CHAPTER FIVE

Techniques for Assessing the Seal of Root fillings

5.1 Techniques used to assess the seal of the root filling

The sealing ability of different root canal filling materials has been investigated by the use of radioisotope, dye penetration and electrochemical techniques. The quality of the apical seal has been investigated by the use of microscopes to evaluate the adaptation of the filling material to the root canal.

The dye penetration and radioisotope techniques are the most commonly used (Barry and Fried, 1975; Brown et al, 1979; Delivanis and Chapman, 1982). Despite their wide use and acceptance, they do have limitations. The techniques must be precisely controlled to eliminate any variables which could affect the results (Delivanis and Chapman 1982). These two techniques are discussed in sections 5.1.1 and 5.1.2 respectively.

The electrochemical leakage technique is not commonly used and has been reported in only a small number of studies (Jacobson and Von Fraunhofer 1976, Delivanis and Chapman 1982, Mattison and Von Fraunhofer 1983, Osins et.al. 1983, Cohen et al 1985, Lim and Tidmarsh 1986). This technique is discussed in section 5.1.3.

The evaluation of the adaptation of the root filling has been investigated using both light and scanning electron microscopes (Goldman, 1975; Torabinejab et al, 1978; Egushi et al, 1985). This technique is discussed in section 5.1.4.

5.1.1 Radioisotopes-autoradiography

Autoradiography is based on the fact that an alpha or beta particle can change the energy state of a photographic emulsion in a way which is qualitatively similar to the action of light. Thus the arrival of a beta particle on the AgBr crystals of the emulsion produces a latent image of its path, which may be reproduced by conventional developing procedures (Matloff et al, 1982).

The factors that affect the resolution of an autoradiograph are: 1) choice of isotope, 2) the distance between source and emulsion, 3) lengths of exposure of the film (Delivanis and Chapman, 1982).

Isotopes which can be used include ^{45}Ca as $CaCl_2$, ^{33}S as Na_2SO_4, ^{32}P as Na_3PO_4, ^{22}Na as NaCl, ^{86}Rb as RbCl and 14C-urea.

The technique for radioisotope leakage varies between studies, but it usually involves the immersion of root-filled teeth in an aqueous solution of isotope for a certain period of time e.g. 48 hours. After immersion, each tooth sample is rinsed thoroughly and sectioned vertically and placed on the emulsion side of a dental X-ray film to expose the film, which is then developed.

The studies that have used autoradiography to assess the seal of root fillings include: Dow and Ingle (1955); Marshall and Massler (1961); Kapsimalis and Evans (1966); Higginbotham (1967); Holland et al (1974); Yee et al (1975); Younis and Hembree (1976); Clark and an del Rio (1977); Moreno (1977); Yates and Hembree (1980); Allison et al (1981); Benner et al (1981); Chaisrisookporn and Rabinowitz (1982); Delivanis and Chapman (1982); Matloff et al (1982); Czonstkowsky et al (1985); Fuss et al (1985); Jacobsen et al (1987).

5.1.2 Dye Penetration

The use of organic dyes is the oldest method in the study of microleakage around restorations and represents a simple and inexpensive technique (Delivanis and Chapman 1982).

Many dyes have been used including, indian ink (Evans and Simon 1986), silver stain (Hovland and Dumsha 1985), butyric acid (Kersten et al 1988), brilliant green (Tagger et al 1984), Eosin dye (Kerekes and Rowe 1982), fluorescent dye (Skinner and Himel 1988), Rodamina solution (Rothier et al 1987) and methylene blue (Ishley and ElDeeb 1983, ElDeeb et al 1985).

Fluorescent dyes were found to be particularly useful as tracers (Going, 1972; Skinner and Himel, 1988) because they were detectable in dilute concentration, were easy to photograph and, according to one study (Going 1972), permitted reproducible results.

The most common dye substance used to assess apical leakage has been a two per cent aqueous solution of methylene blue (Delivanis and Chapman, 1982; Zakariasen and Stadem, 1982; Ishley and ElDeeb, 1983; ElDeed et al, 1985; Mann and McWalter, 1987). Other studies assessing apical seal have used different concentrations of dye.

Michanowicz and Czostkowsky (1984) and Zmener (1987), used a five per cent methylene blue solution, Kersten et al (1986) used a 0.1 per cent solution, while Beaty et al (1988) used a one per cent dye solution.

The technique used in dye penetration is relatively simple (Beaty et al, 1985; Kersten et al, 1986b). It involves covering the root surface with some waterproof medium, usually nail varnish, but leaving the apical foramen exposed. The apical portion of the roots is immersed in a 2% methylene blue solution and left standing for 48 hours (Delivanis and Chapman, 1982; Matloff et al, 1982; Ishley and ElDeeb, 1983; ElDeeb, 1985; ElDeeb et al, 1985; Zidan et al, 1987). Other studies have immersed the roots for a longer period of time. Mann and McWalter (1987) immersed the roots for seven days, Zakariasen and Stadem (1982) for two weeks, while Johnson and Zakariasen (1983) immersed the roots for 30 days.

The following studies have used the dye penetration technique to assess apical leakage: Messing (1970); Grieve (1972); Grieve (1973); Saunders and Dooley (1974); Barry et al (1975); Barry and Fried (1975); Fogel (1977); Curson and Kirk (1978); Ford (1979); Russin et al (1980); Douglas and Zakariasen (1981); Delivanis and Chapman (1982); Harris et al (1982); Kerekes and Rowe (1982); Zakariasen and Stadem (1982); Ishley and ElDeeb (1983); Johnson and Zakariasen (1983); O'Neill et al (1983); Beatty and Zakariasen (1984); Michanowicz and Czonstkowsky (1984); Tagger et al (1984); ElDeeb (1985); ElDeeb etal (1985); Hovland and Dumsha (1985); Evans and Simons (1986); Kersten et al a&b (1986); Beatty (1987); Mann and McWalter (1987); Beatty et al (1988).

5.1.3 Electrochemical leakage

The electrochemical leakage technique for measuring microleakage in root filled teeth was first described by Jacobson and von Fraunhofer (1976). They used a mild steel rod as the anode and a stainless steel rod as the cathode. The electrolyte solution was 1% potassium chloride.

"The underlying principle of this technique is that a metal, such as mild steel, corrodes when in contact with a corrosive agent, such as potassium chloride solution. If a galvanic cell is created by coupling the mild steel to a more electropositive metal, such as stainless steel, the corrosion of the mild steel is accelerated and the current flowing between the two metals can be measured by external means, namely, zero-resistance ammetry" (Jacobson and von Fraunhofer, 1976).

In the method reported by Jacobson and von Fraunhofer (1976) "the mild steel rod is protected from exposure to the chloride solution (and hence is protected from corrosion) by enclosing it in the endodontically-treated tooth. Corrosion will occur only when the chloride solution contacts the mild steel rod, that is, when leakage has occurred and a continuous electrolytic pathway has become established. At this point a current will flow between the mild steel and the stainless steel."

The current can be calculated according to Ohm's law, $V=IR$, where V is the potential difference accross a standard resistance of 10,000 ohms, I is the current in microamperes (uA) and R is the 10,000 ohms standard resistance.

Since Jacobson and von Fraunhofer (1976) reported the electrochemical leakage experiment, other researchers have modified the technique. Use of a steel anode was discontinued and a copper anode was substituted (Delivanis and Chapman 1982, Mattison and von Fraunhofer 1983, Lim and Tidmarsh 1986). There was no reason given by any of the authors for the substitution to a copper anode. One study (Osins et al 1983) used a silver alloy anode and a pure silver cathode which "allows for more accurate measurement of leakage."

The electrolyte solution has generally not been modified from potassium chloride (Delivanis and Chapman 1982, Mattison and von Fraunhofer 1983, Lim and Tidmarsh 1986). Osins et al (1983) modified the experiment by using sodium chloride as an electrolyte because "it appeared to dissociate better than potassium chloride in solution."

The external resistance of 10,000 ohms has been modified to 100 ohms so that the leakage values were measured in milliamperes rather than microamperes (Lim and Tidmarsh 1986).

5.1.4 Evaluation of the quality of adaptation of the root filling

The three techniques already discussed for assessing the seal of root fillings involve the use of quantitative data for direct testing of leakage.

The technique, which evaluates the quality of adaptation and therefore the expected seal of the root filling, provides descriptive information concerning uniformity, density and adaptation of materials used in the radicular space (Goerig and Seymour, 1974; Wollard et al 1976; Egushi et al 1985). Most studies have used either radiography (Larder et al, 1976; Brothman, 1981; Beyer-Olsen et al, 1983; Kersten et al, 1986), light microscope (Goerig and Seymour,1974; Goldman, 1975; Larder et al, 1976; Brotham, 1981; Egushi et al, 1985; Peters, 1986; Beer et al, 1987) or a scanning electron microscope (Wollard et al, 1976; Coviello et al, 1977; Torabinejab et al, 1978) to assess the adaptation of the filling material to the root canal wall.

The quality of the filling material is assessed radiographically for the presence of voids within the filling material or between the filling material and the root canal wall (Beyer-Olsen et al, 1983; Kersten et al, 1986). The density of the root filling can be asssessed by using a radiograph with standard exposure time (Brothman, 1981; Beyer-Olsen et al, 1983).

Three basic techniques have been used to evaluate the adaptation of the filling material to the root canal wall. One technique involves dissolving away the tooth structure with nitric acid (Larder et al, 1976; Brothman 1981), another technique uses an artificial root canal (Wong et al, 1981) and the third technique involves horizontal sections of the root canal (Egushi et al, 1985; Peters, 1986; Beer et al, 1987). A more detailed discussion on the preparation and sectioning of the root canals is found in section 5.1.5.

5.1.5 Preparation and sectioning of the teeth for evaluating leakage.

Radioisotope Penetration

The use of autoradiography has been discussed in section 5.1.1. The teeth are immersed in a radioactive solution for a fixed period of time. The roots are then washed and sectioned longitudinally by either wet grinding on a metallurgical wheel (Delivanis and Chapman, 1982), by using a separating disc (Matloff et al, 1982) or by grinding the buccal and lingual surfaces of the root with a carborundum disc and then splitting the tooth longitudinally with an elevator (Moreno, 1977).

One piece of the sectioned roots, usually the piece not containing the gutta percha, is placed against the emulsion side of a radiograph for a period of time, such as five hours (Moreno, 1977), or 48 hours (Delivanis and Chapman, 1982). The radiograph is then developed to evaluate the ammount of isotope penetration.

Dye Penetration

The dye penetration technique has been discussed in detail in section 5.1.2. The preparation and sectioning of teeth to evaluate the ammount of dye penetration will be discussed in this section.

There are four methods which have been used by investigators to evaluate the degree of dye penetration. Tagger et al (1983) and Tagger et al (1984), used 11 per cent nitric acid to demineralize roots which had been immersed in one per cent Procion green dye for four days. The roots were examined under stereomicroscope to evaluate the degree of linear dye penetration.

Another method to evaluate the degree of dye penetration measures the volume of dye leakage and is known as the "dye recovery method" developed by Zakariasen et al (1981).

The dye recovery method involves the decalcification of the roots in a high concentration of nitric acid (greater than 30 per cent) and then, by using spectrophotometric readings, the volume of dye can be calculated. The following studies have used the dye recovery method to assess apical seal: Douglas and Zakariasen, 1981; Zakariasen et al, 1981; Ishley and ElDeeb, 1983; Johnson and Zakariasen, 1983; ElDeeb et al, 1985.

The third method used to assess dye penetration involves sectioning the root transversely at different levels along the root canal. The technique for sectioning roots and the levels of sectioning varies between studies. Kerekes and Rowe (1982), made cross-sectional cuts at one millimetre intervals, using a thin diamond disc. The pieces were mounted on glass slides with clear glue and examined with a dissecting microscope. Kersten et al (1986 a) sectioned teeth at one millimetre intervals using a diamond bladed sectioning machine and mounted on glass slides. Mann and McWalter (1987) made horizontal cuts at one millimetre intervals using a diamond wafering blade in a low speed saw under continuous water lubrication at 90 degrees to the long axis of tooth and examined under the stereomicroscope. Santini (1987) embedded the roots in clear methyl methacrylate resin and ground transversely on a grinding machine using discs with water spray. The ground surface of the root was examined at 0.5, 1.0, 1.5, 2, 2.5, 3, 3.5, 4, and 5 millimetres from the apex for the presence or absence of dye. Skinner and Himel (1987) made cross-sectional cuts at 1, 3, 5, and 7 millimetres from the apex and the presence or absence of dye was evaluated using a dissecting microscope. The following studies have used horizontal root sections to assess dye penetration: Kerekes and Rowe, 1982; Beyer-Olsen et al, 1983; Kersten et al, 1986 a&b; Mann and McWalter, 1987; Santini, 1987; Skinner and Himel, 1987.

The fourth method of assessing dye penetration involves splitting the root longitudinally. Delivanis and Chapman (1982) used a crosscut fissure bur in a high speed handpiece without water to section the roots longitudinally. Matloff et al (1982) notched the roots longitudinally with a separating disc and the final sectioning was accomplished by cracking the roots with an end-cutting wire cutter. Zakariasen and Stadem (1982) used a separating disc to groove the roots on the buccal and lingual surface and then force was applied in the groove to split the root longitudinally. Zidan et al (1987) used a diamond disc to prepare two longitudinal grooves on opposite surfaces of the root and care was taken not to penetrate the root canal space. A straight elevator was inserted into one groove and slightly rotated to split the root through the canal.

5.2 A comparison of different techniques for assessing the seal

5.2.1 Evaluation of the influence of the type of leakage test

Matloff et al (1982) compared the use of three different isotopes and methylene blue as indicators of leakage in root canals obturated with gutta percha and sealer. They found that methylene blue could penetrate a greater distance along the root canal fillings than the isotopes, making dye penetration a more valuable test. In contrast, Ishley and ElDeeb (1983) suggested that dyes could penetrate through dentine, perpendicular to the direction of the dentinal tubules, making dye penetration useless as a leakage test for root canal fillings, while Kersten et al (1986a) found that teeth, used as controls with cut dentine and a closed apex, showed no sign of transverse leakage through dentine. Zakariasen and Stadem (1982) found that two teeth could show similar distances of leakage, while exhibiting different densities of dye penetration. These variations in patterns of apical leakage indicate that measurements of linear dye penetration may not correlate highly with the actual volumes of fluid leakage. A technique for determining volumetric leakage was reported by Douglas and Zakariasen (1981).

Autoradiography with the use of isotopes is expensive and there is the associated health hazard involved with the use of the materials (Moreno, 1977; Delivanis and Chapman, 1982). Both autoradiography and dye penetration techniques are leak/non-leak methods and do not permit monitoring of the specimens on a continuous basis (Delivanis and Chapman, 1982).

The advantage of the electrochemical technique over autoradiography and dye penetration methods for testing leakage, is that it can be monitored continuously throughout the test period. Both the number of teeth leaking and the degree of leakage can be determined (Mattison and von Fraunhofer, 1983). The magnitude of the leakage current is directly proportional to the degree of leakage or diffusion of ions.

The testing of the sealing ability of root filling materials by leakage is a valuable method. It should be remembered that, when a root filling allows penetration by labelled calcium ions, methylene blue or chloride ions which are not more than one nanometre (nm) in diameter (Stryer, 1981), it does not necessarily imply that the root filling will allow bacterial products (10-30 nm in diameter) to seep into the periapex (Kersten et al, 1986a).

5.2.2 The influence of the method of tooth sectioning on the assessed leakage

To assess the degree of leakage, teeth are sectioned either transversely or longitudinally.

The sectioning of roots transversely enables the operator to evaluate at what level dye penetration had occurred (linear dye penetration) and also to evaluate whether leakage had occurred along the canal/root filling interface or within the body of the root filling (Kersten et al, 1986a; Mann and McWalter, 1987). However, transverse sectioning produces a distorted root filling because the cutting blade heats up and plasticizes the gutta percha (Kerekes and Rowe, 1982; Beyer-Olsen et al, 1983).

Longitudinal sectioning by grooving the root and splitting it by force enables the root filling to remain intact and undisturbed against one wall of the root canal (Beatty, 1987; Rothier et al, 1987). To evaluate the degree of dye penetration, the gutta percha is removed and the linear penetration of the dye along each wall is measured (Zidan et al, 1987).

The longitudinal sectioning of roots has been accepted more widely than transverse sections (Delivanis and Chapman, 1982; Zakariasen and Stadem, 1982; Ishley and ElDeeb, 1983; Michanowicz and Czonstkowsky, 1984; ElDeeb, 1985; Zmener, 1987).

5.3 A comparison of the sealing ability of different root filling techniques

The lateral condensation technique, has generally been found to be superior to other obturation techniques (Zakariasen and Stadem, 1982; O'Neil et al, 1983; Beatty, 1987; Gee, 1987; Mann and McWalter, 1987).

The McSpadden technique became popular in the early eighties and it was shown by some studies (Kerekes and Rowe, 1982; ElDeeb et al, 1985) that teeth obturated by McSpadden compaction exhibited better sealing ability than teeth obturated by lateral condensation. The success of the McSpadden technique was dependent on the use of sealer (Ishley and ElDeeb, 1983).

Moreno, (1977) found that teeth obturated by ultrasonically softened gutta percha and sealer exhibited less leakage than teeth obturated by lateral condensation and sealer. The difference was not statistically significant and the sample size of the study was small, making the significance of the results questionable.

The majority of the studies have found no significant differences in the sealing ability of different root filling techniques. Larder et al (1976) found no difference in leakage between teeth filled by lateral condensation, vertical condensation and Kloroperka techniques. Yee et al (1977) found no difference in leakage between teeth filled by lateral condensation, vertical condensation and injection thermoplasticized techniques. Benner et al (1981) found no difference in leakage between teeth filled by lateral condensation, vertical condensation and McSpadden compaction. Ishley and ElDeeb (1983) found no difference in leakage between teeth filled by lateral condensation and McSpadden compaction. Czonstkowsky et al (1985) found no difference in leakage between teeth filled by lateral condensation and Ultrafil thermoplasticized gutta percha.

While the dye penetration and radioisotope test methods have appeared numerous times in the literature, the electrochemical leakage method has been used in only a limited number of studies: (Jacobson and von Fraunhofer, 1976; Delivanis and Chapman, 1982; Mattison and von Fraunhofer, 1983; Osins et al, 1983; Cohen et al, 1985; Lim and Tidmarsh, 1986). There is no known study which uses the electrochemical leakage method to assess the sealing properties of different root filling techniques. In the present study therefore, the electrochemical leakage method was used to evaluate the sealing properties of four different root filling techniques. These results were compared with linear dye penetration and radiographic adaptation results.

PART TWO

ORIGINAL RESEARCH

CHAPTER 6

EXPERIMENTAL METHOD

6.1 AIMS OF THE RESEARCH

1) To test the apical seal of four root canal obturation techniques by assessing both electrochemical leakage and dye penetration.

2) To relate the quality of the apical seal to the quality of the radiographic adaptation of the gutta percha to the root canal.

Due to results obtained during the experiment, it was necessary to look at the following.

3) Factors influencing the amount of electrochemical leakage.

4) The effect that previous testing for electrochemical leakage has on linear dye penetration.

5) The difference in leakage between root filled teeth with open apices and with closed apices.

6.2 PREPARATION OF THE TEETH

6.2.1 Tooth selection

Sixty human teeth, comprising maxillary and mandibular incisors, canines and lower premolars, were collected from the Oral Surgery Department of Westmead Hospital. The clinicians collecting the teeth were given the following specifications: To save single-rooted teeth with or without an intact crown and without any external resorption, deep root caries or calcified canals. The teeth were stored in ten per cent Formalin saline.

The teeth were then radiographed from a buccal and proximal direction, with 0.25 second exposure time, to determine their suitability. Teeth with badly calcified or tortuous canals were discarded. Teeth having slight apical curvatures (up to 20°) and teeth with immature apices and mature apices were accepted.

6.2.2 Storage

Teeth were extracted and placed in a specimen jar containing ten per cent Formalin saline for storage. Formalin fixes tissue and prevents its degeneration. The teeth were then stored in one per cent sodium hypochlorite solution for 48 hours prior to use to dissolve the periodontal ligament. When not being instrumented or obturated, teeth were subsequently stored in normal saline, 0.9 % sodium chloride.

6.2.3 Preparation of the root surface

After dissolution of the periodontal ligament, a round diamond bur was used to engrave a number on the root surface of each tooth, to assist with identification.

6.2.4 Endodontic preparation of the teeth

The length of each tooth was measured using a millimetre rule.

Access cavities were prepared in each tooth, and a size 15 K file was used to determine the working length. The file was inserted about one millimeter short of the pre-measured length of the tooth and a radiograph was taken to check that the file was at the correct length.

Root Canal Instrumentation

Preparation of the root canals involved a standardized technique, similar to that described by Ingle (1961). The root canal was enlarged by three sizes from the first instrument which bound at the working length. A step-back technique was employed by using progressively larger K files at one millimetre intervals short of the working length until three millimetres short of the apical seat. Hedstroem files were then used 3 mm short of the working length to ensure adequate flaring of the root canal. Recapitulation with the working length file was used to ensure that no loss of length had occurred.

During the mechanical preparation and after using each file, 1% sodium hypochlorite solution was used to irrigate the canal.

Once the teeth were mechanically prepared, a number 10 K file was pushed 2 mm through the apex to ensure a patent foramen. All the root surface except the apical 1 mm was covered with two coats of nail varnish.

The instrumentation of the teeth used for the Ultrafil* obturation was carried out according to the manufacturer's directions. A number 20 K file was used at the working length, and a step back technique to 3 mm short of the working length (with a 35 K file) was carried out. The canal was then flared so that a size 70 K file could reach to within 6 mm from the apical stop.

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* Ultrafil injection system (Hygenic Corp. Akron OH. USA)

The aim of the instrumentation was to create an apical stop which could resist firm pressure from a number 15 K file (George et al, 1987).

6.3 OBTURATION OF THE ROOT CANAL

6.3.1 Pilot study teeth

Four teeth were used as controls. These teeth were instrumented but not root filled. Two teeth had the root surface including the apical foramen covered with two layers of nail varnish and were used as negative controls. The other two teeth served as positive controls, allowing maximum current through the apical foramen.

A pilot study was run for fifteen days to determine the range of values which could be expected during the experiment. The pilot study was run with eight teeth: two positive controls, two negative controls, two teeth obturated by the McSpadden technique, and two teeth obturated by lateral condensation.

6.3.2 Lateral Condensation

After the teeth were mechanically prepared, a trial gutta-percha point, the same size as the last K file used, was fitted at the working length and checked for "tug-back", ensuring a good apical seat. A trial point radiograph was taken to ensure good fit and correct length of the master gutta-percha.

The canal was dried using paper points, and ProcoSol sealer was used to coat the walls of the root canal using a K file which was loose in the canal. The file was turned anti-clockwise as it was withdrawn out of the root canal.

The master gutta-percha point was coated with ProcoSol sealer and inserted to the apical seat. A size 20 finger spreader with a sharpened tip was used to create space for accessory extra fine gutta-percha points*. Every third gutta-percha point was coated with sealer.

Once condensation of the root canal was complete, the gutta-percha was heated out to within 6 mm of the apex. After heating out, the apical mass of gutta-percha was vertically condensed with a plugger to ensure a good seal at the apex. Radiographs were taken from the buccal and proximal to assess the quality of obturation.

6.3.3 McSpadden Compaction

Obturation was performed according to the manufacturer's instructions. A master gutta-percha point was fitted at the working length and tested for "tug-back". A radiograph was taken to ensure a good fit. After the canal was dried with paper points it was coated with Procosol sealer using a K file. A McSpadden compactor (Fig. 6.1), which reached to within 3 mm from the working length without bending, was selected. A rubber stopper was used to indicate the depth of insertion.

The master gutta-percha point was coated with sealer and seated to the working length. The compactor was used in a slow speed contra-angle handpiece, running at full speed (10,000 r.p.m). The compactor was advanced about 6 mm into the root canal to heat up the gutta-percha until it became "fluid-soft". The compactor was then advanced in one fluent movement to the predetermined length and withdrawn whilst still rotating. The gutta-percha was heated out to within 6 mm of the apex.

6.3.4 Ultrasonic Activated Condensation - Enac

This technique is a combination of both lateral and thermomechanical condensation and has been described by Moreno (1977).

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* Progress gutta-percha points (Rudolph Gunz Sydney Australia)

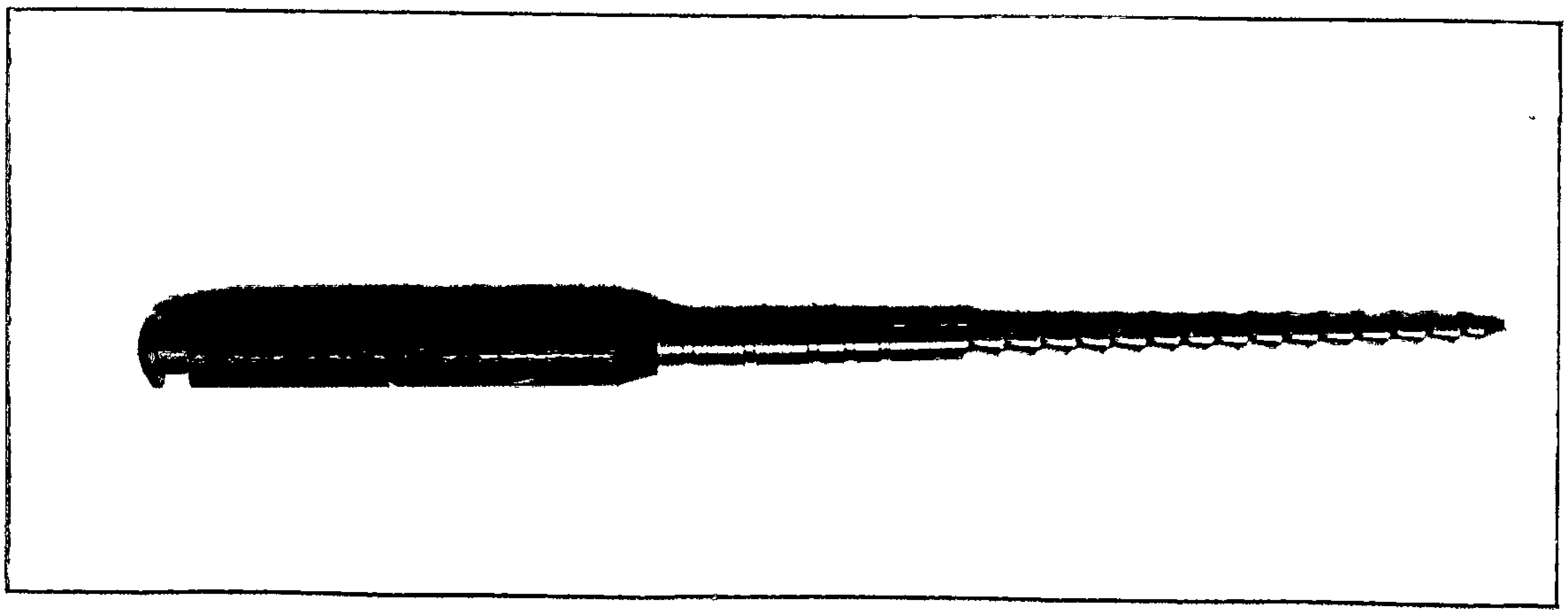

Figure 6.1 McSpadden Compactor

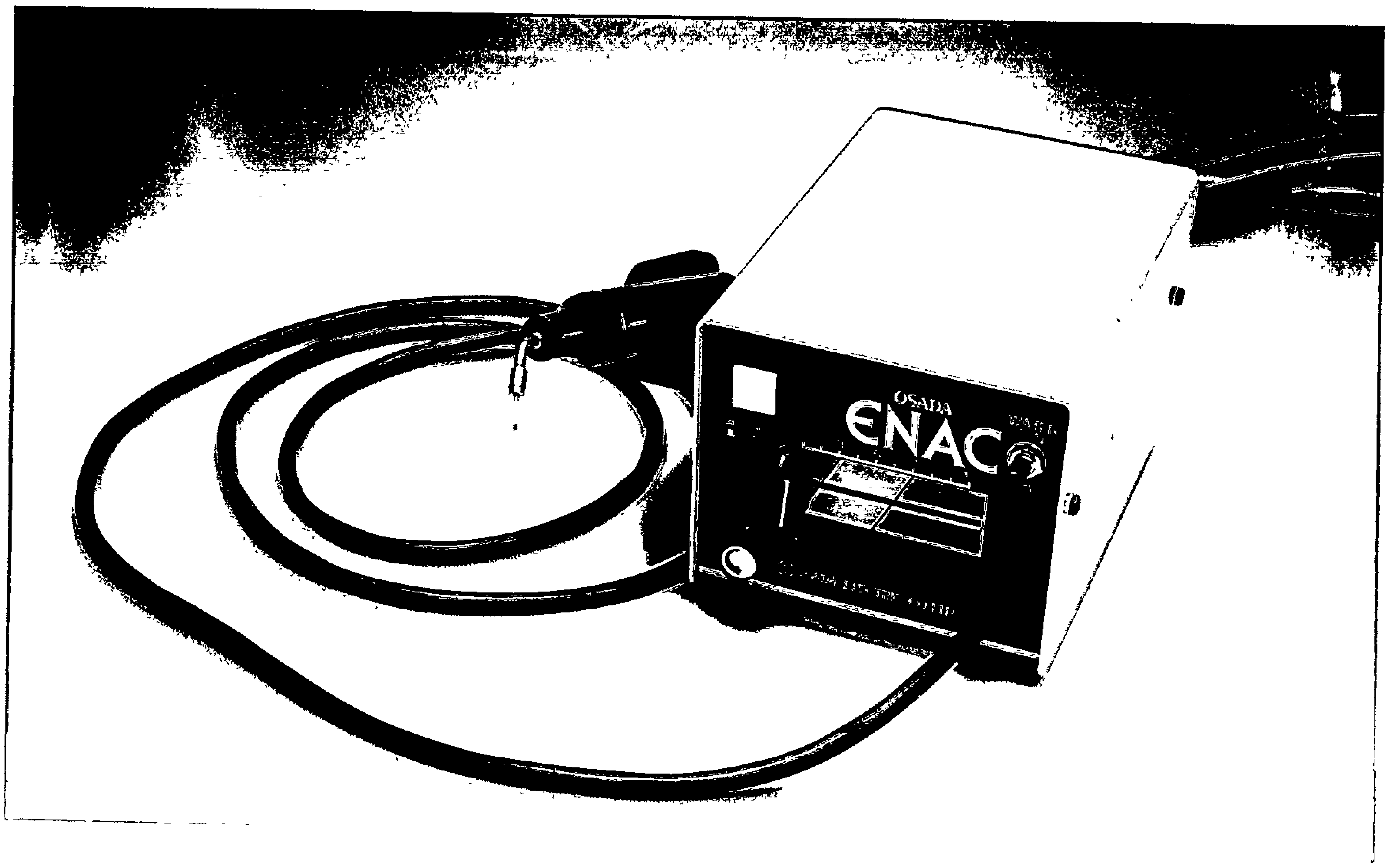

Figure 6.2 The Enac Ultrasonic Device

Moreno (1977) used a K-file which was cut at the shaft and then inserted in an ultrasonic handpiece. In the present study, a number 20 finger spreader was used in which the handle was cut off and its shaft was screwed on to the Enac* handpiece (Fig. 6.2).

