, with or without ultrasound, does not leave a residue within the root canal.

It was felt that the results obtained using the sodium hypochlorite/0.1% FC99 combination warranted further investigation.

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This chapter is based on the paper; The effect of a fluorocarbon surfactant on the surface tension of the endodontic irrigant, sodium hypochlorite. Aust Dent J 1986; 31:5.
12.1 INTRODUCTION

Under some circumstances, the instruments or irrigants used within a root canal may affect the paradental tissues. Recent studies have suggested the use of ultrasound to activate endodontic instruments (Cunningham and Martin 1982b) or irrigating solutions (Cameron 1982). It has been suggested (Moorer and Wesselink, 1982) that the heat generated by ultrasound within the canal could have a deleterious effect on the paradental tissues.

The purpose of this study was to measure the temperature changes inside the root canal and at the external root surface during ultrasonic endodontic techniques using a continuous irrigant flow or an intermittent irrigant flush. The effect of root canal wall thickness was also to be investigated.

12.2 PILOT STUDY

A pilot study was carried out to determine the magnitude of temperature changes at the external root surface during ultrasonic endodontics, and to identify extrinsic factors which could influence the results. In this pilot study the root of an extracted tooth was hand held against a thermistor sensor while continuous flow ultrasonic irrigation was carried out. The temperature registered by the thermistor was affected by air currents from an air conditioning duct, heat from the fingers of the operator, heat from an incandescent light globe, the temperature of the irrigant and the spill of irrigant from the access cavity onto the sensor. When these factors were eliminated, continuous flow ultrasonic irrigation produced a fall in temperature on the external root surface.
Following the pilot study, a Chromel vs Alumel thermocouple was selected as the temperature sensor. The thermocouple was small enough to allow free flow of irrigant within the canal, was easy to install and easy to replace if damaged during the experiment. It was accurate in the range 20°C-50°C with rapid response to temperature changes.

12.3 MATERIALS AND METHOD

A Chromel-Alumel thermocouple was made by twisting together one end of each of the two wires (size 0058=.01mm). The joint was silver soldered to prevent the wires from unwinding under the influence of ultrasonic vibration, and to enhance electrical contact between the two wires. Spaghetti type plastic insulation was placed over each wire to within 3mm of the solder joint. This 3mm section of wire was coated with a fissure seal material\(^1\) to keep the wires separated and to facilitate handling. The free ends of the wires were attached to the terminals of a thermocouple type K digital thermometer\(^2\). Each thermocouple was tested against an alcohol bulb thermometer for accuracy in the 20°C - 50°C temperature range before and after each session of experiments. The digital thermometer recorded temperatures to the nearest degree C. Two thermocouple/thermometer units were used, one to record the intra-canal temperature, the other to record the temperature at the external root surface. An assistant was assigned to each thermometer to monitor the temperature display. The two assistants dictated temperature changes as they occurred into a single tape recorder. This simple system allowed temperatures inside and outside the canal to be recorded simultaneously onto the same audio tape.

Two recently extracted human canine teeth were stored in tap water prior to use. A mature canine, extracted for periodontal reasons, was used to provide a relatively thick root canal wall. This tooth was 30mm long with a crown length of 12mm. A conventional access cavity was prepared in the crown of the tooth and the apical third of the root canal enlarged with Hedstrom files using a twist-pull motion. The canal was enlarged to file size #45 to within 1mm of the visual apical foramen, and then flared slightly using Gates-Glidden drills. An
immature canine, surgically removed for orthodontic reasons, was used to provide a tooth 24mm long, crown length 12mm, a thin canal wall and a wide open apical foramen 4mm x 2mm in diameter. A conventional access cavity was prepared in the crown and the pulpal tissue removed with barbed broaches. A Gates-Glidden drill #6 was used to remove soft tissue remaining on the canal wall. A sheet of boxing wax luted onto both teeth formed a collar at the cemento-enamel junction. This collar acted as a handle for the tooth, a lid for a temperature control bath, a support for the thermocouple wires and it diverted irrigating liquid flowing from the access cavity away from the root of the tooth (Fig 12.1).

