REMOVAL OF DENTAL CARIES USING A PULSED Nd:YAG LASER - *IN VITRO* AND *IN VIVO*

Ghassem Ansari DDS (Iran), MSc. (Med. Sci.) Glasgow

Thesis submitted for the degree of Doctor of Philosophy to the Faculty of Medicine, University of Glasgow

Child Dental Care and Oral Sciences, Glasgow Dental Hospital and School, University of Glasgow

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ABREVIATIONS

ADL:	American dental laser
ANOVA:	Analysis of variance
ADJ:	Amelo-dentinal junction
CEJ:	Cemento-enamel junction
CI:	95% confidence interval
CL:	Curing Light
CO_2:	Carbon dioxide
CRT:	Caries removal time
d.f.:	degrees of freedom
DF:	Degrees of Freedom
defs:	decayed, extracted, filled surfaces
deft:	decayed, extracted, filled teeth
dmfs:	decayed, missed, filled surfaces
dmft:	decayed, missed, filled teeth
EC:	Ethyl Chloride
EPT:	Electric Pulp Tester/testing
FDA:	Food and Drug Association
GA:	Ghassem Ansari
GLM:	General Linear Model
H & E:	Haematoxylin and eosin
HSR:	Hyalonic synthetic resin
kV:	kilovolt
mA:	milliAmpere
MGS:	Maximum gap size
min:	minute
mJ:	milli Joules
MLS:	Microleakage score
MRG	Microradiography
Er:YAG	Eebium: yttrium, aluminium, garnet
Nd:YAG:	Neodymium: yttrium, aluminium, garnet
nm:	nanometer
ns:	nanosecond
OPT:	Orthopantomograph
p:	probability
PBL:	Polymerising blue light
PDJ:	Pulpo-dentinal junction
pps:	pulses per second
RDT:	Remaining dentine thickness
RT:	Restoration time
SD:	Standard deviation
sec:	second
SEM:	Scanning electron microscopy
vG:	van Gieson
W:	Watt
X^2:	Chi-squared
Δ:	Differences in the mean

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DECLARATION

This thesis is the original work of the author.

GHASSEM ANSARI

SUMMARY

The pulsed Nd:YAG laser energy was tested for its effect on carious lesions in both primary and permanent teeth. Four individual experiments were designed to assess the different effects of this laser wavelength on the hard tissue of the teeth.

The first experiment assessed the effect of three different laser energy densities on carious dentine. These energies were also tested for their effect on sound, unaffected dentine, to clarify the effect of the different laser energies on the sound underlying dentine after the dentine caries had been removed. The power of 60 mJ at 15 pps (1.25 W) was confirmed to be the optimal power setting amongst the powers tested in this study. This laser energy was therefore used for the following experiments.

The degree of pulp temperature rise following the exposure of the laser during caries removal was evaluated and compared to the routinely used heat-producing pieces of equipment *in vivo*, namely: the conventional drill and the polymerising blue light. The temperature rise caused by the laser energy of 1.25 W for 30 sec was found to be considerably higher than that of the other two. However, this peak temperature was shown to drop to lower levels, close to the baseline temperature, immediately after the irradiation stopped.

The changes of the dentine surface following laser/drill caries removal was tested by assessing the margins of restorations for the presence of any gap and any microleakage. Results showed that the restorations of teeth in both laser- and drill-treated groups indicated some degrees of microleakage but with no significant differences between the two. The gap sizes measured were also found to have no significant differences between the two groups of laser- and drill-treated teeth. It was suggested, therefore, that preparation of the cavities by the laser can be as efficient as conventional drilling for the adhesion of adhesive restorative materials.

And finally, the applicability of the laser for the removal of dental caries in anxious children was evaluated. This also permitted observations to be made on the *in vivo* effects of this laser on a group of vital pulps. Patients' anxiety was assessed by employing all three parties involved in the child's dental treatment: operator, child, parent. Results of this study indicated that patients had a higher preference for the laser caries removal technique when compared to conventional drilling. Both patient and parent were asked as to their views about the two techniques of caries removal. In addition, the patient's reactions were recorded before, during, and after each treatment. Each child received both treatment modalities to enable the assessment of the effect of individual techniques on patients' anxiety.