A master gutta-percha point was fitted at the working length to ensure tug-back", and a radiograph taken. The canal was coated with ProcoSol sealer using a K file. The master gutta-percha point was rolled in the sealer and seated at the working length.

The spreader was then inserted to within 2 mm of the working length and ultrasonically activated. The ultrasonic vibration should plasticize the gutta-percha sufficiently to allow it to adapt better to the canal walls. Fine accessory gutta-percha points were added to the canal and a size 20 finger spreader was used to condense the mass laterally. After every second accessory point the Enac spreader was used to mould the points together into a more homogeneous mass.

Care was taken to keep the spreader ultrasonically activated throughout the time it was in contact with the gutta-percha. The reason for this was that if the spreader was withdrawn from the canal unactivated, it might have adhered to the gutta-percha mass so that the apical seal would be broken.

The gutta-percha was then heated out to within 6 mm of the working length.

6.3.5 Ultrafil Injection System

The Ultrafil injection system does not use a master gutta-percha point. The gutta-percha is injected in a plastic, softened

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* Enac Ultrasonic Device (Osada Electrical Co. Ltd. Japan)

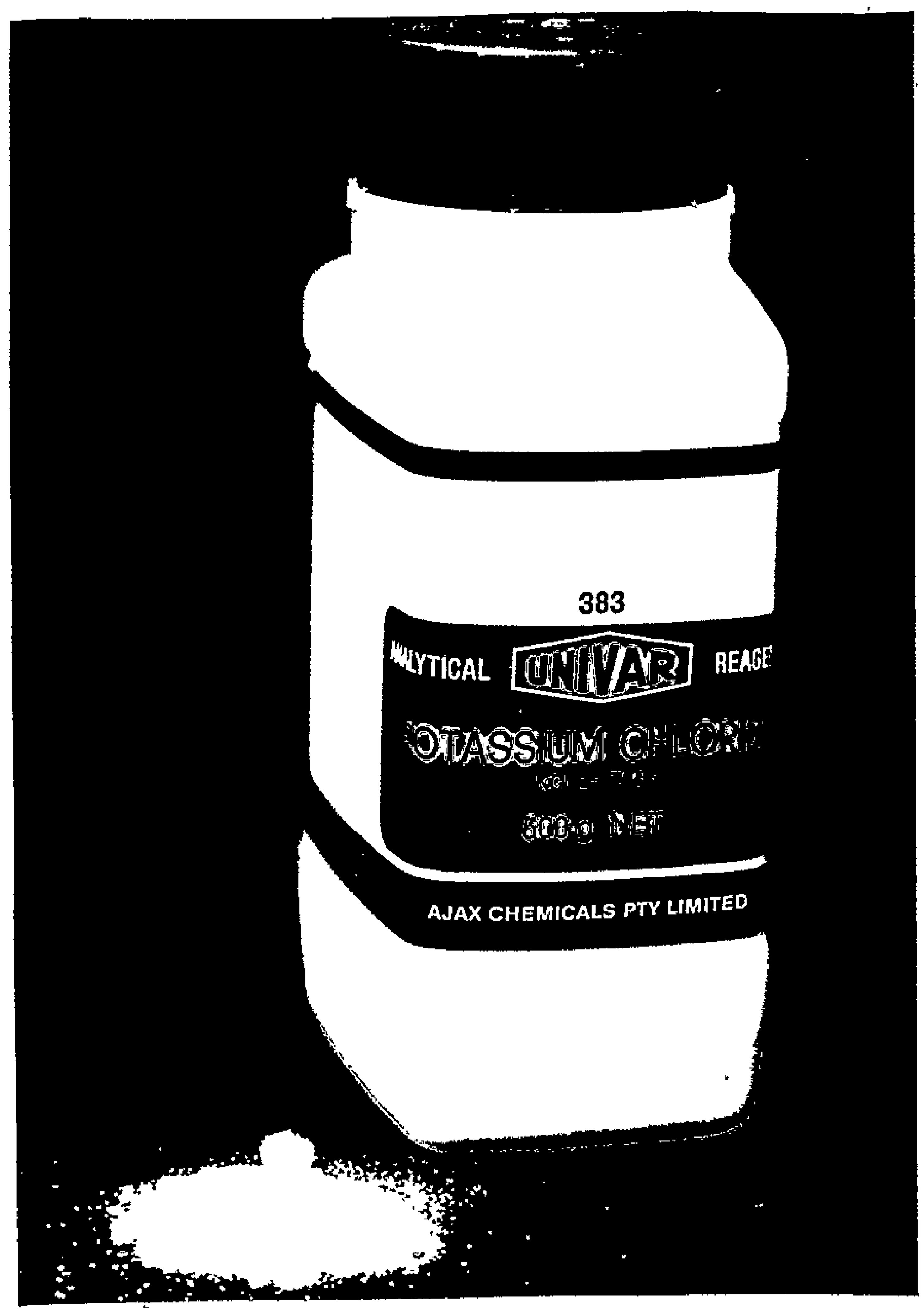

Figure 6.3 The Potassium Chloride solution

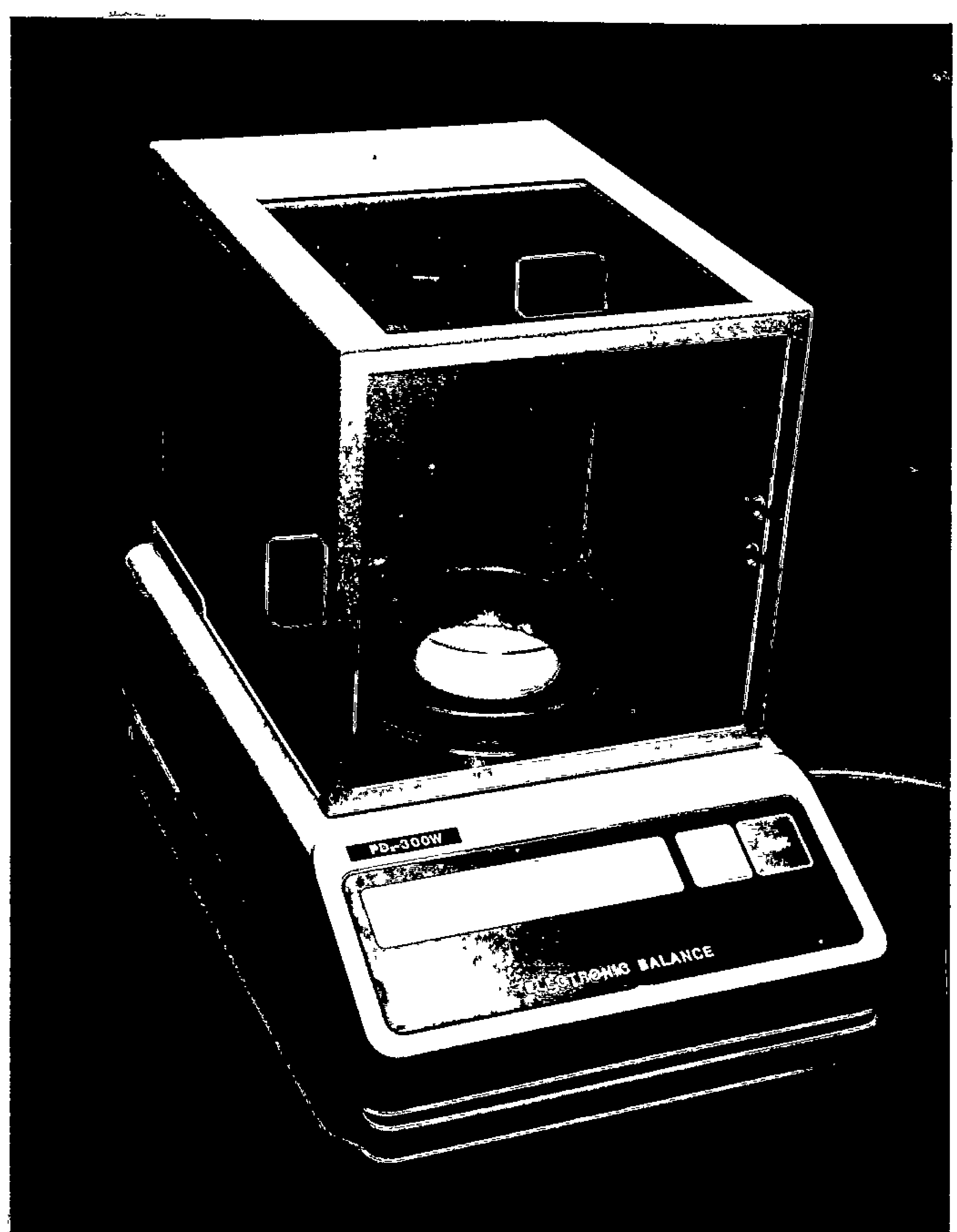

Figure 6.4 The electronic balance used to weigh the potassium chloride

state, from a delivery gun (Fig. 4.4) through a 22 gauge needle which is attached to a disposable carpule.

The gutta-percha is heated in a portable heater (Fig. 4.5) to approximately seventy degrees centigrade.

For this technique it is necessary to develop a sound apical stop during biomechanical preparation of the root canal, to prevent gross over-extension of the gutta-percha. The size of the apical stop should not allow a number 15 K file through the foramen (George et al, 1987). As was mentioned earlier, the canal has to be prepared to at least a size 70 instrument 6 mm short of the working length, so as to allow placement of the needle. The gutta-percha was heated out to within 6 mm of the apex.

Fifteen teeth were used for each technique. After the teeth were obturated they were radiographed to assess the quality of the root fillings and then stored in 100% relative humidity at thirty seven degrees centigrade for twenty four hours, to allow the sealer to set.

All the root surfaces except the apical 1 mm were covered with two coats of nail varnish.

6.4 ASSESSMENT OF THE APICAL SEAL:

METHOD-A - ELECTROCHEMICAL LEAKAGE (ECL)

The teeth were tested for electrochemical leakage (ECL) over a thirty day period after the method used by Jacobson and von Fraunhofer (1976). Fifteen teeth were tested at any time. A plastic tub was used to hold the electrolyte solution of one per cent potassium chloride (KCl) (Fig. 6.3). The KCl was weighed carefully in an electronic balance (Fig. 6.4) and dissolved in distilled water at room temperature. An adjustable transformer was used to convert

240 volts alternating current (AC) into direct current (DC). The voltage in this experiment was kept constant at 20 volts DC.

One stainless steel electrode was used as the cathode and fifteen copper electrodes were used as anodes. The copper electrodes were sharpened to enable insertion into the root canal and contact with the gutta-percha. The teeth were attached on the copper electrodes with sticky wax*. Radiographs were taken of the teeth to ensure that the copper electrodes were contacting the gutta-percha.

The electrical circuit was arranged in such a way that the current was not interrupted when the readings were being recorded.

Figure 6.5 shows a schematic diagram of the test cell used for the electrochemical leakage experiment. Figure 6.6 illustrates the electrical circuit, the electrolyte tub, the electrodes, the Multimeter, and the transformer.

Leakage was measured in terms of the amount of current which flowed through the root canal. The current flow was measured in microamps (uA), with daily readings from a 3.5 digit Multimeter (Fig. 6.6).

6.5 ASSESSMENT OF THE APICAL SEAL: METHOD-B - LINEAR DYE PENETRATION (LDP)

After the completion of the ECL measurements, the apical thirds of the roots were immersed in 2% methylene blue dye for forty eight hours. When the teeth were removed from the dye they were washed under running tap water to remove excess dye and then allowed to dry.

The crowns of the teeth were sectioned horizontally at the cemento-enamel junction with a tungsten carbide bur in an air turbine

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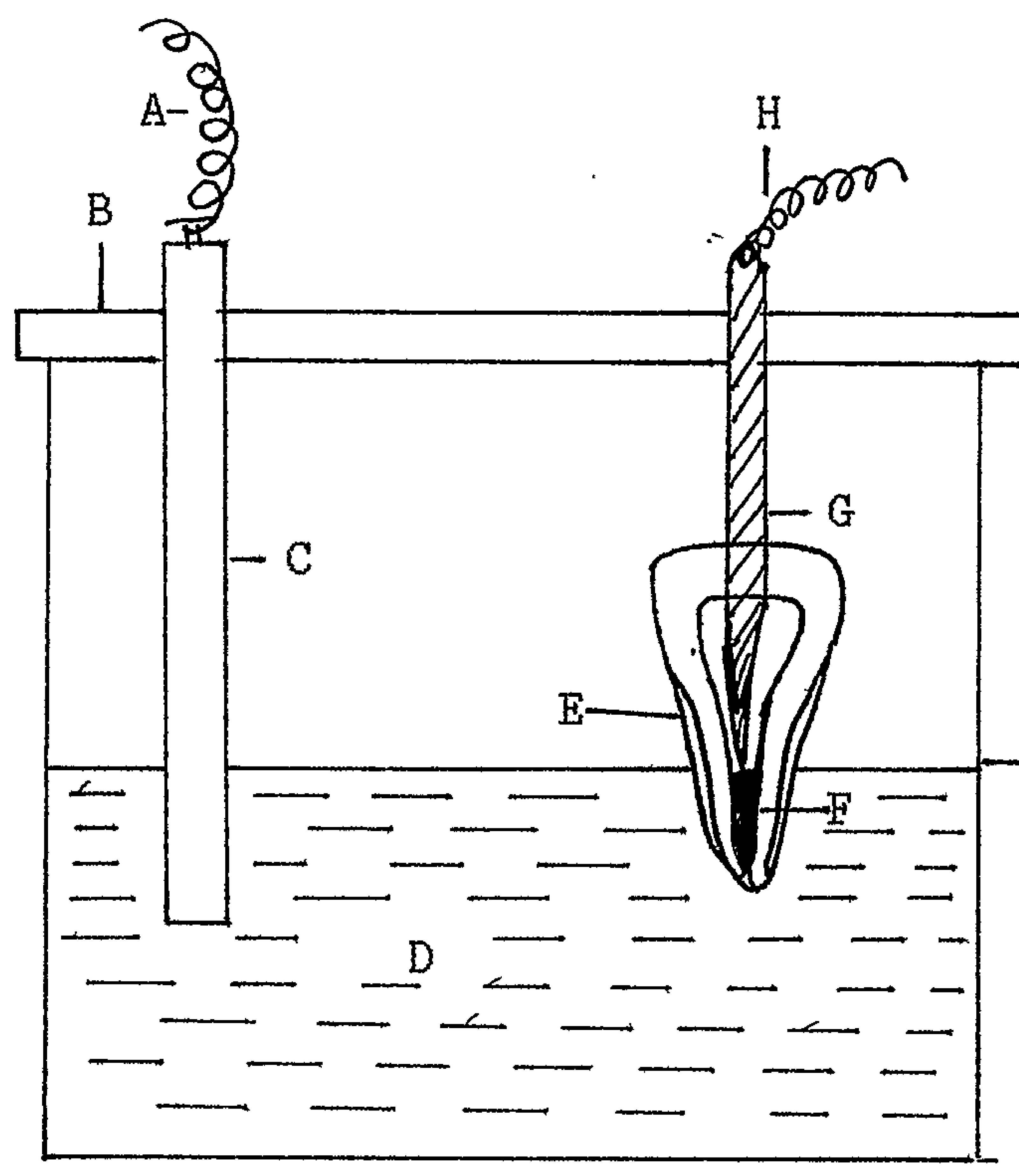
* Sticky Wax. (Wax cement sticks, Ainsworth Dental Co., Sydney, Aust.)



A. Lead to power source (negative)
B. Perspex electrode holder
C. Stainless steel electrode (cathode)
D. 1% Potassium Chloride solution
E. Two coats of nail varnish
F. Gutta-percha root canal filling
G. Copper electrode (anode)
H. Lead to power source (positive)
I. Plastic electrolyte container

Figure 6.5 Schematic diagram of the electrochemical leakage experiment handpiece. The roots were scored vertically on the buccal and lingual surfaces with a diamond disc and were then split vertically by wedging a scalpel blade in the scored surface. By scoring and spliting the roots, overheating of the gutta-percha was avoided and accurate measurement of the dye penetration was possible.

The amount of linear apical-coronal dye penetration was assessed in millimetres under direct vision. The apical reference point was the apical seat.

6.6 METHOD-C - RADIOGRAPHIC ASSESSMENT OF OBTURATED TEETH

The quality of the root canal fillings was assessed radiographically at double magnification. Two parameters were used:

1) the length of the root filling, which was assessed as either Long (gutta-percha through the apex); or Optimal (gutta-percha within 0.5 mm from apical stop with or without sealer overfill); or Short (the filling being more than 1 mm short of the apical stop);

2) the adaptation to the root canal wall was assessed as either Good (no voids present, the filling is well adapted to the canal wall and shows a dense appearance); or Acceptable (voids less than 0.5 mm in length are present in the body of the root filling and/or against the walls of the root canal); or Poor (voids more than 0.5 mm in length are present in the body of the root filling and/or against the walls of the root canal).

Clinically, the quality of the root canal filling can only be assessed radiograhically. This study attempts to link the results obtained in the ECL and LDP assessments with the simulated clinical performance assessed by radiographs.

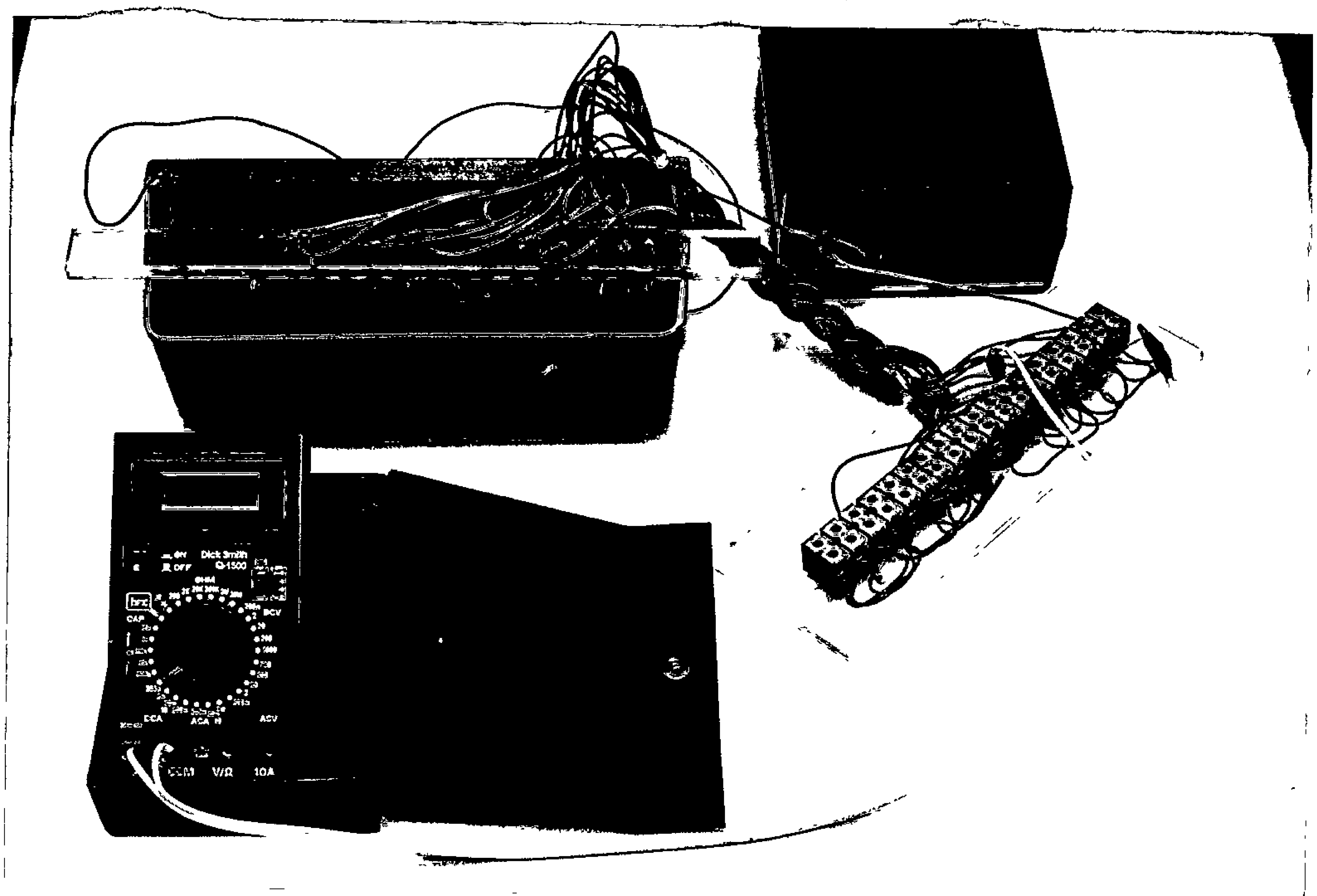


Figure 6.6 The electrochemical experiment showing the power source, the teeth in the electrolyte solution and the multimeter used to measure the current flow.

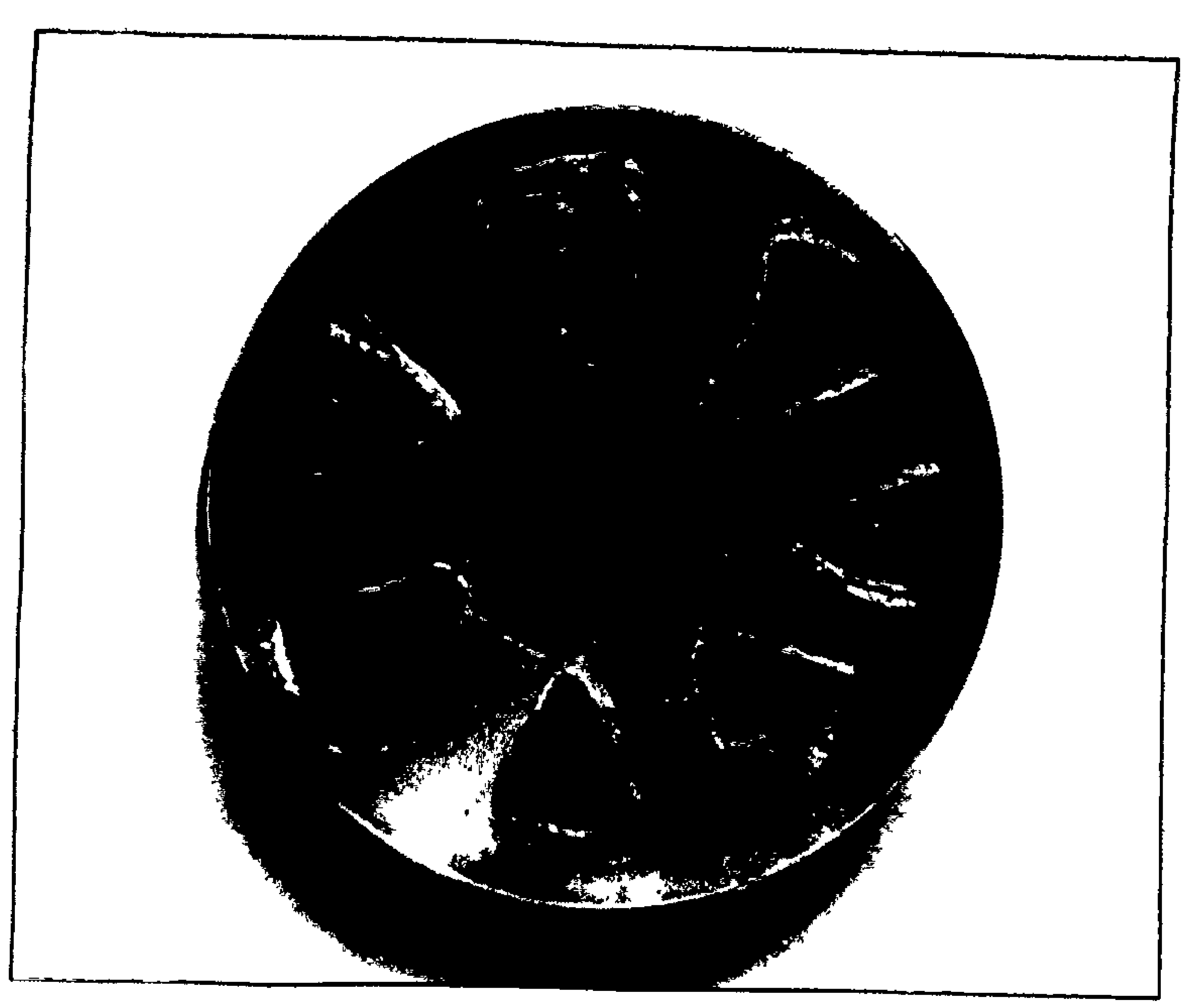


Figure 6.7 The teeth mounted in perspex, ready for the electron microprobe analysis.

6.7 ADDITIONAL STUDIES

As a consequence of the findings of the ECL and LDP experiments, it was necessary to investigate additional factors influencing adaptation and seal.

6.7.1 To determine if ECL had an effect on LDP, 15 teeth were mechanically prepared, obturated by lateral condensation, stored in saline for 30 days at room temperature and immersed in dye for 48 hours. The teeth were then sectioned and the degree of LDP assessed. The LDP of laterally condensed teeth after 30 days exposure to ECL was compared with teeth which had not been exposed to previous ECL testing.

6.7.2 Fifteen teeth were root filled by lateral condensation and stored in saline for 30 days at room temperature and then subjected to ECL for one day. The results of this experiment were compared with teeth exposed to continuous ECL over 30 days. This experiment was designed to demonstrate the influence that thirty days of continuous ECL testing has on final leakage values (at 30 days).

6.7.3 An electron microprobe analysis was undertaken to determine if corrosion products such as copper salts were being deposited around the apical two millimetres during the ECL experiment . Teeth which leaked at high levels and teeth which did not leak at all during electrochemical leakage were sectioned vertically, mounted in clear perspex (Fig. 6.7) and an analysis of any salt deposition was undertaken using the electron microprobe.

6.7.4 To monitor the effectiveness of the electrochemical method of testing over a 30 day period, fifteen single-rooted teeth were mechanically prepared and a number 15 K file was pushed 1 mm through the apex to ensure a patent foramen. The canals were unfilled and all the root surface except the apical 2 mm was covered by nail varnish. The current flow of these teeth should be maximum and ideally a constant current flow should occur, since the root canals had not been filled.

6.7.5 To determine if the size of the apical aperture affected the degree of ECL, fifteen teeth with wide open apices were tested. Some teeth had wide immature apices and others were dilated by passing a number 50 K file one millimetre through the apical foramen. The teeth were otherwise mechanically prepared in a similar manner to those previously prepared for the lateral condensation technique and obturated by lateral condensation. The teeth were then subjected to ECL measurements over a 30 day period.

6.8 STATISTICAL METHOD

The primary aim of the statistical method was to demonstrate similarities or differences in mean ECL between the four obturation techniques and any differences in mean LDP between the four obturation techniques

Therefore the Null hypotheses could be stated as follows:

H_0: There is no difference in the mean ECL (or LDP) between the four different obturation techniques.

H_1: There is a difference in the mean ECL (or LDP) between the four different obturation techniques.

Alpha level: 0.05

The secondary aims of the statistical method are concerned with (a) the correlation between mean ECL and LDP; (b) the differences in ECL and LDP between open and closed apices; (c) the correlation between ECL, LDP and the radiographic adaptation of the root fillings.

PRESENTATION OF THE RESULTS

The results of the Pilot study and Method-A (ECL) are presented in Chapter 7.

The results of Method-B (LDP) are presented in chapter 8.

The results of Method-C (Radiographic assessment are presented in Chapter 9).

The results of the additional experiments as outlined in section 6.7 are found in Chapter 10.

Statistical results are presented in each Chapter.

CHAPTER 7

RESULTS FOR ELECTROCHEMICAL LEAKAGE (METHOD-A)

7.1 Pilot study teeth

The results of the pilot study are shown in Table 7.1. As anticipated no leakage occurred with the two negative controls (two teeth were instrumented, the canals were left unfilled and the entire root surface including the apical foramen was covered with nail varnish). The two positive contols (teeth which were instrumented, left unfilled and the entire root surface except the apical one millimetre was covered with nail varnish; the foramen was patent) showed high early leakage (2220-3670 µA*), which decreased over 15 days to (300-350 µA). Only one of the four teeth obturated showed any significant electrochemical leakage (ECL) and this decreased after the first five days.

The results of the pilot study indicated that the experimental method did distinguish between the experimental teeth, the positive controls and the negative controls.