The external thermocouple was attached to the flat proximal surface of the root with a small square of clear adhesive tape. The thermocouple and adjacent uninsulated wires were covered with wax to ensure that the thermocouple recorded the root surface temperature and not the temperature of the environment. The adhesive tape prevented wax from passing between the thermocouple and the root surface. For both teeth the thermocouple was placed at the same distance from the cemento-enamel junction. This represented the middle third of the mature root and close to the apex of the immature root. At this level the wall of the mature canine was 1.3mm thick, the immature canine wall 0.6mm thick. An internal thermocouple was placed just through the immature apex and fixed in place with an apical wax plug. This wax plug also provided a watertight seal at the apical foramen (Fig 12.2). For the mature canine a #4 round bur was used to prepare a hole through the proximal wall opposite the external thermocouple. A thermocouple was passed through this hole and bent to sit flat against the internal canal wall. A small bead of wax was used to seal the root access hole and to retain all wires in place (Fig 12.3).

The tooth with attached thermocouples was suspended by its wax collar in the air space over a heated water bath. The temperature of the water bath was regulated so that the temperature measured by both internal and external thermocouples stabilised at 37°C. After the temperature had stabilised, the integrity and insulation of both thermocouples was confirmed by irrigating the canal with 5ml of tap water at 25°C. Both units were judged satisfactory if an
initial fall in temperature followed by a slow return to 37°C was recorded. This procedure acted as a control for the experiments. Ultrasonic energy was provided by a Spacesonic 2000 dental unit\(^4\). The Spacesonic unit is rated at 33 watts and was used at the recommended endodontic power setting of #2 on a scale of 5. A Spacesonic endodontic head was used to retain a 25mm #25 Endosonic file\(^5\). The manual tuning knob on the unit was used to tune this file/head combination before the first experiment, and no further adjustment was found necessary. As the Spacesonic unit did not have a reservoir for irrigants, it was connected directly to a water tap. Water flow was adjusted so that a stream of water extended upwards 5mm beyond the tip of the file when the file was held vertically. This flow rate was measured at 30ml/min. All experiments in this study were carried out five times in a room maintained at 20°C with tap water at 25°C.

12.3.1 Mature canine continuous irrigation

The mature canine assembly was suspended in the air space over the water bath, the root canal and pulp chamber filled with tap water at 25°C, and the temperature allowed to stabilise at 37°C. The continuous flow technique required the activated file to be used just short of full working length, but in this 30mm long tooth the file was used at its full 25mm length. The ultrasound unit was activated with the water switch ON. An up and down movement of the file was carried out to simulate clinical use, but no contact was made with the canal wall. In this narrow canal care was needed to avoid damaging the internal thermocouple with the activated file. Water flowing from the coronal access cavity was diverted away from the area of the experiment by the wax collar on the tooth. After three minutes the unit was turned off, the file removed from the root canal, and the system allowed to return to 37°C before the experiment was repeated. All temperature changes were dictated onto audio tape.

12.3.2 Mature canine intermittent irrigation

The mature canine assembly was suspended in the air space over the water bath, the root canal filled with tap water at 25°C, and the system allowed to stabilise at 37°C. In the intermittent flush technique, the sole function of the activated file was to transmit ultrasonic energy to the irrigant within the root canal. This was achieved by placing the file into the canal with its tip
at the junction of the middle and apical thirds of the root canal. No contact with the root canal wall was required. Water supply to the insert was switched OFF, and the unit activated for 30 seconds. Ten seconds was allowed to switch the unit off, remove the file from the root canal, flush the canal with 1ml of 25°C tap water from a plastic syringe, replace the file into the canal, and activate the unit. This sequence was carried out four times, so that the canal received 120 seconds of ultrasound over a period of 160 seconds. The system was allowed to stabilise at 37°C before the experiment was repeated. All temperature changes were dictated onto audio tape.

12.3.3 Immature canine continuous irrigation

The continuous flow technique was repeated in the immature canine with the tip of the file placed just short of the apical wax plug.

12.3.4 Immature canine intermittent flush

The immature canine assembly was suspended over the water bath and stabilised at 37°C. A plastic syringe was used to deliver 1ml of tap water at 25°C into the root canal. The file was placed into the root canal so that its tip was just short of the apical wax plug. Water supply to the insert was switched OFF and the unit activated for four periods each of 30 seconds with a 1ml flush of tap water at 25°C between each 30 seconds period. The system was allowed to stabilise at 37°C before the experiment was repeated.

