FORMOCRESOL PULPOTOMIES IN PRIMARY TEETH

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SUMMARY

The present study determined the incidence of pulp formocresol treatments in primary teeth and the success rate over the five year period 1970 to 1974 inclusive.

Of a total 1,823 children attending The University of Adelaide Pedodontic Clinics, 764 patients had 1,246 pulpotomies, either one or two-stage, ranging from one to eight per patient. The one-stage type comprised 80.74 per cent of the procedures and 60.29 per cent of all teeth treated were in the mandible.

Clinical success was obtained in 97.75 per cent of the procedures but according to radiographic criteria, the success rate was 92.70 per cent. There were no bilateral or sex differences in the number of teeth treated but the event occurred significantly earlier in females. A register of pulpotomy treatments has been set up so that the technique can be continually evaluated.

Because the use of formocresol is empiric, an experiment *in vitro* was carried out to test the effectiveness of a reduced concentration of the drug. It was found that the solution of Buckley's formocresol was bacteriostatic to a minimum concentration of between 0.25 and 0.20 per cent and was bactericidal to a minimum concentration of between 0.50 and 0.33 per cent on cultures of *Streptococcus faecalis*, *Streptococcus salivarius* and *Staphylococcus aureus*; *Streptococcus faecalis* was found to be the most resistant organism. Further investigations *in vivo* are required to assess the clinical effectiveness of reduced concentrations of formocresol.

SIGNED STATEMENT

This project report is submitted in partial fulfilment of the requirements of the Degree of Master of Dental Surgery in The University of Adelaide.

The report contains no material which has been accepted for the award of any other degree or diploma at any University. To the best of my knowledge and belief, it contains no material previously published or written by another person except where due reference is made in the text of the report.

P.J.W. VERCO

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INTRODUCTION

The treatment of the pulps of primary teeth by the formocresol technique has evolved on basically empirical methods. Buckley[1] has suggested that before the beginning of the present century the knowledge that a dental practitioner possessed was more or less guarded with secrecy. As a result, misunderstanding and confusion have arisen concerning accurate diagnosis and the methods of treatment. Quigley[2] noted that during the past century, almost in cyclical fashion, various procedures and medicaments were discovered and advocated, were found wanting, only to be revived and tried again at a later date.

The treatment of primary teeth by the formocresol pulpotomy technique was introduced by Buckley[3] in 1904. Although many other materials have been suggested both before and since, formocresol is still successfully used in the treatment of vital and non-vital primary teeth.

With the present accent on the prevention of dental disease and the provision of dental care for all individuals, it is apparent that the only way to provide a comprehensive dental health service is to begin with the young child. Dentistry for children has progressed considerably, judged by Alvord's description of the type of dentistry practised at the turn of the century.

> "Parents of that day expected to have dental care for their children gratis or at the most to pay a quarter for an extraction. The repair of broken down deciduous teeth was rarely permitted. Certainly no fee was allowed for filling, and the treatment of a pulpless deciduous tooth was out of the question".[4]

If preventive dentistry is practised and optimal dental health is maintained, any carious lesion which develops should be minimal in extent. However, many children still present

to the dental practitioner complaining of toothache due to a grossly carious tooth. If this tooth is to be retained in the dental arch, a pulpotomy may be necessary followed by a final restoration with amalgam or a stainless steel crown.

AIMS OF THE INVESTIGATION

The purpose of the present study was to review the literature on pulp treatments of primary teeth and to gain epidemiological information on the population treated in The University of Adelaide Pedodontic Clinics from 1970-1974 inclusive. The success of the formocresol technique was evaluated by the examination of patients who had had teeth treated by this procedure.

In the past, systematic and long-term records of formocresol pulpotomies in primary teeth have not been kept. A patient register has now been designed and a continuing review will be maintained from the patients' case notes.

Because the organic components of formocresol are toxic, the feasibility of reducing the concentration of the medicament has been assessed in vitro.

CHAPTER I

REVIEW OF LITERATURE

I-1 History of Formocresol Pulp Treatments

For centuries materials used on or around teeth were primarily for relieving pain. As long ago as 2,700 B.C. the Chinese recognised nine kinds of toothache or Ya Tong.[5] Many empirical treatments were suggested but oil of cloves was not mentioned in the literature until the Babylonian Talmud A.D. 352-427.[6]

Before 1840 there were no published books on medicines used in dentistry and the knowledge possessed by the individual practitioner was rarely divulged. However, after Lister's demonstration of antisepsis in the late nineteenth century, it was found that most remedies for treating the dental pulp possessed antiseptic properties. This finding generated a more scientific approach and as a result many articles were published on the antiseptic treatment of the dental pulp and root canal.[7]

Buckley[1] cites Hullihen, who in 1852 introduced a new method of treating exposed dental pulps. A lateral opening was bored through the root of the tooth into the pulp chamber or canal so that gases could escape from the dead pulp. In 1852 Harding, cited by Buckley,[1] described a method of destroying the dental pulp by electrical heat. In 1866, McQuillen[8] used local anaesthesia in the extirpation of the dental pulp even before Koller[9] introduced cocaine into medicine and dentistry in 1884.

Castagnola[10] cites Albrecht (1856) who used opiates, caustics and eugenol on exposed pulps. M'Kown[11] recommended cotton soaked in creosote and tannic acid, and Taft[12] cauterized recently exposed pulps with nitric acid and placed a filling immediately. Only subjective evaluations were made and none of the authors attempted to critically assess their results.

The history of vital pulpotomy and pulp preservation began with Atkinson[13] who wrote strongly in favour of conserving the vital pulp before restoration. He suggested amputation of all projecting cornua of exposed pulps and the placement of a temporary dressing until the tissue was healthy. Only then was the tooth restored permanently. Atkinson believed that the habit of saturating every cavity with creosote before filling would do more to preserve the vitality of the exposed pulp than any other single method. The technique was known in Europe as "Atkinson's method" or the "Great American Invention".

In 1873 Jack[14] maintained that the preservation of pulp vitality was possible, and especially favourable in teeth where a new formation of secondary dentine within the pulp sealed off the exposure. Jack stressed that the treatment should bring about the formation of secondary dentine and that the vitality of the tooth should be preserved.

Witzel[15] deliberately amputated the infected coronal portion of the pulp as a therapeutic measure. He covered the remaining radicular stumps with antiseptics and concluded that the pulps healed by formation of scar tissue. He was of the opinion that if the vitality of the tooth was maintained, secondary dentine would form. Witzel cited by Biro[16] stressed that antiseptic treatement was dependent upon cleanliness; this principle is still a keynote of successful healing.

In 1888 Baume[17] used alum or borax to saturate the remains of the pulp following amputation. Although 300 successfully treated cases were reported initially, Baume later admitted many failures.

Biro[16] pointed out that Baume[17] was the first to recognize that pulps treated with arsenic not only died, but also decomposed, and that such teeth could only be preserved on a more permanent basis if the devitalized pulps were extirpated.

However, a demand soon arose not only for the preservation of the tooth but also for a tooth with a vital pulp. As a result, many compounds were fabricated in an attempt to aid healing of the exposed pulp although no serious effort was made to differentiate between various pulpal conditions. Consequently the results were generally unpredictable and often unfavourable so that techniques to conserve the pulp fell into disrepute.

In 1889 Abraham[18] recommended Formagen for capping exposed pulps. Formagen was a formalin cement containing carbolic, eugenol and a neutral porous powder saturated with formaldehyde vapour. This type of material relieved pain by devitalizing the tooth.

The use of formaldehyde for the disinfection of infected pulps was first reported in 1897 by Lepkowski.[19] A 40 per cent solution of formaldehyde in water was placed over the pulp, causing intolerable pain. However, of 4,697 teeth treated, only 43 were regarded as failures. In the same year Bönnecker[20] reported 500 successful formalin mummification treatments of pulps after the use of arsenical devitalization.

The present formocresol technique has been developed after a series of related formalin compounds were used in pulp therapy for primary teeth.[4, 20, 21, 22] In 1889, Gysi[23] advocated a paste containing paraformaldehyde, tricresol, creolin and glycerin for the treatment of infected pulps. The amputation site was not limited to the coronal pulp, but could be created at any level in the root canal. The paste was to be used after the pulp had been devitalized and sterilized and was intended to fix the pulp tissue in a permanently sterile condition. The action of the medicament was to slowly liberate formaldehyde from the paraformaldehyde and was given the name "Gysi's Triopaste".

Dentists of the era were becoming increasingly aware that failures of the pulpotomy procedure might be due to

incorrect diagnosis of the pulp before treatment.[17,24,25,26] Accurate assessment of the state of the pulp is not completely possible even today, yet successful therapy depends upon this criterion.[27,28]

Buckley[3] introduced formocresol into the Unites States of America in 1904 and it is now considered to be the most successful medicament for treating primary teeth. The importance of sealing formocresol into the pulp chamber was stressed so that the drug came into contact and united chemically with the end products of pulpal decomposition, converting them into odourless and non-infectious compounds. The medicament was used for both vital and non-vital teeth. Buckley emphasized the importance of adhering to general surgical principles of drainage for abscessed teeth, and in the care of using formocresol which he described as one of the most irritating agents known to the clinician. He also stated that in a non-vital tooth containing non-suppurative material there was no necessity to use formaldehyde in the same concentration as in teeth where the pulp chamber, root canals and tubuli were filled with putrescent tissue.

The formula of the medicament was:-

Tricresol	4.0 cc
Formalin	2.0 cc

Tricresol, a refined mixture of meta, ortho and para-cresol, not only had germicidal properties but also was a good antiseptic. Buckley stated that if the canals were dried with alcohol, the tricresol would dissolve any fatty globules in the root canals and would react with the alcohol to form lysol. The tricresol was selected as a vehicle with which to dilute the formalin because it was miscible with formalin in all proportions, had good germicidal properties and chemically acted upon the fatty constituents, completely disposing of these substances.

Buckley recommended soaking a pellet of cotton wool in formocresol and hermetically sealing it in the pulp chamber for 24-48 hours, one treatment being sufficient.

Sweet[29] later suggested a five-treatment, modified pulpectomy procedure for primary teeth with carious exposures. The pulp was devitalized by proprietary Novo wafers saturated with phenol and treated for three periods of 48 hours each. The pulp chamber was filled on the fifth visit with carbo-eugenol, followed by a cement base and metallic restoration.

In 1930 Sweet[30] reduced the procedure to four appointments and utilized zinc oxide-eugenol for final filling of the pulp chamber. The treatment was claimed to be 100 per cent successful. On the first visit the caries was removed and a devitalizing wafer of 95 per cent phenol was placed over the exposure site. This was covered with a temporary restoration and the patient was dismissed for 48 hours. On the second visit the tooth was isolated with cotton rolls, sterilized with alcohol and the devitalizing substance was removed. The formocresol was placed and sealed for another 48 hours. On the third visit a pulpotomy procedure was carried out and formocresol was placed for three to four days under a temporary dressing. Finally the pulp chamber was cleaned again and hydrogen peroxide was used to remove any stain. The chamber was dried with warm air and filled with a creamy mixture of zinc oxide-eugenol, the paste being forced into the root canals with a cotton pellet. The pulp chamber was filled with a crown and bridge cement and covered with a metallic restoration.

Foster[31] advocated a similar technique but added a crystal of silver nitrate to the final zinc oxide-eugenol dressing to give a persisting germicidal property to the root canal filling. Gardner[32] condemned the use of arsenical devitalization and utilized local anaesthetics when performing pulpotomies in

primary teeth. After amputation haemorrhage was controlled with formocresol on a cotton pellet for three to five minutes. The chamber was filled with zinc oxide mixed with beechwood creosote and a trace of formocresol. Sweet[30] also discarded the use of devitalizing wafers and made his technique a three-appointment procedure.

Enthusiasm concerning formalin-containing drugs waned in the 1930's because of the histological reports of Coolidge[33] and Orban.[34] These investigators indicated that formalin, creosol and paraformaldehyde were irritants to healthy connective tissue in dogs, leading to degenerative changes in the pulp and periapical inflammatory involvement.

In 1920 Hermann cited by Castagnola[10] recommended a calcium hydroxide preparation to aid healing of the exposed pulp. However, in 1938 when Teuscher and Zander[35] introduced calcium hydroxide into the United States of America, the use of formocresol was replaced by a more biological type of pulp dressing. There can be no doubt that the majority of researchers favoured calcium hydroxide as a suitable wound dressing, based on radiographic and clinical criteria.[36, 37, 38, 39, 40, 41, 42] Excellent results were reported with the use of calcium hydroxide but under critical analysis, calcium hydroxide pulpotomies in primary teeth gave discouraging results. Publication of carefully evaluated data by Shoemaker,[43] Via,[44] Law[45] and Wittich[46] indicated a pulpotomy success rate of 35-40 per cent in primary teeth. Among the principal causes of failure were intra-radicular and internal resorption which in some instances occurred in approximately 70 per cent of the teeth treated.[45]

In 1949 Zander and Glass[47] studied the effects of phenol applied to the pulp before capping healthy young pulps with calcium hydroxide and zinc oxide-eugenol. These investigators

concluded that the alkaline pH was an important factor in promoting pulpal healing, although the production of a necrotic layer appeared to be necessary.