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* µA = Microamperes (10^{-6}A)

Table 7.1 Elecrochemical Leakage (µA) - Pilot Study

	Lateral Condensation		McSpadden Compaction		Positive Controls		Negative Controls	
			Tooth	Number				
Day	1	2	3	4	5	6	7	8
1	0	0.2	0.1	1.7	2,220	3670	0	0
2	0	0	0.1	3.7	770	440	0	0
3	0	0	0.1	4.3	710	550	0	0
4	0	0	0	4.0	650	500	0	0
5	0	0	0	3.9	610	500	0	0
6	0	0	0	3.5	550	450	0	0
7	0	0	0	3.1	500	480	0	0
8	0	0	0	2.1	480	410	0	0
9	0	0	0	1.1	480	350	0	0
10	0	0	0	0.9	450	300	0	0
11	0	0	0	0.4	430	320	0	0
12	0	0	0	0.3	400	350	0	0
13	0	0	0	0.3	390	380	0	0
14	0	0	0	0.3	300	350	0	0
15	0	0	0	0.2	300	350	0	0

7.2 The Electrochemical Leakage for the four obturation techniques over the period of 30 days.

Results for the four techniques of obturation are shown separately in Tables 7.2-7.5 and in Fig. 7.1-7.4. Figure 7.5 illustrates the ECL of all four obturation techniques over the 30 day period.

Figure 7.1 shows the mean ECL of teeth obturated by lateral condensation and Table 7.2 the mean daily tooth readings. The interesting finding was the lack of leakage by all 15 teeth for the first 20 days and the high leakage after day 22 by three of the teeth.

Figure 7.2 shows the mean ECL of teeth obturated by McSpadden compaction. The high early leakage, approximately 20 µA, decreased over the first five days to less than 3.0 µA. The mean daily tooth leakage is shown in Table 7.3.

Figure 7.3 shows the mean ECL of teeth that were root filled by Enac ultrasonically plasticized gutta-percha. Daily ECL measurements are shown in Table 7.4. This technique exhibited a constant low level of leakage throughout the 30 day period.

Figure 7.4 shows the mean ECL of teeth obturated by Ultrafil. The high initial leakage around 20 µA decreased over two days to less than 1 µA. Table 7.5 shows the mean daily leakage for teeth filled by the Ultrafil technique.

Figure 7.5 shows the mean ECL for all four obturation techniques. All techniques showed relatively low ECL between days 10 and 25. McSpadden and Ultrafil had high early leakage and lateral condensation exhibited increasing microleakage after the 22nd day.

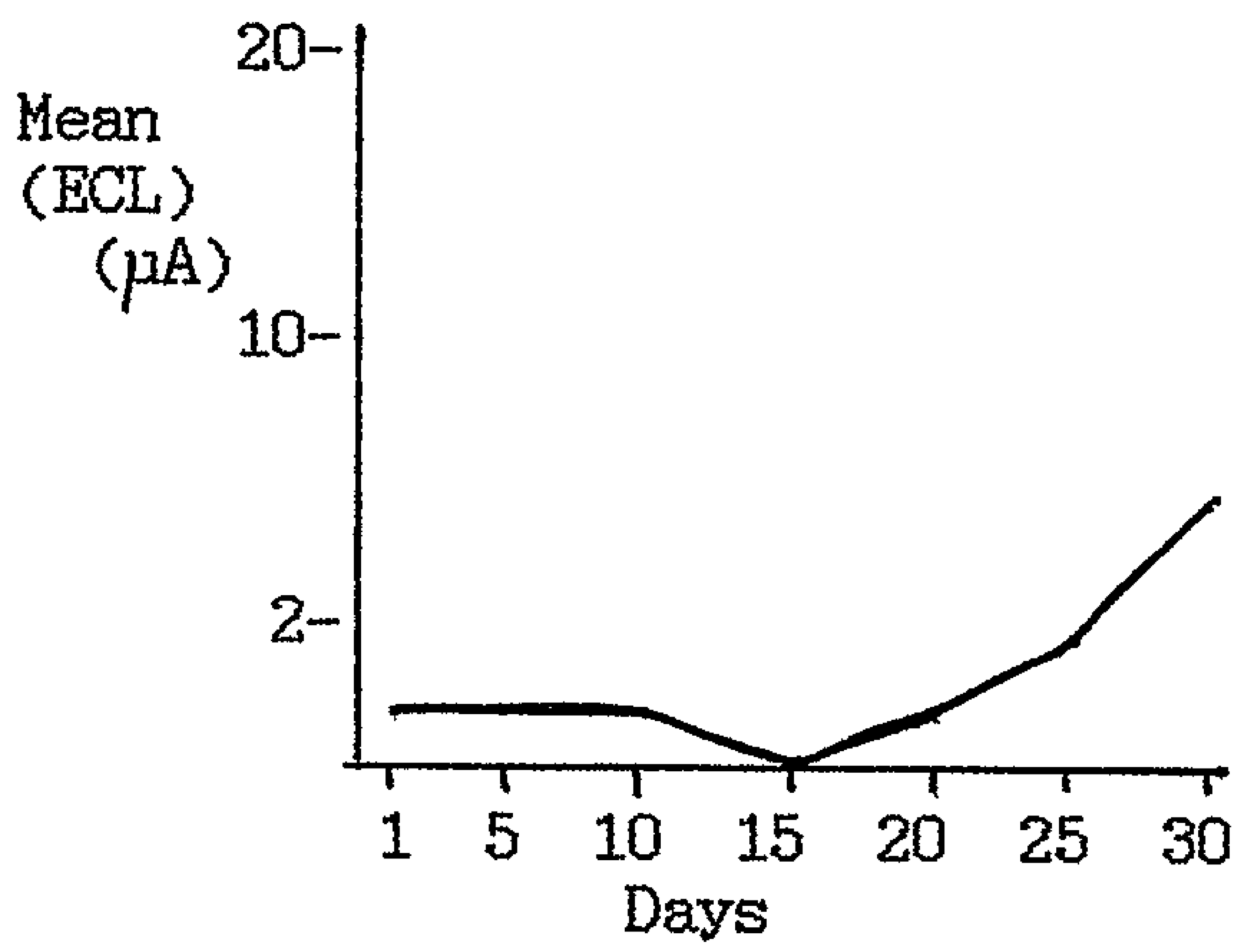

Figure 7.1 Lateral condensation

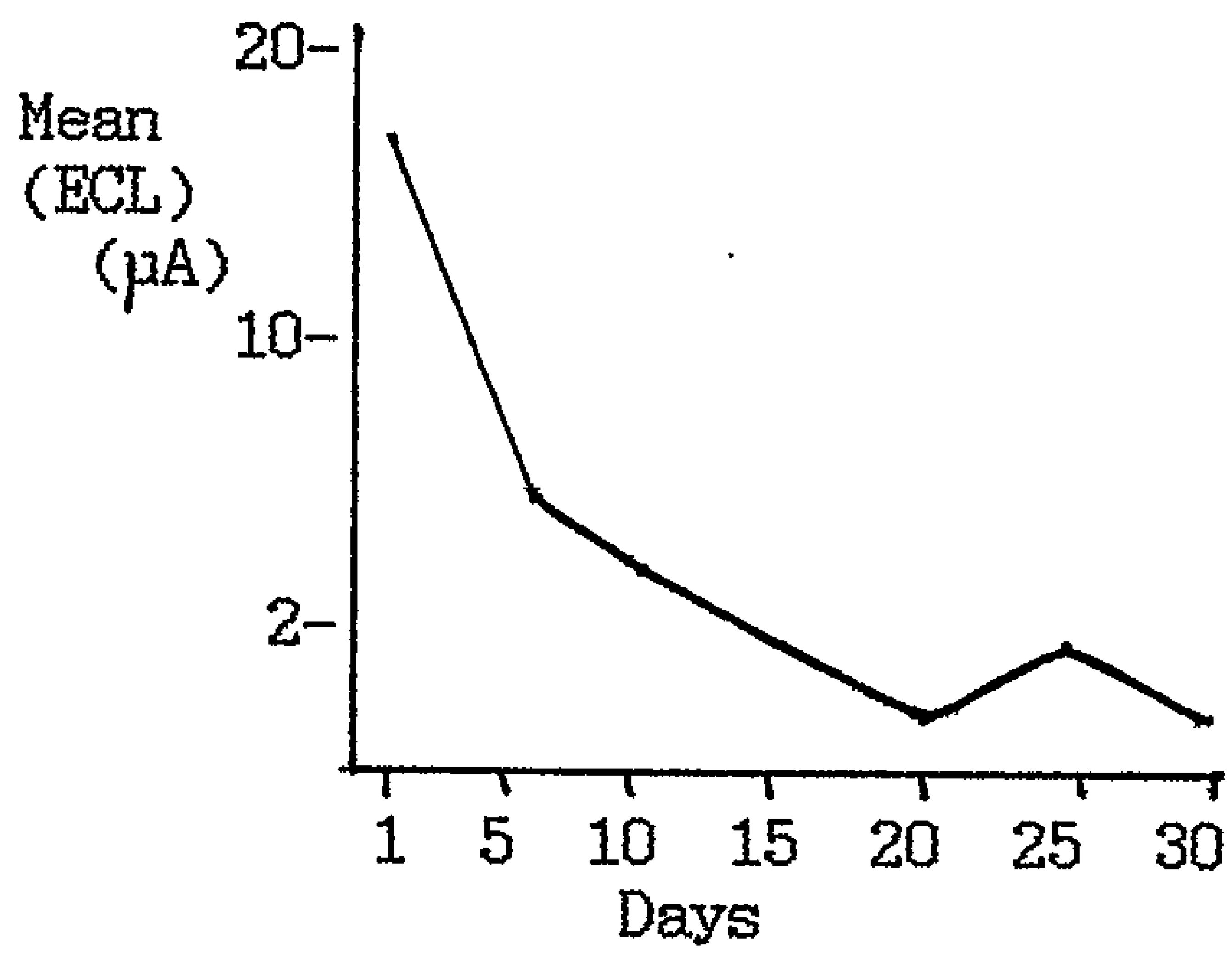

Figure 7.2 McSpadden Compaction

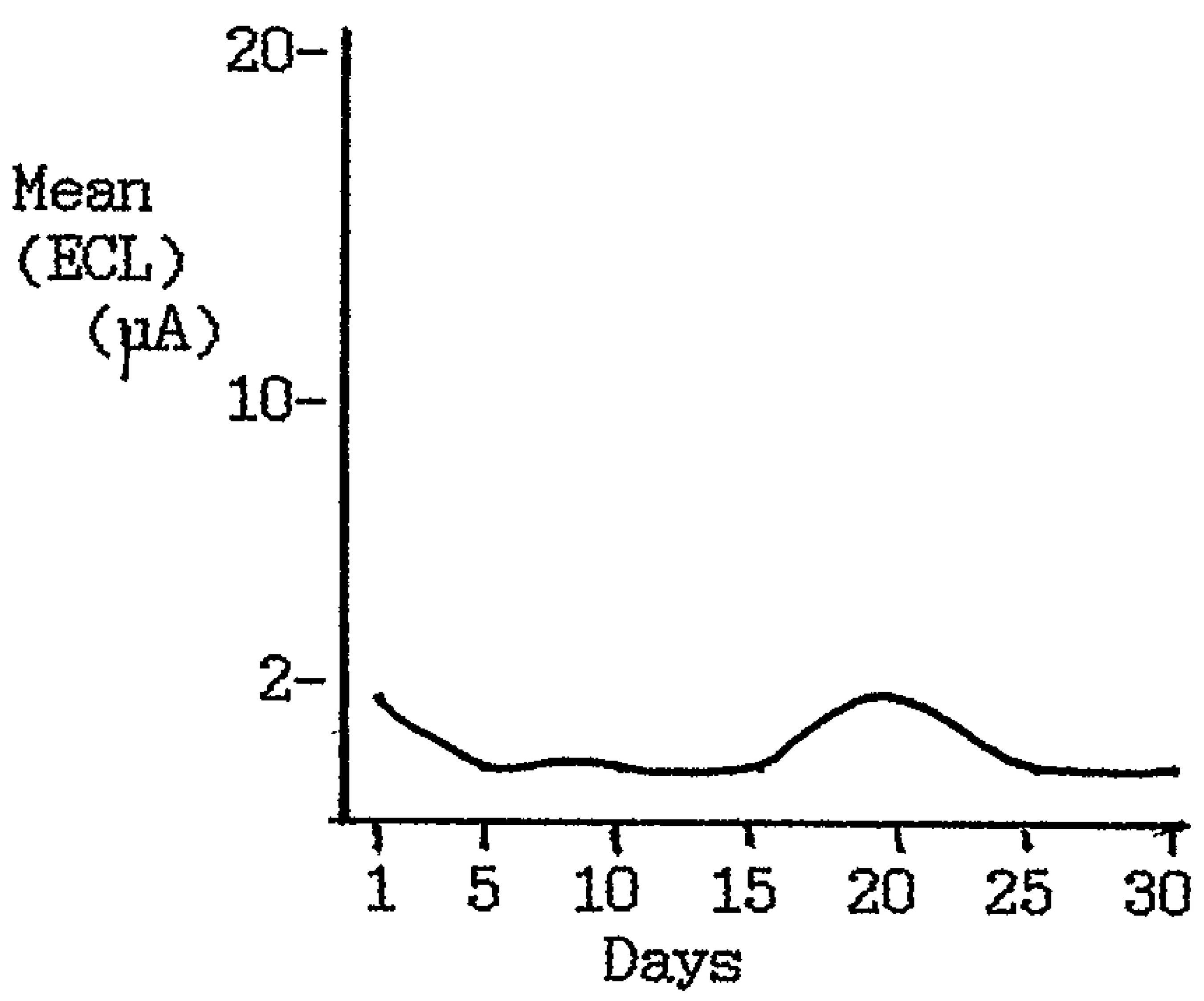

Figure 7.3 Enac

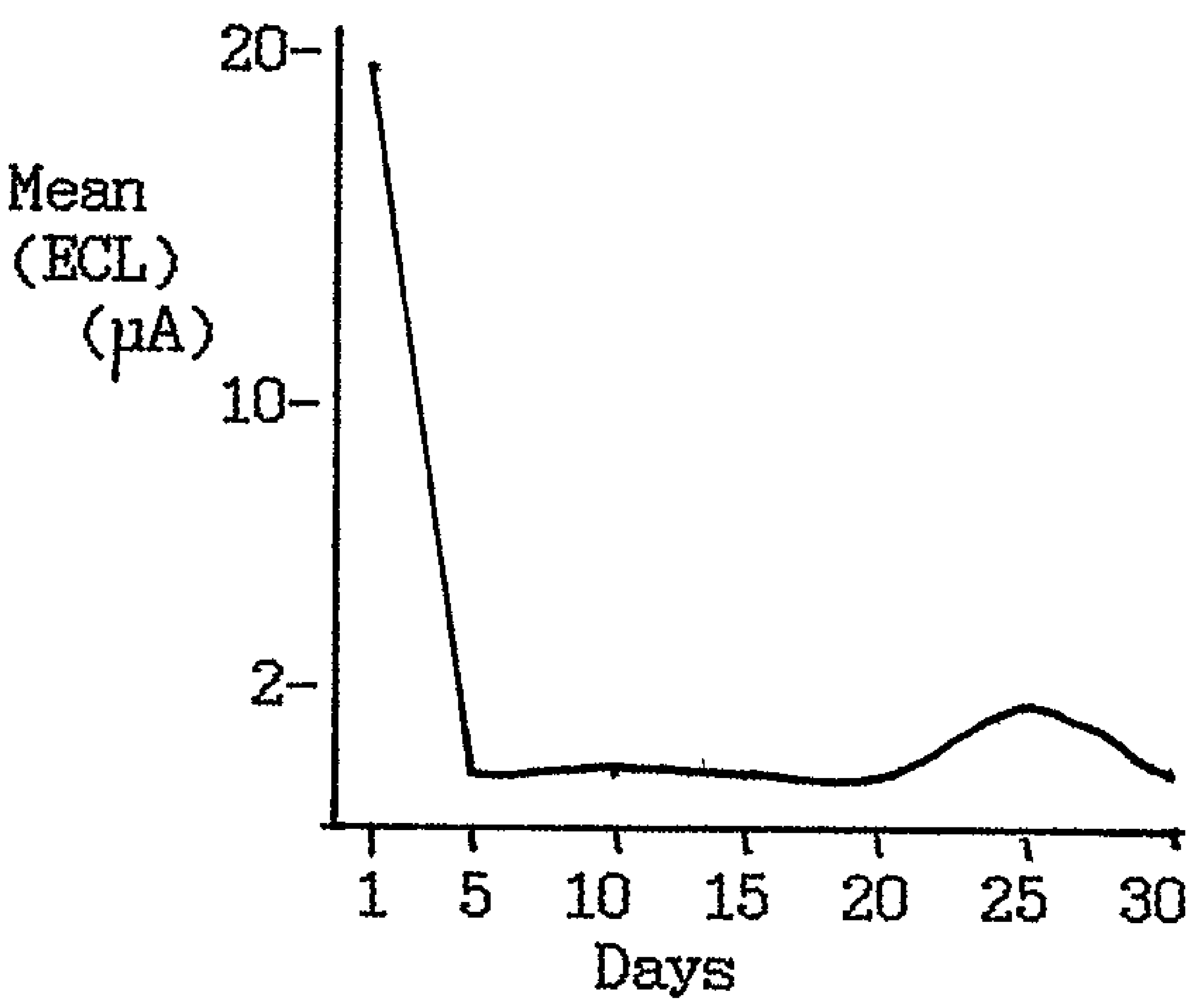

Figure 7.4 Ultrafil

Table 7.2 Mean daily electrochemical leakage (ECL) for teeth (N=15) obturated by lateral condensation.

DAY	Mean (ECL) (μA)	Standard Deviation (SD)	DAY	Mean (ECL) (μA)	Standard Deviation (SD)
1	0.05	0.05	16	0.00	0.00
2	0.07	0.05	17	0.01	0.04
3	0.07	0.05	18	0.01	0.04
4	0.05	0.05	19	0.01	0.04
5	0.01	0.26	20	0.01	0.04
6	0.00	0.00	21	0.03	0.12
7	0.00	0.00	22	0.13	0.40
8	0.00	0.00	23	0.47	1.36
9	0.00	0.00	24	0.90	2.63
10	0.01	0.04	25	1.63	5.03
11	0.01	0.04	26	3.77	12.63
12	0.01	0.04	27	3.78	12.34
13	0.01	0.26	28	3.78	12.30
14	0.01	0.26	29	5.39	18.10
15	0.00	0.00	30	4.08	12.70

Table 7.3 Mean daily electrochemical leakage for teeth (N=15) obturated by McSpadden compaction.

DAY	Mean (ECL) (μA)	Standard Deviation (SD)	DAY	Mean (ECL) (μA)	Standard Deviation (SD)
1	16.50	49.20	16	0.59	1.70
2	9.50	24.70	17	0.61	1.70
3	6.40	12.47	18	0.70	1.70
4	7.94	17.84	19	0.21	0.40
5	4.95	11.59	20	0.15	0.27
6	2.87	6.28	21	0.11	0.19
7	2.94	7.44	22	0.13	0.19
8	2.28	7.40	23	0.25	0.62
9	2.18	7.10	24	0.81	2.60
10	2.00	6.60	25	1.25	4.10
11	1.91	6.30	26	1.16	2.80
12	1.14	3.70	27	0.75	1.90
13	1.04	3.20	28	0.72	1.90
14	0.79	2.50	29	0.46	1.01
15	0.57	1.70	30	0.46	1.04

Table 7.4 Mean daily electrochemical leakage for teeth (N=15) obturated by Enac plasticized gutta-percha.

DAY	Mean (ECL) (μA)	Standard Deviation (SD)	DAY	Mean (ECL) (μA)	Standard Deviation (SD)
1	1.42	0.69	16	0.52	0.24
2	0.59	0.29	17	0.51	0.23
3	0.61	0.26	18	0.48	0.03
4	0.87	0.37	19	0.44	0.21
5	0.58	0.29	20	1.50	1.06
6	0.93	0.46	21	1.46	1.00
7	0.58	0.29	22	1.51	1.01
8	0.51	0.24	23	1.41	0.90
9	0.51	0.27	24	1.19	0.70
10	0.77	0.44	25	1.03	0.60
11	1.28	0.85	26	0.76	0.50
12	1.85	1.50	27	0.83	0.44
13	0.83	0.47	28	0.79	0.46
14	0.72	0.37	29	0.76	0.45
15	0.55	0.26	30	0.76	0.45

Table 7.5 Mean daily electrochemical leakage for teeth (N=15) obturated by Ultrafil thermoplasticized gutta-percha.

DAY	Mean (ECL) (μA)	Standard Deviation (SD)	DAY	Mean (ECL) (μA)	Standard Deviation (SD)
1	18.60	13.40	16	0.06	0.03
2	1.60	0.70	17	0.06	0.03
3	0.80	0.30	18	0.06	0.03
4	0.40	0.15	19	0.04	0.02
5	0.20	0.07	20	0.05	0.02
6	0.20	0.08	21	0.11	0.07
7	0.40	0.31	22	0.21	0.09
8	0.30	0.18	23	0.49	0.33
9	0.20	0.12	24	0.77	0.61
10	0.17	0.10	25	0.25	0.13
11	0.15	0.08	26	0.90	0.52
12	0.09	0.05	27	0.65	0.43
13	0.05	0.03	28	0.39	0.22
14	0.06	0.03	29	0.27	0.13
15	0.06	0.03	30	0.17	0.08

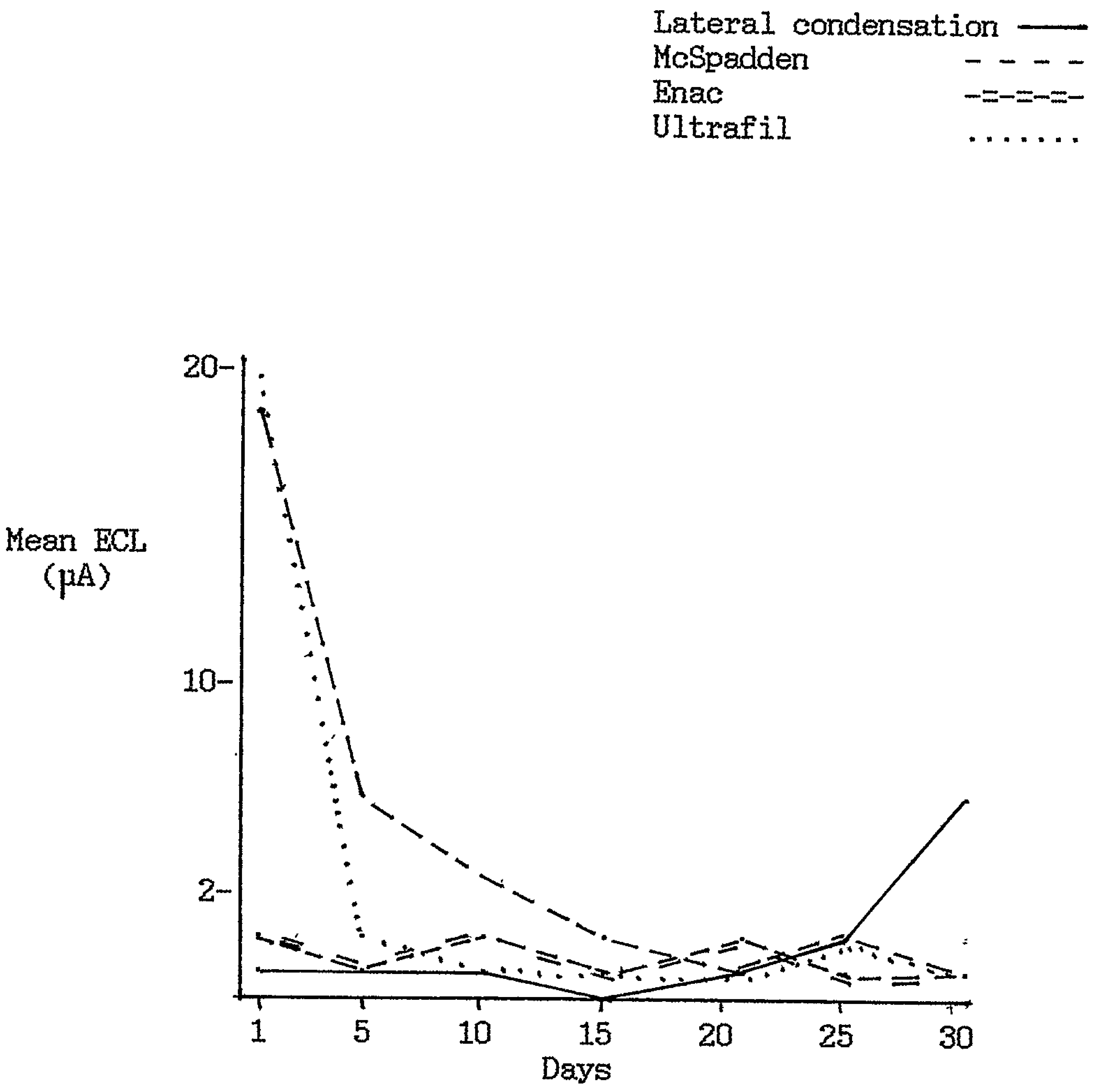

Figure 7.5 Mean electrochemical leakage of all four obturation techniques.

7.3 The number of teeth exhibiting leakage for the four obturation techniques during the period of 30 days.

For the lateral condensation technique seven teeth initially showed ECL and by day 15 no teeth showed any leakage (Fig.7.6). By day-30, three teeth with immature (open) apices were again leaking. On average three teeth leaked throughout the 30 day period. However no single tooth showed substantial leakage throughout the 30 day period.

For the McSpadden technique all 15 teeth showed ECL on the first day (Fig. 7.7). The number of teeth exhibiting leakage decreased to five by day 15. During the 30 day period the mean of the number of teeth leaking was 7.5.

Of the four techniques, the Enac technique showed the highest number of teeth leaking throughout the 30 day period (Fig 7.8). On average, ten teeth were leaking at any one time. However, as shown in Table 7.4, the amount of leakage of these teeth was comparatively small.

For the Ultrafil technique the number of teeth leaking decreased from 11 on day 1 to 5 on day 20 (Fig. 7.9). By day 25, however, 11 teeth were again leaking. During the 30 day period the mean number of teeth leaking was 9.5.

Figures 7.6 to 7.9 illustrate the number of teeth showing ECL during the 30 day period, for the four obturation techniques.