Pulps of the treated teeth were assessed by means of ethyl chloride and the Electric Pulp Tester, in addition to the radiographic and clinical examination of the surrounding structures. Results of these investigations revealed that pulpal status was not only different in those teeth treated with the laser, when compared with the drill, when they were examined after 18 to 24 months follow-up. The clinical assessment of restored teeth was also carried out over the same period (18-24 months) and indicated comparable success to conventional cavity preparation for the laser irradiated teeth. In conclusion, it seems that the pulsed Nd:YAG laser, with the energy level of 1.25 W for a maximum of 30 sec for each exposure may be used with minimal pulpal damage for the treatment of caries in primary teeth. This may provide an acceptable alternative to conventional drilling for young, fearful patients and may, therefore, reduce the amount of dental fear and anxiety in this group of the society.

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Dental caries is one of the most common of human diseases, affecting the mineralised dental tissues, and has been studied extensively for many years (Kidd and Joyston-Bechal, 1987). Failure to seek dental treatment can ultimately lead to pulpal involvement, which in turn will cause pain, abscessing and consequent loss of the tooth. Any of these sequealae can increase the patient's emotional stress, leading to fear and anxiety about future dental treatment. This fear, especially in younger patients with less experience of dental treatment, can lead to the avoidance of essential dental care and an increase in oral health problems. The highest level of fear related to dental treatment is reported to be from the use of the slow speed handpiece followed by the high speed handpiece and lastly, local anaesthesia (Petruzillo and McNierney, 1988). The use of a laser has been advocated as an alternative method of caries removal, which requires neither drilling nor local anaesthetic (Goldman *et al.,* 1965; Frentzen and Koort, 1990), and therefore offers a new approach to dentistry, especially for the treatment of anxious individuals. In this study, the potential of laser technology is investigated for treatment of dental caries in anxious children. The potential pulpal effects of this particular laser wavelength will also be investigated while testing the laser efficacy for removing caries, in addition to the suitability of the prepared surface for adhesive restorations.

1.2 The structure of healthy enamel and dentine

Enamel covers the anatomical crown of the tooth, and is the most highly calcified tissue of the body. It varies in thickness considerably from different parts of the crown and from tooth to tooth. The hardness of enamel decreases from the anatomical surface towards the amelo-dentinal junction, both in primary and permanent teeth. The thickness of enamel is less in primary teeth than in permanent teeth, but is less well mineralised and, therefore, appears whiter. The colour of a tooth is based on the degree of translucency of the enamel. Enamel translucency permits the transmission of the colour of underlying dentine through enamel and, therefore, reflects the colour of dentine (Scott and Symons, 1982).

The microscopic structure of sound enamel indicates that enamel is made up of prisms or rods, which in turn are made up of crystallites, which run through the entire thickness of enamel, from the surface to the amelo-dentinal junction. The prisms exist within an organic matrix, which is made up of a mixture of non-collagenous proteins, defined as amelogenins and enamelins. The orientation of enamel prisms in primary and permanent teeth is approximately the same. The inorganic component of enamel is made up of 96 to 97% mineral, the remainder being made up of organic material and water. The inorganic material of enamel consists of a hydroxyapatite-like mineral [$Ca_{10}(PO_4)_6(OH)_2$] (Scott and Symons, 1982).

Dentine forms the bulk of the tooth, and is covered by enamel in the crown, while cementum covers the root part. Compared to enamel, dentine has a higher organic content and is, therefore, more elastic. Hydroxyapatite also forms the inorganic part of dentine, which is 75% of the weight of dentine, while 19 to 21% is collagen, the remainder being water (Scott and Symons, 1982).

Dentine consists of cells, odontoblasts, and an intercellular substance. The structure of dentine also has a characteristic feature of its own known as dentinal tubules, which house the odontoblastic processes which pass through the bulk of the dentine to the dentino-enamel junction, although the distance through which these processes go will vary, especially with age. This part is considered to be the most sensitive part of dentine which receives stimuli, transferring them to the pulp. Dentinal tubules are more closely packed towards the pulp than the natural surface, and the amount of intertubular inorganic material, therefore, will be higher at the amelo-dentinal junction. This means that the outer dentinal surface, close to the ADJ, will be harder than the pulpal surface (Scott and Symons, 1982). Dentinal tubules, themselves have been introduced as a possible path by which bacteria can invade the pulp directly during the carious process, even before there is alteration of the dentine structure (Kidd and Joyston-Bechal, 1987).

1.3 Dental caries - Definition:

By definition, dental caries is an infectious transmittable and progressive disease of the tooth structure by microbial activity, causing irreversible damage to the dental hard tissue (Pindborg, 1970).