Castagnola[10] did not recommend the use of zinc oxide-eugenol in pulp therapy. He maintained that the successes claimed by other workers on the basis of clinical and radiographic criteria needed to be verified histologically. Castagnola reported bridging following the use of zinc oxide-eugenol, but maintained that this was due to the dentine spicules that had penetrated the pulp tissue and was not due to the medicament alone.

Later, Massler, Perreault and Schour[48] tested the effects of various medicaments on pulpal wound healing in the amputated pulp of a rat's incisor. No marked differences between healing with calcium hydroxide or with zinc oxide-eugenol were detected.

As late as 1956 Sweet Jr.[49] advocated the empirical use of formocresol and reported an extremely high success rate. He reduced the number of visits for a formocresol pulpotomy procedure to three, by opening the pulp chamber on the first visit following the removal of caries. After the canals were thoroughly dried, cresolated formaldehyde was inserted. However, it was not until the technique was changed to a one or two-appointment procedure that pedodontists accepted the clinically shorter treatment.

Nacht[50] developed a modified formaldehyde paste containing phenol, formalin, creosote, thymol, and a powder containing barium sulphate. The treatment consisted of one visit only in which the coronal portion of the pulp was removed under local anaesthetic and a thick layer of the formaldehyde paste was applied to the pulp stumps. A cement was placed over the paste and the cavity was sealed with a permanent

restoration. Radiographs were taken every six months for five years. In general, the teeth were in good condition radiographically for about two years, after which there was progressive bone loss but no clinical changes were evident. Thirty of the 456 teeth treated were lost due to acute symptoms. Of the remaining teeth, there was premature loss of primary molars and early eruption of the succedaneous teeth.

Wong[51] studied the effects of a paraformaldehyde paste on the amputated pulp and periapical tissues of primary and permanent teeth in Rhesus monkeys. He observed a marked increase of fibrous tissue in the primary pulps. While there was no untoward effect on the periapical tissues, there was evidence of lymphocytic infiltration in the underlying dental sac of the permanent teeth.

Emmerson, Miyamoto, Sweet and Bhatia[52] found that the reaction of the primary pulp varied with the total time that the formocresol was in contact with the amputated pulp stump; the changes varied from surface fixation to complete calcific degeneration. When formocresol was in contact with the amputated stump for periods of up to three days, normal pulp tissue was evident below an area of fixed tissue and there was an absence of inflammatory cells. From these findings the authors concluded that the technique could be classified as either vital or non-vital depending on the length of time for which formocresol was applied.

Dietz[53] sealed formocresol in the pulp chamber of 40 primary teeth for seven days, after which the chamber was filled with zinc oxide-eugenol. Over a 16 week period, he observed a progressive non-inflammatory degeneration with an attempt to wall off the medication with a collagenous acellular band immediately below the amputation site. It appeared that there was greatest tissue breakdown in the middle portion of

the amputation site. Some areas showed slight resorption of dentine and there was minimal tissue breakdown at the apex.

Doyle, McDonald and Mitchell[54] compared the use of calcium hydroxide clinically, radiographically and histologically in a two-appointment pulpotomy procedure on 65 primary teeth. The effects of the medicaments were studied histologically from four to 380 days and clinically from five to 19 months. The effects of formocresol were almost as pronounced after four days as in later specimens. Superficial debris from the blood clot and dentine chips were seen at the amputation sites, below which there was loss of definition of odontoblasts. Teeth treated by the formocresol pulpotomy technique showed no evidence of calcification or organisation for calcific bridging. Formocresol did not stimulate a healing response at the stump of the amputated primary dental pulp, but appeared to fix nearly all of the remaining pulp tissue. The authors concluded that the formocresol pulpotomy procedure was superior to that using calcium hydroxide. The teeth treated with formocresol clinically were 100 per cent successful and radiographically and microscopically 93 per cent and 92 per cent successful, respectively.

Spedding[55] also compared a one-appointment formocresol pulpotomy technique with a similar technique using calcium hydroxide. Twenty primary teeth of Rhesus monkeys were examined histologically for 17 to 286 days post-operatively. In almost all instances normal vital pulp tissue was found in the apical third of formocresol-treated teeth. Fixation of the other two-thirds of the pulp was evident with similar frequency. Secondary dentine formation was seen in some of the pulps; others showed leukocytic infiltration or osteodentine below the fixed tissue in the apical regions. The results indicated that formocresol was a superior medicament to calcium hydroxide in

primary teeth.

Berger[56] compared the effects of a formocresol medication and a zinc oxide-eugenol paste placed on the pulpal tissue of human primary molar teeth which had undergone pulpotomy. Pulpotomies were performed on 52 teeth, 35 of which were dressed with formocresol for five minutes, followed by a zinc oxide-eugenol-formocresol base and restoration. In the remaining 17 teeth, a zinc oxide-eugenol dressing was placed over the pulp stumps after the application of a physiological control solution. In teeth which had been treated with formocresol the coronal pulp canal tissue was well defined, preserved and compressed, and blended with areas of coagulation necrosis and inflammation towards the apex which was mainly acellular. During the seventh week of the 38 week study, there was evidence of an ingrowing granulation tissue which in time closely approximated the amputation site. It was found that formocresol on vital primary teeth produced necrotic changes which were replaced by granulation tissue. The granulation tissue eventually changed to osteodentine and narrowed the lumen of the canals. The teeth treated with zinc oxide-eugenol cement showed chronic inflammatory reactions and some areas of internal resorption. Those treated with formocresol were on the basis of radiographic criteria 97 per cent successful.

Droter[57] studied the effects of formocresol in vital and non-vital primary teeth over a two-year period. The author had used the calcium hydroxide technique for many years and had achieved a success rate of 60-65 per cent. Over a two-year period the formocresol technique had resulted in only one failure in 113 vital pulpotomies, and one failure in 63 non-vital teeth. In the case of the vital tooth, failure was due to perforation of the root, and the non-vital tooth was extracted because the patient preferred this procedure. Droter used the

same two-appointment technique for vital and non-vital teeth. After five days the cotton pellet containing Buckley's formocresol was removed and zinc oxide-eugenol cement was placed over the pulp stumps. The tooth was restored with amalgam.

Law and Lewis[58] carried out a four year study on 324 vital primary teeth treated by the two-appointment pulpotomy technique. They found that formocresol did not produce calcific bridging; furthermore, internal resorption was not seen. There was surface tissue fixation which appeared to minimize bacterial invasion and allowed the remaining root canal tissue to maintain its vitality. One tooth was extracted after two-and-a-half years and had a viable pulp. The authors therefore regarded the formocresol treatment as a vital procedure. The success rate for each year of the four year period was greater than 90 per cent.

Spedding, Mitchell and McDonald[59] investigated the success of formocresol and calcium hydroxide pulpotomies in Rhesus monkeys. The pulps of teeth treated with formocresol were fixed in the apical half or third. The results showed that formocresol was superior to calcium hydroxide as the success rates were 70 per cent and 60 per cent, respectively.

In 1968 Redig[60] evaluated one and two-stage pulpotomy techniques using Buckley's formocresol. Forty teeth in 20 children were investigated over a period of 18 months. In the one-stage technique formocresol was placed over the pulp stumps of vital teeth with deep carious lesions, and in the two-stage procedure formocresol was sealed in the tooth for three to five days. The one-stage and two-stage procedures were 85 per cent and 90 per cent successful, respectively. By chi-square analysis there was no significant difference in the success rate between the two techniques.

Spedding[61] reviewed the primary pulp techniques taught

in 56 North American dental schools. Of the 48 schools in which formalin preparations were preferred, 45 used Buckley's formocresol. Nine schools exclusively taught a two-stage technique and 47 selected either a one-stage or a two-stage procedure. The two-stage technique was adopted when there was a history of pre-operative pain, the pulp was putrescent, haemorrhage was excessive or if time was limited. Spedding recommended more research into clinical and histological evaluations and also recognized the diversity of results reported when the same agents were applied in a similar manner. High percentages of success were reported but no technique was 100 per cent effective.

Punwani and Molven[62] recently reviewed the teaching of endodontic procedures on primary and young permanent teeth in Scandinavian dental schools. There was disagreement in the choice of agents for covering pulp stumps, although calcium hydroxide was used most frequently, followed by formocresol and zinc oxide-eugenol. The formocresol method routinely was a one-stage technique but in cases of heavy bleeding, half the group resorted to a two-stage approach in which the dressing remained for three to seven days. The overall result appeared to be unsatisfactory and six of the eight schools were dissatisfied with the pulpotomy technique.

Hobson[63] described the two pulp treatment techniques, one for teeth with vital pulps and the other for non-vital teeth. A two-stage technique was followed in which a paraformaldehyde medication was inserted and at the second visit was replaced by Putridomors 22 containing thymol, cresol and iodoform in a zinc oxide base. This preparation was thought to be more effective than a 50/50 mix of formocresol and zinc oxide-eugenol in controlling any infection which remained in the canals or surrounding dental tissues.

In 1973 Loos, Straffon and Han[64] studied the biological effects of formocresol. They concluded that the undiluted drug was effective in developing full cytostasis but could produce irrecoverable damage to connective tissues and might delay recovery of normal biologic activities of the connective tissue cells. A 1/5 concentration of formocresol was as effective as the original Buckley's formula and produced an earlier recovery of cellular activities in connective tissues. Additionally, the authors suggested that certain clinical and histologic problems reported by other investigators might be eliminated by using a 1/5 concentration of the original formula.

Starkey[65] reported on pulpotomy and root canal fillings in primary molars and noted that teeth which had undergone pulpectomy or pulpotomy were shed up to one year before the normal exfoliation time. He stressed the difficulty in interpreting radiographic findings where radiolucence occurred in the bifurcation area, despite treatment being clinically successful for a number of years. In such instances, a low grade pathologic condition was thought to be responsible for the bone loss, or, when there was no bone loss, over-retention could be anticipated.

Dannenberg[66] reviewed vital and non-vital formocresol techniques in primary teeth. He confirmed that when formocresol was placed in contact with a vital, healthy pulp for three to five minutes, the surface layer of cells was fixed and the remaining pulp maintained its vitality. There was no dentine bridge formation, and when formocresol was sealed in the cavity for several days, penetration proceeded apically until the entire pulp was mummified. Dannenberg stressed the importance of limiting the quantity of formocresol because it was not a self-limiting drug.

The literature shows that Buckley's formocresol is the

most successful medicament used for pulpotomy of vital and non-vital primary teeth. The shortening of the procedure from five visits to a five minute single treatment has resulted in fewer management problems in young children and a wider acceptance of the procedure by dental practitioners. Not until recently have investigators attempted to use the drug in more dilute concentrations, which is reported to lead to an earlier recovery of connective tissue cells beneath the amputation site.

I-2 Chemistry and Pharmacological Actions of Formocresol

The effects of formocresol are discussed by referring to the chemistry and pharmacological actions of the components of the drug.

Formaldehyde is a gas produced by the incomplete combustion of methanol and has the chemical formula $H\text{-}C\overset{O}{\underset{H}{}}$. It is readily soluble in water and the aqueous solution, formalin, is 30 to 40 per cent formaldehyde by weight. Paraformaldehyde, the polymerised form of formaldehyde, is normally found in formalin and precipitates from the more concentrated solutions. As the formalin is diluted the paraformaldehyde is redissolved to form the aqueous formaldehyde.[67] The major actions of formocresol on pulp tissue have been attributed to the formaldehyde portion of the drug. Glycerine was added to lessen the polymerisation to paraformaldehyde which causes "clouding" of the solution.[68] A solution of 10 per cent formalin (4 per cent formaldehyde) is widely used as a tissue fixative. The solution is thought to prevent autolysis of tissue by the combination of formaldehyde and protein to produce a chemical complex. This reaction of binding is reversible and the bond may be hydrolized in the human body by enzymatic action.[69,70] The exact site of the chemical binding is thought to be the peptide groups of certain side chain amino acids, particularly those having dual peptide groups. Formaldehyde is also believed to link adjacent protein molecules by the formation of methylene bridges between the peptide groups of adjacent amino acids. These cross-linkages connect protein molecules without changing their basic overall structure and probably underlie some of the altered chemical reactivity and increased tissue hardness. Formalin may be classified as an additive, non-coagulative fixative because of its chemical binding action. This property may be contrasted with other fixative solutions or to

heat, both of which drastically and irreversibly alter the chemical and physical properties of the protein molecules. The chemical binding with the proteins of micro-organisms is thought to be the basis of the action of formaldehyde as a bactericidal agent.[71]

The reaction between formaldehyde and protein is slow when compared with other fixatives, and in histologic techniques the fixation is always considered to be slightly incomplete.[68] The diffusion of formalin through soft tissues is approximately five times slower than its diffusion through blood plasma.[72] The penetration of formalin into pulp tissue is an example of slow diffusion of the fixative.[73] The pH of the environment has a complex effect on the binding of formaldehyde and protein, with the greatest interaction occurring under slightly alkaline conditions (pH 7.5-8.0). Fixation with formaldehyde does not cause a loss in volume of soft tissues, but subsequent dehydration in absolute alcohol and embedding in paraffin will cause shrinkage and distortion.