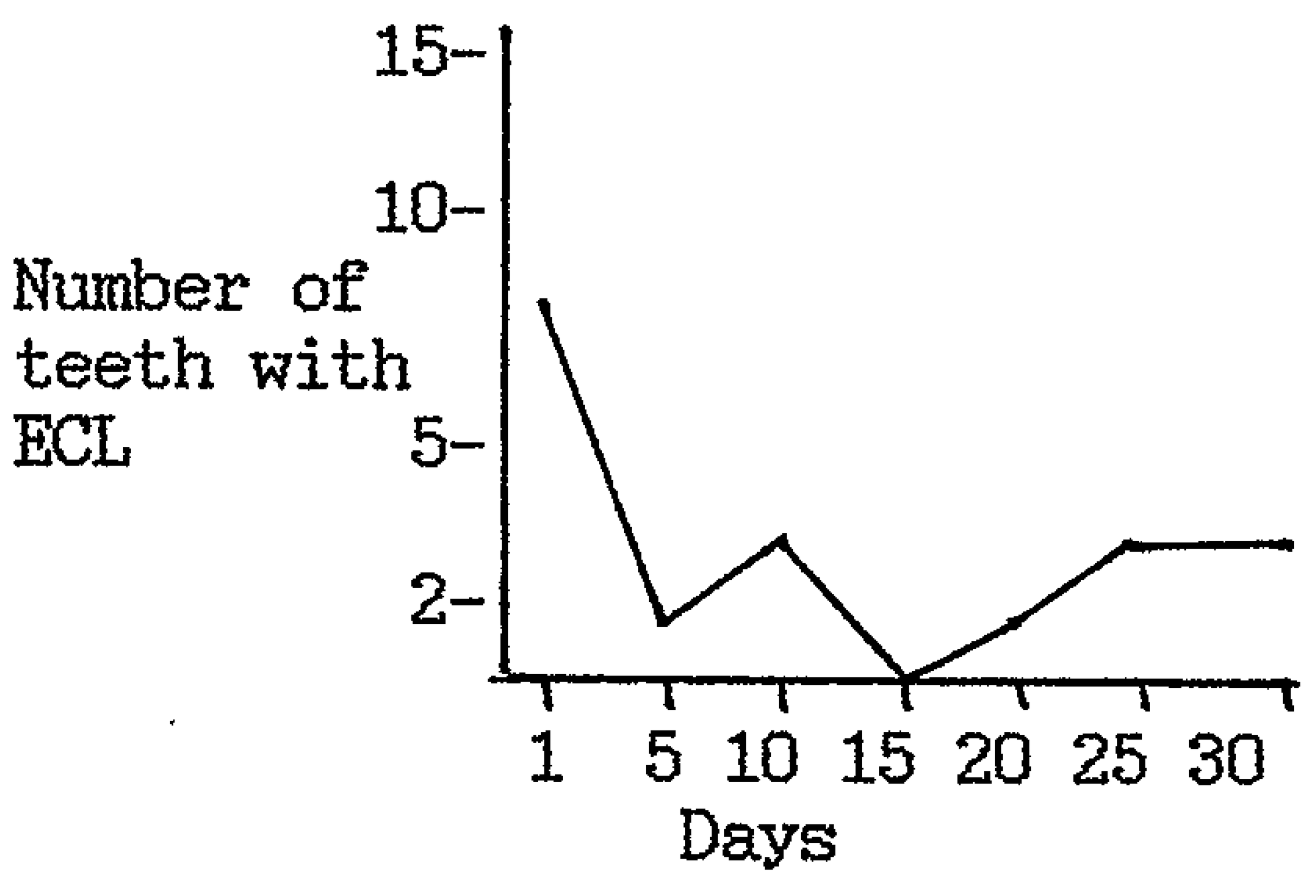

Fig. 7.6 Lateral Condensation (N=15)

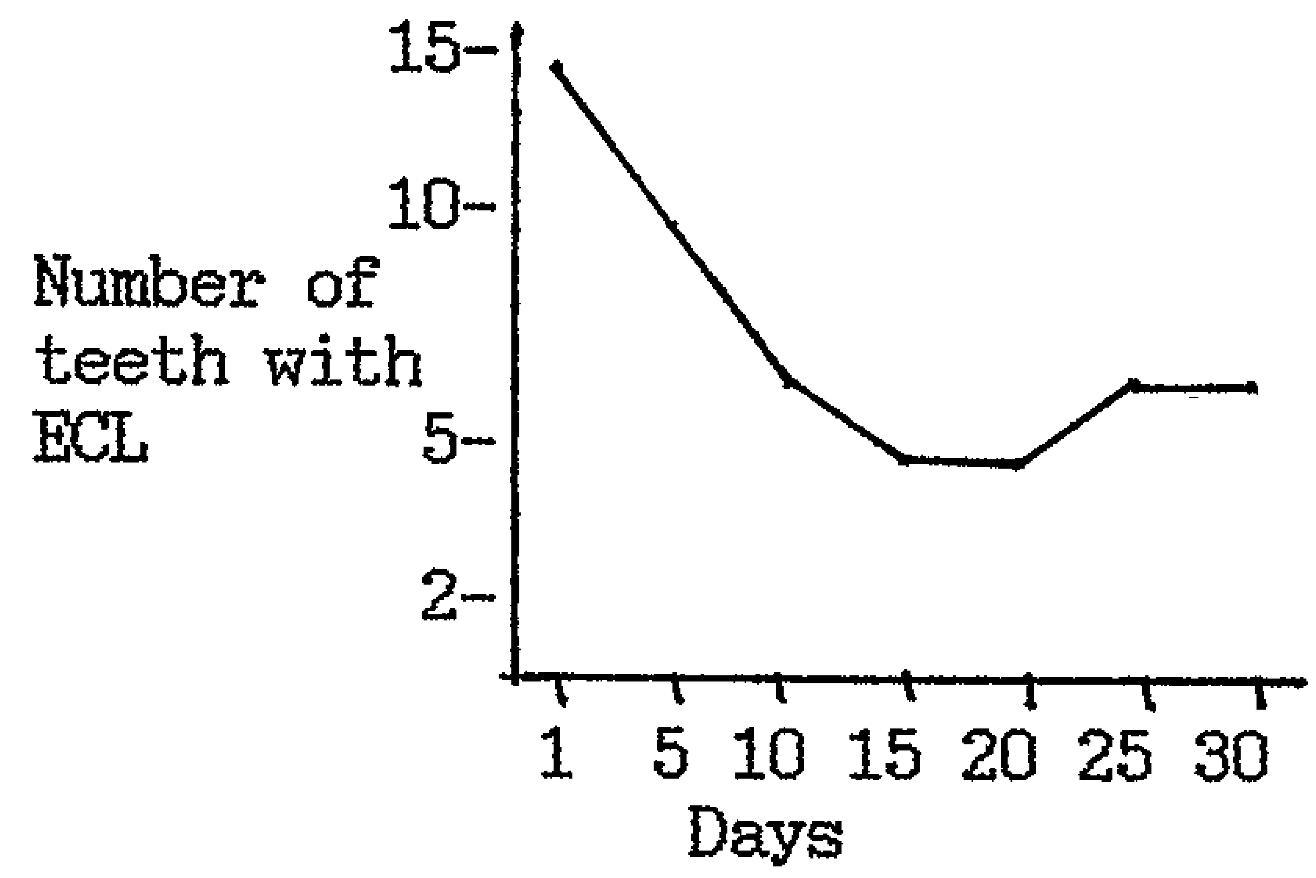

Fig. 7.7 McSpadden (N=15)

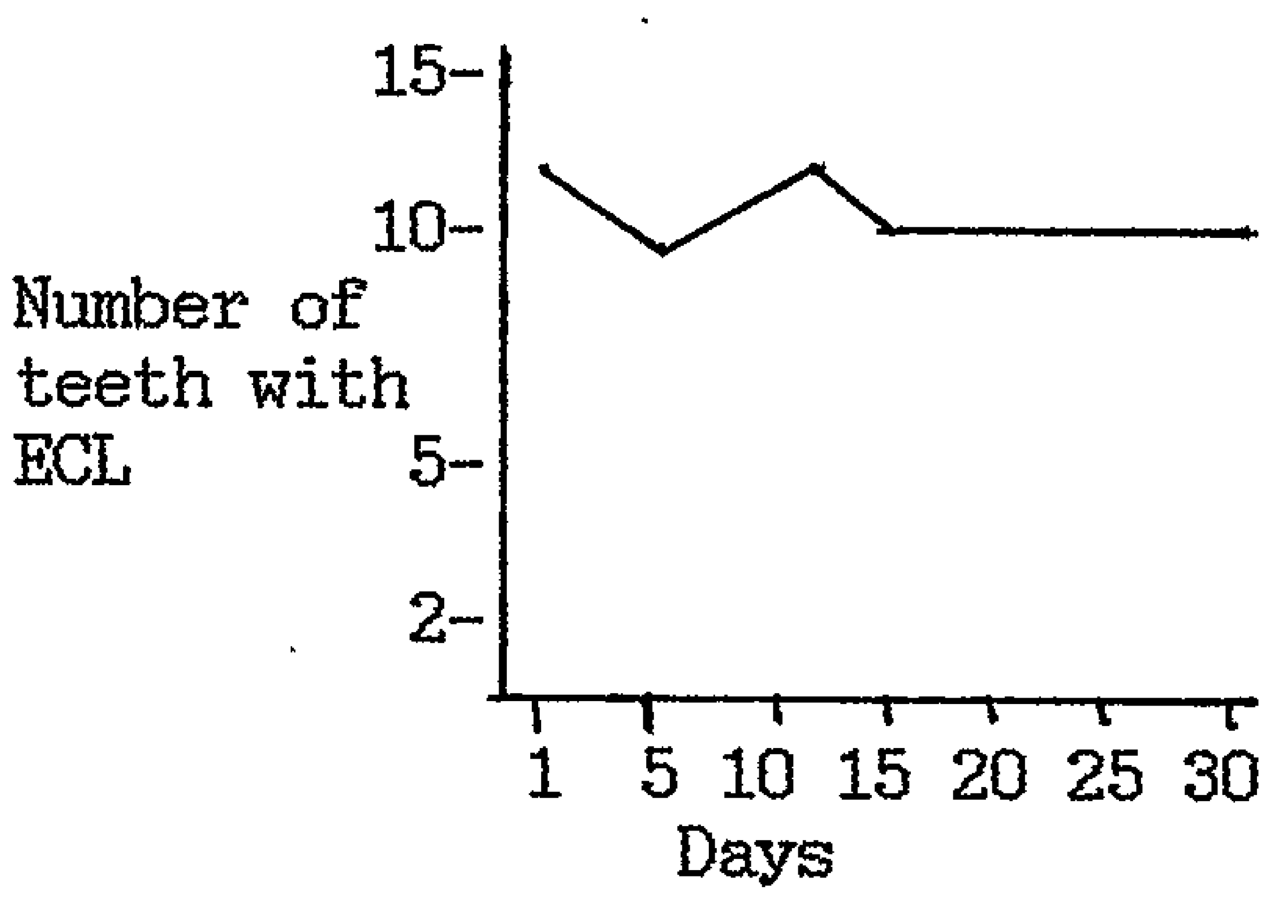

Fig. 7.8 Enac (N=15)

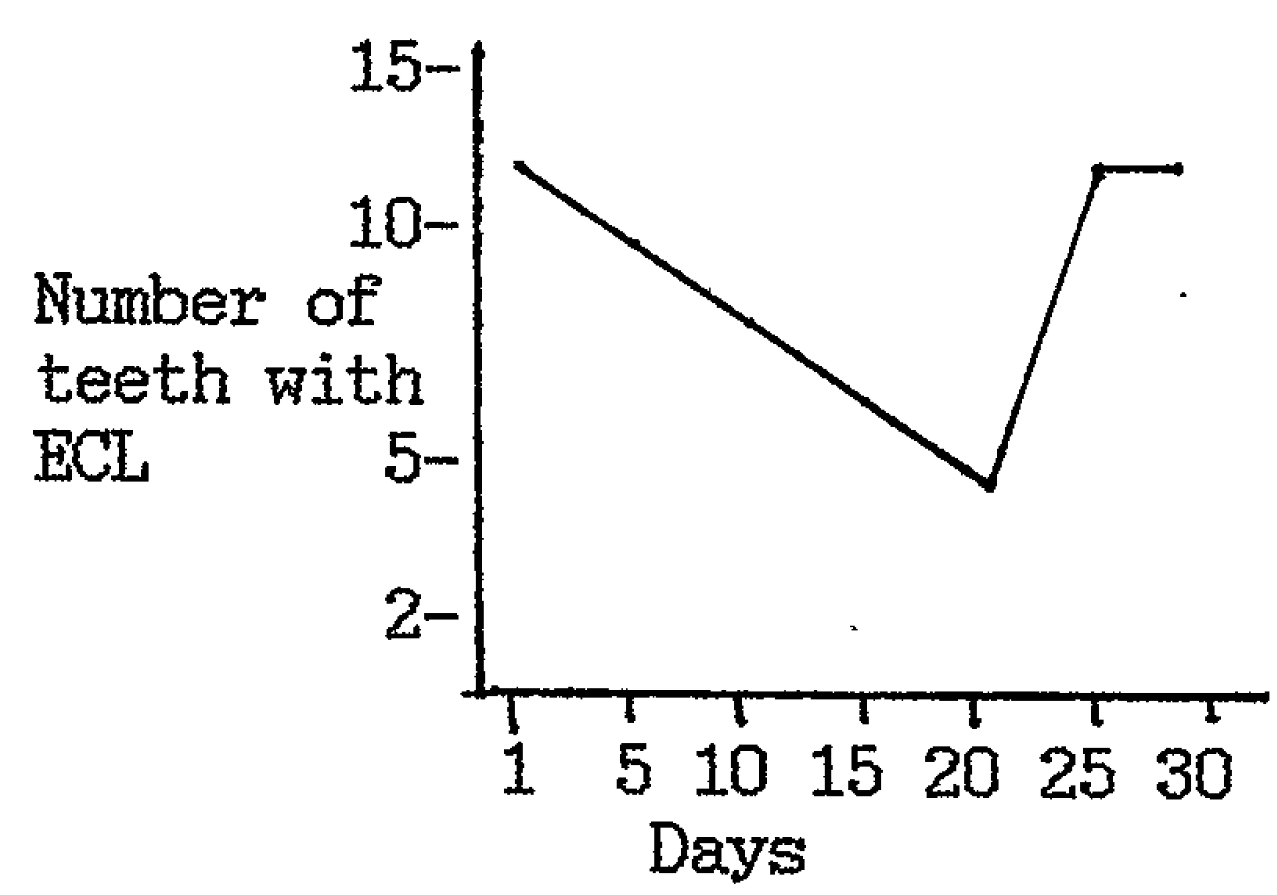

Fig. 7.9 Ultrafil (N=15)

7.4 Statistical Analysis

The results shown in Figures 7.2, 7.3, 7.4, and 7.5, were calculated by obtaining the mean leakage for the 15 teeth on each particular day. Additional information can be provided by examining the mean leakage for each individual tooth over the 30 day period. The average of the mean leakage during the 30 day period for all 15 teeth (the 15 tooth averages) provides the "overall" mean for each obturation technique.

The differences in the results obtained by different teeth (in their individual tooth averages) provided data that were often skewed. Values for the median are regarded as better measures of central tendency for such data (Phillips 1978).

Table 7.6 Comparison of the measures of central tendency of the 15 individual tooth averages for each obturation technique.

Obturation Technique	Measure of central tendency for the 15 tooth averages for each obturation technique.		
	Mode (μA)	Median (μA)	Mean (μA) *
Lateral Condensation	0.02	0.02	1.70 (5.2)
McSpadden	0.10	0.65	4.95 (11.4)
Enac	0.15	0.32	0.88 (1.5)
Ultrafil	-	0.63	0.92 (1.6)

* Value for one standard deviation in parenthesis

Using the median scores, the techniques could be ranked in order of increasing leakage:

Lateral condensation, Enac, Ultrafil, McSpadden

To examine for statistically significant difference between pairs of techniques, t-tests were used to test the Null Hypothesis that the mean difference was zero, at a significance level of alpha= 0.05. No significant difference was found between the four obturation techniques!

Due to the results obtained in this experiment, it was necessary not to place a heavy emphasis on the differences in the means because the data were heavily skewed, as evident in the following summaries.

The overall mean ECL for Lateral condensation over the 30 day period was 1.7 µA. Seven of the 15 teeth had a mean leakage over the 30 days of 0.02 µA. This value constitutes the mode of the 15 averages. The mode is defined as the most frequently occurring score. The middle occurring score of the 15 teeth (the median) was also 0.02 µA. For the ECL results for the lateral condensation technique, in which the data were skewed, the median is a better representative of the average leakage than the mean.

CHAPTER 8

RESULTS FOR LINEAR DYE PENETRATION (METHOD-B)

8.1 Linear Dye Penetration

The results for Linear dye penetration (LDP) are shown in histograms presented for lateral condensation (Fig. 8.1), McSpadden compaction (Fig. 8.2), Enac (Fig. 8.3), and Ultrafil (Fig. 8.4). These histograms indicate, for each technique, the amount (length) of dye penetration for the 15 teeth. The dye penetration was measured from the apical stop in millimetres after the teeth had been subjected to electrochemical leakage testing over the 30 day period.

Teeth obturated by lateral condensation showed high LDP (Fig. 8.1). The mean LDP was 3.3 mm, the distribution was bimodal at 1 mm and 4 mm and the median was 4 mm.

Teeth obturated by McSpadden compaction exhibited a low LDP with seven teeth not showing any leakage at all (Fig. 8.2). The mean LDP was 1.67 mm, the mode was 0 mm and the median was 1 mm.

Figure 8.3, shows the LDP for teeth obturated by Enac. The mean LDP was 2.45 mm and the median was 2 mm. There was a bimodal distribution at 1mm and 5mm.

Figure 8.4, illustrates the LDP for teeth obturated by Ultrafil. The mean penetration was 2.1 mm, the median was 2.0 mm and there was a bimodal distribution at 1 and 2 mm.

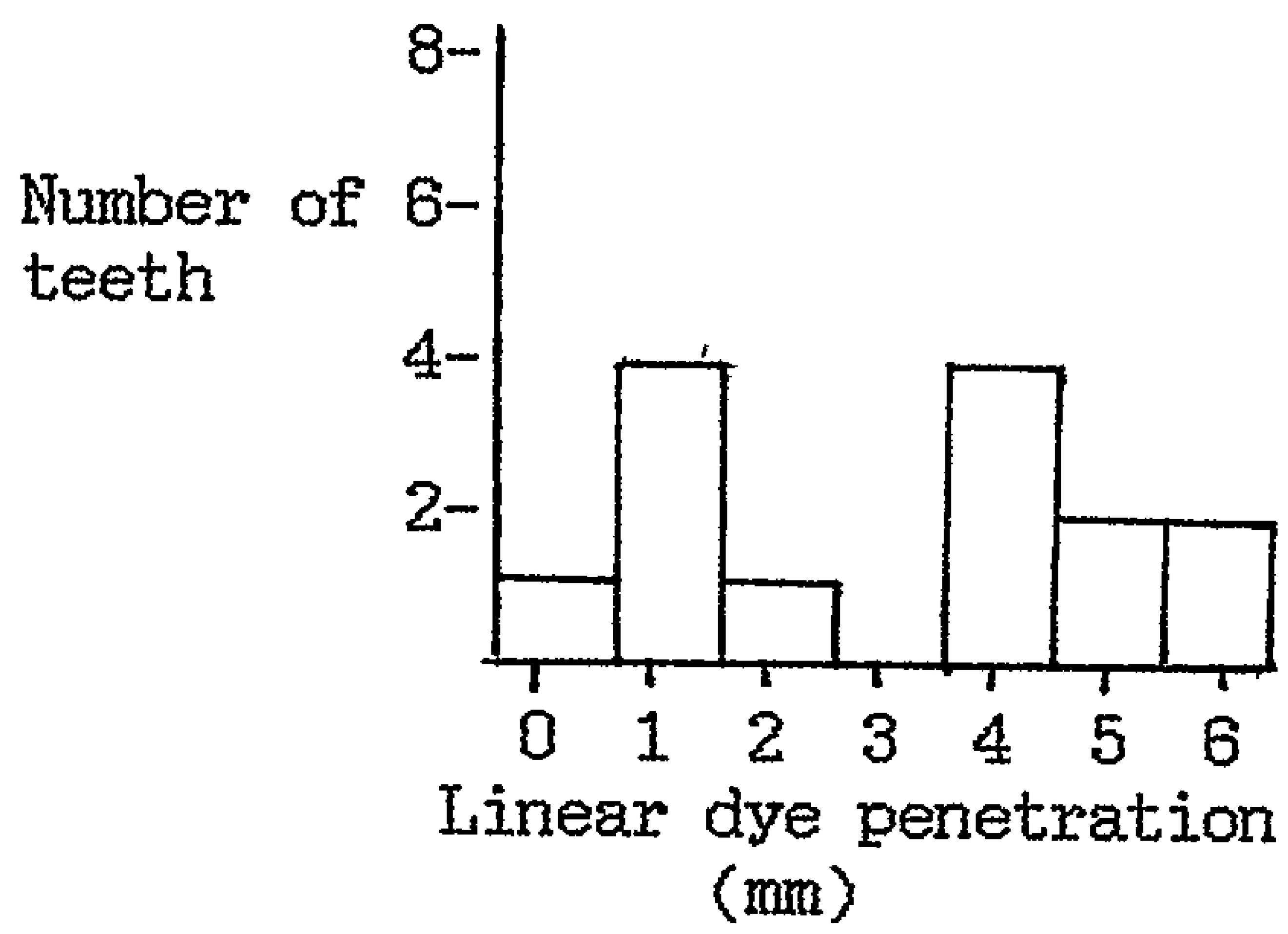

Fig. 8.1 Linear dye penetration for teeth obturated by lateral condensation.

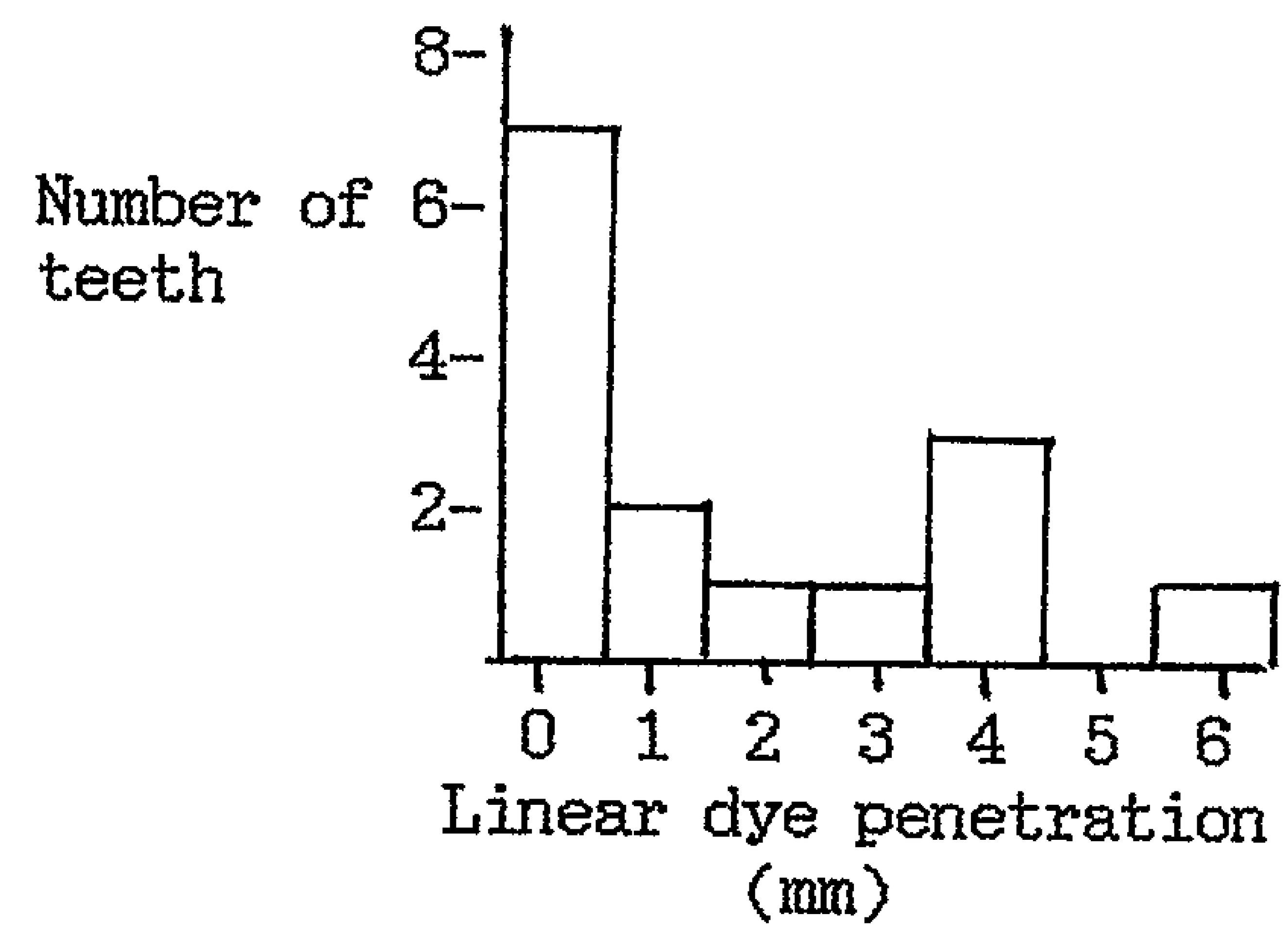

Fig. 8.2 Linear dye penetration for teeth obturated by McSpadden compaction.

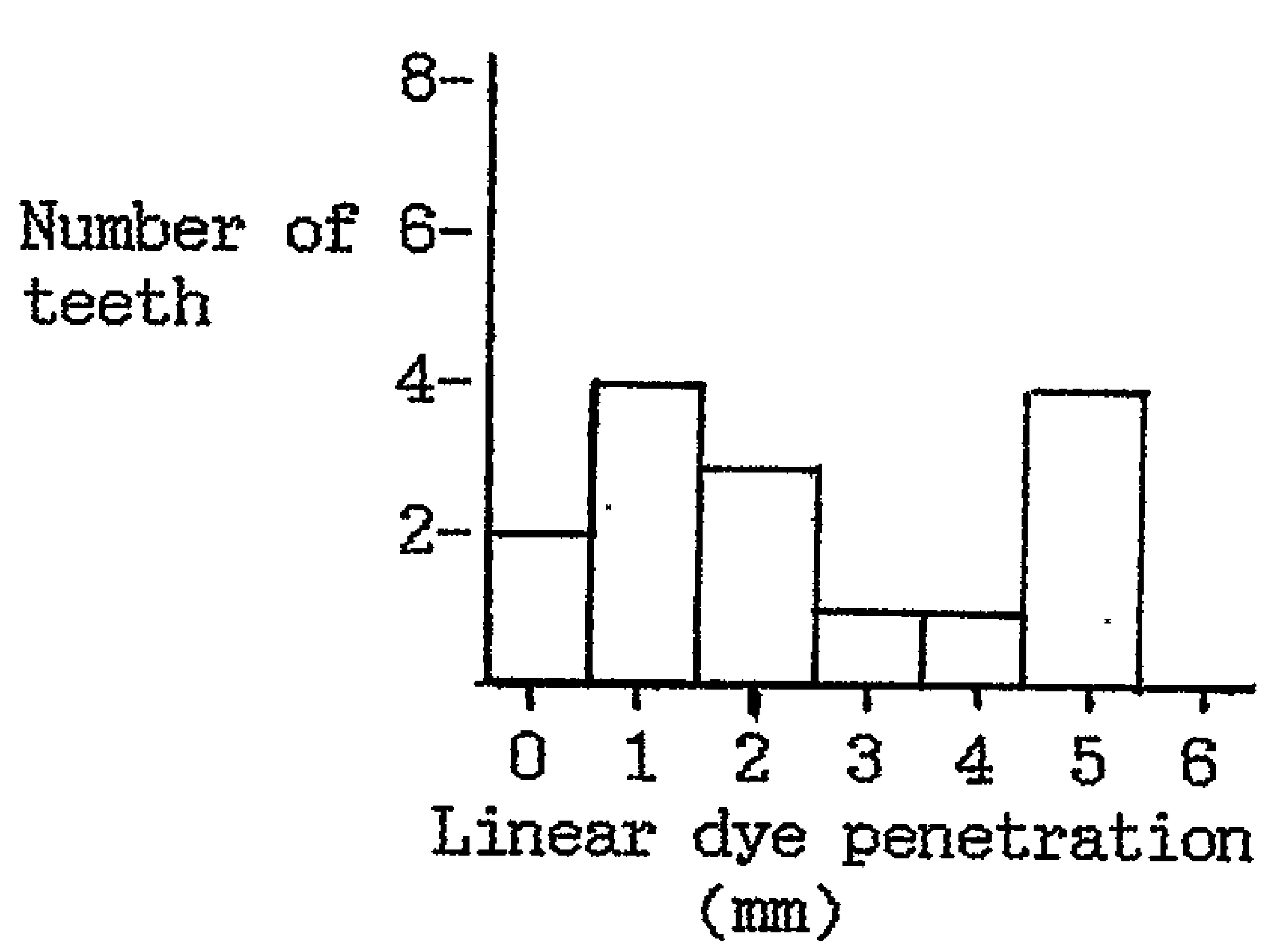

Fig. 8.3 Linear dye penetration for teeth obturated by Enac.

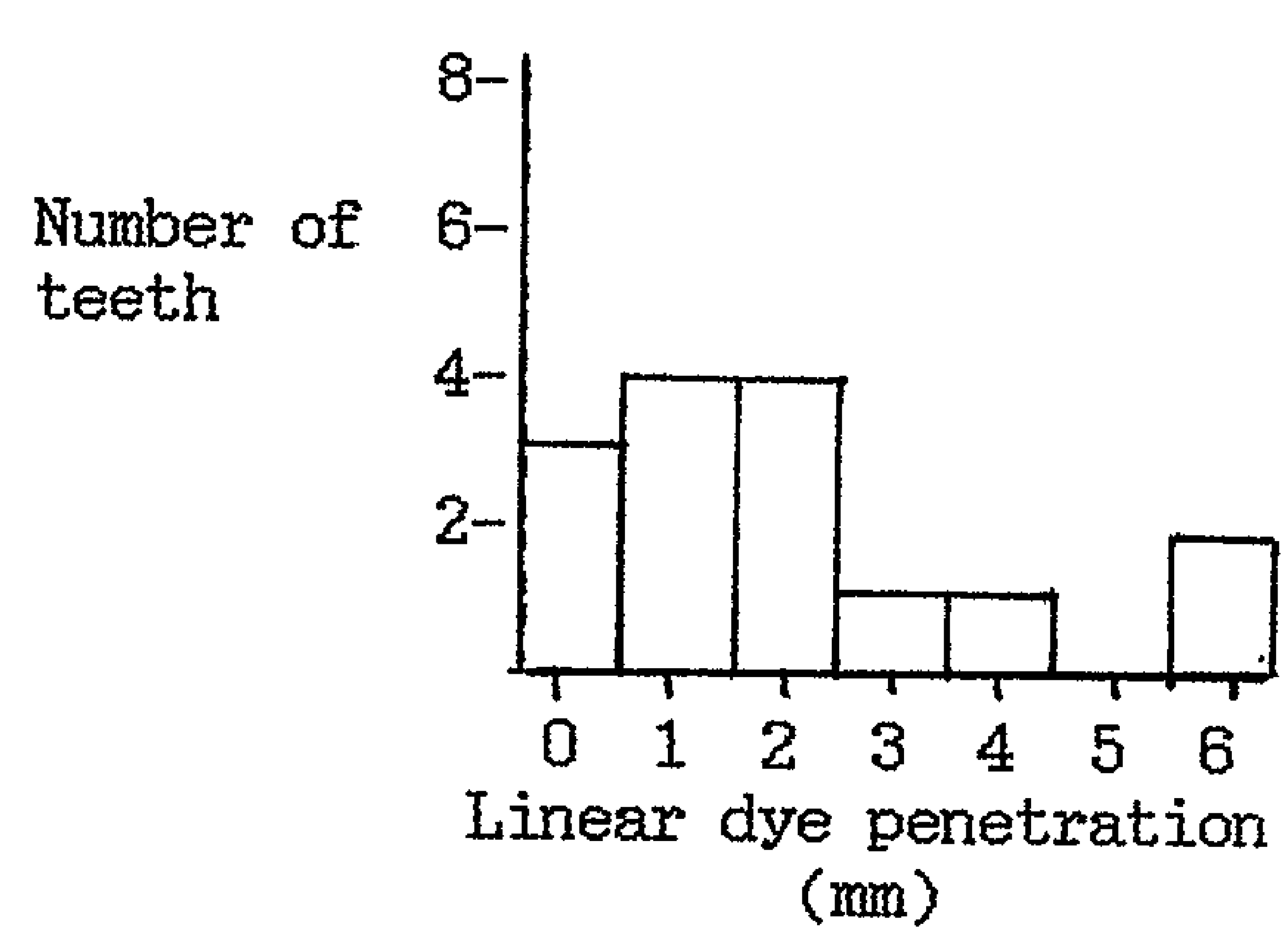

Fig. 8.4 Linear dye penetration for teeth obturated by Ultrafil.

The mean LDP values for the four different obturation techniques are shown in Figure 8.5.

The obturation techniques can be ranked in order of increasing LDP

McSpadden, Ultrafil, Enac, Lateral Condensation.