12.3.5 Irrigant temperature vs power setting

The temperature of tap water entering the ultrasound unit was 25°C. Correct tuning of the endodontic head and file was verified, water flow left at 30ml/min and the power setting reduced to #1 on a scale of 5. The ultrasound unit was activated and water flowing from the end of the file was collected in a small plastic cup. The temperature of the water was recorded by a thermocouple on the bottom of the plastic cup. This experiment was repeated for power settings of #2 and #3. Because the endodontic insert was not designed for use at higher power settings it was then replaced with a scaler tip, the unit retuned, and the water temperature measured at power settings #4 and #5.
12.4 RESULTS

12.4.1 Mature canine continuous irrigation

The internal temperature fell to 31°C within 5 seconds and stabilised at 29°C after 15 seconds. The external root temperature fell to 32°C during the first 60 seconds and remained at this level. These time/temperature relationships were recorded each time the experiment was performed (Table 12.1).

12.4.2 Mature canine intermittent irrigation

During this experiment it was noted that the highest intra-canal temperatures were recorded when the tip of the file, the ultratip, was placed close to the thermocouple. Because the distance between the ultratip and the thermocouple was subject to operator control, the temperatures recorded inside the canal for this experiment and for experiment 12.4.4 should be regarded as having qualitative rather than quantitative significance. A typical readout forms part of Table 12.2. Two thermocouples were broken when the ultratip touched the wires within the canal. Results from these experiments were discarded. For this group no further attempt was made to bring the ultratip close to the thermocouple. This could explain why the highest intra canal temperature recorded was 41°C. The lowest internal temperature recorded near the junction of the apical and middle thirds was 31°C. When the canal was not given an initial flush with water at 25°C the heat generated by the ultrasound within the canal raised the external root temperature from 37°C to 40°C within 30 seconds. Flushing the canal with 1ml of water at 25°C reduced the external root temperature from this high of 40°C to 36°C.

12.4.3 Immature canine continuous irrigation

The internal temperature fell to 30°C during the first 5 seconds and stabilised at 28°C after 15 seconds. The external temperature fell to 32°C during the first 30 seconds and stabilised at this level (Table 12.1).
12.4.4 Immature canine intermittent flush

When the canal received an initial flush with 1ml water at 25°C, the internal temperature fell instantly to 27°C. A maximum temperature of 45°C was recorded when the ultratip was almost touching the thermocouple. The external temperature fell to 31°C over a period of 90 seconds and then fluctuated between 31°C and 33°C. The cooling effect of 1ml irrigant at 25°C every 30 seconds seemed more significant than the heat generated by the ultrasonic energy. A typical time/temperature read-out forms part of Table 12.2.

In experiments 12.3.1 to 12.3.4 the temperatures recorded on the external surface of the immature canine were always lower than the corresponding temperatures for the mature canine. Three possible reasons for this could be:

1) the greater volume of irrigant at 25°C retained within the larger immature root canal.
2) better circulation of irrigant within the wider immature root canal.
3) more heat energy was stored within the thicker root canal wall of the mature canine.

12.4.5 Irrigant temperature vs power setting

The power setting of the Spacesonic unit had some effect on the temperature of the water as it flowed through the endodontic head and over the vibrating file. At power setting #1 the temperature rose from 25°C by 1°C, at #2 by 2°C and at #3 by 3°C. With the scaler tip in place and at power settings #4 or #5 the temperature rose by 2°C. At these higher power settings the water left the tip of the scaler as a fine spray.

12.5 DISCUSSION

Heat generation is obvious during the dental use of ultrasound. Water flowing through a prophylaxis tip can feel warm; metal parts of non water cooled inserts can become too hot to touch; liquid in an ultrasonic instrument cleaning bath becomes warm during use.
There are many factors other than the power of the ultrasound generator which either contribute to the production of heat or influence the temperature achieved at the external root surface during ultrasonic endodontics.