The literature contains few references concerning the tissue reaction to tricresol, the other major constituent of formocresol. Tricresol is an aqueous suspension of three isomeric forms of methylphenol derived from coal tar and was added empirically to formocresol to lessen the irritating properties of formalin. Tricresol is a strong antiseptic, four to five times as active as phenol in its local action but is considered to be less caustic.

In vivo, formaldehyde in formocresol fixes the adjacent pulp tissue because of the chemical interaction between the drug and cellular proteins. Formaldehyde also alters blood flow by inducing thrombus formation with resulting areas of ischaemia. Loss of cellular integrity of the erythrocytes in the middle to apical thirds of the pulp may indicate such a condition.[68] The

ischaemia thus produced would give rise to autolytic changes and coagulation necrosis due to the deprivation of normal respiration and nutrition.[74] Because the formalin diffuses apically, the tissues may be fixed *in vivo* in varying stages of tissue necrosis, depending on the duration of ischaemia before fixation. Thus it seems likely that the tissues farthest from the site of application of the drug will show the greatest coagulation necrosis. Enzymatic hydrolysis of the necrotic tissue may take place with replacement by connective tissue. Spedding[55] has shown no adverse effects to the periapical tissues after formocresol pulpotomy procedures.

The clinical success of formocresol pulpotomies in primary teeth can be attributed not only to the bactericidal action of the drug, but also to its fixative qualities and its ability to unite the tissues and to render them incapable of autolysis yet amenable to replacement by granulation tissue.[68]

This review of the chemistry and pharmacological actions of formocresol shows that the medicament is a non-coagulative fixative which is most effective under slightly alkaline conditions. Tricresol was added to the formulation not only to lessen the irritating effects of formalin but also for its antiseptic properties. Formocresol has not been found to affect the periapical tissues after pulpotomy procedures and to this extent is self-limiting in its action.

I-3 Histological Studies

The success of pulpotomy procedures in the primary dentition has been based predominantly on clinical and radiographic criteria, and on the retention of teeth until exfoliation. Histologic studies have been limited in scope because the evaluative criteria have been so indefinite that investigators have found it difficult to compare their findings.[75]

Despite descriptions of the anatomy of teeth by people such as Fauchard cited by Rowe[6] and Tomes,[76] histological appraisal of the action of formocresol did not appear in the literature until approximately 17 years ago.

In 1958 Mandler[77] histologically studied the action of formocresol on human pulps. The pulps of 12 healthy primary and permanent teeth were exposed under local anaesthesia and formocresol was applied for time periods ranging from five minutes to three years. It was found that the pulp in contact with the formocresol for about three minutes showed acute inflammation and prolonged contact of more than 14 days resulted in amyloid degeneration of the entire pulp.

In 1959 Wong[51] evaluated the effects of a paraformaldehyde paste on the pulpal and periapical tissues of 28 primary and six permanent teeth in monkeys. After treatment the teeth were studied histologically over a period of nine to 84 days. Inflammatory reactions in the pulps of both primary and permanent teeth were noted and fibrous changes, similar in appearance to those occurring in the periodontal ligament, were observed in the apical pulpal tissues. Osteodentine was seen in the apical third of the permanent teeth but not in the primary teeth. Tissue changes of a degenerative nature such as reticular atrophy, vacuolization of odontoblasts and mucoid degeneration were thought by Langeland[78] to be the result of poor fixation or inadequate clearing during histologic preparation.

Therefore, histologic studies using these criteria for prognosis should be re-evaluated.

Mansukhani[79] studied the effects of formocresol on the pulps of rats and also on 43 primary and permanent human teeth. The treatment intervals for the human teeth varied from one to 36 minutes up to periods of from one to three years. Histological interpretation indicated that the surface of the pulp immediately under the formocresol became fibrous and acidophilic within minutes after the application of the medicament. This finding was interpreted as indicating that the tissue had been fixed.

A further study by Massler and Mansukhani[80] investigated the effects of formocresol on 205 molar teeth of rats and 43 primary and permanent human teeth. No differences from the controls were observed in the rat molars at seven days after amputation. By the 14th day a defence reaction occurred, consisting of fibrous encapsulation of the inflammatory cells followed by calcification of the capsule and reparative dentine formation. At 21 and 28 days reparative dentine formation was less frequently present in the experimental teeth than in the controls. However, bridging occurred by the apposition of secondary dentine along the walls lateral to and some distance from the amputation site. In human teeth, by contrast, the surface immediately beneath the formocresol became fibrous and acidophilic within a few minutes after the application of formocresol. This was interpreted as fixation of the living tissue. Three distinct zones developed within the pulp after seven to 14 days. Immediately below the formocresol was a broad acidophilic zone of fixation, beneath which was a broad pale-staining atrophic zone in which the number of cells and fibres was greatly diminished. The zone adjacent to the pulp was broad and contained inflammatory cells concentrated at the

junction with the pale-staining zone and diffusing into the sub-adjacent normal pulp tissue.

The outstanding differences between the pulpal reactions in rat and human teeth were the absence of any attempt at fibrous encapsulation of the inflammatory zone and a lack of secondary or reparative dentine formation in the human specimens. The authors concluded that the human pulp did not possess the defensive and reparative potentials that characterized the rat tissue. Formocresol placed on human pulps for more than 14 days produced a fibrous fixation of the living tissue within the pulp canal. Therefore, to ensure minimal invasion of tissue it was suggested that formocresol be applied for no more than seven days.

Emmerson and his co-workers[52] studied the effect of formocresol on human and rat pulp tissues. The pulps of 20 human teeth were treated with formocresol for periods ranging from five minutes to three weeks. At the second visit the pulp stumps were either dusted with calcium hydroxide and the teeth filled with zinc oxide-eugenol, or the pulp stumps were covered with zinc oxide-eugenol-formocresol paste and a restoration placed. The teeth were extracted for histological evaluation from two to eight weeks later. The pulp reaction in both human and rodent teeth varied with the time that formocresol was in contact with the pulp. Tissue changes varied from surface fixation to complete calcific degeneration. Directly beneath the amputation site was a homogeneous zone thought to represent the immediate reaction of the formocresol with the blood clot. Below this was an area in which the pulp appeared normal and was considered to be fixed tissue. Sub-adjacent to the fixed tissue, normal tissue was seen after applications of the drug for five minutes to three days, but treatment for more than three days was thought to cause calcific

degeneration. The authors concluded that this technique could be classified as either vital or non-vital, depending on the length of time formocresol was applied.

Dietz[53] described the effects of formocresol on 40 non-carious human primary teeth. Following pulpotomy, the drug was sealed in the pulp chamber for seven days, the pulp stumps were wiped with formocresol and the pulp chamber was filled with zinc oxide-eugenol. The experimental period varied from 24 hours to 16 weeks. Dietz observed that a progressive non-inflammatory degeneration occurred with an attempt to wall off the medication with a collagenous acellular band immediately below the amputation. After 24 hours this band was seen as a thin zone which progressively widened at each time interval until 16 weeks. At this stage slight areas of resorption appeared in the dentine. The greatest area of tissue breakdown was in the middle portion of the pulp tissue and the least was in the apical third.

In 1962 Doyle, McDonald and Mitchell[54] compared the effects of calcium hydroxide and Buckley's formocresol as a capping material after a pulpotomy procedure in healthy dental pulps of human primary teeth. The treated teeth were examined clinically and radiographically for up to 19 months, and histologically for intervals from four to 388 days. The effects of formocresol on the pulp were similar whether the treatment had lasted for four days or for over one year. It was concluded that the principal effects of formocresol on the primary dental pulp occurred within four days. Healing of the pulp at the amputation site did not occur in pulps treated with formocresol and some bizarre changes were noted microscopically. At the amputation site superficial debris from the blood clot and occasional dentine chips were found, beneath which was a compressed layer of dark-staining tissue having a fibrous

appearance. Below these zones, cells had started to degenerate by karyolysis and karyorrhexis. As the middle third of the root canal was reached odontoblasts were scarcely evident. However, blood vessels and contained blood cells were relatively well preserved throughout the pulp. When the apices were not excised for histological examination, there was transition from the faded fixed area to healthy vital tissue in the apical area. Only one tooth of the 17 exhibited internal root resorption, a phenomenon which had not been reported by other workers.[3, 79] The success rate of formocresol pulpotomies clinically, radiographically and histologically was 100, 93 and 92 per cent, respectively, compared with 71, 64 and 50 per cent, respectively for calcium hydroxide.

Spedding, Mitchell and McDonald[59] studied the effects of formocresol and calcium hydroxide on 36 primary molars and 12 first permanent molars in three Rhesus monkeys. Histological studies conducted 17 to 286 days post-operatively showed that in most instances the teeth treated with formocresol exhibited normal vital tissue in the apical third of the pulp; fixation of the other two-thirds occurred with similar frequency. However, in five teeth, dentine chips obstructed the canals and apparently prevented pulpal fixation. Some of the pulps showed secondary dentine formation and others showed leukocytic infiltration or osteodentine apically below the fixed tissue. It was found also that the periapical tissues were not affected by either formocresol or calcium hydroxide.

Berger[68] compared the reactions of the pulp between a one-stage formocresol treatment and a zinc oxide-eugenol cement. Cariously exposed human primary molars were evaluated clinically, radiographically and histologically from three to 39 weeks post-operatively. Three weeks after treatment with formocresol, well defined compressed tissue was seen in

the coronal portion of the canal, blending to a tissue with complete absence of cellular detail in the apical third. After seven weeks there was an ingrowth of granulation tissue through the apical foramen which replaced the necrotic tissue in the pulp canals. The granulation tissue progressed coronally until 35 to 38 weeks when it was close to or, in some instances, at the amputation site. Osteodentine was present, repairing small areas of internal resorption and slightly narrowing the lumen of the canal. On the basis of histological criteria, 82 per cent of the teeth treated with formocresol were successful. Histologically, all teeth treated with zinc-oxide-eugenol had a poor prognosis. The pulps of all teeth in the latter group had active inflammatory reactions and internal resorption was found consistently.

Beaver, Kopel and Sabes[81] investigated the difference in pulp reaction after a five minute formocresol application to sub-bases of either zinc oxide-eugenol with formocresol added, or to zinc oxide-eugenol alone. The authors summarized the responses of the pulp into six categories: (1) normal, drug-fixed pulp tissue; (2) fibrotic pulp; (3) fibrotic pulp with inflammatory cells; (4) coagulation necrosis; (5) cellular pulp tissue with evidence of internal resorption; (6) amorphous debris or abscess formation. Well defined zones of degeneration, inflammation, calcific deposits, resorption or osteodentine were not found, although these phenomena had been reported by other investigators. There appeared to be no major difference in the histological reaction, whether formocresol was or was not used in the sub-base. Also, there was not enough granulation tissue in any of the sections to presume that this tissue had gradually replaced radicular pulp tissue.

More recently, Ranly, Montgomery and Pope[82] carried

out an in vitro study on the loss of ^{3}H-Formaldehyde from zinc oxide-eugenol cement. They found that there was little or no chemical binding of formaldehyde by zinc oxide-eugenol, but rather a physical binding from which formaldehyde could be leeched with minimal loss of zinc oxide-eugenol matrix. The authors suggested that although the practice of placing formocresol over the amputated pulp stump may be an unnecessary clinical procedure, the possibility deserved further investigation.

Straffon and Han[83] studied the reaction of connective tissue to formocresol-impregnated, polyvinyl sponge implants in femur wounds of hamsters. Quantitative radio-autography following injection of tritiated proline was utilized. In a later study[84] formocresol in 1/50 concentration caused degeneration of cells in the immediate vicinity of the sponge implant, but the animals treated with formocresol showed a definite reduction in the number of infiltrating inflammatory cells. By the tenth post-operative day the sponges in both the experimental and control groups showed a similar recovery of connective tissue ingrowth. Repair was similar also in the femur wound area. It was concluded that formocresol did not interfere with prolonged recovery of connective tissue and that it might have suppressed the initial inflammatory response.