This finding was opposite to that for the ECL method of testing apical seal. (Section 7.4)

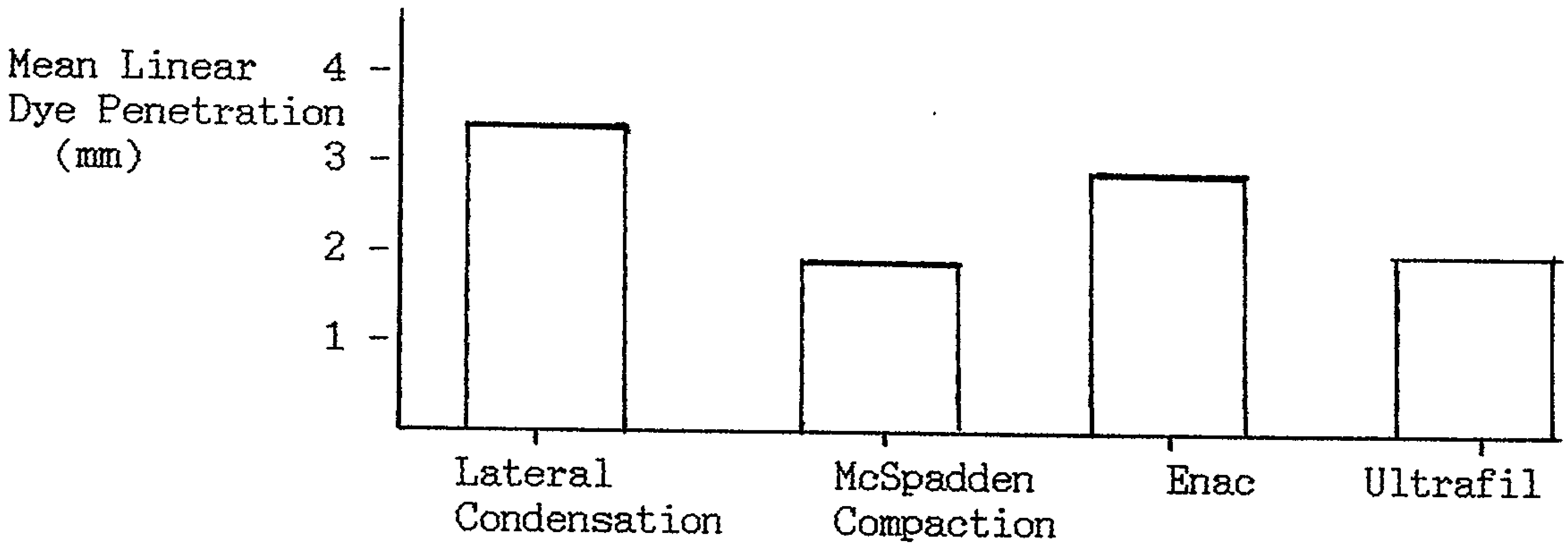

Figure 8.5 Mean linear dye penetration of the four obturation techniques.

Figures 8.6 to 8.13 show teeth exhibiting different lengths of linear dye penetration.

Figures 8.14 to 8.18 show examples of LDP for each of the four obturation techniques.

Interesting findings included the corrosion product build-up, in the coronal half of the root canal, resulting from the ECL experiment (Figure 8.19) and examples of corrosion causing the copper electrode to break (Figures 8.20-8.21).

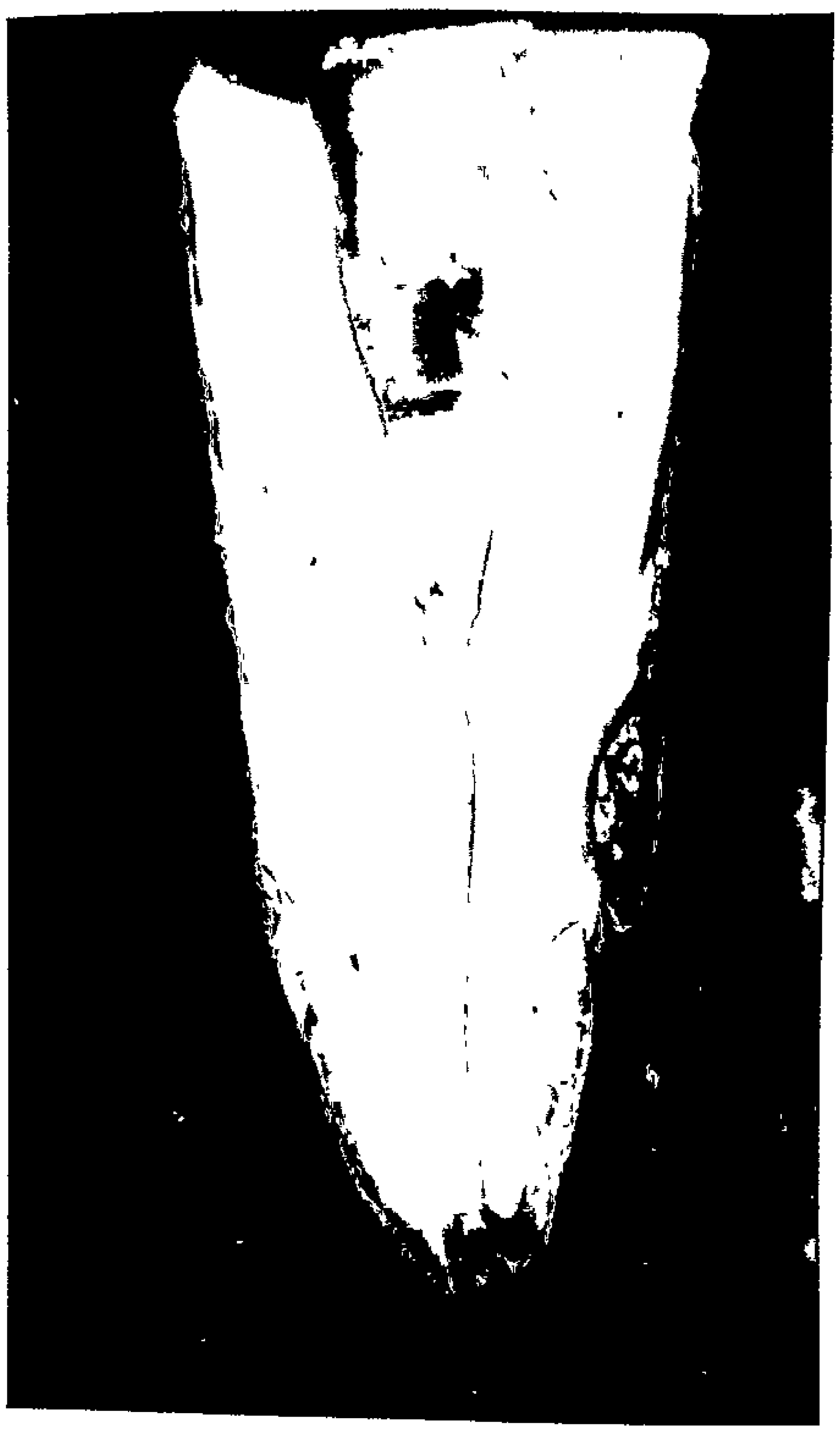

Figure 8.6 Sectioned root showing no linear dye penetration

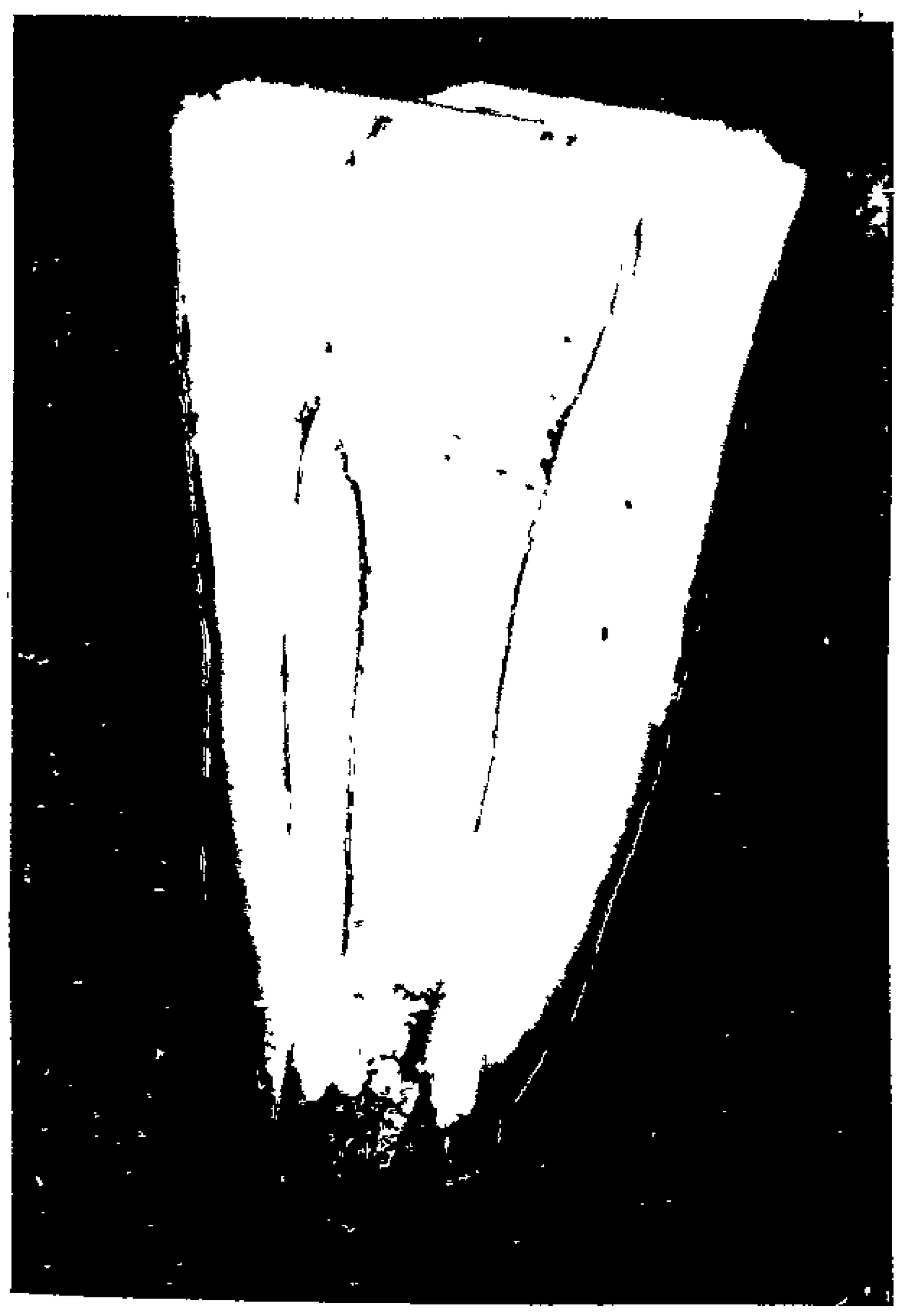

Figure 8.7 Sectioned root with 1 mm dye penetration

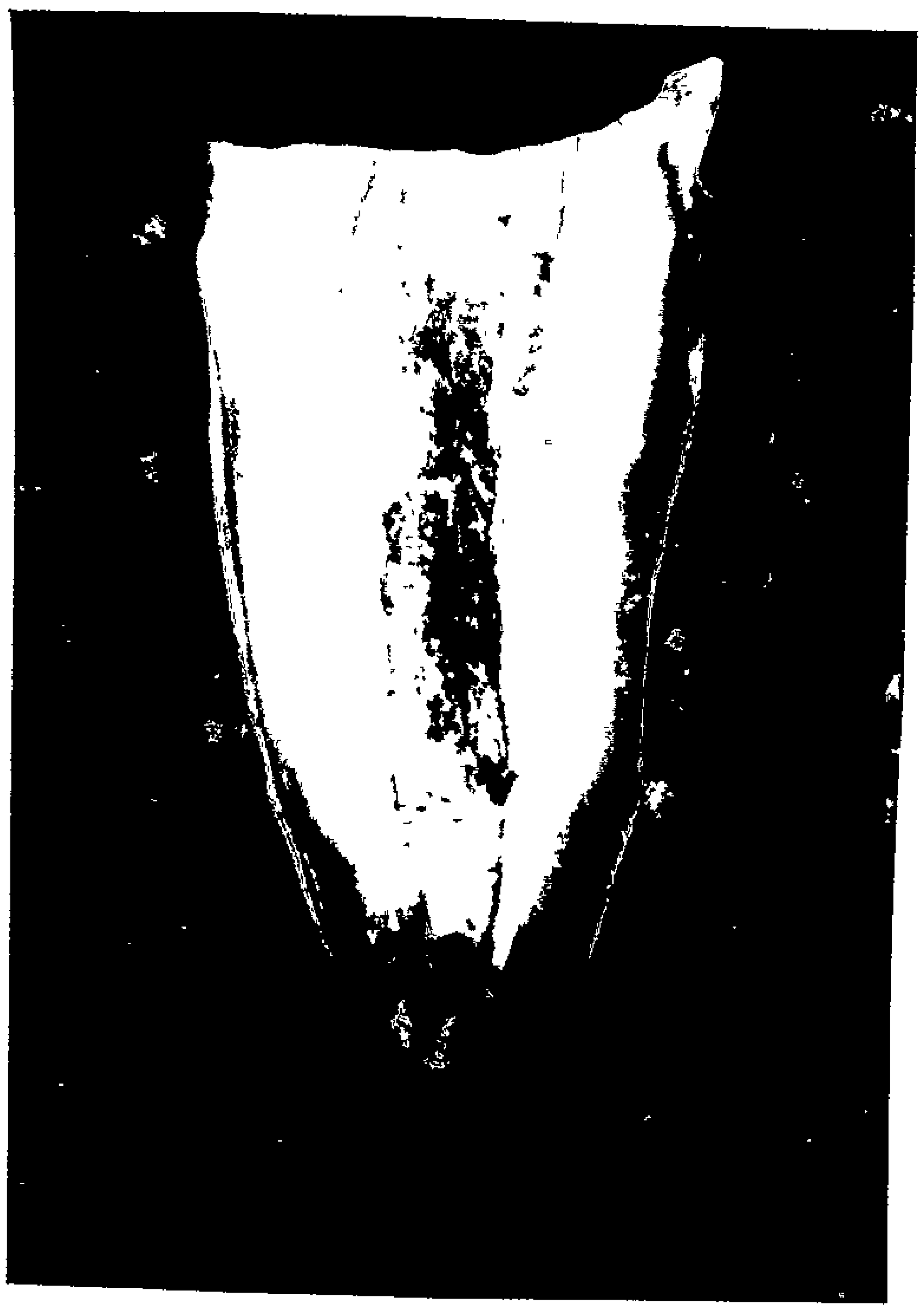

Figure 8.8 Sectioned root with 2 mm dye penetration

Figure 8.9 Sectioned root with 3 mm dye penetration

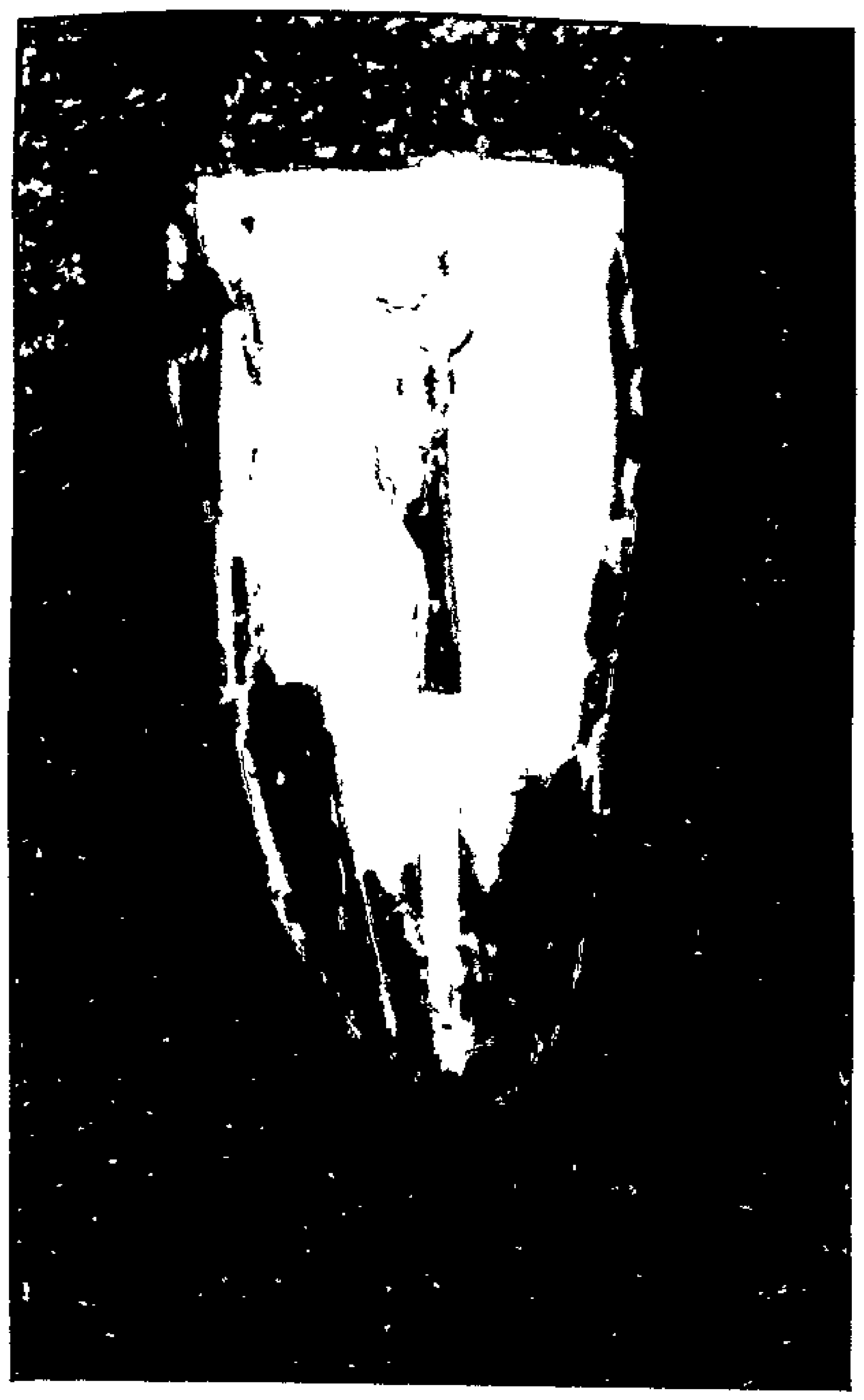

Figure 8.10 Sectioned root with no dye penetration

Figure 8.11 Sectioned root with 4 mm dye penetration

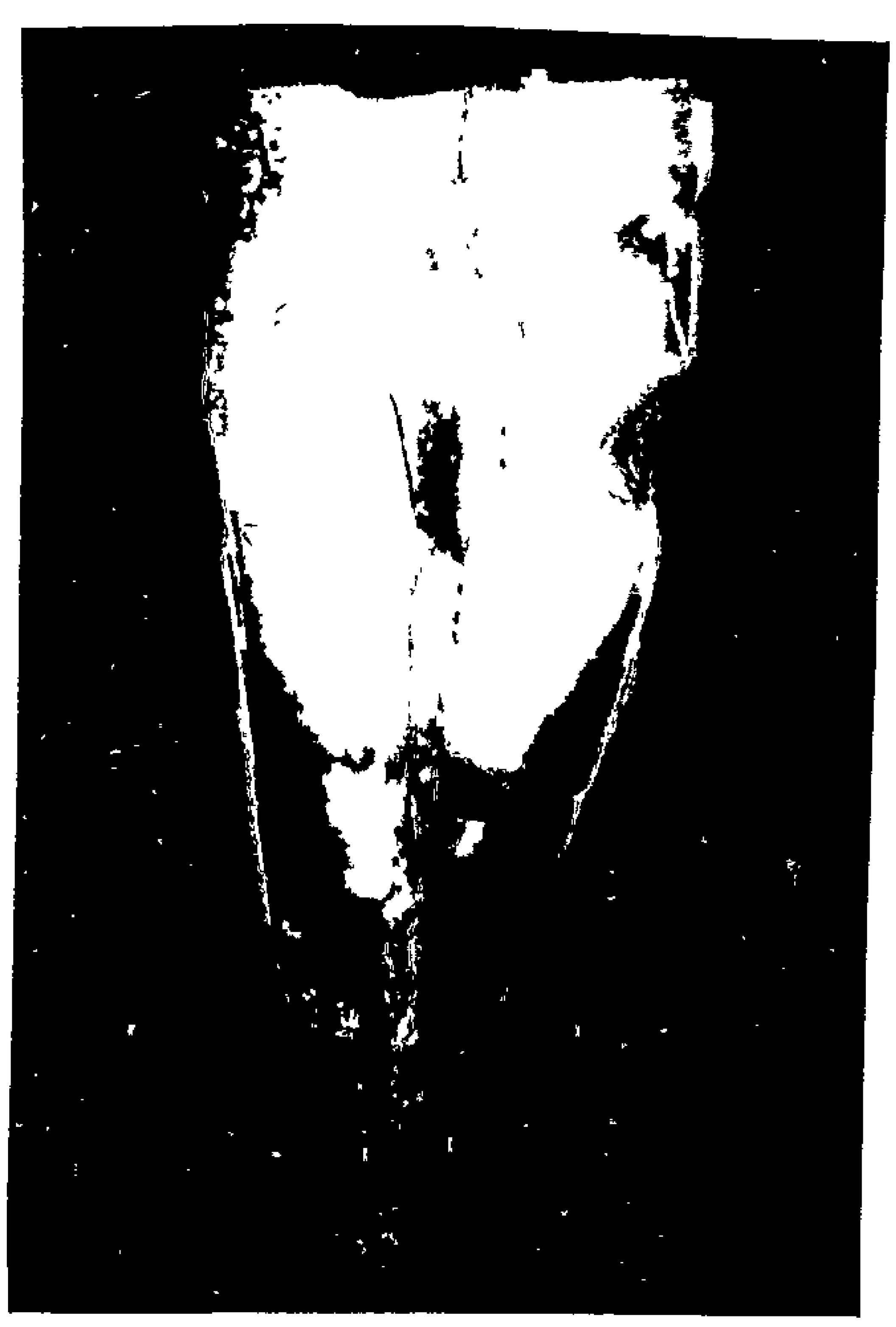

Figure 8.12 Sectioned root with 5 mm dye penetration

Figure 8.13 Sectioned root with 6 mm dye penetration

Figure 8.14 Sectioned root showing the sealer covering the gutta-percha mass Filled by Enac

Figure 8.15 Sectioned root with dye penetration in dentinal tubules. Filled by Ultrafil

Figure 8.16 Sectioned root with large volume of dye penetration. Tooth was filled by McSpadden.

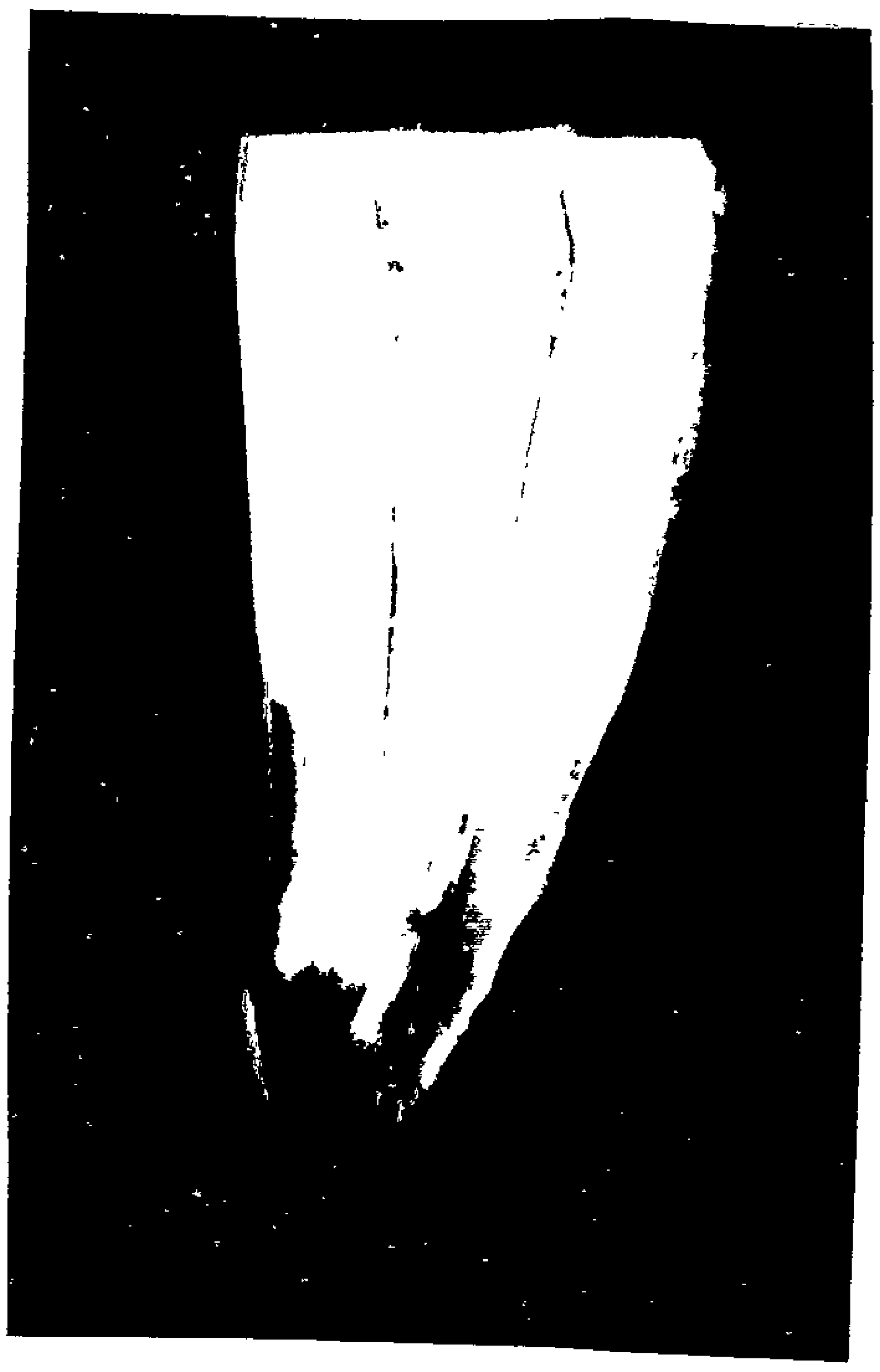

Figure 8.17 Sectioned tooth with open immature apex filled by lateral condensation.

Figure 8.18 Ultrafil filled teeth without sealer. The lack of seal is evident even though the gutta percha appears well adapted to the canal wall.

Figure 8.19 Sectioned root with 6 mm dye penetration which also had large amount of ECL
The built up of corrosion products is evident in the coronal portion of the root canal.

Figure 8.20 Sectioned root with no dye penetration. Note the large amount of corrosion products in the coronal half of the root canal.
The corroded end of the copper electrode still in the root canal.

Figure 8.21 Sectioned root with 6 mm dye penetration and showing signs of heavy corrosion during the electrochemical leakage technique.
The copper anode is in the canal.

8.2 Statistical Results

There was no significant difference in LDP between teeth obturated by lateral condensation, Enac and Ultrafil, nor was there any difference between Enac, Ultrafil, and McSpadden; however there was a significant difference between the lateral condensation and McSpadden techniques at the 99.5% level of confidence.

CHAPTER 9

RESULTS FOR RADIOGRAPHIC ADAPTATION (METHOD-C)

9.1 Introduction

The results for the radiographic examination assessing the level of adaptation of the obturated teeth are presented in this chapter. Clinically, the quality of the root filling can only be assessed by its radiographic appearance. Therefore, if a root filling shows a well-adapted, dense appearance, and is at the correct length, it is accepted as a good root filling. The radiographic adaptation results are used in Chapter 10 to determine if there is a correlation between the adaptation, electrochemical leakage (ECL) and the linear dye penetration (LDP) results.

9.2 Adaptation of Root canal filling

The root canal fillings were assigned one of the following ordinal scale categories by the author, based on the radiographic assessment.

Good (G): No voids present, the root filling is well adapted to the canal wall. The root filling has a dense appearance radiographically. (Fig. 9.1)

Acceptable (A): Voids, less than 0.5 mm in the longest dimension, present in the body of the root filling and against the walls of the root canal. These voids are not present in the apical three millimetres of the root canal. The root filling appears dense radiographically. (Fig. 9.2)

Poor (P): Voids more than 0.5 mm measured in the longest axis are present in the body of the root filling or against the walls of the root canal and voids may be present in the apical three millimetres of the root filling. (Fig. 9.3)

Figure 9.1 Radiograph of a root filled tooth showing "Good" adaptation to the root canal, with no voids and with an overall good radiographic density.

Figure 9.2 Radiograph of a root filled tooth showing a few small voids in the apical 2 mm of the root filling. This type of root filling is classified as "Acceptable".

Figure 9.3 Radiograph of root filled tooth showing several large voids in the body of the root filling. This type of root filling is classified as "Poor".

Table 9.1 presents the number of teeth exhibiting good, acceptable and poor radiographic adaptation for the four obturation techniques.

Table 9.1 The number of teeth exhibiting good, acceptable and poor radiographic adaptation for the four obturation techniques.

Obturation Technique	Number of teeth exhibiting radiographic evidence of adaptation		
	Good Adaptation	Acceptable Adaptation	Poor Adaptation
Lateral Condensation	11	4	0
McSpadden Compaction	12	2	1
Enac	7	7	1
Ultrafil	9	4	2

McSpadden had the most teeth with Good adaptation (12) followed by lateral condensation (11), Ultrafil (9) and Enac (7).

9.3 Length of the root canal filling

The length of the root canal fillings was assessed radiographically. Results are presented in Table 8.2. The following rating system was used:

Long (L) : Extrusion of gutta-percha through the apex. (Fig. 9.4)

Optimal (O): Gutta-percha within 0.5 mm of apical stop (Fig. 9.5) Sealer over-fill may be present.