Some dental ultrasound units have a tank for the storage of a medicated irrigant. The temperature of this irrigant would be close to the prevailing room temperature, and hence subject to wide variation. Other units are attached directly to the water main. In these experiments, the tap water temperature of 25°C was higher than one would expect in more temperate climates.

Dental ultrasound units use either a metal strip magnetostrictive stack or a piezo crystal as the method of generating ultrasound. When experiment 12.3.5 was repeated with a magnetostrictive stack generator the temperature of the water leaving the instrument tip was 7°C warmer than the water entering the machine. Part of this temperature rise could have occurred as the water passed over the magnetostrictive stack of the insert. The more powerful piezo crystal Spacesonic unit only produced a 3°C rise in temperature.

When ultrasound waves pass through a metal there is an increase in the motion of positive ions that form the crystal lattice of that metal. During this process some ultrasound energy is converted to heat energy. It is possible that the amount of heat generated in the insert is related to the type of metal used in its construction and the mass of the metallic head. One would anticipate that the block-like head of the Cavitron insert #P105 would generate more heat than the smaller Spacesonic head, with the tube like inserts of the ENAC and HARMOSONIC units generating little heat at all.

The maximum power of a dental ultrasound insert is determined during design and manufacture. The operating power of the insert is controlled by a knob on the ultrasound generator. The ultrasound energy transmitted to an irrigant will determine if heat is generated by visco-elastic mechanisms (low energy), pseudo-cavitation (medium energy), or true cavitation (high energy). Some dental inserts are not powerful enough to generate cavitation (Ahmad et al 1987a).
For the two techniques investigated, different volumes of liquid were exposed to ultrasound. In the intermittent flush technique 0.5ml of irrigant was activated for 30 seconds. The continuous flow technique activated 15ml of irrigant every 30 seconds. These differences in volume were reflected in the intra-canal temperatures recorded. The greater the volume of irrigant the smaller the temperature rise recorded.

Experiment 12.3.5 demonstrated that the irrigant was heated as it passed through the insert. At the recommended endodontic power setting the temperature of the irrigant rose from 25°C to 27°C. In the continuous irrigant flow experiments the intracanal temperature stabilised at 28°C in the immature canal and 29°C in the mature canal. This represented a rise of 1°C or 2°C as a result of energy absorbed by the irrigant within the root canal. Part of this energy would be absorbed from the root canal wall at 37°C, and part from the ultrasonic vibrations of the file. These low intracanal temperatures, measured near the tip of the file, indicate that the irrigant flowed to the end of the file even when confined by the root canal. The temperature difference between the immature and mature canals could have been as a result of more efficient irrigant circulation within the wider canal, or because of the inability of the apparatus to record temperature differences of less than 1°C.

One factor not considered in this experiment was the heat generated by the contact of the vibrating file with the canal wall during the ultrasonic instrumentation technique. Part of the heat generated would pass into the root canal wall and part would be carried away by the irrigant. These experiments have demonstrated an efficient flow of irrigant along the whole length of the file and this should eliminate the potential for any localised heat build up.

In the intermittent flush technique the temperature was not uniform throughout the irrigating liquid. The intensity of ultrasound is a function of the distance from its source, so the liquid close to the source is heated more than the liquid remote from the source. If the distance between the ultratip and the thermocouple was varied, intracanal temperatures as high as 45°C or as low as 33°C were recorded after 30 seconds of ultrasound. A temperature of 45°C was
recorded when the ultratip touched the wires of the thermocouple. Because of this potential for operator control these experiments give a possible range of intra-canal temperatures rather than an exact temperature for all of the irrigant within the root canal. Immediately after the 1ml flush of irrigant at 25°C the intra-canal temperature was consistently 26°C in the immature root and varied between 31°C and 34°C in the mature tooth. This could mean that the cooling efficiency of the intermittent flush was dependent upon canal diameter, and that a flush with 2ml of irrigant could be necessary to protect against overheating in a mature canal.