In 1969 Kouri, Matthews and Taylor[85] studied the effects of epinephrine on the healing of the pulp of a primary tooth after a formocresol pulpotomy. When the vasoconstrictor was used, the bleeding time was reduced and a superior blood clot resulted. The band of tissue at the amputation site was primarily osteoid, but in some instances it had a fibrous appearance. The middle and apical thirds of all teeth appeared to be normal.

Harris[86] studied the different pulpotomy amputation techniques and reported on the five-minute reaction of the pulp

to formocresol. Little difference was found in amputation techniques between the spoon excavator and the low-speed or high-speed round bur, although slightly more debris was seen with bur amputations. Tissue reaction to formocresol, compared with controls, showed a wider deep-staining zone at the amputation site, with the nuclei and fibroblasts being spindle shaped with long stellate processes. It was thought that these cells were fixed in vivo. Fixation in vivo was also shown by retention of the zone of Weil near the amputation site with the formocresol medication. The vascular reaction to formocresol was distinctive in the apical two-thirds of the pulp, presenting as congested vessels with coagulated erythrocytes and having the appearance of sludged blood. The band of tissue at the amputation site was primarily osteoid but in some instances it had a fibrous appearance. The middle and apical thirds of all teeth appeared to be normal.

Loos and Han[87] applied techniques of liquid scintillation spectrometry, radio-autography and enzyme cytochemistry to study the reaction of rodent subcutaneous connective tissue to 1/5 concentration of full-strength Buckley's formocresol. Four oxidative and three hydrolytic enzymes were studied. It was concluded that a 1/5 concentration was as effective as Buckley's full-strength formula, and that it allowed for a faster recovery of the affected cells and therefore represented a safer medicament for pulpotomies.

In 1973 Kelley, Bugg and Skjonsby[88] histologically evaluated formocresol and Oxpara pulpotomies in Rhesus monkeys. The histologic findings in the teeth treated with Oxpara and with formocresol were comparable at 22, 85, 167 and 260 days. The similar histologic findings were considered to be due to the similar pharmacologic properties of the Oxpara and formocresol medicaments. The primary molars

in the 22 day sample showed a region of well preserved pulpal tissue in the coronal third which blended into a region of coagulation necrosis of pulpal tissue in the middle third of the canal. Granulation tissue occupied the apical third of the canal. More extensive necrosis of the pulpal tissue, and repair by granulation tissue was observed at 85 and 167 days. By 260 days the canals were filled completely with granulation tissue and osteodentine repair lined the canal walls. The authors concluded that either Oxpara or formocresol could be used as a germicide and a fixative without permanent damage to the process of connective tissue repair. Because of the similar histologic findings the choice of medicament should be left to the preference of the operator.

Kennedy, El-Kafrawy, Mitchell and Roche[89] studied the effects of formocresol pulpotomy in teeth of dogs with induced pulpal and periapical pathosis. The technique employed was a one-stage pulpotomy on vital primary and permanent teeth in beagle puppies. The response of primary teeth was similar to that already described. Immediately adjacent to the pulp dressing there was a band of homogeneous eosinophilic tissue, apical to which less eosinophilic zones gradually approached normal.[54, 59, 68, 80, 81] The formocresol acted as a protein coagulant to produce the area of fixation. The histochemical study by Loos and Han[87] using subcutaneous implants in rats supported this interpretation. Formocresol apparently suppressed metabolism and acted as a cytotoxic agent.

Long term studies have indicated that formocresol pulpotomy techniques are from 90 to 100 per cent clinically successful. However, despite earlier advice contra-indicating the use of formaldehyde products or advising extreme care in their use, it appears that formocresol has beneficial effects in the treatment of vital and non-vital teeth.[90] As a result of

further research the majority of pedodontic departments in the United States of America now use formocresol as the medicament of choice for pulpotomies in primary teeth.[61] Furthermore, a number of investigators have indicated that the one-stage procedure is as successful as the two-stage.[51, 55, 61, 68]

I-4 Bacteriological Action of Formocresol

The elimination of micro-organisms from an infected tooth had been an essential part of endodontic therapy. In the pulpotomy procedure, disinfection of the pulp chamber was carried out by thorough biomechanical preparation followed by the application of formocresol. The two basic requirements for a root canal drug are that it must be an effective anti-bacterial agent and non-injurious to periapical tissues. The cytotoxic effects of formocresol, although known to earlier workers, were not fully understood but were based on subjective criteria. Nevertheless, Buckley[3] stated that there was no necessity to use formaldehyde in the same strength in non-vital teeth containing non-suppurative material as in teeth which contained putrescent material.

In 1936 Walker was cited by Bartels[91] to have stated that formocresol should be used in very small quantities and if paper points or cotton wool were used, these should be moistened rather than saturated with the drug.

Bartels[91] found that bacterial inhibition of Staph. aureus with freshly expectorated saliva on 10 per cent serum infusion agar plates was most marked with formocresol. The results were compared with five other drugs which included oil of cinnamon, eugenol, beechwood creosote, zonite and chloramine T, and azochloramide.

Pear[92] outlined the requirements for drugs used in pulp therapy. The agent should retain its germicidal effect for 48 to 60 hours when sealed in the tooth; it should sterilize without irritation and give off germicidal vapours at body temperature. These vapours should be eliminated slowly to establish and maintain sterility, and to avoid the daily change of applications. Of nine drugs tested formocresol was the only one which inhibited growth of a culture from putrescent pulp canals, the other materials allowing growth to varying degrees.

Beaver, Kopel and Sabes[81] questioned the efficacy of allowing formocresol to remain in contact with the pulp tissue, beyond the initial application, by its incorporation into the sub-base of zinc oxide-eugenol under a final restoration. They concluded that the responses of the remaining pulpal tissue were reactions to the zinc oxide-eugenol alone. This conclusion confirmed the work of other investigators in that the clinical and radiographic findings were inconsistent with the histologic findings.

Cohen, Joress and Calisti[93] studied the bacteria found in infected primary molars of children aged four to eight years, and concluded that the organisms present and their order of frequency were similar to those in permanent teeth. Cultures from the pulp chambers of open, contaminated primary molars revealed that Strep. salivarius, Staph. albus, β-haemolytic streptococci and enteric bacilli comprised the majority of organisms. The practice of maintaining open infected primary teeth should be condemned because of the variety of micro-organisms present and their potentially harmful effects. Because destruction of bone within the bifurcation of primary molar roots occurred in all instances, such teeth should either be extracted or given appropriate root canal therapy.

Marsh and Largent[94] bacteriologically studied aerobic and anaerobic micro-organisms in infected primary molar pulp canals. The most frequently occurring organisms were the streptococci which were noted in 82 per cent of the teeth. Staphylococci were present with such frequency as to cause concern regarding their role as potential pathogens. Staph. albus was noted in 27 per cent and Staph. aureus in 14 per cent of the teeth. Although a total of 15 types of organisms were found in 22 teeth, no tooth had less than two or greater than five different varieties of organisms. Previous workers had failed to show the presence of anaerobes, but Marsh and Largent demonstrated anaerobic

cocci in 36 per cent of their sample.

Wesley, Marshall and Rosen[95] quantitated a minimal effective dose for volatile root canal medicaments. The effect of Buckley's formocresol was studied, using petri dishes seeded with Staph. aureus and Strep. faecalis, on extracted teeth inoculated with the same two organisms. The petri dish study showed only bacterial inhibition and was a screening method to limit the effective dosage of formocresol. The study of extracted teeth was more clinically oriented and by direct observation showed bactericidal effectiveness.

The petri dish study showed that formocresol was volatile and that it inhibited growth of Strep. faecalis on blood agar media when a solution of 0.004 ml or more was applied. The growth of Staph. aureus was similarly inhibited with the much smaller dose of 0.0025 ml applied under the same conditions. In extracted teeth a 0.0025 ml solution of formocresol applied for 48 hours was claimed to sterilize teeth inoculated with both organisms when the canals were dry. When the canals were wet, 0.0025 ml of formocresol applied for 48 hours was only partially effective in sterilizing similarly inoculated teeth. A second 48-hour application of the same amount of formocresol was required to produce complete sterility. The authors stated that drug doses and drug irritation during treatment could be reduced if smaller and properly quantitated amounts were used. They also stressed that drug requirements in vivo might be different.

Vander Wall, Dowson and Shipman[96] studied the antibacterial efficacy and cytotoxicity of three endodontic drugs which included Buckley's formocresol. When tested against Staph. aureus and two enterococci it was found that formocresol was the only effective drug when not in contact with the bacterial lawn. The cytotoxicity of the drugs was measured in a mammalian cell culture system. Clinical doses of formocresol,

if confined to the pulp chamber of the tooth, were relatively non-toxic to either a hamster kidney cell line (BHK-21/4), or to diploid human embryonic long cells (HEL-199).

Treaner and Goldman[97] studied the bacterial efficiency of intra-canal medications by testing the ability of drugs to vapourize and the subsequent effect of vapours on Strep. viridans. Although it was found that the medicaments vapourized, the vapours failed to penetrate the root apex. Formocresol was most effective after 72 hours and was the most bactericidal medicament in the study. However, formocresol failed to completely sterilize the canal.

Edwards and Nord[98] identified micro-organisms isolated from 110 infected primary molars of children aged two to five years. In 30 of 110 teeth no bacterial growth was observed. From the remaining 80 teeth, 96 different strains of micro-organisms were isolated. In 70 of the specimens showing growth there were different types of streptococci. Pure cultures were found in 54 teeth: Strep. mitis in 46, micrococci in four, peptostreptococci, Strep. faecalis and lactobacilli, respectively, in two teeth. Approximately 19 per cent of the isolated micro-organisms were anaerobic. Strep. pyogenes and Staph. aureus organisms were not observed.

In contrast to Cohen, Joress and Calisti[93] other investigators have failed to identify strains typed as Staph. albus in root canals.[98,99] Edwards and Nord[98] stated that the differences in results might depend on the method of bacterial cultivation and identification. They also pointed out that the possible role of the micro-organisms inducing the release of endogenous histolytic enzymes was unknown. Immunoglobins might participate with different antigens in a great number of immune reactions. These reactions could include the release of histamine and other active agents from mast cells in the pulp and periapical tissues or the release of lysosomal enzymes from

tissue leucocytes. All these reactions in the pulp and periapical tissues might be microbiologically non-specific but biochemically specific. They probably depended on a combination of micro-organisms capable of elaborating a number of toxins and immunological tissue reactions.

In 1973 Powell, Marshall and Melfi[100] histopathologically evaluated tissue reactions to endodontic drugs, one of which was formocresol. The authors used cotton pellets in polyethylene tubes which were implanted into the subcutaneous connective tissues in rats, to determine the tissue reactions. Formocresol produced the most severe reaction at three, seven and 14 days but the tissues recovered and were nearly normal after 30 days. The tissue reaction to formocresol appeared to occur in two stages; there were acute reactions after three days and after 14 days, between which intermediate reaction necrosis was apparent after seven days. Possibly, the first reaction was due to the formocresol, the tissue necrosis was due to fixation, and the findings after 14 days were reactions to the degraded tissue produced after seven days. The results of this study supported the work of Loos and Han.[87]

Although pulpotomy is now an accepted dental procedure, in the past potential bacteraemia was a contra-indication for patients with certain medical problems. Farrington[101] studied 13 different micro-organisms in blood samples obtained from the median ante-bracheal vein. He concluded that following a one-stage pulpotomy the incidence of transient bacteraemia appeared to be less than that following other oral procedures. Pulpotomy was claimed to be safe even in the patient had an adverse medical history. Moreover, in the case of multiple pulpotomies, it was the gingival manipulation, the placement of rubber dam and restorative procedures which were considered to be the cause of transient bacteraemia.

Brilliant, Marshall and Rosen[102] quantitated and compared the antibacterial activity of camphorated parachlorophenol,

cresatin, eugenol, formocresol and phenol. The drugs were applied to cotton pellets placed in the pulp chamber of infected root canals *in vitro*, or were placed in the lids of petri dishes inoculated with either *Staph. aureus* or *Strep. faecalis*. All medications exhibited anti-bacterial activity against *Staph. aureus*. Formocresol, camphorated parachlorophenol and phenol exhibited anti-bacterial activity when in direct contact with *Strep. faecalis*, whereas cresatin and eugenol failed to do so. When fumes of the medications were tested, only formocresol was effective against both organisms.

I-5 The Effect of Pulp Exposure and Infection of Primary Teeth on the Succedaneous Teeth

A number of investigators have reported that infected primary teeth can affect both periapical tissues and the succedaneous teeth.[103, 104, 105, 106, 107, 108.]

Using autopsy material from an eight year old child, Morningstar[109] described the destruction of the enamel and sections of the enamel-forming elements of a permanent molar as the results of infection of the primary precursor.