Short (S) : Gutta-percha is more than 1 mm short of the apical constriction. (Fig. 9.6)

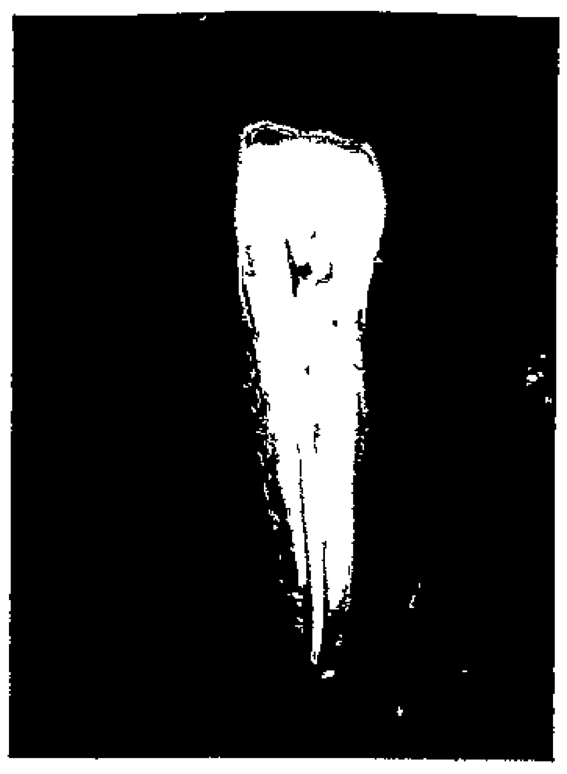

Figure 9.4 Radiograph of root filled tooth showing an over-extended root filling. The root filling is classified "Long"

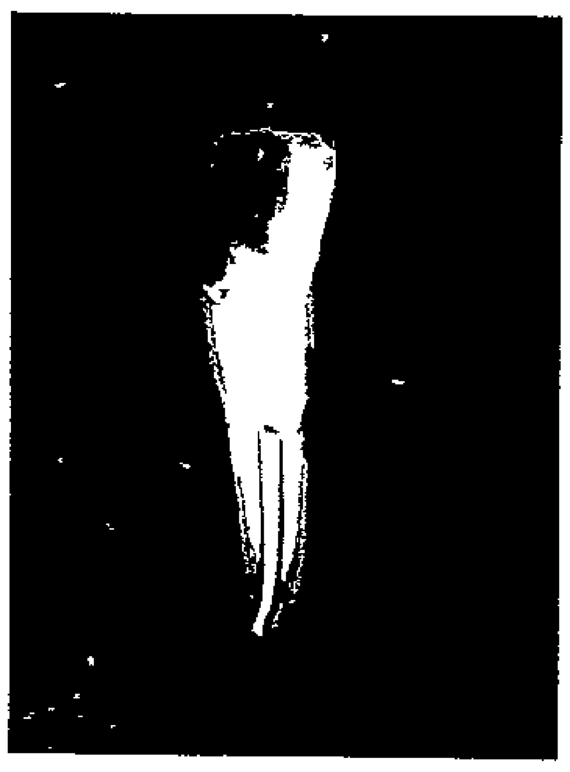

Figure 9.5 Radiograph of root filled tooth showing "Optimal" length.

Figure 9.6 Radiograph of root filled tooth showing a root filling "Short" of the optimal length.

Table 9.2 The number of teeth exhibiting long, optimal, and short root fillings for the four obturation techniques.

Obturation Technique	Number of teeth exhibiting radiographic evidence of length		
	Long Length	Optimal Length	Short Length
Lateral Condensation	0	15	0
McSpadden Compaction	4	7	4
Enac	1	13	1
Ultrafil	5	4	6

All 15 teeth obturated by the lateral condensation technique exhibited radiographic evidence of optimal length (Table 9.2). Teeth obturated by Ultrafil and McSpadden compaction showed poor length control compared with teeth obturated by lateral condensation or Enac. Only four teeth obturated by Ultrafil exhibited optimal length, six teeth had fillings that were too short, and five teeth exhibited over-fill.

The best results for length of root canal filling were obtained by lateral condensation, followed by Enac, McSpadden and Ultrafil.

CHAPTER 10

RESULTS OF ADDITIONAL EXPERIMENTS

10.1 Comparison of Results Obtained from Methods A, B, & C

Clinically, the quality of the root canal filling can only be assessed by radiographic examination. The operator looks for the following qualities in a root filling: It must show good adaptation to the apical half of the root canal, without any voids, and must show a dense radiopaque appearance. The length of the root filling must also be optimal without overfill or underfill. The aim of this section was to relate the results obtained in ECL and LDP experiments to the radiographic adaptation of the root fillings. With these results it may be possible to predict the clinical performance (sealing ability) of the different obturation techniques.

To facilitate these assessments, ordinal scale values were assigned to the interval data obtained in methods A and B, in the following way:

Mean electrochemical leakage	Ordinal Value assigned
(0.0–0.5 μA)	Good (G)
(0.5–1.0 μA)	Acceptable (A)
(>1.0 μA)	Poor (P)

Linear dye penetration	Ordinal value assigned
(0.0–1.5 mm)	Good (G)
(1.5–2.5 mm)	Acceptable (A)
(2.5–6.0 mm)	Poor (P)

Table 10.1 Comparison of the results obtained for each of the 15 teeth obturated by lateral condensation.

Asssessment Method	Results for the 15 teeth (by Tooth Number) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Adaptation*	G	G	A	A	G	G	G	G	G	G	A	G	G	G	A
ECL	G	G	G	G	G	P	G	G	G	G	P	G	G	G	G
LDP	G	P	G	P	P	P	P	A	G	G	G	P	P	P	P

* Radiographic

Table 10.2 Comparison of the results obtained for each of the 15 teeth obturated by McSpadden compaction.

Assessment Method	Results for the 15 teeth (by Tooth Number) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Adaptation*	G	G	G	G	G	G	G	G	G	G	A	G	G	P	A
ECL	A	P	G	G	G	G	P	G	P	G	P	P	A	G	P
LDP	G	G	G	P	G	P	G	G	P	A	G	G	P	G	P

* Radiographic

Table 10.3 Comparison of the results obtained for each of the 15 teeth obturated by Enac plasticized gutta-percha.

Assessment Method	Results for the 15 teeth (by Tooth Number) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Adaptation*	A	A	A	G	G	G	G	A	A	A	G	A	P	G	G
ECL	G	G	G	G	P	G	G	A	G	P	A	G	G	G	P
LDP	G	A	G	P	P	G	P	P	P	G	G	G	A	A	P

* Radiographic

Table 10.4 Comparison of the results obtained for each of the 15 teeth obturated by Ultrafil thermoplasticized gutta-percha

Assessment Method	Results for the 15 teeth (by Tooth Number) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Adaptation*	G	P	G	G	A	A	G	G	P	A	G	A	G	G	G
ECL	A	G	P	P	G	A	P	G	G	P	G	G	G	G	A
LDP	G	A	A	A	G	G	P	G	G	G	P	P	G	P	A

* Radiographic

Table 10.5

Comparison of the overall number of teeth showing good, acceptable or poor results for Adaptation, ECL and LDP which have been obturated by one of the four techniques.

Obturation Technique	Assessment Method	Number of Teeth: Good Result	Acceptable Result	Poor Result
Lateral Condensation	Adaptation*	11	4	0
	ECL	13	0	2
	LDP	5	1	9
McSpadden Compaction	Adaptation*	12	2	1
	ECL	7	2	6
	LDP	9	1	5
Enac Plasticized Gutta-percha	Adaptation*	7	7	1
	ECL	10	2	3
	LDP	6	3	6
Ultrafil Plasticized Gutta-percha	Adaptation*	9	4	2
	ECL	8	3	4
	LDP	7	4	4

* Radiographic

The results of the assessments for individual teeth are presented in Tables 10.1 to 10.4. These results are summarized in Table 10.5

Table 10.1 shows results for radiographic Adaptation, ECL and LDP, for the 15 teeth obturated by lateral condensation. Ten teeth (67%) showed identical readings for Adaptation and ECL, three teeth showed identical readings for Adaptation and LDP, and five teeth had identical readings for ECL and LDP However, only three teeth had identical readings for Adaptation, ECL and LDP By using the Kruskal-Wallis (H) test for the data in Table 10.5 (Lateral condensation) it was found that there was a significant difference among Adaptation, ECL and LDP results at an alpha level of 0.02 and degree of freedom (d.f.= 2). By observation of the data, results obtained using LDP were significantly worse than the results obtained using the ECL or Adaptation methods of assessment.

Table 10.2 shows results for Adaptation, ECL and LDP, for teeth obturated by McSpadden compaction. There were six teeth (40%) with identical readings for Adaptation and ECL, seven teeth with identical readings for Adaptation and LDP, and five teeth had identical readings for ECL and LDP However there were only three teeth with identical readings for Adaptation, ECL and LDP The Kruskal-Wallis test on data in Table 10.5 (McSpadden) found that there was a significant difference (alpha level of 0.05) among the overall Adaptation, ECL and LDP By observation, results obtained by radiographic assessment of Adaptation, were significantly better than those obtained by ECL or LDP.

Table 10.3 shows the results for Adaptation, ECL and LDP, for teeth obturated by Enac. There were five teeth (33%) with identical readings for Adaptation and ECL, three teeth with identical readings for Adaptation and LDP, and five teeth with identical readings for ECL and LDP Only one tooth had identical readings for Adaptation, ECL and LDP The Kruskal-Wallis test for data in Table 10.5 (Enac) found that there was no significant difference among the overall Adaptation, ECL and LDP results.

Table 10.4 shows the results for Adaptation, ECL, and LDP, for teeth obturated by Ultrafil. There were five teeth (33%) with identical readings for Adaptation and ECL, three teeth with identical readings for Adaptation and LDP, and six teeth with identical readings for ECL and LDP Only two teeth had identical readings for Adaptation, ECL, and LDP. There was no significant difference among the overall Adaptation, ECL and LDP results using the Kruskal-Wallis test on data in Table 10.5 (Ultrafil).

To determine if there was any correlation between ECL and LDP results for each obturation technique, Pearson's "r" was calculated using the original data (interval scale) and then tested to determine if the "r" was significantly different from zero at a 0.05 alpha level. No significant correlation was found. (Table 10.6)

Table 10.6 Correlation between electrochemical leakage and linear dye penetration.

	Obturation Technique			
	Lateral Condensation	McSpadden Compaction	Enac	Ultrafil
Pearson's "r"	+ 0.16	- 0.23	- 0.13	+0.18
Significantly different from zero Alpha= 0.05	No	No	No	No

In summary, significantly different results were obtained among Adaptation, ECL and LDP when the results for Lateral condensation and McSpadden were analysed. Results for the three evaluation methods for Enac and for Ultrafil were not significantly different.

Neither ECL nor LDP consistently provided results that better coincided with the results of the radiographic adaptation method of evaluation.

Of the 60 teeth tested in different ways and with different obturation techniques, only 9 had identical categories for all three evaluation methods.

9.2 An Assessment of the effect of daily exposure to ECL testing on 30 Day ECL results

An additional 15 teeth were mechanically prepared as previously described and obturated by lateral condensation using gutta-percha and ProcoSol sealer. The teeth were stored in saline, at room temperature for 30 days. On day 30 the teeth were prepared for ECL Measurements were taken after 24 hours exposure to 20 volts direct current.

Table 10.7

A comparison of 30 day ECL readings for teeth subjected to 30 days continuous ECL experiment and for teeth exposed to ECL at 30 days after storage in saline.

Group of Teeth	Number of teeth in different categories of ECL readings (µA)				
	0 µA	>0 but <0.5 µA	0.5 - 1.0 µA	>1 but <2 µA	>2µA
Lateral Condensation Continuous ECL (N=15)	12	0	0	0	3
Lateral Condensation Saline storage (N=15)	4	5	5	1	0

There is a substantial difference in ECL between lateral condensation continuous and lateral condensation saline groups (Table 10.7). With the lateral condensation continuous ECL group there were 12 teeth with zero leakage and 3 teeth with greater than 2 µA leakage (2.1 µA, 50.9 µA, 8.2 µA). With lateral condensation and saline storage until 30 days, only 4 teeth had zero leakage but no teeth showed leakage greater than 2 µA; 14 of the 15 teeth had ECL at 30 days that did not exceed 1.0 µA.

10.3 An assessement of the effectiveness of the ECL experiment in measuring microleakage.

An additional 15 teeth were mechanically prepared as previously described but were not filled. These teeth were then subjected to ECL, over 30 days to observe the pattern of leakage.

Table 10.8 shows the mean daily ECL measurements for the unfilled teeth. A high first day mean ECL of 1,810 μA decreased to 50.6 μA by day 5 (Fig. 10.1). By day 30 the mean leakage was 6.0 μA. It was also observed that by day 30, five teeth had broken away from the copper anodes because the copper anodes had corroded. (Fig. 8.20, 8.21)

10.4 Results of Electron Microprobe Analysis

At the end of the ECL tests, four teeth were sectioned vertically and mounted on a clear perspex block (Fig. 6.9) for electron microprobe analysis. No deposits of copper salts (corrosion products) were detected around the apical two millimetres of the root canals.

Table 10.8 Mean daily electrochemical leakage (ECL) of positive controls. (N= 15 at day 1)
Teeth were left empty after preparation with patent foramina.

DAY	Mean ECL (µA)	Standard Deviation (SD)	DAY	Mean ECL (µA)	Standard Deviation (SD)
1	1,810	460	16	18.5	18.8
2	184.7	160	17	56.4	157
3	168.3	222	18	18.7	32.2
4	61.4	42	19	17.4	36
5	50.7	39	20	19.5	39
6	57.5	60	21	21.2	41
7	64.1	77	22	19.7	40
8	70.7	91	23	17.6	34
9	39.5	35	24	15.9	32
10	33.5	24	25	7.3	3.6
11	29.7	21	26	7.5	4.2
12	28.6	22	27	7.2	4.1
13	26.9	22	28	6.8	4.3
14	26.2	23	29	6.6	4.4
15	26.2	26	30	6.0	4.5

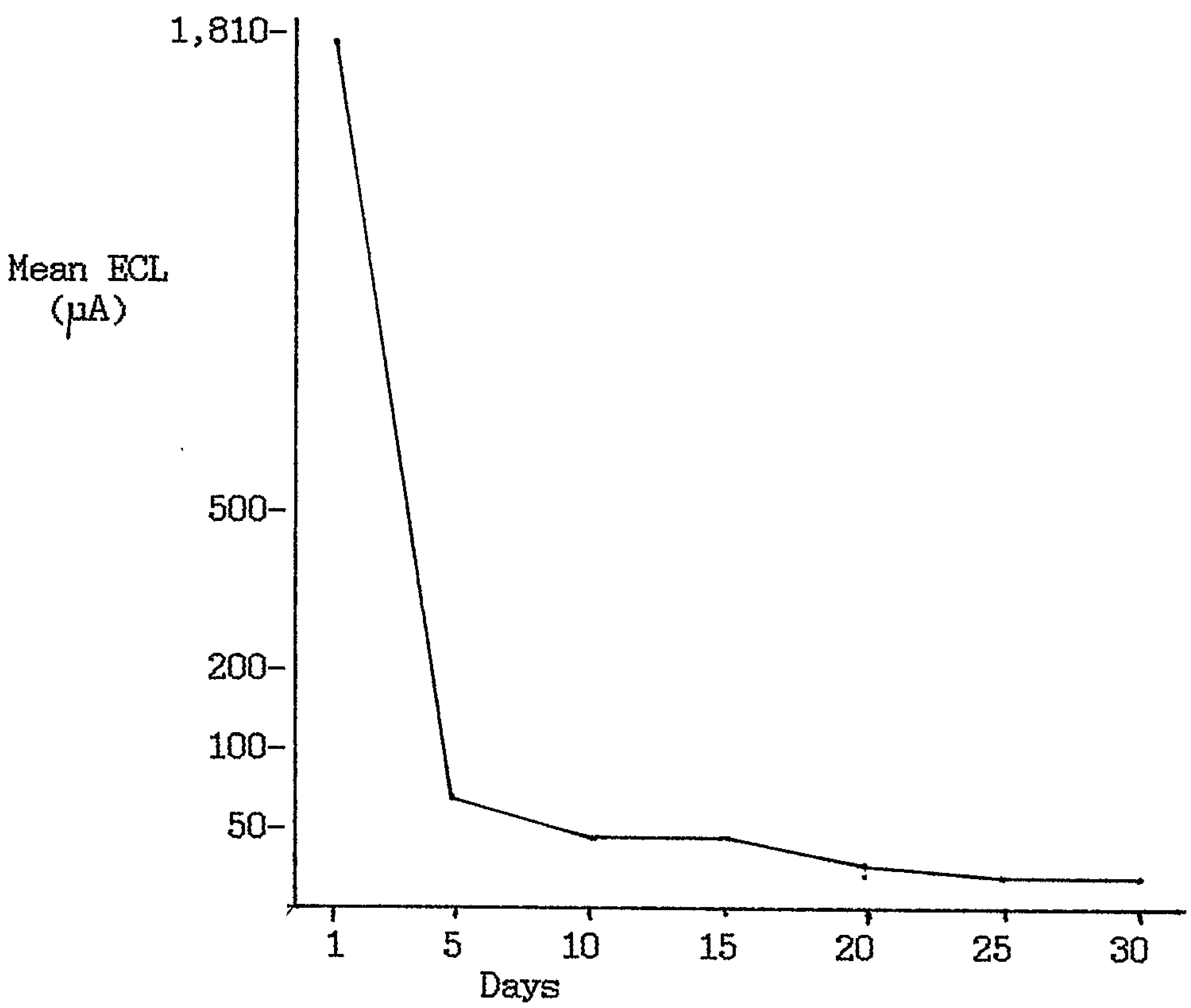

Figure 10.1 Mean ECL of positive controls (N=15) at day 1.
Teeth left empty with patent foramina.

10.5 An assessment of the effect of ECL on LDP

To assess the effect on LDP of 30 day exposure to ECL, fifteen teeth were mechanically prepared and root filled by lateral condensation of gutta-percha and ProcoSol sealer. The 15 teeth were stored in saline at room temperature for 30 days and were then immersed in 2 per cent methylene blue dye for 48 hours. These were compared with results for 15 teeth obturated by lateral condensation and subjected to ECL before immersion in dye to assess LDP Table 10.9 shows the LDP results of the teeth (a) exposed to ECL testing for 30 days and then LDP testing for 48 hours and (b) teeth stored in saline for 30 days and then immersed in dye for 48 hours.

Table 10.9

The influence of previous ECL testing on the LDP results

Group of Teeth	Linear Dye Penetration (mm)
30 Days ECL testing before LDP testing (N=15) (a)	0 1 1 1 1 2 4 4 4 4 5 5 6 6 6.
30 Days Saline storage before LDP testing (N=15) (b)	0 0 0 0 0 1 1 1 1 1 2 3 3 4 6.

It was found that teeth tested for ECL for 30 days before application of the LDP test exhibited a significantly greater leakage (LDP) compared with teeth stored in saline for 30 days before LDP testing (t-test, alpha= 0.02).

10.6 The Difference in ECL results between open (immature) apices and closed apices

The ECL results for 15 teeth filled by lateral condensation (Fig. 7.1) showed low leakage over the first 22 days and then a sudden increase to a mean leakage of 4 µA by day 30. However only three of the teeth showed this leakage after 22 days and it was found that these teeth had open (immature) apices. Three teeth with open apices had significantly greater leakage than teeth with closed apices.

Upon examination of the findings from the other three obturation techniques, no statistically significant differences were found between teeth with open apices and teeth with closed apices.

It was decided to examine the lateral condensation findings further. Fifteen teeth with immature open apices or apices artificially opened to a size 50 K file, were mechanically prepared and then obturated by lateral condensation of gutta-percha with ProcoSol sealer.

Table 10.10 shows the mean ECL over a 30 day period for teeth with open apices and obturated by lateral condensation.

A comparison of the ECL results for teeth with closed apices (N=10) and obturated by lateral condensation (Table 7.2) and for teeth with open apices (N=15, Table 10.10), confirmed (using a t-test) that there was a statistically significant difference in ECL between teeth with open and teeth with closed apices at an alpha level of 0.05.

Table 10.10 Mean daily electrochemical leakage (ECL) for teeth obturated by lateral condensation (N= 15), and having open apices.

DAY	Mean ECL (µA)	Standard Deviation (SD)	DAY	Mean ECL (µA)	Standard Deviation (SD)
1	0.00	0.00	16	0.66	0.40
2	0.00	0.00	17	1.07	0.70
3	0.00	0.00	18	1.50	0.90
4	0.00	0.00	19	2.90	1.60
5	0.00	0.00	20	4.50	5.10
6	0.00	0.00	21	8.30	12.90
7	0.00	0.00	22	7.50	11.10
8	0.00	0.00	23	6.10	8.20
9	0.00	0.00	24	5.20	4.70
10	0.00	0.00	25	3.40	2.90
11	0.00	0.00	26	2.30	1.80
12	0.01	0.03	27	1.90	1.60
13	0.03	0.08	28	1.40	1.50
14	0.09	0.23	29	0.90	0.70
15	0.24	0.39	30	0.50	0.20

CHAPTER ELEVEN

DISCUSSION

The purpose of this investigation was to test the apical seal achieved by four obturation techniques, by assessing dye penetration and electrochemical leakage. These measures of apical seal were then compared with the quality of adaptation of the root filling assessed on radiographs.

11.1 Electrochemical leakage (ECL) in root filled teeth.

Although the ECL technique has not been widely used to assess apical seal, it has been considered by some (Jacobsen and von Fraunhofer, 1976; Delivanis and Chapman, 1982; Lim and Tidmarsh, 1986) to be a useful method for quantitative measurement of leakage. The ECL technique involves the use of an anode inserted into the root canal and a cathode which is immersed in an electrolyte solution. A potential difference is applied accross the electrodes and the presence of any current flow between the two electrodes indicates leakage.

To test the ECL technique a preliminary study was conducted, where teeth were instrumented but left unfilled. The teeth were divided into positive controls, where the apical foramen was not covered by nail varnish, and negative controls, where the apical foramen was covered by nail varnish. If the ECL technique was valid no current flow should have been observed with the negative control teeth because of the impermeable varnish layers, while current flow should have been maximum with the positive control teeth throughout the test period. The positive control teeth exhibited immediate ECL, of between 2200-3000 µA, which decreased rapidly over time to plateau at 300-400 µA (Refer to Table 7.1). In other studies (Mattison and von Fraunhoher, 1983; Osins et al, 1983; Cohen et al, 1985) it was reported that their positive controls leaked immediately at approximately 1500 µA, but decreased more slowly to plateau at a level of approximately 800 µA.

Theoretically the positive control teeth should have leaked at the same level throughout the test period. This did not occur in any study. A possible explanation for this could have been the build-up of corrosion products around the copper anode which may produce a diffusion barrier to the flow of ions. It is possible that the relatively high initial leakage of the positive control teeth in this study caused greater deposition of corrosion products and a more rapid subsequent decrease in current flow.

In the main investigation, teeth obturated by lateral condensation and sealer showed minimum ECL for the first twenty days but then exhibited an apparent increase after day 22 (See Fig.7.1). Examination of the results from individual teeth revealed that the increase in mean ECL was due mainly to three of the five teeth subsequently found to have open immature apices . If these five teeth had been excluded from the calculations (Refer Fig. 11.1, 11.4), the mean ECL would have remained close to zero.

An ECL experiment was subsequently performed on teeth with open apices to ascertain whether there was a difference in leakage pattern between open and closed apex teeth. Fifteen open apex teeth, or teeth artificially prepared through the apex with a number 50 K file, were obturated by lateral condensation and sealer. It was found (Table 10.11) that the mean ECL for teeth with open apices began to increase about day 12, reached a maximum of approximately 8.3 μA at day 21 and then decreased to almost 0.5 μA by day 30. The increase in ECL after day 12 may have been the result of sealer dissolution in the first 10 days which could have allowed increased ionic flow and thereby increased ECL. The decrease after maximum ECL at day 22 may have resulted from corrosion products around the anode. These results showed that there was a statistically significant difference between the open and closed apex teeth.

It is difficult to compare the results from this investigation with those obtained in other studies because most studies (Delivanis and Chapman,1982; Mattison and von Fraunhofer 1983; Osins et al 1983; Lim and Tidmarsh 1986) used the ECL technique to evaluate the sealing properties of root canals filled <u>only</u> with sealer rather than, as in this study and in clinical practice, canals filled with gutta percha and sealer. However, Delivanis and Chapman (1982), Mattison and von Fraunhofer (1983) and Osins et al (1983) all showed a slow increase in ECL over the first ten days which reached a steady level after day 15. Each of these studies suggested that the increase in mean ECL was related to sealer dissolution and the production of microscopic spaces where ionic leakage could occur. However, none of these studies with sealer-filled canals reported a subsequent decline in leakage over a 30 day period. The above mentioned studies do not appear to relate their findings of sealer dissolution with the ECL experiment to any clinical situation.

Teeth obturated by McSpadden compaction appeared to exhibit high initial ECL which decreased to a minimum by day 21 and was followed by some fluctuation in ECL to day 30. The high initial mean ECL was mainly attributable to one tooth which was subsequently found to have a vertical root fracture along the apical half of the root canal. If this tooth and one tooth found to have an open apex were excluded from the results, the mean ECL of teeth filled by McSpadden compaction would have been at a lower level (Refer Fig. 11.2) and the ECL pattern of teeth obturated by McSpadden compaction could have resembled that of teeth obturated by lateral condensation. The occurrence of the root fracture, however, is a cause for some concern, as this may have been associated with the obturation technique itself.

The teeth obturated by Ultrafil exhibited a very high average early ECL which decreased to almost zero after the first five days. Most of the leakage was observed with two teeth which were found to have open apices. The other thirteen teeth were exhibiting very low ECL. The cause of the very high initial leakage could be because no sealer was used with the Ultrafil technique and the presence of the two open apex teeth (as described for teeth in the open apex study). Without the two open apex teeth the mean ECL was at a very low level (Refer Fig. 11.3, 11.4) The subsequent fall in leakage may have resulted from the build-up of corrosion products (Fig. 8.19) around the copper anode or from the consumption of chloride ions during the experiment.

Teeth obturated by Enac and sealer exhibited a low continuous pattern of leakage, which fluctuated between 0.5 and 1.0 μA. No fractured or open apex teeth were found to have been included.

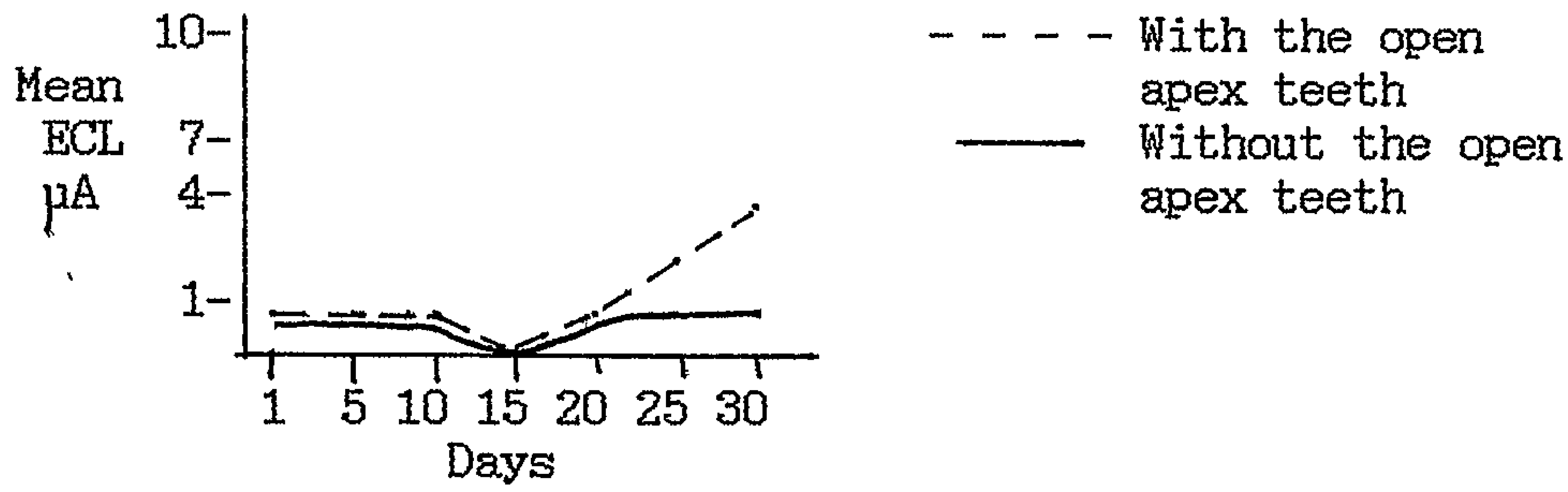

Fig 11.1 Teeth obturated by lateral condensation and sealer. With the five open apex teeth, ECL increases at day 22. Without the inclusion of the five open apex teeth, the ECL would be at a constantly low level during the 30 day period.

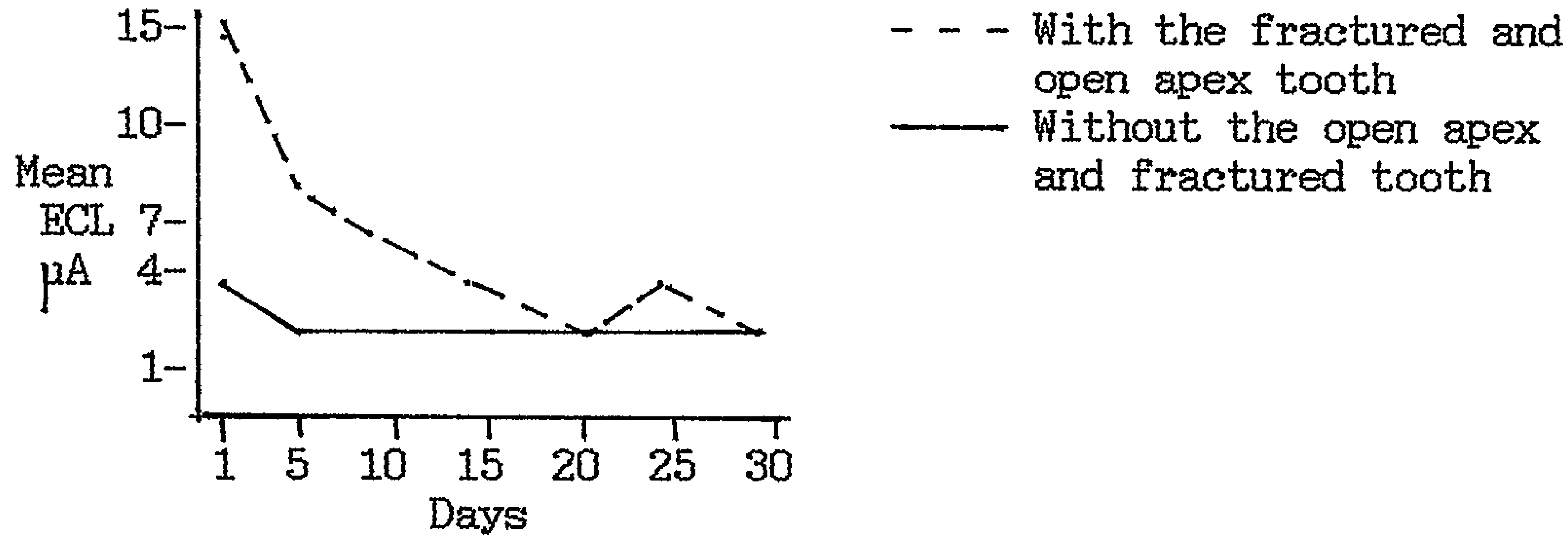

Figure 11.2 Teeth obturated by McSpadden compaction and sealer. With the fractured and open apex teeth, the ECL is generally greater than when these two teeth are excluded.