At the interface between the liquid irrigant and the solid root canal wall, not all of the ultrasound passes into the dentine. The ability of a sound wave to cross from one medium to another depends on the difference in acoustic impedance between the two media, and the angle at which the sound wave meets the interface (Hussey 1975). A large difference in acoustic impedance and a shallow angle of incidence will increase reflection of the incident wave. The characteristic acoustic impedance for water is 1.4(kg/m²s x 10⁻⁶), and for dentine is 8.0 (kg/m²s x10⁻⁶) (Lees 1971). From these values it can be calculated that less than half of the incident ultrasonic wave can pass across the irrigant /dentine interface. Most of the wave is reflected and remains in the irrigant. The wave that does pass into dentine is refracted, scattered or absorbed by the dentine. During this process mechanical energy of ultrasound is converted into heat energy.

It had been suggested that high temperatures would be recorded inside the root canal, and that heat energy could pass outwards through the root canal wall to the external root surface (Moorer and Wesselink 1982). Under the conditions of this experiment high intracanal temperatures were not recorded, and dentine, a poor conductor of heat, insulated the external root surface from the temperature changes within the root canal. The thicker root canal wall was the more efficient insulator. In the continuous flow technique the external root temperature fell from 37°C to 32°C in both specimens. A stable reading of 32°C was obtained after 30 seconds in the immature tooth and after 60 seconds in the mature tooth. In the intermittent flush technique the cooling effect of 1ml of irrigant was more apparent on the external surface of the
immature root. These experiments demonstrated that increases in temperature at the external root surface lagged behind intra-canal changes. This delay, caused by the slow passage of heat through dentine, would prevent a transient high intra-canal temperature from being transmitted to the external root surface. It would seem that the duration of a temperature change could be as important as the magnitude of that change in determining the temperature recorded at the external root surface. Because of this time-temperature relationship it is recommended that, in the intermittent flush technique, the canal be flushed with 1-2 ml of room temperature irrigant after each 30 seconds of ultrasound. Conversely a continuous flow of low temperature irrigant could induce a significant fall in the external root temperature. The effect of hypothermia on the cells in this area is not known.

This in vitro study was designed for an environment maintained at 37°C so that any cooling effect of the irrigant could be measured. To ensure that only the root surface temperature was measured, the external thermocouple was insulated from the environment with a layer of wax. Under in vivo conditions the magnitude of the temperature changes on the root surface would be buffered by the paradental tissues. These tissues would act as a heat sink and tend to maintain the temperature within a much narrower band.

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CHAPTER 13
SUMMARY AND CONCLUSIONS

13.1 Clinical technique

A technique has been described for the ultrasonic activation of the endodontic irrigant sodium hypochlorite. The clinical impression was that this technique removed most of the debris in the first minute of ultrasonic irrigation.

13.2 Activation time

One minute of ultrasonic irrigation with 3% sodium hypochlorite removed the superficial smear layer. Three minutes of ultrasonic irrigation removed the superficial smear layer and most of the debris plugs from the dentinal tubules. Five minutes of ultrasound removed all debris from instrumented and uninstrumented areas. These results are in agreement with the clinical impression that most of the debris was removed during the first minute of ultrasonic irrigation.

13.3 Sodium hypochlorite concentration

Endodontic irrigation using sodium hypochlorite with up to 4% available chlorine will not remove a smear layer from an instrumented root canal wall. The scrubbing action of ultrasonic waves travelling through water will not mechanically remove a smear layer. Two percent sodium hypochlorite activated by ultrasound will remove a smear layer within three minutes. This experiment would indicate that a synergistic relationship does exist between ultrasound and sodium hypochlorite, and this relationship becomes clinically significant with sodium hypochlorite containing more than 2% available chlorine.

13.4 Immature root canals

Following pulp extirpation, irrigation of an immature root canal with 4% sodium hypochlorite for one minute removed most retained pulpal debris, but had limited effect on the predentine. After three minutes exposure to sodium hypochlorite the coronal predentine was removed.
When the irrigant was activated by a dental ultrasound unit, a clean canal was produced in three minutes. The presence of calcospherites indicated that the full thickness of the root canal wall had been maintained, and that ultrasonic irrigation with 4% sodium hypochlorite had little if any effect on calcified tissues. The soft tissues associated with root end development were not removed by ultrasonic irrigation. Case histories presented would indicate that if any damage is caused in the periapical tissues by the short exposure to sodium hypochlorite or ultrasound, then this damage is better tolerated by these tissues than the damage caused by continuous exposure to the toxins and protein degradation products found in a necrotic root canal. Ultrasonic irrigation with 4% sodium hypochlorite would appear to produce conditions favourable to root end closure using calcium hydroxide paste. There is minimum risk of instrument damage to periapical tissues and no loss of existing or induced calcified tissue.