Two maxillae and one mandible taken at autopsy from three children were used by Bauer[110] to describe the effects of apical periodontitis of primary teeth on the developing permanent successors. With mild periodontitis the epithelial structure adjacent to the apical process of the primary teeth was reduced to a flat, hyalinized and keratinized membrane. In some instances the inflammation stimulated the enamel epithelium to proliferate; in others the united enamel epithelium was destroyed, allowing the enamel to be exposed to inflammatory oedema and granulation tissue. The former was found to be harmless to the enamel and the latter caused erosion and deposited a well-calcified cementum-like substance on the surface of the enamel.

In 1957 Muhler[104] studied the effects of apical inflammation of primary teeth on dental caries in the permanent dentition. He noted that a number of teeth, usually premolars, were affected by dental caries before they entered the oral cavity. Radiographic examination of unerupted teeth in situ showed interproximal caries and frequently occlusal caries was found in many instances when the teeth first erupted.

Schiere and Frankl[105] made a longitudinal radiographic and study-model analysis of the effects of primary tooth infection on permanent teeth. The authors concluded that the longer the infected teeth were retained for space maintenance, the more severe were the sequelae. Fanning[111] had shown that dental

caries caused accelerated root resorption of primary molars but the rate of acceleration was reduced if the lesion was treated.

In a clinical study, Lauterstein, Pruzansky and Barber[112] described the effects of primary molar pulpotomy on the eruption of the permanent premolar. The findings also showed that the procedure caused accelerated or aberrant eruption.

In 1962 Fanning[113] studied the effects of environmental insults on the rate of tooth formation and the eruptive movement of permanent teeth in children with premature loss of the primary precursors. It was found that there was no change in the rate of formation of the premolar, but an immediate spurt occurred in its eruption, regardless of the stage of development and the age at which the primary tooth was extracted. Premolar eruption was accelerated in the presence of long-standing necrosis of the primary tooth, especially if accompanied by loss of surrounding bone. In very young patients, before the premolar crown was completely formed, the spurt levelled off and the tooth then remained stationary, erupting later than one which had a normally resorbing primary precursor.

In 1967 Binns and Escobar[106] studied the effects in dogs of endogenous infection of the pulps of primary teeth on the permanent tooth germs at different stages of tooth formation. They concluded that pulp exposure and infection of primary teeth could result in hypoplasia and hypocalcification of the enamel in the succedaneous teeth, if the insult occurred during the period of crown formation.

McCormick and Filostrat[107] found that dental infection occurring at an age of high caries activity between six and nine years, damaged the enamel of permanent teeth in more than 25 per cent of their sample. Also, abscess formation and alveolar bone destruction led to early eruption and 90 per cent of the premolars erupted without space loss in the primary molar region. Hence, the retention of abscessed teeth is an undesirable

type of space maintenance, especially if the possible enamel defects and systemic effects of a long-standing osteomyelitis are taken into account.

The effects of pulpal exposure in the primary dentition on the succedaneous teeth were investigated by Kaplan, Zach and Goldsmith.[114] Inflammation was induced by exposing the pulps of primary teeth of five Rhesus monkeys. Of a total of 41 teeth treated, 19 of the exposed pulps were injected with a drop of concentrated hydrochloric acid (12N). It was found that three untreated pulps and six treated with acid developed periapical areas which affected only the enamel of the underlying succedaneous teeth. The authors noted that necrosis of primary pulps resulted in relatively little damage to the succedaneous dentition because the inflammatory response remained localized. They also concluded that the effects on permanent teeth were irregular and unpredictable.

In 1972 Berk and Krakow[103] compared the management of pulpal pathosis in primary and permanent teeth and summarized the effects on developing teeth. These effects included cyst formation which might envelop the permanent tooth bud, interruption of amelogenesis, enamel hypoplasia, discolouration, changed eruption sequence, ectopic eruption, axial rotation and loss of space. Reported effects on the periapical tissues included abscess and cyst formation and osteomyelitis. The authors concluded that infected primary teeth should not be retained but should have either pulp treatment or be extracted.

Pulp exposure and infection of primary teeth has been found to affect the succedaneous teeth in many different and unpredictable ways. To avoid undesirable sequelae, primary teeth with pulpal pathosis should be treated by formocresol pulpotomy or be extracted and where necessary a space maintainer inserted.

I-6 Criteria for Success and Contra-indications for the Pulpotomy Procedure

The vital pulpotomy technique is used in primary teeth when there is a doubtful prognosis for pulp capping, but the prognosis for maintaining the vitality and function of the radicular pulp is favourable. The prognosis is favourable even when the odontoblastic membrane has been pathologically penetrated, provided the disease process is confined within the coronal pulp tissue.[103]

Davies and King[115] state that the pulpotomy technique may be used in non-vital teeth and the presence of periapical degeneration does not necessarily contra-indicate conservative treatment. However, periapical rarefaction associated with pathological root resorption or the progression of the rarefaction to the permanent tooth bud below should preclude the procedure.

Many workers have stressed that clinical and radiographic assessments are essential before pulpotomy treatment.[49, 67, 85, 116, 117, 118, 119, 120, 121, 122, 123] According to these investigators the criteria for successful treatment require an absence of prolonged toothache and of clinical or radiographic signs of extensive pulpal degeneration or of any peri-radicular pathology. The pulp tissue should be vital with at least two-thirds of the root intact. The crown of the tooth should be sufficiently intact to enable restoration and a space analysis carried out to exclude the possibility of extraction for orthodontic reasons.

CHAPTER II

MATERIALS AND METHODS

II-1 Formocresol Pulpotomy Procedure

The technique carried out in the Pedodontic Clinics of the University of Adelaide was that outlined by Allen.[124] The procedure was undertaken in pulp exposures of vital primary teeth where there was no history of toothache and an absence of clinical or radiographic evidence of apical infection.

The formocresol solution had the following composition:

Formaldehyde (37%)	19 ml
Cresol B.P.	35 ml
Glycerine	46 ml
pH approximately	3.7-4.0

The technique described by Wittich,[46] Sweet,[49] Redig,[60] Berger[68] and Allen[124] included a recent periapical radiograph, the administration of a local anaesthetic and the isolation of the tooth with rubber dam.

The cavity outline was completed and all caries and undermined enamel along the dentino-enamel junction removed. The caries over the exposure site was left until the remainder of the cavity was complete. Excessive removal of tooth structure was avoided to prevent weakening of the crown. Where possible, the roof of the pulp chamber was removed in one piece by outlining the pulpal line angles with a No. 699 tapered fissure bur in the contra-angle low speed handpiece.

The entire coronal portion of the pulp was removed by running a No. 6 round bur in reverse under light pressure. This lessened the risk of removing pulp filaments in the root canals and also the danger of perforating the root bifurcation. The area of amputation and consequent haemorrhage were reduced by siting the amputation more apically in the root canal with a No. 3 round bur. Alternatively, the pulp was excised

with a sharp excavator. The pulp chamber was irrigated with sterile normal saline and wiped clean with cotton wool pellets, either dry, or moistened in anaesthetic solution, or in formocresol.

The pulpotomy procedure was carried out in either one or two stages depending on excessive pulp haemorrhage, the behaviour of the child and time factors.

A One-Stage Procedure: After haemorrhage had been controlled a pellet moistened with formocresol was placed in the pulp chamber for five minutes (Figure 1). When the pellet was removed the pulp stumps usually appeared brown and there was no haemorrhage. If haemorrhage persisted, another moistened pellet was placed for a further five minutes. The pulp chamber was filled with a layer one to two mm thick of a 50/50 mix consisting of one drop of formocresol and one drop of eugenol mixed with zinc oxide to a thick paste. The paste was pressed over the amputation sites in the root canals with a large cotton pellet. The tooth was restored finally with silver amalgam and in some instances with a preformed stainless steel crown (Figure 2).

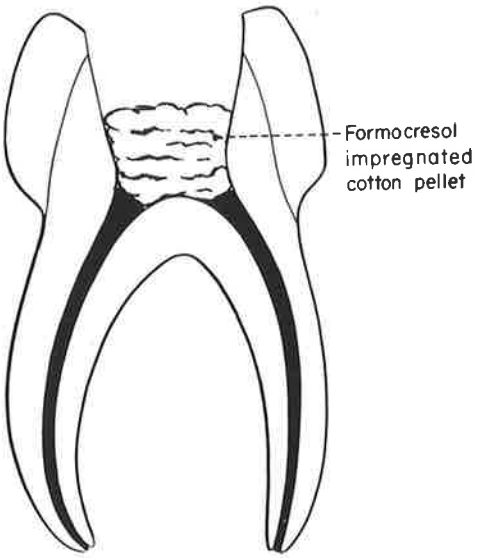

Figure 1
The amputated coronal pulp is covered with a pellet of formocresol for five minutes.

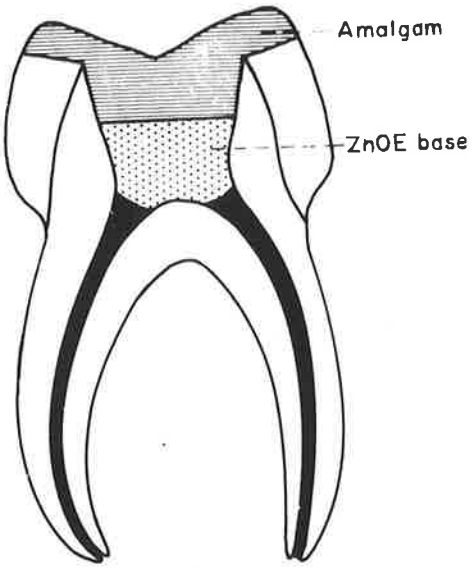

Figure 2
The completed restoration may cover the cusps for greater protection. In many cases a stainless steel crown may be used.

(Reproduced from Finn, S. B. [125])

B Two-Stage Procedure: The moistened pellet was sealed in the pulp chamber with zinc oxide-eugenol cement for seven days. Care was taken to avoid excess formocresol as any leakage could cause ulceration of the gingival tissues. On removal of the pellet a 50/50 mix of formocresol was inserted and a permanent restoration placed.

The post-operative follow-up for both procedures included six-monthly radiographs to confirm that the lamina dura was intact, the alveolar bone was normal and there was an absence of

internal resorption.

Apically infected primary molars were usually extracted and a space maintainer constructed, if necessary.

In this survey, success or failure of the pulpotomy procedure was determined by both clinical and radiographic criteria. A successful pulpotomy satisfied both criteria. The clinical criteria to determine failure were mobility of the tooth and abscess or sinus formation. The radiographic criteria of failure were the presence of a granuloma or root end cyst, internal resorption of the crown or root of the tooth, or ankylosis of the tooth. However, failure could be a progressive and lengthy procedure until the tooth eventually was extracted.

II-2 Preparation of a Register of Patients

In order to assess the success or failure of the formo-cresol pulpotomy procedure, a register was compiled of pedodontic patients whose teeth had been treated by the technique. The intention is that all future pulpotomy treatments will continue to be entered in the register so that a constant review can be maintained. For this reason a record sheet was prepared containing the patient's personal data, the clinical examination, operative procedures, a post-operative review and the reason for discharge (Appendix I).

II-3 Selection and Examination of Sample Studied

A total of 1,823 patients attended The University of Adelaide Pedodontic Clinics between 1970 and 1974 inclusive. A search of the patient records revealed that 764 had had one or more teeth treated by pulpotomy. This group formed the nucleus of the register of pulpotomy treatments, information on which will be kept up to date in future. The information gained from the case notes of each patient is set out in Appendix I.

In 1974, letters were sent to the 542 patients who retained teeth treated by pulpotomy. The reasons for the study were explained and co-operation in the survey was requested (Appendix 2). Upon return of the letter indicating parental consent, an appointment was made for the clinical and radiographic examinations. The 269 patients who attended were examined, periapical radiographs were taken and an assessment was made of the tooth, or teeth, which had been treated by pulpotomy. The information derived from the case notes of 335 patients who failed to respond was included in the present data.

In 1975, the data were reviewed by a search through patient records to confirm the ability of operators to complete the pulpotomy record sheets. The data were transferred from the record sheets to computer punched cards and programmes written to analyse the findings. Some items of information sought on the record sheet were not available from the case notes but the register has been designed so that this information will be available in the future.

CHAPTER III

RESULTS

III-1 The Clinical Examination

Table 1 sets out the number of pulpotomies treated per patient during the five year period 1970-1974 inclusive.