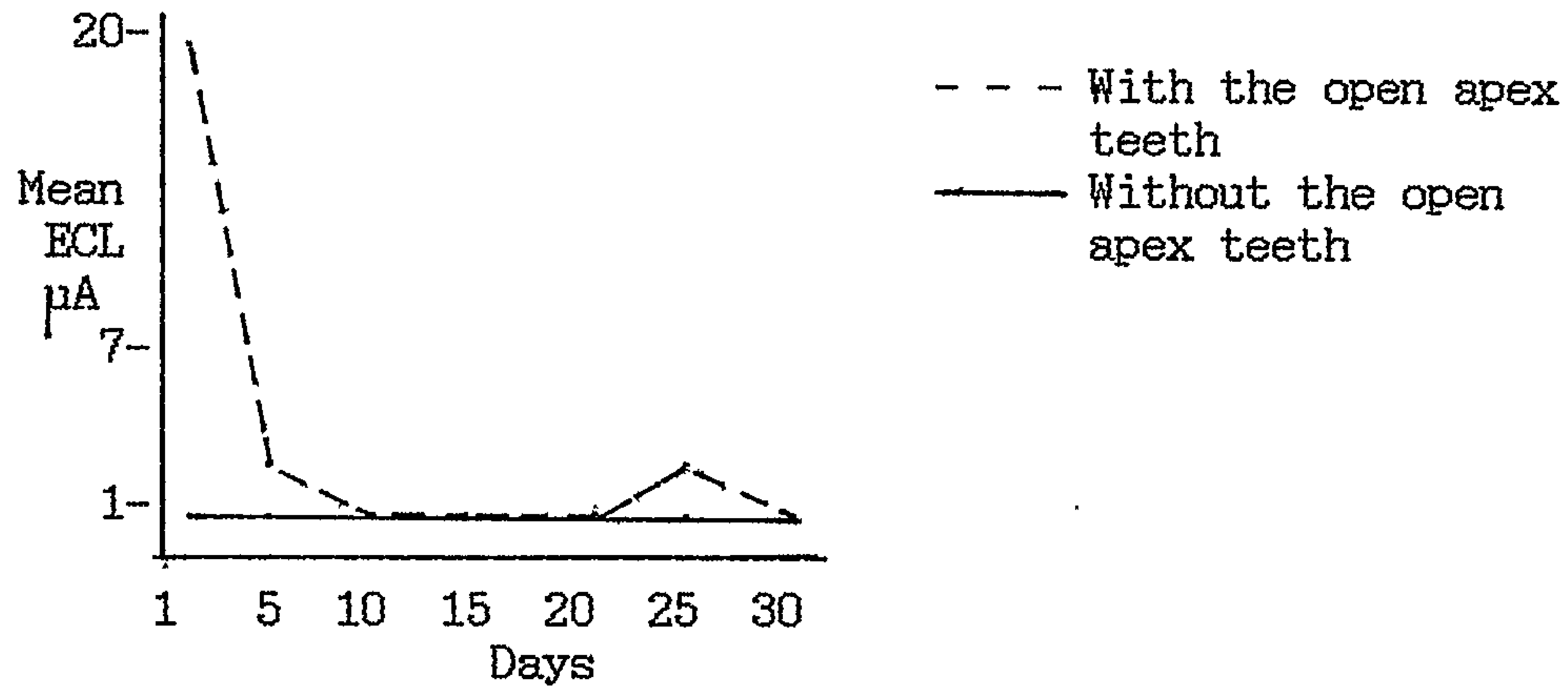

Figure 11.3 Teeth obturated by Ultrafil without sealer. Without the open apex teeth the ECL remains at a constant low level.

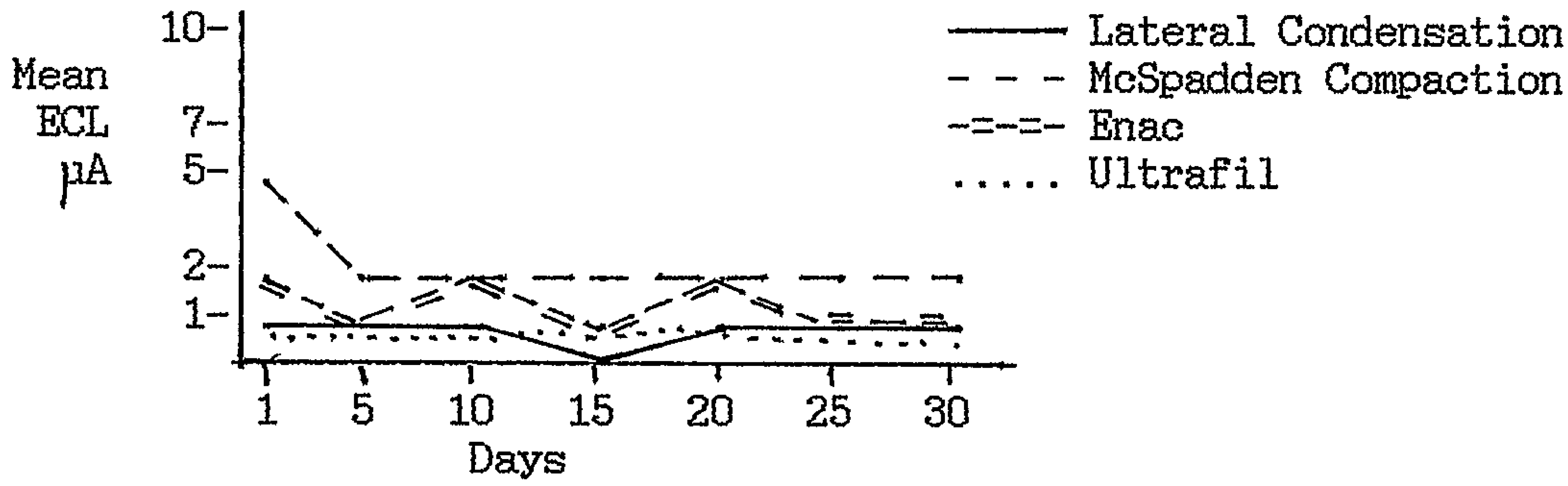

Figure 11.4 A comparison of the teeth obturated by the four obturation techniques. The lateral condensation, Ultrafil and the McSpadden techniques are without the open apex and fractured teeth.

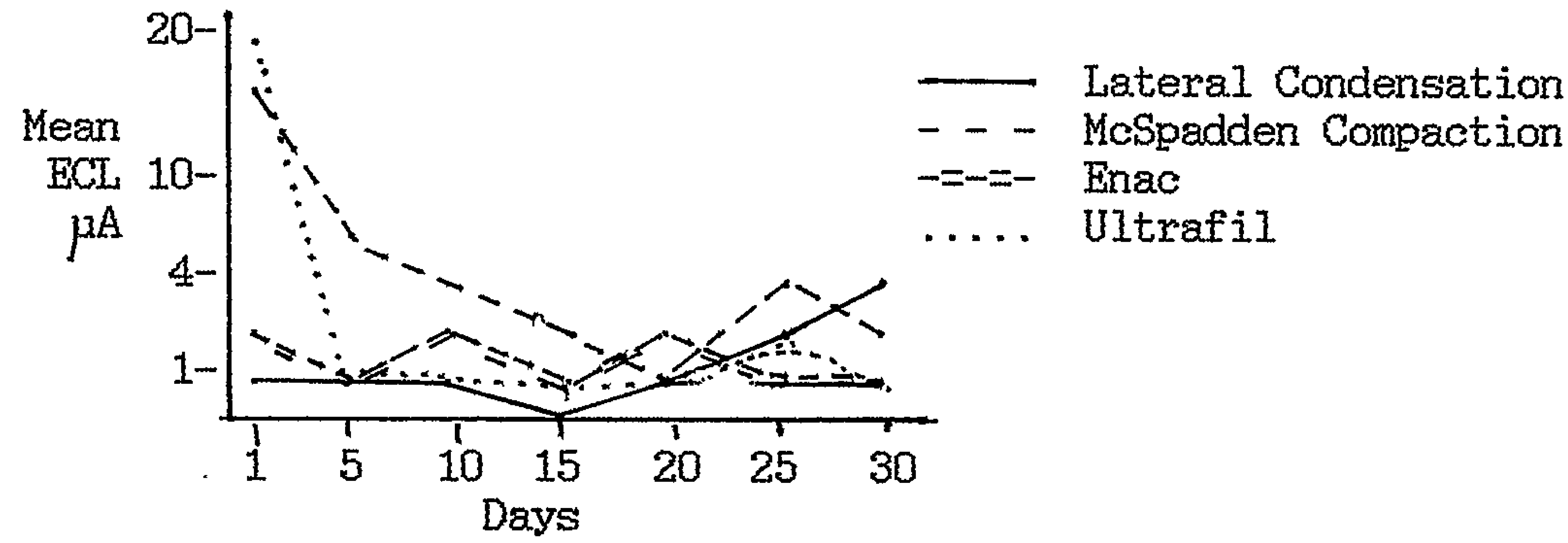

Figure 11.5 A comparison of the teeth obturated by the four obturation techniques including open apex and fractured teeth. (As shown previously in Fig. 7.5)

To assess whether the continuous nature of the ECL testing had an effect on the results over the 30 day period, 15 teeth were obturated by lateral condensation and sealer, stored in saline for 30 days and then tested for ECL. The results were shown in Table 10.8. At 30 days, only four teeth of the 30-day-stored group showed zero ECL compared to twelve teeth which showed zero ECL at 30 days after continuous ECL testing over 30 days. There were no teeth with ECL greater than 2μA in the 30-day-stored group. Three teeth exhibited more than 2 μA of leakage after 30 days of continuous testing; these were the three teeth with open apices. With the exception of these open apex teeth, the effect of continuous ECL testing was to reduce the ECL measured at 30 days when compared to teeth stored for 30 days before testing. The findings suggested that the continuous nature of the ECL testing method itself could influence the ECL results during and at the end of a 30 day period.

This finding is of importance when attempting to correlate ECL and LDP findings at 30 days. However, when comparing only ECL results, it must be assumed that the ECL method had a similar potential effect on the results for all obturation techniques.

A comparison among techniques for ECL findings is therefore possible, although interpretation of the results in absolute terms is difficult because it is apparent that there is currently an incomplete understanding of the factors affecting results obtained with the ECL method.

When the known problems of the eight teeth with open apices and the tooth with the root fracture are omitted, **the ECL results for the four obturation techniques appear to be very similar** (Refer Fig. 11.4). Although differences were not statistically significant, teeth obturated by the lateral condensation technique tended to leak less at most times than those obturated by the McSpadden technique generally had the highest leakage.

On the other hand if the results for teeth with the open apices and the root fracture are included, and using the median scores (Table 7.6) for ECL, the obturation techniques would be ranked in increasing order of leakage: Lateral condensation, Enac, Ultrafil, McSpadden. Teeth obturated by McSpadden compaction tended to show the most leakage, while teeth obturated by lateral condensation exhibited minimal leakage. Even so, the difference in the results was not statistically significant at an alpha level of 0.05 ($P > 0.05$).

It is not possible to make any definite conclusions on the relative sealing properties of the various obturation techniques based on the ECL results.

11.2 Linear dye penetration (LDP) into root filled teeth

At the end of the ECL experiment, that is, after 30 days continuous ECL testing, each group of 15 teeth was immersed in 2% methylene blue dye for 48 hours. Longitudinal sectioning of the roots enabled the assessment of LDP along each wall of the root canals. Longitudinal sectioning was selected, because it was a technique used by many authors (Delivanis and Chapman, 1982; Zakariasen and Stadem, 1982; Ishley and ElDeeb, 1983; and ElDeeb, 1985).

When all 15 teeth are included, teeth obturated by lateral condensation exhibited a greater mean LDP than teeth obturated by McSpadden compaction which showed the least ammount of LDP. (Refer to Fig.8.5) The difference between the lateral condensation and McSpadden results was statistically significant at an alpha level of 0.05.

Generally, when leakage has been tested using LDP without previous ECL, the lateral condensation technique has been found to exhibit less LDP than other obturation techniques (Zakariasen and Stadem, 1982; O'Neil et al, 1983; Beatty, 1987; Gee, 1987; Mann and McWalter, 1987). In the present experiment, the lateral condensation technique exhibited more LDP than the other obturation techniques. Delivanis and Chapman (1982) tested teeth for LDP after exposure to ECL. They filled the root canals with sealer cement only without using any gutta-percha. A direct comparison with their results is therefore not possible.

Teeth obturated by McSpadden compaction and sealer exhibited significantly less LDP than teeth obturated by lateral condensation and sealer. There may be several explanations for this. One possible explanation for this finding may be related to the greater number of open apex teeth included in the lateral condensation group (five) compared to the McSpadden group (one, plus one vertical root fracture). If these open apex teeth are omitted, the difference, in the LDP results between teeth obturated by lateral condensation and McSpadden compaction, is negligible (Table 11.1).

Table 11.1 Mean Linear Dye Penetration of teeth obturated by lateral condensation and McSpadden compaction

Type of apex	Mean LDP (mm) for two obturation techniques			
	Lateral Condensation		McSpadden Compaction	
	N *	LDP	N *	LDP
Including open apex teeth	15	3.3	15	1.7
Excluding open apex and fractured teeth	10	1.8	13	1.5

* Number of teeth evaluated

Another explanation, for the poor LDP results for teeth obturated by lateral condensation, could have been related to the previous exposure of the teeth to the ECL experiment. During the 30 day ECL testing period, the continuous immersion of teeth in an electrolyte solution may have caused dissolution of the sealer cement thereby creating a pathway for the penetration of dye into the root canal. As noted previously (11.1), other authors using the ECL method have suggested the potential for sealer dissolution in this method of testing.

To investigate this further, LDP results for root filled teeth immersed in dye after 30 days of continuous ECL, were compared with results for root filled teeth stored in saline for 30 days. A statistically significant difference was found between these two sets of LDP results (Refer Table 10.10). This tended to confirm that prior ECL testing does affect LDP results at 30 days, probably by increasing the mean LDP as a result of sealer dissolution.

Several studies (Kerekes and Rowe, 1982; Tagger et al, 1983; Tagger et al, 1984; Kersten et al, 1986a) have shown that teeth obturated by thermomechanical compaction (McSpadden) and sealer exhibited less LDP than teeth obturated by lateral condensation and sealer. Wong et al (1981) found that the McSpadden technique had the ability to replicate root canals significantly better than lateral condensation. Eguchi et al (1985) found that teeth obturated by lateral condensation had significantly more sealer and less gutta-percha in the apical third of the root canal than teeth obturated by McSpadden compaction. Peters (1986), in an in-vitro study, evaluated the solubility of sealer in distilled water over two years and found that sealer was easily dissolved from tooth sections obturated by lateral condensation, whereas very little sealer was dissolved from teeth obturated by McSpadden compaction. "Distilled water appeared to have little effect on gutta percha or a mixture of gutta percha and sealer such as occurs when using the thermomechanical technique." (Peters, 1986)

11.3 Adaptation of root canal fillings as assessed on radiographs

Teeth were assessed by the author for adaptation and length of root filling on radiographic examination using a simple grading system. The teeth were placed in one of three categories for adaptation:- good, acceptable and poor (Fig. 9.1-9.3). Three categories were used to describe the length of the root filling:- long, short or optimal (Fig. 9.4-9.6).

Teeth obturated by lateral condensation had the best adapted fillings and all teeth showed optimal length. This finding was consistent with that of Ishley and ElDeeb (1983), Elkerton (1984), Kersten et al (1986a) and Beer et al (1987). The McSpadden technique showed good adaptation, but poor length control which was consistent with the findings of Kerekes and Rowe (1982) and Kersten et al (1986b). Somewhat surprisingly the teeth obturated by Enac had only fair adaptation results but good length control. There are no known studies that have looked at the radiographic adaptation of teeth obturated by Enac. Teeth obturated by Ultrafil showed fair adaptation results but very poor length control. This finding is supported by Abou-Rass (1984) and George et al (1987).

Although the relative importance of adaptation and control of length is a controversial subject, the findings for the radiographic assessment indicated that Lateral condensation performed best and suggested that Enac (providing good control of length) may have been preferable, overall, to McSpadden and Ultrafil.

11.4 Comparison of findings from the three techniques of assessment

It is of interest to attempt to compare the relative assessments for the four obturation techniques using each of the three methods of assessment. The rankings are presented in Table 11.2. It should be noted that differences between techniques were often not statistically significant and that the relative importance of adaptation and control of length is difficult to define.

Because of the many factors that were found in this study to influence results, it would be inappropriate to attempt to derive too much information from this comparison.

Table 11.2 A comparison of the results for ECL, LDP and Radiographic assessment between the four obturation techniques.

Obturation Techniques	Ranking of Obturation techniques *				
	ECL Method		LDP Method		Radiographic assessment
	All spec ** (n=15)	Excl OA&F (n)***	All spec	Exclud OA&F (n)	(n=15)
Lateral Conden	1	1 (10)	4	1 (10)	1
McSpadden Compac	4	2 (13)	1	1 (12)	3
Enac	2	2 (15)	2	2 (15)	2
Ultrafil	3	2 (13)	3	2 (13)	4

* 1= best; 4= worst
** All specimens (n=15)
*** Excluding specimens with open apices and visible fracture. Number of specimens (n) is shown in brackets.

It is evident however, that, if those teeth known to have open apices or fracture are omitted, both ECL and LDP tend to relate reasonably well to each other and to the radiographic assessment. The lateral condensation technique tended to be the best and the Ultrafil technique tended to perform more poorly than others.

11.5 Clinical Implications of the study

The quality of a root canal filling can be assessed clinically by radiographic examination and by the patient's subjective symptoms (Elkerton, 1984; Kersten et al, 1986a). Many authorities in Endodontics, such as Grossman, Ingle, Nicholls and Schilder, recommend that a symptom-free tooth, exhibiting the radiographic appearance of a well-condensed root filling at the correct length, has a high probability of remaining free of symptoms and of maintaining a good seal.

In this study it was found that several teeth with good radiographic adaptation and length of root filling showed poor sealing ability while several teeth with poor radiographic adaptation appeared to exhibit good sealing ability. It is therefore very difficult to relate the results of an in-vitro test directly to the clinical situation. Just because a root canal filling exhibits leakage to an ionic solution with a maximum particle size of less than 50 nm, does not necessarily mean that it would allow bacteria and their products to penetrate between the canal walls and the root filling. Beyer-Olsen et al (1983) found that the radiographic detection of voids was not necessarily accompanied by lack of material in that region. They also found that teeth with the radiographic detection of voids did not always exhibit leakage. As a consequence of their findings Beyer-Olsen et al (1983) concluded that a radiographically well-adapted root filling had a good chance of being resistant to leakage and that the presence of small radiographic voids in root fillings should not lead to the assumption of leakage in-vivo.

It is, of course, recognized by clinicians that a radiograph is a two dimensional picture of a three dimensional object and, clinically, the radiograph shows the bucco-lingual view but not the mesio-distal view. In particular, the quality of adaptation to the mesial and distal walls of the canal are usually identified clearly in this bucco-lingual view. However, the bucco-lingual view may not be totally reliable because the root filling may be condensed well against the buccal or lingual wall and yet there may be a large void present in the body of the root filling which may not be detectable on the radiograph. A mesio-distal or an oblique view, if possible, may show the presence of voids along the buccal or lingual walls of the root canal or in the body of the root filling.

In summary, there appears to be a reasonable relationship between ECL, LDP and the radiographic assessment of root filled teeth. This general agreement between ECL, LDP and radiographic assessment appears to be important clinically, when one is assessing the quality of a root canal filling.

The effect of the open apex and the fractured teeth on the results is of some concern. Clinically, the quality of the apical seal on teeth with open apices may be inferior to those with closed apices. It may therfore be prudent to attempt apexification procedures before attempting to obturate the root canal.

CHAPTER 12

CONCLUSION

1. It was found that the ECL results for the four obturation techniques were very similar. Although differences were not statistically significant, teeth obturated by the lateral condensation technique tended to leak less at most times than those obturated by the McSpadden technique, which generally had the highest leakage.
2. Teeth with open apices exhibited increased mean ECL during the 30 day period.
3. Continuous ECL testing appeared to affect 30 day ECL results.
4. When open apex teeth were excluded, there was no significant difference in mean LDP between the lateral condensation, McSpadden compaction and the Enac obturation techniques. Teeth obturated by Ultrafil exhibited relatively high mean LDP, probably because no sealer was used.
5. Continuous 30 day ECL testing appeared to affect LDP results.
6. Teeth obturated by lateral condensation and sealer exhibited good radiographic adaptation and length control while teeth obturated by Ultrafil exhibited relatively poor radiographic adaptation and length control.
7. There was a moderate relationship between ECL, LDP and the radiographic assessment of root-filled teeth. This general agreement between ECL, LDP and radiographic assessment is of clinical importance, when one is assessing the quality of a root canal filling.

8. Interesting findings included:

i: The build-up of corrosion products during the ECL experiment has not been reported by other studies.

ii: The vertical root fracture associated with the McSpadden technique

iii: The different leakage patterns associated with open and closed apex teeth.

9. Future investigations could examine:

i: a more standardized tooth sample (all closed apices).

ii: the build-up of corrosion products which may be able to be eliminated by exposing teeth to ECL testing once a day rather than continuously over the 30 day period.

iii: filled teeth by the same technique could be tested for apical seal using either the ECL method or the LDP method independently. With this type of independent testing, the true relationship between ECL and LDP results might be established.

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ORIGINAL ARTICLE

CERAMIC BRACKET DEBONDING: THE EVALUATION OF TWO DEBONDING TECHNIQUES AND THEIR EFFECT ON ENAMEL

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second molar teeth. The resultant force appears to be lingually directed and removal of the third molar (and thus the force) results in the subsequent buccal movement of the second molar teeth. This is presumably under the influence of functional occlusal forces. The force appears to affect only the adjacent second molar teeth as there was no change in arch width or arch depth seen at any other level. These results are in agreement with those Southard, Southard and Weeda[9] who found that a mesially directed force was absent in dental arches with impacted third molar teeth.

Significant disturbances to the masticatory system have been demonstrated electromyographically with experimental occlusal interferences of only 0.5 mm[13]. Mandibular second molar teeth were observed to move distances of similar magnitude in this study. Therefore the potential of impacted mandibular third molar teeth to produce tooth movement which exceeds the adaptive potential of the masticatory system and may produce mandibular dysfunction should be recognised. At surgery, it was noted that many mandibular mesioangular impactions were adjacent to a second molar tooth which had a lingual tilt. The third molar was often obliquely placed in the investing bone. In these cases the crown of the third molar was lingually orientated and was wedged tightly against the distal surface of the second molar. This position would be expected to give rise to a resultant lingual vector of force. The degree of transverse alignment of the impacted third molars and the amount of contact between these teeth and the second molars was not measured at the time of surgery. Thus objective evidence to substantiate this hypothesis cannot be presented and further study in this area is required.

Conclusions

1. Mandibular arch width increased significantly at the level of the second molar teeth following third molar removal.
2. The largest increase in mandibular arch width was seen in cases where bilateral mesioangularly impacted third molars were removed.
3. The largest tooth movements subsequent to surgery were seen in cases where lingual tipping of the second molar teeth was present before surgery.
4. The ability of the mandibular third molars to affect the position of teeth in the arch appears to be limited to the adjacent second molar teeth in the short term and then only in a lingual direction.
5. There were no significant differences in arch depth after surgery in either arch.
6. Further investigation is required to ascertain the exact relation between the observed arch width increase and the transverse position of the related third molar teeth in bone.

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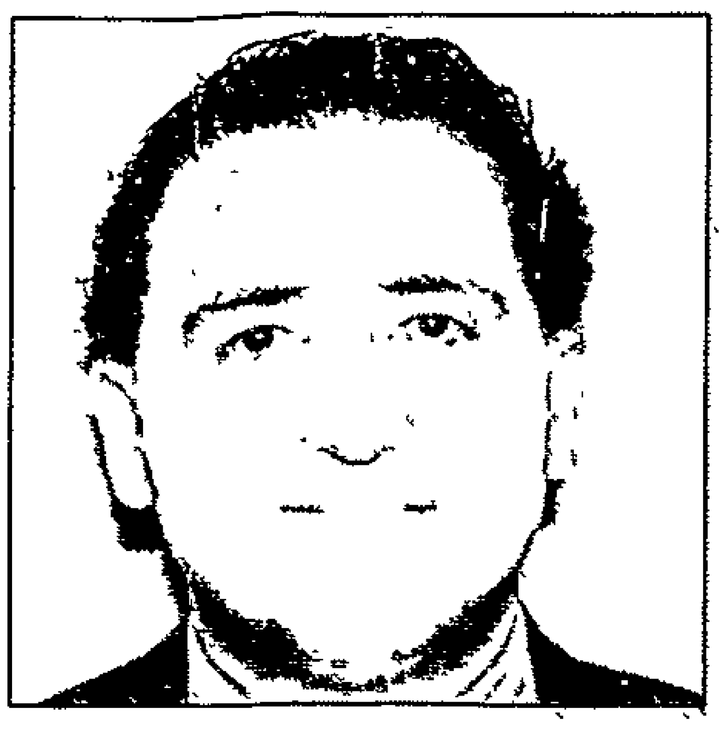

CERAMIC BRACKET DEBONDING: THE EVALUATION OF TWO DEBONDING TECHNIQUES AND THEIR EFFECT ON ENAMEL

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Enamel fractures have been associated with the debonding of some ceramic brackets which have a chemical bond to the enamel. The purpose of this study was to assess the enamel surface subsequent to debonding Transcend* series 2000* ceramic brackets using two debonding techniques. One hundred extracted human premolars were divided randomly into groups of two and prepared for bonding. Group 1 teeth had brackets bonded with Transbond* light-cured adhesive and Group 2 teeth had brackets bonded with Unite* chemically-cured adhesive. Bonded teeth were stored in normal saline at 37°C for 5 days and thermocycled. Teeth in both groups were subdivided randomly into Subgroups A and B. Teeth in Subgroup A had brackets debonded with the Transcend debonding instrument while teeth in Subgroup B had brackets debonded with ligature cutters. Each tooth was examined under light microscopy and those teeth suspected of enamel fracture were assessed by scanning electron microscopy.

Three out of the 100 teeth exhibited enamel fracture. There was no difference between the adhesive used and the number of enamel fractures or between the debonding technique used and the number of enamel fractures. A high proportion of brackets debonded with ligature cutters exhibited tie wing fracture.

Key Words:
Ceramic brackets, debonding, enamel fracture.

* Uniteck/3M Corporation, Monrovia, CA, US

Introduction

With the introduction of ceramic brackets there has been increased interest in their clinical perrformance.[1-2] The ceramic brackets currently available are composed of aluminium oxide in either a monocrystalline or in a polycrystalline form[3-5]. Both forms are superior to metal brackets in compressive strength and hardness but they both have inferior fracture toughness[6-7].

Bonding

The retention of direct-bonded brackets to enamel is achieved by etching the enamel surface with orthophosphoric acid as described by Buonocore[8]. Currently a 37 per cent phosphoric acid enamel etching solution is most commonly used. The etching time has been reduced from two minutes[9-10] to one minute[9-14] and to as low as fifteen seconds[15-19]. Several studies[15-19] have shown that a fifteen second etching time is sufficient for bonding.

Debonding Technique

One technique for removing brackets involves using a sharp ligature cutter placed at the adhesive-enamel interface to apply a peel force[20]. Most of the time this can be done easily without any associated enamel fracture. However, the enamel can occassionally be damaged by this force[10,21,22].

Several studies[18,23] have shown that conventional debonding techniques may lead to enamel fracture or bracket fracture when debonding ceramic brackets. All the manufacturers advocate the use of their debonding pliers with their ceramic brackets. One manufacturer (American Orthodontics) recommended sectioning their Starfire† ceramic brackets close to the base using a disc, breaking them off and then using a high speed diamond bur to remove any bracket remnants and adhesive.

Bond Strengths of Ceramic Brackets

Since the introduction of ceramic brackets there have been many reports of enamel fracture/damage on debonding[2, 23-24]. The first ceramic brackets had silanated bases to increase the bond strength between the composite and the base. Several in-vitro studies[13, 25-7] have shown that the shear bond strength of chemically treated ceramic brackets was greater than metal brackets. Britton *et al*[17], in contrast to the previous studies, found no significant difference in shear bond strength between different types of ceramic brackets and one type of metal bracket. Several investigators[27,28] have shown that the bond strength of silane-treated ceramic brackets to enamel was greater than untreated brackets. Guess *et al*[11] found that there was no significant difference in bond strength between silane-treated AllureIII‡ and untreated ceramic brackets. Another study[17] showed that the Allure ceramic brackets exhibited higher shear bond strengths than the chemically-retained ceramic brackets. Ostertag *et al*[29] found that, contrary to other research already presented[27,28], the mechanically retained ceramic brackets showed greater bond strength than the chemically retained ceramic brackets. The variation in results between studies is due mainly to the different adhesives used.

Debonding Ceramic Brackets and Enamel Damage

Several studies[18, 30-31] have shown the incidence of enamel damage to be higher with smooth-based, silane-treated ceramic brackets. Bamford[32], on the

† Starfire ceramic brackets, "A" Company, San Diego, CA, USA.

‡ Allure III, GAC International, Central Islip, NY, USA.

other hand, found no gross enamel damage on debonding two types of chemcially retained ceramic brackets. Recently, one study[33] found the incidence of enamel damage from debonding smooth-based silane-treated ceramic brackets to be as high as 86 per cent for monocyrstalline brackets and 40 per cent for polycrystalline brackets.