13.5 Effect of fluorocarbon surfactant

The surface tension of 4% sodium hypochlorite can be reduced from 70 dynes/cm to 27 dynes/cm by the addition of the fluorocarbon surfactant FC99, at 0.1% concentration. This reduction was maintained unchanged over a test period of one month. The concentration of available chlorine decreased by 5% over a one month test period, and by 26% after two months. The tissue solvent capacity of sodium hypochlorite was stable over a two month test period. After ultrasound irrigation using a sodium hypochlorite/0.1% FC99 medium, no crystalline debris or chemical smear was observed using the scanning electron microscope at magnifications up to x4,500.

In vitro experiments will be needed to fully assess the clinical potential of this new irrigant, with special emphasis on the possibility of more conservative root canal instrumentation.

13.6 Heat generation

Heat generated within the root canal did not appear to pose a threat to the paradental tissues when the irrigant was changed every 30 seconds. With a continuous flow of irrigant the temperature of the external root surface actually fell from 37°C to 32°C.
CHAPTER 14

QUESTIONS NEEDING ANSWERS

In 1957, the dental profession was not ready to accept ultrasonic endodontics as presented by Richman. He was too far ahead of his time. Thirty years later, the profession is still not ready for ultrasonic endodontics as it could be practised. An overview of the literature would indicate that we are not carrying out ultrasonic endodontics at all, but merely conventional instrumentation with hand instruments activated by ultrasound. Is the canal round or ovoid or irregular, does it produce a smooth tapered canal, is it faster than sonic or step-back preparation, is there a zip or an elbow? Apart from the retrieval of scrap metal from the root canal, 95% of the articles have been in vitro studies.

It is possible there will be a genuine change in endodontic philosophy. Instrumentation, irrigation and obturation will all need to progress together.

What we need to know is just how little instrumentation is really needed to achieve a canal free from degradable soft tissues. If we knew how ultrasound worked within the root canal we could design one tip for minor canal shaping, and another tip for the activation of an irrigant. We need an ultrasound generator and inserts that have a wide power band to cover the separate needs of instrumentation and irrigation. Manual tuning should be available to permit the efficient and safe use of any length or size of instrument produced by any manufacturer.

Is sodium hypochlorite the best tissue solvent available? Does EDTA fit into the technique? Would an irrigant with low surface tension permit a more conservative approach to root canal enlargement?
How will these clean narrow canals be obturated? The options seem to be:

1) a condensed filling with a smear of sealer,
2) a canal full of sealer with a core, or
3) a canal full of sealer.

Option #1 is our present system and with gutta-percha needs a well instrumented canal. Option #2 would require a sealer paste that would not be lost (dissolve) from the root canal but could be easily removed with a solvent. The core could be of non-stick flexible plastic that could either be pulled out of the set cement if the need arose, or could be drilled out to create post space. Option #3 could require the development of an adhesive biocompatible injectable paste plus an appropriate solvent.

When the answers have been found to all these questions we will have a true ultrasonic endodontic technique. This technique might have little effect on the success rate of a skilled endodontist, but it could help the general practitioner produce quality endodontics.
CHAPTER 15

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APPENDIX 1

FOOTNOTES

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Chapter 5


Chapter 6

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Chapter 11

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Chapter 12

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8. Selkoshca Co., Tokyo, Japan.
## Table 11.1
Average surface tension corrected for temperature (dynes/cm)

<table>
<thead>
<tr>
<th>Time</th>
<th>4%NaOCl</th>
<th>4%NaOCl/0.1%FC99</th>
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<tr>
<td>Start</td>
<td>69.6</td>
<td>27.3</td>
</tr>
<tr>
<td>1 hour</td>
<td>70.2</td>
<td>27.2</td>
</tr>
<tr>
<td>1 day</td>
<td>69.7</td>
<td>24.2</td>
</tr>
<tr>
<td>1 week</td>
<td>71.9</td>
<td>25.6</td>
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<td>1 month</td>
<td>69.7</td>
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## Table 11.2
Available chlorine