TABLE 1

Number of Primary Teeth per Patient Treated by Formocresol Pulpotomy

No. of pulpotomies per patient	1	2	3	4	5	6	7	8	Total
Males									
No.	223	98	37	19	6	0	0	1	384
%	58.07	25.52	9.64	4.95	1.56	0	0	0.26	100.00
Females									
No.	232	97	32	16	1	2	0	0	380
%	61.05	25.53	8.42	4.21	0.26	0.53	0	0	100.00
Total									
No.	455	195	69	35	7	2	0	1	764
%	59.56	25.52	9.03	4.58	0.92	0.26	0	0.13	100.00

It can be seen that 384 males and 380 females had teeth treated by pulpotomy, the number of pulpotomies per patient ranging from one to eight. Approximately 60 per cent of the children had only one tooth treated by the procedure. There were no significant sex differences in the number of patients treated nor in the number of pulpotomies per patient.

TABLE 2

Age at which Primary Teeth were Treated
by Formocresol Pulpotomy

Age in years	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	Total
Males											
No. of pulpotomies	10	58	96	145	126	97	81	26	3	1	643
%	1.56	9.02	14.93	22.55	19.59	15.08	12.60	4.04	0.47	0.16	100.00
Females											
No. of pulpotomies	11	72	132	126	115	82	51	8	6	0	603
%	1.82	11.94	21.89	20.89	19.07	13.60	8.46	1.33	1.00	0	100.00
Total											
No. of pulpotomies	21	130	228	271	241	179	132	34	9	1	1,246
%	1.69	10.43	18.30	21.75	19.34	14.37	10.59	2.73	0.72	0.08	100.00

Table 2 shows the age distribution in males and females at which 1,246 primary teeth were treated by the formocresol technique.

The mean age at which teeth were treated was 6.99 years for the total sample. The mean age for males was 7.16 and for females 6.81 years. This difference was significant at the 5 per cent level, t = 3.69.

Table 3 gives the numbers and percentages of teeth treated by pulpotomy per quadrant.

TABLE 3

Numbers of Teeth Treated by Pulpotomy per Quadrant

	Quadrant							
	5		6		7		8	
Tooth	No.	%	No.	%	No.	%	No.	%
1	3	0.24	3	0.24	0	0	0	0
2	0	0	0	0	0	0	0	0
3	6	0.48	7	0.56	2	0.16	2	0.16
4	132	10.59	112	8.99	178	14.29	172	13.80
5	114	9.15	118	9.47	197	15.82	200	16.05
Total	255	20.46	240	19.26	377	30.27	374	30.01

Table 3 shows that 98.26 per cent of the teeth involved were first and second primary molars, the mandibular left and right quadrants containing 30.27 and 30.01 per cent respectively, of the teeth treated. The difference in the numbers of maxillary and mandibular teeth was significant, $\chi^2_1 = 52.60$, cf. χ^2_1 at 5 per cent level = 3.84. No pulpotomies were performed on mandibular

central incisors nor on maxillary and mandibular lateral incisors.

The distribution of teeth treated by pulpotomy in males and females is given in Table 4.

TABLE 4

Distribution of Pulpotomies in Males and Females

	Quadrant								
	No.	%	No.	%	No.	%	No.	%	Total
Males	123	18.13	135	21.00	193	30.01	192	29.86	643
Females	132	21.89	105	17.41	184	30.52	182	30.18	603
Total	255	20.46	240	19.26	377	30.27	374	30.01	1,246

When the number of teeth treated per quadrant was compared in males and females no significant difference was found. $\chi^2_3 = 3.25$, cf. χ^2_3 at 5 per cent level = 7.81.

Table 5 divides the sample into three groups, namely those for whom pre-operative radiographs had not been taken, those who had only pre-operative radiographs and those who had had post-operative radiographs only.

TABLE 5

	Radiographic Groups						
	None		Pre-operative		Immediately post-operative		
	No.	%	No.	%	No.	%	Total
Males	142	22.08	493	76.67	8	1.25	643
Females	125	20.73	473	78.44	5	0.83	603
Total	267	21.43	966	77.53	13	1.04	1,246

TABLE 6

State of the Pulp prior to Pulpotomy

	No Information		Vital		Non-Vital Non-Suppurative		Non-Vital Suppurative		Previous Pulp Filling		
	No.	%	No.	%	No.	%	No.	%	No.	%	Total
Males	570	88.64	45	7.00	11	1.71	3	0.47	14	2.18	643
Females	533	88.39	45	7.46	10	1.66	3	0.50	12	1.99	603
Total	1,103	88.52	90	7.22	21	1.69	3	0.48	26	2.09	1,246

TABLE 7

Initial Condition of the Tooth before Pulpotomy

	No Information		Decayed		Filled		Filled and Decayed		
	No.	%	No.	%	No.	%	No.	%	Total
Males	128	19.91	333	51.79	2	0.31	180	27.99	643
Females	117	19.40	322	53.40	2	0.33	162	26.87	603
Total	245	19.66	655	52.57	4	0.32	342	27.45	1,246

Table 6 describes the state of the pulp prior to pulpotomy and the number of teeth which previously had been pulp treated. No information was available on 88.52 per cent of the teeth treated.

Table 7 describes the initial condition of the tooth before pulpotomy. Eighty per cent of the teeth were either decayed, or filled and decayed before the pulpotomy.

Table 8 shows the state of root resorption at the time of pulpotomy. The amount of root remaining was either one-third or less, two-thirds or more than two-thirds; or the tooth was mobile.

In 60.27 per cent of the teeth treated, two-thirds or more of the root structure was present at the time of operation. However, 10.59 per cent of the teeth were mobile or had one-third or less of the root remaining.

TABLE 8

Initial Stage of Root Resorption

	No Information		≥ 2/3		2/3		≤ 1/3		Mobile		
	No.	%	No.	%	No.	%	No.	%	No.	%	Total
Males	179	27.84	145	22.55	254	39.50	62	9.64	3	0.47	643
Females	184	30.51	103	17.08	249	41.29	66	10.95	1	0.17	603
Total	363	29.13	248	19.91	503	40.37	128	10.27	4	0.32	1,246

TABLE 9

Types of Pulp Exposure

	No Information		Near		Carious		Mechanical		Traumatic		
	No.	%	No.	%	No.	%	No.	%	No.	%	Total
Males	131	20.37	2	0.31	477	74.18	32	4.98	1	0.16	643
Females	117	19.40	6	1.00	445	73.80	35	5.80	0	0	603
Total	248	19.90	8	0.64	922	74.00	67	5.38	1	0.08	1,246

TABLE 10

Types of Pulpotomy Procedure

	One-Stage		Two-Stage								
			1 Week Separation		1-2 Week Separation		2-4 Week Separation		>4 Weeks Separation		
	No.	%	No.	%	No.	%	No.	%	No.	%	
Males	518	80.56	68	10.58	28	4.35	16	2.49	13	2.02	643
Females	488	80.93	54	8.96	42	6.96	15	2.49	4	0.66	603
Total	1,006	80.74	122	9.79	70	5.62	31	2.49	17	1.36	1,246

III-2 Operative Procedures

The types of pulp exposure were categorized in Table 9 as near, carious, mechanical by the operator or traumatic.

Table 9 shows that 74 per cent of the pulpotomies were performed because of carious exposure of the pulp.

Table 10 gives the numbers and percentages of one and two-stage pulpotomies.

It can be seen from Table 10 that 80.74 per cent of the pulpotomies were one-stage procedures. In 1.36 per cent of the teeth treated, the time between appointments was greater than four weeks, this period coinciding, in some cases, with the University's long vacation.

Table 11 indicates whether the pulpotomy was completed with a final restoration and the type of restoration placed.

Approximately 88 per cent of the teeth treated by pulpotomy were restored with amalgam or with amalgam and a stainless steel crown. The 8.91 per cent of teeth not permanently restored had had either zinc phosphate cement or an intermediate restorative material inserted.

TABLE 11

Type of Final Restoration

	Not Completed		Amalgam		Stainless Steel Crown		Amalgam and Crown		Composite		
	No.	%	No.	%	No.	%	No.	%	No.	%	Total
Males	50	7.78	425	66.09	14	2.18	153	23.79	1	0.16	643
Females	61	10.12	371	61.53	24	3.98	146	24.21	1	0.16	603
Total	111	8.91	796	63.88	38	3.05	299	24.00	2	0.16	1,246

TABLE 12

Failures of Pulpotomy by Radiographic Criteria

	No Information		Granuloma or Root End Cyst		Internal Resorption of Root		Internal Resorption of Crown		Ankylosis		
	No.	%	No.	%	No.	%	No.	%	No.	%	Total
Males	609	94.71	29	4.51	5	0.78	0	0	0	0	643
Females	546	90.55	47	7.79	7	1.16	1	0.17	2	0.33	603
Total	1,155	92.70	76	6.10	12	0.96	1	0.08	2	0.16	1,246

III-3 Post-operative Review

Information relating to the post-operative clinical examination was available on only 28 teeth of the 1,246 treated. These data have therefore been omitted from the report.

The results of the post-operative radiographs are given in Table 12. The radiographic criteria for failure of a pulpotomy were a granuloma or root end cyst, internal resorption of the root, internal resorption of the crown or ankylosis of the root. Internal resorption of the root occurred in 12 teeth, each of which had been treated by the one-stage procedure. In one individual three teeth were affected by internal resorption. Figure 3 is a bite-wing radiograph of these teeth.

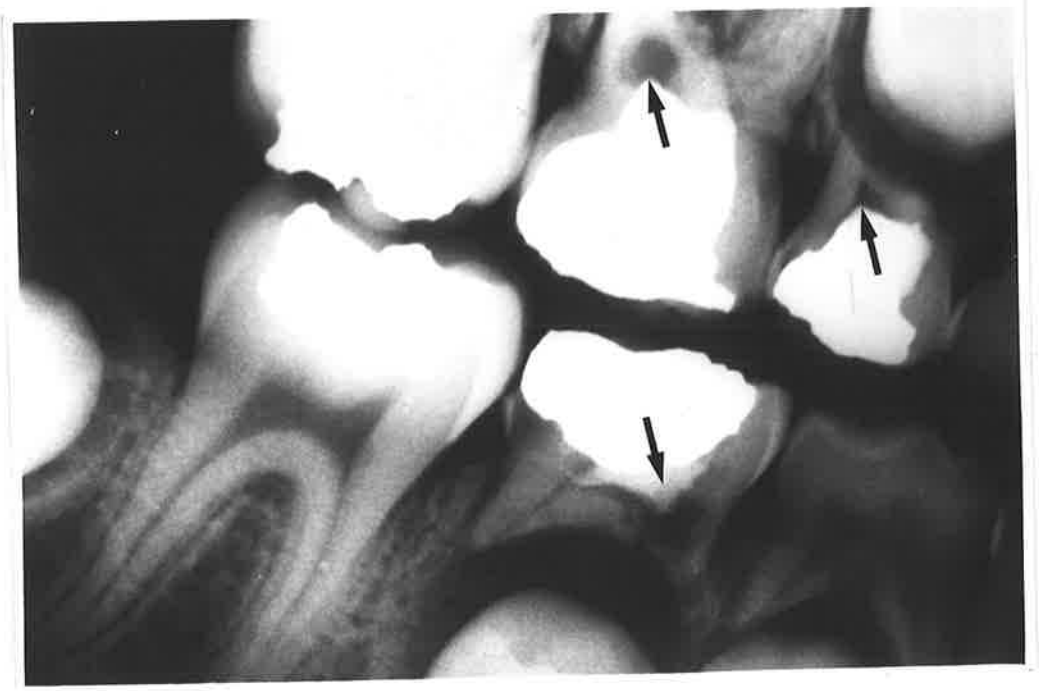

Figure 3

Table 13 gives the successes and failures of pulpotomies by clinical and radiographic assessment.

TABLE 13

Success and Failure of Pulpotomy - Clinical and Radiographic Assessment

		Radiographic		
		Success	Failure	Total
Clinical	Success	1,139	79	1,218
				97.75
	Failure	16	12	28
				2.25
	Total	1,155	91	1,246
	%	92.70	7.30	100.00

The findings indicated that over a five year period, the clinical success rate using Buckley's formocresol was 97.75 per cent and the radiographic success rate was 92.70 per cent.

It was assumed that unless there was evidence to the contrary, a pulpotomy was deemed successful as outlined in Appendix 1, 3 Post Operative Review, Q.1 and Q.2. However, amongst the group classed as both clinically and radiographically successful in Table 13, there were 57 teeth treated by pulpotomy which were extracted due to failure, but there was not any supporting evidence available in these case notes. This inconsistency has been resolved by considering all 57 pulpotomies as failures, and thus providing the slightly more conservative estimates given in Tables 15 and 16.

TABLE 14

Reason for Tooth Loss

	No Information		Following Perforation		Extraction Following failure of Pulpotomy		For Orthodontic reasons		Exfoliation		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	
Males	583	90.67	3	0.47	41	6.37	5	0.78	11	1.71	643
Females	532	88.22	4	0.66	43	7.13	6	1.00	18	2.99	603
Total	1,115	89.49	7	0.56	84	6.74	11	0.88	29	2.33	1,246

The reasons for tooth loss were extractions, following perforation of the root bifurcation or trifurcation, failure of the procedure, orthodontic reasons or normal exfoliation of the tooth.