With the increased incidence of enamel fractures occurring with smooth-based silane-treated ceramic brackets[30-33], several investigators[35-36] advocated the use of ceramic brackets with mechanical retention only. Recently, Unitek introduced the Transcend™ Series 2000 ceramic brackets* with purely mechanical retention which was achieved by the new microcrystalline bonding surface. Unitek recommended the use of their new debonding instrument when debonding their series 2000 brackets. Winchester[37], in an in-vitro study comparing the "old" Transcend and the "new" Transcend series 2000 brackets, found that only one out of forty teeth exhibited enamel fracture on debonding the Transcend series 2000 brackets. The bracket which exhibited enamel fracture was debonded with a shear force. There were no enamel fractures when a tensile force was used to debond the bracket.

The aim of this study was to assess the effects of two debonding techniques (Transcend debonding instrument and ligature cutters) on the enamel surface when debonding Transcend Series 2000 ceramic brackets which were bonded to the enamel surface using either a chemically-cured resin, or a light-cured resin.

Method and materials

One hundred human maxillary and mandibular premolars that were extracted for orthodontic reasons were stored in 70 per cent ethyl alcohol for decontamination and removal of debris. The teeth were examined under a light microsope at ten times magnification for the presence of perikymata. Young teeth with the presence of perikymata were accepted for the experiment, while teeth without perikymata and/or with enamel damage were discarded. Teeth that were accepted were stored in water until they were required for the start of the experiment.

The teeth were mounted in plaster blocks which enabled better manipulation and which also simulated a tooth embedded in the alveolus. The labial surface of each tooth was cleaned for five seconds with a slurry of pumice and water applied with a rubber cup in a contra-angled slow-speed handpiece. The pumice was then washed off and each tooth dried using the air from a triplex syringe.

The enamel surface was treated with 37 per cent phosphoric acid gel for 15 seconds, washed with water for 20 seconds and dried with uncontaminated air for 10 seconds. A white frosty appearance of the enamel indicated a properly etched surface.

One type of ceramic bracket was used in this experiment. This was considered necessary for standardisation purposes. A Transcend™ Series 2000 bicuspid bracket (code number 2001-716) with 0.022" slot and without hooks was used.

Teeth were divided randomly into groups of two and labelled at the base of the plaster blocks for future identification. Group 1 teeth were painted with a coating of Transbond adhesive primer**. Transbond adhesive paste was applied to the base of the bracket which was then positioned onto the tooth and any excess adhesive around the bracket base was removed using a probe. The adhesive was cured by shining light from an Elipar curing light*** for 15 seconds through the ceramic bracket (manufacturer's instructions). The plastic long-axis indicators used to hold and position the bracket onto the tooth surface were removed immediately after bonding the last bracket.

Teeth in Group 2 were painted with a coating of Unite adhesive primer****. A thin primer coating was also painted onto the base of the ceramic bracket. A small amount of Unite adhesive paste was syringed onto the base of the bracket. The bracket was positioned immediately onto the tooth surface and any excess paste around the bracket base removed carefully using a probe. The plastic long-axis indicators were removed five minutes after bonding the last bracket, starting with the first bracket bonded.

The bonded specimens were then stored in 0.9 per cent sodium chloride (physiological saline) and kept at 37°C for five days.

Specimens were thermally cycled in a thermocycling machine with thermostatically controlled hot bath and ice chilled cold bath. Thermocycling consisted of 200 cycles per day for five days, making a total of 1000 cycles. Specimens were cycled between baths at 5° and 65°C with +3°C standard deviation. Temperatures of both baths were checked continuously using thermometers. The thermocycling machine was set to immerse the specimens for 30 seconds in each bath with a five second transfer period between each of the baths.

At the completion of the thermocycling period the specimens were washed under running tap water and debonded. Specimens in both Groups 1 and 2 were subdivided randomly into Subgroups A and B. Teeth in Subgroup A had brackets debonded with the Transcend series 2000 debonding instrument¶, while teeth in Subgroup B had brackets debonded with a pair of ligature cutters¶¶.

The Transcend debonding instrument was used according to the manufacturer's instructions. The claws of the debonding instrument were inserted in the grooves behind the wings of the bracket and the handle was squeezed until the plastic shoulders of the instrument were resting on the enamel surface and the bracket was debonded by a pure tensile force. The beaks of the ligature cutters were engaged at the adhesive-enamel interface and the bracket was debonded with a peeling action.

The presence of any tie-wing fractures or bracket base fractures was recorded. The interface or site where debonding had occurred - either at the adhesive-enamel interface, adhesive-bracket interface, within the adhesive, or within the enamel - was also recorded.

All the specimens were examined under a light microscope at 25 times the magnification to verify the interface where bond failure had occurred and to determine whether enamel damage had occurred. Enamel fracture was suspected if there was an absence of perikymata or in the presence of an uneven enamel

* Transcend™ Series 2000 ceramic brackets, Unitek Corporation/3M, Monrovia, CA, USA.

** Transbond light-cured adhesive, Unitek Corporation/3M, Monrovia, CA, USA.

*** Elipar Visio, Espe, Seefeld/Oberbay, Germany.

**** Unite Adhesive, Unitek Corporation/3M, Monrovia, CA, USA.

¶ Transcend Series 2000 debonding instrument Code 444-770 Unitek Corporation/3M, Monrovia, CA, USA.

¶¶ Ligature cutter (i-552), Rock Mountain Ortho, USA.

surface as viewed under the light microscope.

After viewing under the light microscope, the specimens that were suspected of having enamel fractures were also examined under the scanning electron microscope (SEM) to verify the results. Ten teeth from the sample that were not suspected of enamel damage were selected randomly and were also examined under SEM. The specimens were coated with gold and were examined in a JEOL (JSM-84) 15 Kv SEM at different magnifications and electron micrographs were taken.

Two non-bonded teeth, one maxillary and one mandibular premolar, were used as controls for the SEM examination. The buccal surface of the teeth was cleaned with slurry or pumice, etched with 37 per cent phosphoric acid gel for 15 seconds, washed for 20 seconds and dried. They were then examined in the SEM at various magnifications. The electron micrographs produced from these two teeth were used as controls for assessing the enamel surface of the debonded specimens as seen on the micrographs.

Statistical Method

A Chi square test was used to assess differences in the number of enamel fractures and tie-wing fractures between Groups and between Subgroups.

Results

None of the teeth showed any macroscopic evidence of enamel damage from debonding ceramic brackets. Upon light microscopic examination, only six out of the hundred teeth were suspected of having enamel fracture/ damage caused by debonding. Subsequent to SEM examination, only three out of the hundred teeth had discernible enamel damage caused by debonding (Table 1).

Table 1 shows the sites of separation and enamel fracture associated with each group of teeth subsequent to debonding. Groups 1A, 1B and 2B had one tooth out of twenty-five teeth with enamel fracture, while group 2A had no teeth with enamel fractures. The difference between the four groups was not significant. Brackets bonded with Transbond adhesive showed two enamel fractures on debonding while those brackets bonded with Unite adhesive showed one tooth with enamel fracture on debonding (Table 1). The difference in the number of fractures between the two groups of adhesives was not significant. Two teeth exhibited enamel fracture when brackets were debonded with ligature cutters, while only one tooth exhibited enamel fracture when the Transcend debonding instrument was used (Table 1).

Figure 1 is an electron micrograph of a control tooth showing an intact enamel surface. Figure 2 is an electron micrograph of a randomly selected tooth with no evidence of enamel fracture on debonding. Figures 3 and 4 are electron micrographs of a tooth from group 2B exhibiting enamel fracture. The other two teeth exhibiting enamel fracture were from Groups 1A and 1B and are illustrated in figures 5 and 6 respectively.

Teeth in Groups 1A and 2A exhibited separation predominantly at the adhesive-bracket interface (68 per cent and 64 per cent respectively). Separation at the adhesive-bracket interface occurred the same number of times for both the Transbond group (48 per cent) and the Unite group (48 per cent) (Table 1). Brackets debonded with the Transcend debonding instrument showed a higher incidence of separation at the adhesive-bracket interface (66 per cent) when compared to those brackets debonded with ligature cutters (30 per cent) (Table 1). The difference between the two debonding techniques was not significant. Teeth in Group 1B exhibited a high proportion (40 per cent) of separation at the adhesive-bracket-enamel interface, while teeth in group 2B showed a high incidence of tie-wing fracture (44 per cent) but a high proportion (64 per cent) of separations at the adhesive-bracket interface. Tie-wing fracture was also found to be common in group 1B (28 per cent). Brackets debonded with ligature cutters showed significantly more tie-wing fractures (alpha = 0.001) than brackets debonded with the debonding instrument.

An interesting finding was that only one tooth out of the whole sample had complete separation at the enamel-adhesive interface. This tooth was in group 2B.

Group	Adhesive /bracket	Adhesive /bracket /enamel	Adhesive /enamel	Within enamel	Adhesive /bracket /TWF	Adhesive /bracket /enamel /TWF
GROUPED BY ADHESIVE AND SEPARATE DEBONDING METHOD						
Transbond & Transcend Instrument 1A (n = 25)	17 (68%)	6 (24%)	0	1 (4%)	1 (4%)	0
Transbond & Ligature Cutter 1B (n = 25)	7 (28%)	10 (40%)	0	1 (4%)	5 (20%)	2 (8%)
Unite & Transcend Instrument 2A (n = 25)	16 (64%)	7 (28%)	0	0	2 (8%)	0
Unite & Ligature Cutter 2B (n = 25)	8 (32%)	4 (16%)	1 (4%)	1 (4%)	8 (32%)	3 (12%)
All Teeth (n = 100)	48	27	1	3	16	5
GROUPED BY ADHESIVE						
Transbond Transcend Instrument & Ligature Cutter (n = 50)	24 (48%)	16 (32%)	0	2 (4%)	6 (12%)	2 (4%)
Unite Transcend Instrument Ligature Cutter (n = 50)	24 (48%)	11 (22%)	1 (2%)	1 (2%)	10 (20%)	3 (6%)
GROUPED BY DEBONDING TECHNIQUE						
Transcend Instrument Transbond & Unite (n = 50)	33 (66%)	13 (26%)	0	1 (2%)	3 (6%)	0
Ligature Cutter Transbond & Unite (n = 50)	15 (30%)	14 (28%)	1 (2%)	2 (4%)	13 (26%)	5 (10%)

1A: Transbond, Transcend debonding instrument
1B: Transbond, ligature cutters
2A: Unite, Transcend debonding instrument
2B: Unite ligature cutters
TWF: Tie wing fracture

Table 1. Sites of ceramic bracket separation upon debonding (including enamel fractures) which occurred in the four groups of teeth. In the bottom half of the table the four groups have been combined into two groups of fifty teeth according to adhesive used and debonding technique used. The combined groups allows for direct comparison of results among groups.

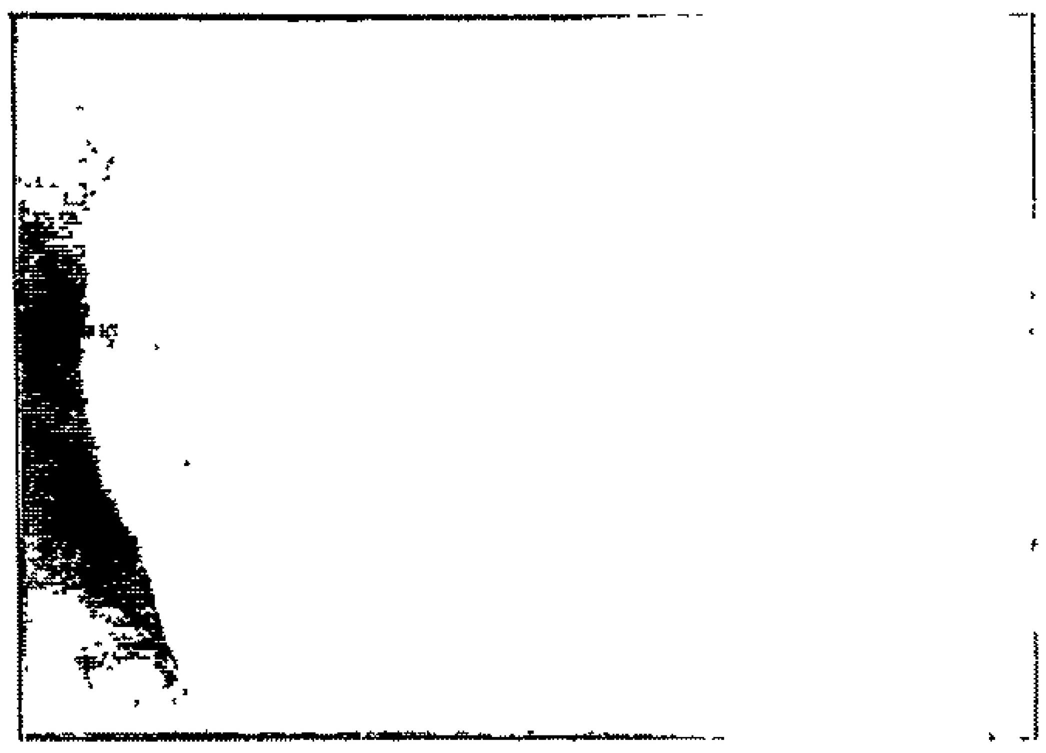

Figure 1. Electron micrograph of a control tooth (not bonded) with intact enamel surface. Magnification 27.5X. Bar = 1mm.

Figure 2. Electron micrograph of a tooth without enamel fracture which was randomly selected to be assessed under SEM. This tooth was from Group 2A. Magnification 27.5X. Bar = 1mm.

Figure 3. Micrograph of a tooth with enamel fracture. Note the undulated, rough appearance of the enamel towards the bottom of the micrograph and a small amount of fractured ceramic on the middle left. This tooth was from Group 2B and was debonded with ligature cutters. Magnification 27.5X. Bar = 1mm.

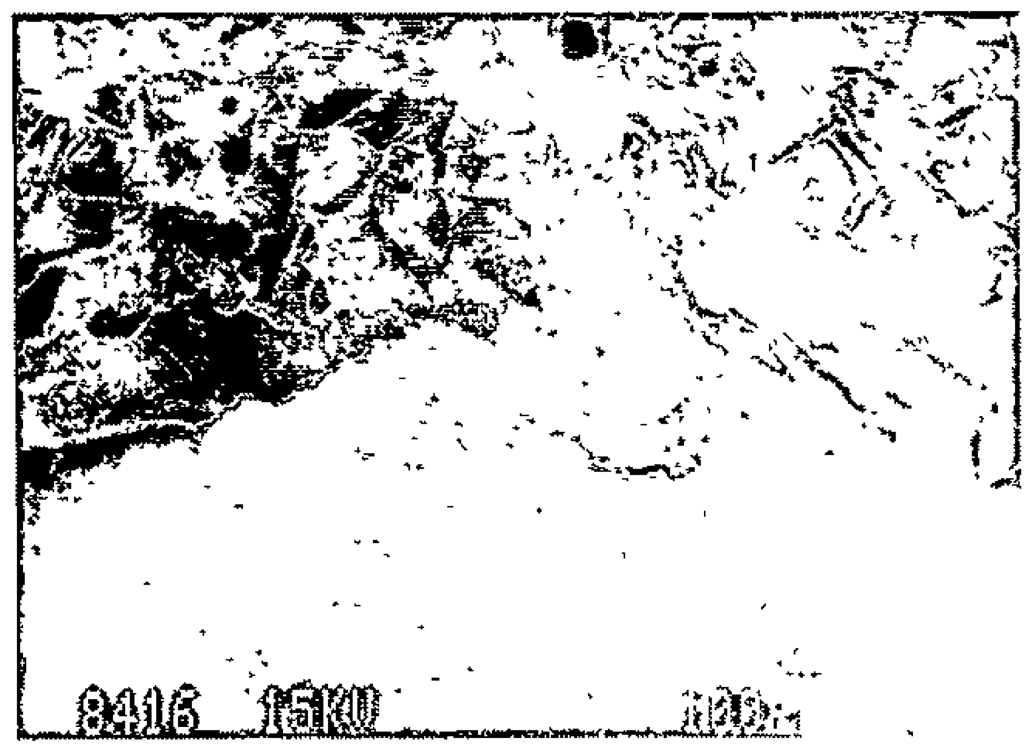

Figure 4. Higher magnification (70X) of area shown in Fig. 3. Note the enamel damage adjacent to the composite adhesive. It appears that the enamel surface has peeled away upon debonding. Bar - 100 micrometres.

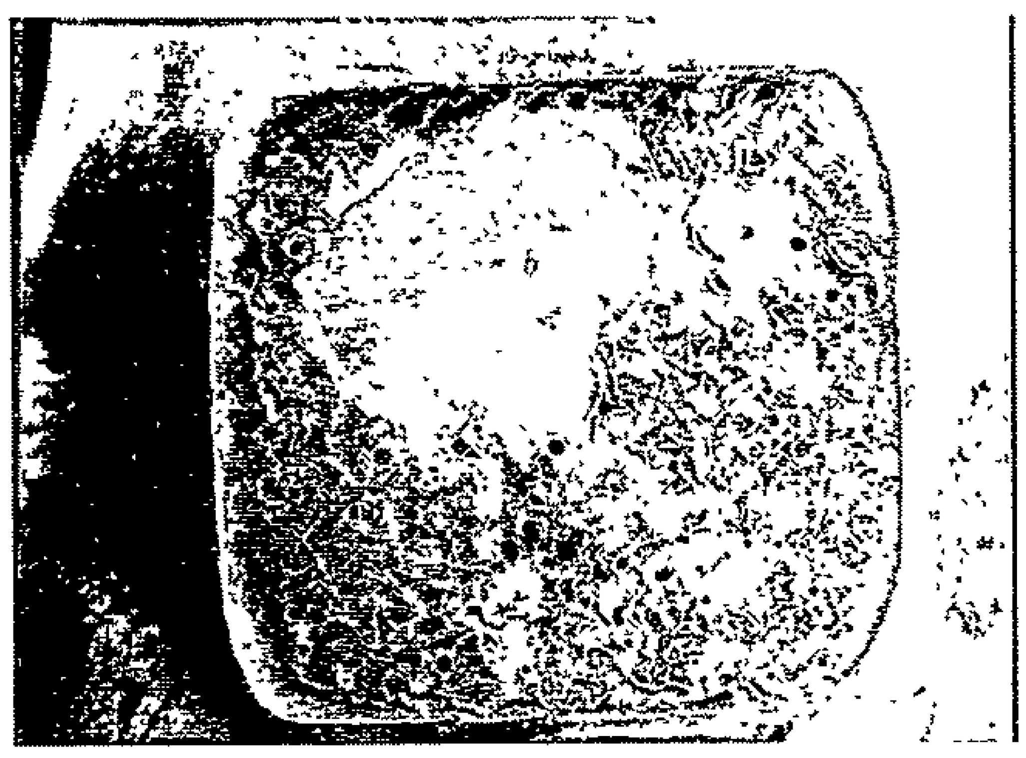

Figure 5. Electron micrograph of tooth from Group 1A (Transcend debonding instrument). Note the rough enamel surface towards the top of the micrograph where enamel damage has occurred. Magnification 27.5X. Bar = 1mm.

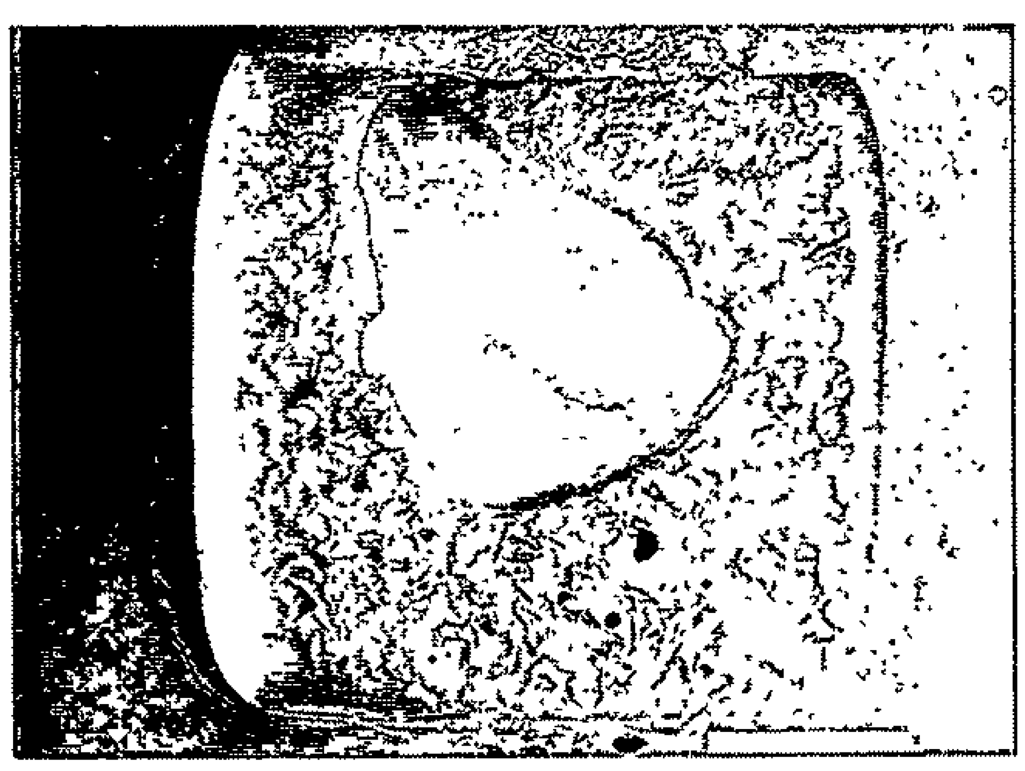

Figure 6. Electron micrograph of tooth from Group 1B (ligature cutter) exhibiting enamel fracture in the middle of the debonded enamel surface. Magnification 27.5X. Bar = 1mm.

Discussion

The results from this study showed that none of the teeth exhibited any macroscopic signs of enamel damage upon debonding ceramic brackets. This finding is supported by several other studies[18, 33, 35-36] which also found no visual evidence of enamel damage upon debonding different types of ceramic brackets.

In this study, it was found that, under light microscopic investigation only 3 out of 100 teeth exhibited enamel damage subsequent to debonding. The enamel fractures were assessed and photographed under SEM. An example of a tooth exhibiting enamel fracture upon debonding is shown in Figure 3. The bracket in Figure 3 was debonded with ligature cutters. The enamel appears to have been peeled off upon debonding (Figure 4), perhaps also gouged-out by the beak of the ligature cutter.

Figure 5 illustrates enamel damage caused by debonding the ceramic bracket with the Transcend debonding instrument. Although there were no visible signs of enamel damage upon debonding, the micrograph (Fig. 5) shows an area of rough enamel surface towards the top of the figure. It appears that the enamel in this area had been pulled off when the bracket was debonded. Figure 2 illustrates a tooth debonded with the Transcend debonding instrument but without any enamel damage. The debonded enamel surface looks like the untouched enamel surface of the control tooth (Fig. 1).

Figure 6 exhibits a tooth debonded with ligature cutters which shows a different pattern of enamel fracture/damage to that seen in Figure 3. The location of the area of enamel fracture is in the centre of the debonded surface and the enamel appears to have been sheared off upon bracket separation.

When debonding the original Transcend ceramic brackets, Storm[18] noted that only 2 out of 80 teeth exhibited enamel, while another study[33] found that 3 out of 15 teeth exhibited enamel damage subsequent to debonding Transcend series 2000 ceramic brackets with the Transcend series 2000 debonding instrument. A recent *in vitro* study[29] showed that there was no incidence of enamel damage upon debonding Transcend series 2000 brackets under shear, torsional or tensile forces. The brackets were debonded by an Instron machine under laboratory conditions and not by the recommended debonding instrument[29]. A manufacturer-sponsored clinical study[38] showed that out of 215 Transcend series 2000 brackets that were bonded, there was no clinically visible loss of tooth enamel or enamel fracture upon debonding. Winchester[37] in an *in vitro* study assessing the bond strengths and site of separation of Transcend series 2000 brackets found that only 1 out of 40 teeth exhibited enamel fracture upon debonding. The tooth which exhibited enamel fracture was debonded with a shear force and was originally bonded with a heavily filled light-cured adhesive. Interestingly, there were no enamel fractures when a pure tensile force was used to debond these brackets.

Direct comparison among the various studies that have examined enamel damage upon debonding ceramic brackets is difficult. Each study uses different adhesives, different sample sizes, variable enamel-etching times, different storage media, and different types of ceramic brackets.

An interesting finding in this investigation was that the site of separation for more than 60 per cent of the brackets debonded by using the Transcend series 2000 debonding instrument occurred at the adhesive/bracket interface (Table 1). The manufacturer's *in vitro* evaluation of the Transcend series 2000 brackets[38] found also that separation of brackets occurred primarily at the adhesive/bracket interface, leaving the bulk of the composite on the enamel surface. Ostertag *et al*[29] found that all the Transcend series 2000 brackets separated at the adhesive/bracket interface when debonding such brackets using a tensile force applied by an Instron machine. In contrast, the same study found that only between 17-30 per cent of debonded brackets exhibited bond failure at the adhesive/bracket interface when a shear or torsional force was applied[29]. Another *in vitro* study[33] found that approximately 45 per cent of the Transcend series 2000 brackets failed at the adhesive/bracket interface upon debonding. Winchester[37] found that the site of separation of brackets was affected by adhesive used. Brackets bonded with a lightly filled adhesive tended to separate at the adhesive-bracket interface, while brackets bonded with heavily filled adhesive separated at the adhesive-enamel interface. An *in vivo* evaluation of 215 Transcend series 2000 brackets[38] debonded with the Transcend series 2000 debonding instrument resulted in 88 per cent of bond failures occurring at the adhesive/bracket interface, as determined clinically.

In the present investigation, less than 40% of brackets debonded with ligature cutters failed at the adhesive/bracket interface (Table 1). Bond failure at the adhesive/bracket interface is considered preferable to the adhesive/enamel interface[10,18].

Another interesting finding from the presenty study was that there was an increased incidence of tie-wing fracture with brackets debonded with ligature cutters. Approximately 28 per cent of the Transbond bonded brackets and 44 per cent of the Unite bonded brackets exhibited tie-wing fracture upon debonding with ligature cutters (Table 1). In contrast, only 4 per cent of exhibited tie-wing fracture upon debonding with the Transcend series 2000 debonding instrument. Tie-wing fracture makes complete bracket removal difficult and perhaps uncomfortable for the patient[1,18].

Redd and Shivapuja[33] found that 33 per cent of teeth exhibited tie-wing fracture upon debonding with the Transcend debonding instrument while another study[29], found no incidence of tie-wing fracture when debonding Transcend series 2000 brackets, with a tensile force applied by an Instron machine. In the manufacturer-sponsored clinical study[37] it was found that 21 per cent of debonded brackets exhibited tie-wing fracture compared to 8 per cent found in the present investigation. The manufacturer claimed that the high incidence of tie-wing fracture upon debonding was due mainly to one operator who used the original Transcend debonding instrument by applying a torsional force on the bracket. When these brackets were excluded from the sample, the incidence of tie-wing fractures decreased to 11 per cent which is similar to the incidence found in the present investigation.

Conclusions

1. There was no significant difference between the debonding technique used and the number of teeth exhibiting enamel fracture.
2. There was no significant difference between the type of adhesive used and the number of enamel fractures.
3. A high proportion of bond failures occurred at the adhesive/bracket interface when debonding with the Transcend debonding instrument.
4. There was a high incidence of tie-wing fracture when debonding ceramic brackets with ligature cutters.
5. Although there were no significant differences between debonding techniques or between adhesive used, it appears that the use of the manufacturer's recommended Transcend series 2000 debonding instrument produces more reliable results that do ligature cutters when debonding Transcend series 2000 ceramic brackets.

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THE ROLE OF CT, MRI AND 3D IMAGING IN THE DIAGNOSIS OF TEMPOROMANDIBULAR JOINT AND OTHER OROFACIAL DISORDERS IN CHILDREN*

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Advances in medical imaging techniques add a new third dimension (3D computer reconstruction of CT, MR and Ultrasound images) to the diagnostic armamentarium of practitioners in orofacial medicine, surgery and Orthodontics. In particular, Computerized Tomography and Magnetic Resonance Imaging with, to a lesser extent, Nuclear Medicine Imaging and Sonography provide more accurate and detailed information on abnormalities and disorders of craniofacial osseous and soft tissues, especially the temporomandibular joint, than was previously available from plain films or tomography. Greater familiarity with these new imaging modalities by dental specialists will result in their more effective use in paediatric patients.

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Introduction

Diagnosis of a temporomandibular joint disorder can often by made by a history, palpation and observation of mandibular movement. High quality imaging is necessary for accurate diagnosis and correct management of both an acute problem and later pathological changes. This paper briefly reviews conventional techniques used in the imaging of the temporomandibular joint and considers the role which newer imaging techniques can play in paediatric orofacial medicine, surgery and Orthodontics - especially with regard to temporomandibular disorders.

During the past ten years radiology has matured from a purely diagnostic discipline restricted to radiography, to a rapidly expanding specialty involving various modalities of organ imaging including ultrasound, nuclear medicine, computerised tomography (CT) and magnetic resonance imaging (MRI)[1].

Disturbance to normal growth of the orofacial structures, and especially the temporomandibular joint, is not uncommon in children and can occur as a result of a congenital defect such as hemifacial microsomia (Fig. 1); traumatic injury to the mandible in infancy[2,3,4] (Fig. 2); infection localizing in the condyle head in infancy[5]; and inflammatory changes in the temporomandibular joint due to Juvenile Chronic Arthritis.

The resulting abnormal or absent condyle or bony ankylosis, pseudoankylosis (from fibrosis of ligaments, muscle sheaths and fascia), or hypertrophied coronoid processes[6], results in disturbance to normal mandibular and maxillary growth. The younger the age at the time of injury, infection or onset of disease, and the more complete the ankylosis, the more severe will be the growth disturbance;

Figure 1. 6 year old boy with hemifacial microsomia showing early facial asymmetry due to the congenital malformation of the mandibular condyle and ramus on the left side.

Figure 2. 6 year old boy with almost total loss of mandibular movement (~6mm MID) due to bony ankylosis of right condyle secondary to traumatic injury at 3 years of age.