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<th>4%NaOCl/0.1%FC99</th>
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<td>3.81</td>
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<td>3.83</td>
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*Table 11.1* Surface tension of 4% NaOCl with or without surfactant

*Table 11.2* Available chlorine of NaOCl with or without surfactant
<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Immature Canine Temperature (°C)</th>
<th>Mature Canine Temperature (°C)</th>
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*Table 12.1*  
Temperature of root canal wall during ultrasonic irrigation with a continuous flow of irrigant
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</table>

Table 12.2: Temperature of root canal wall during ultrasonic irrigation with an intermittent flush of 1ml of irrigant.
APPENDIX 3

FIGURES

Figure 5.1 Photograph of Cavitan insert #PR30 with smooth broach in place.

Figure 6.1 Hand instrumented canal wall showing intact smear layer which obliterated presence of dentinal tubules. x4,500

Figure 6.2 One minute of ultrasonic irrigation removed superficial smear layer. x4,500

Figure 6.3 Three minutes of ultrasonic irrigation removed superficial smear layer and most debris plugs from dentinal tubules. x4,500

Figure 6.4

A. Five minutes of ultrasonic irrigation completely removed both elements of smear layer. Surface now appeared eroded. x4,500

B. Uninstrumented area in apical third of root canal. Note absence of predentine, smear layer, and gross debris. x4,500
Figure 7.1  Hand instrumentation with 4% NaOCl produced a tightly adherent smear layer free from surface soft tissue debris.  x2,000

Figure 7.2  Ultrasonic irrigation with 4% NaOCl produced a smear-free root canal wall.  x2,000

Figure 7.3  Ultrasonic irrigation with 2% NaOCl removed superficial smear layer and most debris plugs.  x2,000

Figure 7.4  Ultrasonic irrigation with 1% NaOCl failed to remove smear layer.  x2,000

Figure 7.5  Ultrasonic irrigation with 0.5% NaOCl failed to remove the smear layer.  x2,000

Figure 7.6  Ultrasonic irrigation with water failed to remove the smear layer or soft tissue debris.  x2,000

Figure 7.7  Hand instrumentation with water produced a heavily smeared root canal wall with debris on the surface.  x2,000
**Figure 8.1**

A. Membrane-like predentine surface after pulp removal with barbed broaches.  
B. Cellular debris on predentine surface.  

*$x2,000$

**Figure 8.2**

Uninstrumented root canal wall after one minute irrigation with 4% NaOCl  
A. Coronal area.  
B. Apical area.  

*$x2,000$

**Figure 8.3**

Three minutes irrigation with 4% NaOCl  
A. Clean coronal root surface.  
B. Connective tissue fibres on apical surface.  

*$x2,000$
**Figure 8.4**  One minute ultrasonic irrigation with 4% NaOCl

A. Mature calcaspherites in canal area.  \( \times 2,000 \)
B. Connective tissue fibres in apical area.  \( \times 2,000 \)
C. Immature calcaspherites in apical area.  \( \times 2,000 \)

**Figure 8.5**  Three minutes ultrasonic irrigation with 4% NaOCl

A. Mature calcaspherites in coronal area.  \( \times 2,000 \)
B. Immature calcaspherites in apical area.  \( \times 2,000 \)
C. Soft tissue of developing apex.  \( \times 2,000 \)
Figure 9.1 Replanted, avulsed tooth with severe root resorption.

Figure 9.2 Resorbed tooth, 19 months after root filling showing loss of sealer.

Figure 9.2 Resorbed tooth, 14 months after retreatment.
Figure 10.1  Immature tooth on day of trauma.

Figure 10.2  Immature tooth four years after root end closure and canal obturation.

Figure 10.3  Retreatment diagnostic radiograph.

Figure 10.4  Retreated tooth, 12 months after canal obturation.
Figure 11.1 Scanning electron photomicrograph of smeared root canal wall and debris-free fin. x35.
Figure 12.1 Tooth and attached thermocouples suspended in air-space over heated water bath.
Figure 12.2  Position of thermocouples for immature tooth.