Table 14 gives the reasons for tooth loss in males and females.

The mean age at which teeth were lost following failure of the pulpotomy was 8.00 years; the mean length of time between the date of operation and the time at which these teeth were extracted was 1.27 years. The mean age at which teeth were removed for orthodontic reasons, or were exfoliated, was 9.49 years. The mean ages were not significantly different between males and females at the 5 per cent level, $t = 0.69$. The length of time teeth remained in the mouth, before being extracted for orthodontic reasons or before being exfoliated, was 2.21 years in males and females.

III-4 Analysis of Successes and Failures

In the present study a successful pulpotomy has been defined as one which allows the tooth to be retained without signs and symptoms of clinical or radiographic failure. The length of survival time of the tooth could only be determined by the date of tooth loss and in the majority of teeth this event had not yet occurred. As the data become available the results will be continually reviewed.

The mean age at which a tooth was successfully treated by pulpotomy is shown in Table 15.

TABLE 15

Successful Pulpotomies - Mean Age when Treated

	No.	Mean Age (years)	Standard Error
Males	571	7.19	.005
Females	511	6.82	.005
Total	1,082	7.02	.003

The difference between the mean ages for males and females was significant at the 5 per cent level, $t = 3.67$.

Table 16 shows the mean ages at which treatment failed as a result of the procedure.

TABLE 16

Failed Pulpotomies - Mean Age when Treated

	No.	Mean Age (years)	Standard Error
Males	72	6.90	.046
Females	92	6.77	.033
Total	164	6.83	.019

n.s., $t = 0.46$

Pulpotomies which failed lasted for a mean time of 1.27 years, with a time range immediately following perforation of the floor of the pulp chamber to a maximum of five years. Table 17 shows the mean length of time which elapsed from the date of treatment to the extraction of the tooth in males and females.

TABLE 17

Failed Pulpotomies - Period between Treatment and Extraction

	No.	Mean Time (Years)	Standard Error
Males	42	1.19	.043
Females	40	1.36	.038
Total	82	1.27	.015

n.s., t = 0.59

The mean ages at which teeth were extracted following failure of the pulpotomy are shown in Table 18.

TABLE 18

Failed Pulpotomies - Mean Age at Extraction

	No.	Mean Age (Years)	Standard Error
Males	42	7.75	.118
Females	40	8.26	.095
Total	82	8.00	.038

n.s., t = 1.10

One of the reasons for tooth loss was perforation of the bifurcation or trifurcation of roots which occurred in 0.56 per cent of the pulpotomies. All seven teeth which were perforated

were in the left quadrants.

Teeth treated by pulpotomy which were subsequently extracted for orthodontic reasons or were exfoliated, remained in the mouth for a mean period of 2.21 years. This period was identical in both males and females. The mean ages of patients whose teeth were extracted for orthodontic reasons, or were exfoliated, are shown in Table 19.

TABLE 19

Mean Ages at Orthodontic Extraction or at Exfoliation

	No.	Mean Age (Years)	Standard Error
Males	8	9.68	.107
Females	14	9.38	.080
Total	22	9.49	.045

n.s., t = 0.69

The success and failure of one and two-stage pulpotomies are shown in Table 20.

TABLE 20

Success and Failure of One and Two-Stage Pulpotomies

	Type of Procedure		
	One-Stage	Two-Stage	Total
Success:			
No. of pulpotomies	870	212	1,082
Failure:			
No. clinically failed	25	3	28
No. radiographically failed	49	13	62
No. failed and extracted	62	12	74
Total	1,006	240	1,246

There was no significant difference between success or failure of the one and two-stage procedures.

$\chi^2_3 = 1.95$, cf. χ^2_3 at 5 per cent level = 7.81.

The numbers of successful and failed pulpotomies in males and females are shown in Table 21.

TABLE 21

Successful and Failed Pulpotomies

	Males	Females	Total
Success:			
No. of pulpotomies	571	511	1,082
Failure:			
No. clinically failed	11	17	28
No. radiographically failed	25	37	62
No. failed and extracted	36	38	74
Total	643	603	1,246

The difference between males and females in the number of successful and failed pulpotomies was not significant.

$\chi^2_3 = 5.71$, cf. χ^2_3 at 5 per cent level = 7.81.

CHAPTER IV

DISCUSSION

Of a total 1,823 children who attended The University of Adelaide Pedodontic Clinics over a five year period, 764 had 1,246 primary teeth treated by pulpotomy. The contributing factors responsible for the large number of teeth treated by the pulpotomy procedure is probably related to the high caries rate associated with a generally low socio-economic status of patients seeking treatment at the Dental Department of the Royal Adelaide Hospital. A survey conducted in the Adelaide metropolitan area has previously reported the association between dental caries and the socio-economic status.[126] Another factor which increased the number of pulpotomies was the concern on the part of the staff to prevent the premature loss of primary teeth and the resulting undesirable sequelae.

The significantly younger age at which females had teeth treated by pulpotomy is difficult to explain as sex differences in the emergence of primary teeth have not been reported.[127] However, primary teeth complete their development and are exfoliated earlier in females when compared with males of the same chronological age.[128, 129] As might be expected there were no sex differences in the numbers of teeth treated, the quadrants involved nor the success or failure of either the one or two-stage procedure.

Although there was symmetry between the number of teeth treated in left and right quadrants, there was a significantly larger number of mandibular teeth (60.28 per cent) when compared with those treated in the maxilla. This finding is contrary to the results reported in the permanent dentition where teeth in the maxillary arch contributed approximately 57 per cent of the carious teeth in a study involving 2,500 secondary schoolchildren.[130]

Neither central nor lateral incisors were treated by pulpotomy, a fact which supports the finding that mandibular anterior teeth are the least susceptible to dental caries.[130]

Part of the present study has involved the preparation of a register of patients with primary teeth treated by formocresol pulpotomy. It has been evident in compiling the data that relevant information relating to the pre-operative and operative procedures were consistently omitted from the case-note records. For instance, the state of the pulp prior to pulpotomy was not answered in 88.52 per cent of the teeth treated. Also questions relating to the size and position of the exposure, the degree of haemorrhage and whether rubber dam was used were not answered in more than 90 per cent of cases in each instance. Although the use of rubber dam was compulsory for all conservative procedures in the pedodontic clinics, in only one instance was it stated that rubber dam was not used. It is hoped in setting up a pulpotomy register that in future, information essential for the accurate diagnosis and successful treatment will be available.

In 10.59 per cent of the teeth treated, pulpotomies were undertaken when in fact the procedure was contra-indicated because less than one-third of the root remained or the tooth was mobile. In these instances the preferred treatment should have been extraction.

There was no significant difference between the success and failure rates of the one and two-stage pulpotomies. The one-stage procedure was performed in 80.74 per cent of the teeth because it required less clinical time. An important factor in the successful management of young children is to reduce the treatment time as much as possible. Also the one-stage pulpotomy has economic advantages for the patient as the number of operative appointments is markedly decreased.

Internal resorption, which has been reported as a rarity

in primary teeth treated by the formocresol technique, was found in twelve teeth each of which had undergone the one-stage procedure. In the majority of instances the area of resorption was confined around, or adjacent to, the amputation sites. However, in three teeth internal resorption appeared along the whole length of one root canal only. A possible explanation of internal root resorption at the amputation site could be trauma either during the amputation procedure, or pressure when the 50/50 mix of zinc oxide-eugenol was packed into place.

One reason for the extraction of primary molars following pulpotomy which could have been avoided, was perforation of the root bifurcation or trifurcation. All seven teeth extracted for this reason were positioned in the left quadrants, suggesting that operators had difficulty in carrying out mechanical procedures on the left side of the maxilla and mandible. Apparently, more care must be exercised when operating in left quadrants.

The data derived from the case notes and from clinical and radiographic examinations over a five year period, confirmed the high success rate of formocresol pulpotomies as reported by other workers. Moreover, unlike a number of previous studies, the success rate was based on post-operative radiographs taken for most of the subjects at regular intervals after treatment. Also, children were recalled every six months for a dental examination and any failures which occurred were promptly treated; in fact 2.09 per cent of teeth treated by pulpotomy had had a previous pulp filling and the retreated teeth were successfully retained.

The treatment of non-vital teeth was successfully undertaken in 53 selected cases and the results were in line with those reported by Davies and King.[115] The debridement of multiple, thin infected canals of non-vital primary teeth may present difficulties. Therefore, the need for careful selection of

non-vital teeth for treatment is accented.

The present five-year study may help to overcome deficiencies in the pulpotomy treatment procedure. It would also be helpful if more non-vital teeth, whether suppurative or non-suppurative, were treated by the technique and the results compared with those of vital teeth. However, when treating abscessed teeth general surgical principles should be adhered to, the focus of infection removed and the abscess drained as a preliminary treatment.

CHAPTER V

MICROBIOLOGICAL TESTS OF THE EFFECTIVENESS OF A REDUCED CONCENTRATION OF BUCKLEY'S FORMOCRESOL

V-1 Introduction

Formocresol is widely used in the treatment of exposed pulps of vital primary teeth. However, there is a need for research into the mode of action of the drug as the rationale for its use is empiric. It is possible that lesser concentrations of formocresol could achieve a similar clinical result and that drug irritation of the pulpal tissues during treatment could be decreased if formocresol were used in a properly quantitated manner.

For this reason an in vitro study was designed to assess the efficacy of reduced concentrations of Buckley's formocresol on three organisms, each of which has been reported to be present in the pulps of infected primary molars.

V-2 Review of Literature

The anti-bacterial effect of formocresol has been described in Chapter I-4, pages 31-36.

V-3 Materials and Methods

The effect of reduced concentrations of Buckley's formocresol was investigated using serial dilutions in Todd-Hewitt broth (THB; Oxoid) and in Brain Heart Infusion agar (BHI; B. B. L). The organisms studied were local isolates of Strep. faecalis, Staph. aureus, found in infected primary molars and used by Wesley, Marshall and Rosen,[95] and Strep. salivarius which was found in 70 per cent of infected primary molars by Cohen, Joress and Calisti.[93]

Two experiments were designed to study the bactericidal and bacteriostatic nature of formocresol. The micro-organisms

in the study were subcultured and plated at regular intervals to ensure purity.

Experiment I

Initially, a broad screening method assessed the growth of Strep. faecalis, Strep. salivarius and Staph. aureus in various concentrations of Buckley's formocresol in TH broth. The concentrations were a control, 1/10, 1/100, 1/1000, 1/10,000 and 1/100,000. It was envisaged that growth could be determined by turbidity of the broth. However, the 1/10 formocresol concentration which had been autoclaved had a milky appearance, and the 1/100 concentration was turbid; the other concentrations were clear. As a result, it was decided to use concentrations of formocresol in BHI agar on which growth colonies could be seen once the solution had been plated and dried in petri dishes.

Experiment II

This experiment was carried out in three phases. First, the broad screen phase involved a control BHI agar plate and five concentrations of 10.00, 1.00, 0.20, 0.01 and 0.001 per cent Buckley's formocresol in BHI agar. The petri dishes were divided into thirds and an overnight broth culture of each micro-organism was plated onto each third. The plates were incubated aerobically at 37°C and were observed directly at 24-hourly intervals for 72 hours. Microscopic analysis of the agar for colony growth was not done. The organisms failed to grow at a concentration of 0.2 per cent Buckley's formocresol after 48 hours, but there was growth of Staph. aureus after 72 hours at the same concentration.

A similar procedure was carried out in a narrow screen using a control BHI agar plate and nine concentrations of Buckley's formocresol, 1.0, 0.50, 0.33, 0.25, 0.20, 0.167, 0.134, 0.125 and 0.01 per cent. The plates were incubated

aerobically at 37°C and observed at 24-hourly intervals for three days.

After 72 hours the micro-organisms on plates which showed no growth were subcultured with a sterile swab onto plates of BHI agar without formocresol to differentiate between the bacteriostatic and bactericidal actions of the drug. The subcultures of organisms from plates of 1.00, 0.50, 0.33 and 0.25 per cent formocresol in BHI agar were incubated at 37°C and were observed at 24-hourly intervals for 72 hours.

The experiment was limited to short periods of three days to avoid the possibility of contamination which may have provided false readings if the subculturing had been done after a period of seven days.

V-4 Results

Strep. faecalis was the most resistant organism of those tested and under the above conditions Buckley's formocresol was bactericidal to a minimum concentration of between 0.50 and 0.33 per cent formocresol in BHI agar.

A summary of the results is shown in Tables 22, 23 and 24.

TABLE 22

The Effect of Varying Concentrations of Formocresol on Streptococcus faecalis

		Growth on day:-					
		1	2	3	4	5	6
Concentration of Formocresol %	0	++	++	++			
	0.100	++	++	++			
	0.125	-	++	++			
	0.134	-	++	++			
	0.167	-	+	++			
	0.200	-	-	+			
	0.250	-	-	-	(++)	(++)	(++)
	0.333	-	-	-	(++)	(++)	(++)
	0.500	-	-	-	(-)	(-)	(-)
	1.000	-	-	-	(-)	(-)	(-)

In each of the tables + indicates growth and - indicates no growth; (+) or (-) indicates growth or no growth after the organisms had been subcultured.

TABLE 23

The Effect of Varying Concentrations of Formocresol on Streptococcus salivarius

		Growth on day:-					
		1	2	3	4	5	6
Concentration of Formocresol %	0	++	++	++			
	0.100	++	++	++			
	0.125	-	++	++			
	0.134	-	+	++			
	0.167	-	+	++			
	0.200	-	-	+			
	0.250	-	-	-	(++)	(++)	(++)
	0.333	-	-	-	(+)	(+)	(++)
	0.500	-	-	-	(-)	(-)	(-)
	1.000	-	-	-	(-)	(-)	(-)

TABLE 24

The Effect of Varying Concentrations of Formocresol on Staphylococcus aureus

		Growth on day:-					
		1	2	3	4	5	6
Concentration of Formocresol %	0	++	++	++			
	0.100	++	++	++			
	0.125	-	++	++			
	0.134	-	++	++			
	0.167	-	+	++			
	0.200	-	-	+			
	0.250	-	-	-	(+)	(+)	(+)
	0.333	-	-	-	(-)	(-)	(-)
	0.500	-	-	-	(-)	(-)	(-)
	1.000	-	-	-	(-)	(-)	(-)

V-5 Discussion

In the past, potent medications were utilized in an effort to destroy all micro-organisms completely.[131] Schilder[132] stated that while potent drugs killed micro-organisms they also destroyed cells and tissues. Schilder was of the opinion that over-instrumentation and over-medication were prime causes of inflammation and pain, and suggested that drugs should be selected on the basis of tissue tolerance rather than on anti-microbial action. A number of investigators in recent years have observed the necessity for a reduced concentration of formocresol which would avoid the delay in recovery of normal biological activities of affected connective tissue cells.[64, 83, 95] In fact, the present findings indicated that formocresol was bacteriostatic to a minimum concentration between 0.25 and 0.20 per cent, and bactericidal to a minimum concentration between 0.50 and 0.33 per cent.

Apparently, only the bacteriostatic potential of Buckley's

formocresol in liquid or vapour has been tested. Therefore, the present *in vitro* experiment should be followed by a long term study *in vivo*. Most authors who have reported on formocresol and its potency have sought to achieve sterility of a root canal with a minimal effective dose. However, it may be possible to mechanically debride a pulp chamber during a pulpotomy procedure, to apply a bacteriostatic concentration of the drug, and to rely on the host's defence mechanisms to overcome infection.

Experiment I was abandoned after it was noticed that some of the serial dilutions of formocresol in TH broth had a milky appearance even before the solutions were inoculated with micro-organisms. As a result, experiment II was designed so that colony growth of micro-organisms could be directly observed on serial dilutions of formocresol in BHI agar. The technique of this experiment was to select a concentration such that when added to the agar it was further diluted by 1/10 and the diluted formocresol was mixed into the agar while the latter was still molten. This technique seemed to provide a better method for gaining an even distribution of a particular concentration over a wide area, making the observance of colony growth easier.

It appears that some authors who achieved areas of no growth, or sterility due to the bacteriostatic nature of formocresol, did not realize that they may have produced inhibition of growth which, if subcultured onto BHI agar with no formocresol, would have demonstrated growth. It should be pointed out that in the present experiment a selective inhibitor was not used on plates on which re-growth was carried out, so contaminants could not be positively identified. However, the experiment was repeated three times and the results were consistent. Also, it could be argued that the method of swabbing plates which showed no growth was not ideal, although acceptable, as the cotton wool swabs may have picked up not only the micro-organisms but also a surface layer of diluted

formocresol in BHI agar.

The present experiment may suggest a different approach to drug-sensitivity and tissue tolerance studies on Buckley's formocresol. The results confirm the bacteriostatic study of Wesley, Marshall and Rosen[95] who found *in vitro* that when relying on vapour alone a minimal effective dose of 0.004 ml (1/250) was required to inhibit *Strep. faecalis* after 48 hours and *Staph. aureus* required a dose of 0.0025 ml (1/400) applied under the same conditions.

Strep. faecalis was the most resistant organism of the three tested. This finding agrees with that of Marshall and Rosen,[95] Myers,[133] Winkler and Van Amerongen[134] and Engstrom.[135] These investigators all reported that the organism was one of the most difficult to eradicate from the root canal.

A long term study *in vivo* is the next logical area for investigation of success and failure rates, histological confirmation and a better understanding of the pharmacology of the components of formocresol. Vital and non-vital teeth showing signs of suppuration could be treated with a lesser concentration of formocresol. Buckley[3] suggested this technique in 1904 and a study as outlined above may provide a scientific basis for his suggestion.

CHAPTER VI

CONCLUSIONS

The present investigation was conducted on data derived from the case notes of 1,823 children who attended The University of Adelaide Pedodontic clinics from 1970 to 1974 inclusive. A total of 1,246 primary tooth pulpotomies were performed for 764 patients and the medicament used in all instances was Buckley's formocresol. The technique was either one-stage or two-stage, the former comprising 80.74 per cent of all treatments.

The teeth which had been treated during the five year period were clinically and radiographically evaluated. Clinical success was achieved in 97.75 per cent and treatment was judged to be successful, by radiographic criteria, in 92.70 per cent of the teeth.

The mean age of patients with teeth treated by the pulpotomy procedure was 6.99 years. Teeth which failed as a result of the procedure remained in situ for a mean time period from minutes following perforation of the pulp chamber, up to five years.

Symmetry was observed between left and right maxillary and mandibular quadrants and of the teeth treated 60.29 per cent were in the mandible. No maxillary lateral incisors or mandibular central or lateral incisors were treated by pulpotomy.

Internal resorption of the root which has been reported as a rare occurrence as the result of the formocresol technique, was found in 12 teeth, 0.96 per cent, each of which had been treated by the one-stage procedure.

There was no significant difference between the success and failure rates of the one and two-stage procedure nor was there any sex difference in these rates. The one-stage technique saved clinical time and was especially advantageous in the

management of young children.

This long-term study confirms the results of other workers in the high clinical and radiographic success rates of pulpotomy procedures with Buckley's formocresol. Although the medicament itself and the methods of use have been developed empirically, it is hoped that additional research will provide the basis for better diagnostic criteria and methodology.

The information derived from the study will be continually reviewed and, where necessary, methods and materials will be altered to obtain the highest success rate possible.

An in vitro experiment was carried out to test the efficacy of a reduced concentration of Buckley's formocresol. A subculturing technique established the concentrations at which the drug was bactericidal and bacteriostatic. Reduced concentrations of between 0.50 and 0.33 per cent of the standard solution were found to have bactericidal effects in vitro on cultures of Strep. faecalis, Strep. salivarius and Staph. aureus. Of the three organisms investigated Strep. faecalis was the most resistant. Further bacteriological investigations in vivo are required to assess the clinical effectiveness of reduced concentrations of Buckley's formocresol.

THE UNIVERSITY OF ADELAIDE

DEPARTMENT OF DENTAL HEALTH

FORMOCRESOL PULPOTOMIES OF PRIMARY TEETH

(Complete one for each tooth)

NOTE: A separate form is required for each pulpotomy procedure.

1. Case Note number: C1 ... C6 C7 [1]

2. Patient's Surname: C8 ... C21

3. Sex of Patient (place M or F): C22

4. Date of Birth: C23 ... C28 (Day Month Year)

5. Date of Operation: C29 ... C34 (Day Month Year)

6. Operator's Surname: C35 ... C49

CLINICAL EXAMINATION

Q.1 Tooth treated:
1. Quadrant number [5 6 / 8 7] — C50
2. Tooth number [1-5] — C51

Q.2 X-rays Available: Tick one — C52
1. No pre-operative
2. Pre-operative
3. Immediately post-operative

Q.3 State of pulp prior to pulpotomy: Tick one — C53
1. Vital
2. Non-vital/non-suppurative
3. Non-vital/suppurative
4. Previous pulp filling

Q.4 Initial condition of tooth: Tick one — C54
1. Decayed
2. Filled
3. Filled and decayed

Q.5 Initial Stage of root resorption:

1. One-third or less remaining
2. Two-thirds remaining
3. More than two-thirds remaining
4. Mobile

Tick one

C55 1 2 3 4

OPERATIVE PROCEDURE

Q.1 Pulp Exposure:

1. Near
2. Carious
3. Mechanical-by operator
4. Traumatic

Tick one

C56 1 2 3 4

Q.2 Size of Exposure:

1. Minute
2. No. 3 Round bur
3. 3-6 Round bur
4. > 6 Round bur

Tick one

C57 1 2 3 4

Q.3 Position of Exposure:

1. M-B
2. M-L
3. D-B
4. D-L
5. O
6. B
7. L

Tick one

C58 1 2 3 4 5 6 7

Q.4 Haemorrhage:

1. None
2. Slight
3. Heavy

Tick one

C59 1 2 3

Q.5 Type of Procedure:

1. One stage
2. Two stage < 1 week separation
3. Two stage 1-2 week separation
4. Two stage 2-4 week separation
5. Two stage > 4 weeks

Tick one

C60 1 2 3 4 5

Q.6 Rubber dam used:

1. Yes
2. No

Tick one

C61 1 2

Q.7 Final Restoration:

1. Not completed
2. Amalgam
3. Stainless steel crown
4. Amalgam and crown
5. Composite

Tick one

C62 1 2 3 4 5

THE UNIVERSITY OF ADELAIDE

DEPARTMENT OF DENTAL HEALTH

FORMOCRESOL PULPOTOMIES OF PRIMARY TEETH

(Complete one for each Pulpotomy Reviewed)

1. Case Note Number: C1 C6 ☐☐☐☐☐☐

2. Tooth Treated: 1. Quadrant number 5 6 / 8 7 C7 ☐

2. Tooth number 1 - 5 C8 ☐

3. POST-OPERATIVE REVIEW

Q.1 Can you determine clinically whether a failure has occurred?

If YES, answer the following. Otherwise go to Q.2.

Clinical Examination: 1. Mobility C9
NO ☐ 0
YES ☐ 1

2. Abscess formation C10
NO ☐ 0
YES ☐ 1

3. Sinus formation C11
YES ☐ 0
NO ☐ 1

NOW GO TO Q.3.

Q.2 Enter date of latest X-ray: C12 C17 ☐☐☐☐☐☐
Day Month Year

Can you determine radiographically whether failure has occurred?

If YES, answer the following. Otherwise go to Q.3.

Radiographic Examination: C18
1. Granuloma or root end cyst ☐ 1
2. Internal resorption of root ☐ 2
3. Internal resorption of crown ☐ 3
4. Ankylosis. ☐ 4

Q.3 Loss of tooth, when applicable, caused by:

1. Extraction following perforation)
2. Extraction following failure) Tick
3. Extraction for ortho (crowding)) one
4. Exfoliation)

C19 [ ] 1 2 3 4

Date of above
(to nearest month, if exfoliated)

C20 [ ][ ][ ][ ][ ][ ] C25
Day Month Year

4. REASON FOR DISCHARGE

Q.1 Patient

1. Treatment complete
2. School Dental Service
3. Own private dentist
4. Not eligible
5. Does not wish treatment
6. Moved interstate
7. Left address/address unknown
8. Failed to attend
9. Other

C26 [ ] 1 2 3 4 5 6 7 8 9

THE UNIVERSITY OF ADELAIDE

Adelaide · South Australia · 5001

Department of Dental Health
'Phone 223 4333

11th April, 1974

Dear

I am writing to seek your help with an important study being conducted by the Department of Dental Health. This study includes children who have had treatment of the nerve (pulpotomy) of a primary tooth.

As ..... has received this type of treatment it would be appreciated if you would allow to be included in the study. Your permission is being sought to x-ray the teeth on which pulpotomy was performed.

The x-rays are taken by specially trained staff who will take all the precautions to ensure that the x-ray exposure is minimal, so that your child is safeguarded. Naturally there will be no charge for these x-rays.

It is hoped that you will assist us in this investigation. If you are willing to do so, please sign below and return this letter as soon as possible in the reply paid envelope enclosed, so that an appointment for taking the x-rays can be forwarded to you.

Yours sincerely,

A. M. HORSNELL
Professor

PARENTAL SIGNATURE _____

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