1.4 The initiation of dental caries

Dental caries, like any other human disease, involves initiation and progression of the disease. The disease has been known to scientists from the early ages. Earlier theories involved in the aetiology of dental caries were: a. The tooth worm theory suggested by the Babylonians, b. Endogenous theories including: Humoral theory suggested by Glen (Greece), Vital theory by Hippocrates, Celcus (Greece) and Avicenna (Persia). While Exogenous theories including Chemical (Acid) theory (Robertson, 1835) and Parasitic (septic) theory (Dobus, 1954) were postulated later (Nikiforuk, 1985a).

1.4.1 Current theories on the aetiology of dental caries:

Several theories have been advocated to help explain the aetiology and progression of dental caries, including: 1. Chemoparasitic theory (Acidogenic theory) Miller, (1890), 3. Proteolytic theory (Gottlieb, 1944), 4. Proteolysis - chelation theory (Schatz and Martin 1962), 5. Sucrose chelation theory (Eggars-Lura, 1963). Among these, the most accepted theory is the acidogenic theory (Silverstone *et al.,* 1981).

The disease occurs in the presence of the following three essential elements: 1. the tooth, 2. micro-organisms 3. a substrate for microbial metabolism. Time, as a separate element, has been described as an important additional factor in the development of dental caries. The interaction of time in the caries process can be appreciated better when, if all three other factors come together just for a moment, caries will not develop (Figure 1.1).

1. 4.2 Dental plaque and oral microflora:

To have an influence on the enamel surface, micro-organisms require to adhere to the tooth surface; they then break down substrate and, as a by-product, they produce acid (Acidogenic) for their survival within that environment (Aciduric). Plaque is described as a highly efficient environment for such microbial activity to occur. The mechanism of initial tooth colonisation by micro-organisms include bacterial adhesion to: 1. pellicle or enamel, 2. other bacteria, and finally 3. defects of enamel (Gibbons and van Houte, 1973). The formation of dental plaque continues by the formation of extracellular chains of carbohydrates known as glucans and fructans (Dextrans and Levans). These polysaccharides are believed to play an important role in reducing the buffering effect of saliva thereby inhibiting remineralisation of enamel.

The fermentation of substrate, and in particular refined carbohydrates, by plaque bacteria will produce acid, which reduces the plaque pH to a level below 5.0 within 1 to 3 min (Kidd and Joyston-Bechal, 1987). This lowered plaque pH

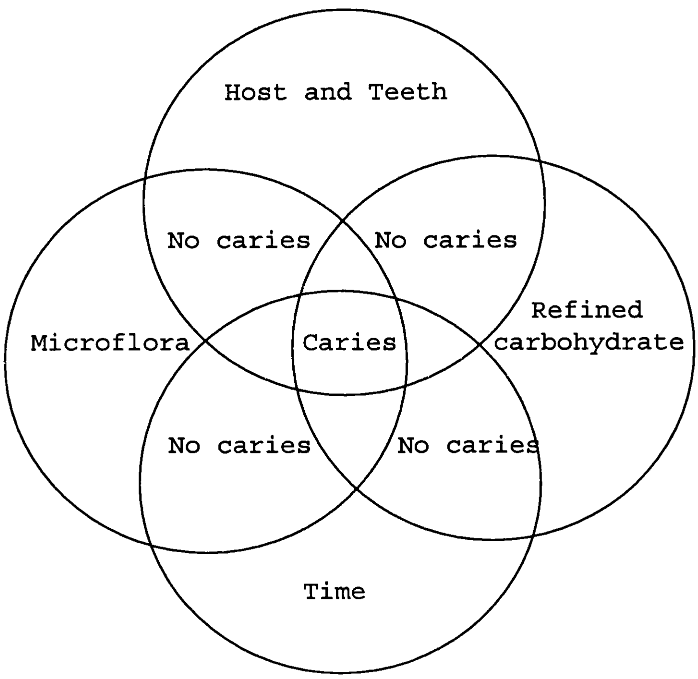


Figure 1.1: Venn diagram, presentation of the factors involved in dental caries process and their relationship.

will recover within a period of 30 to 60 min following each episode of carbohydrate consumption (Kidd and Joyston-Bechal, 1987).

The major micro-organisms involved in the aetiology of dental caries are reported as the *Streptococcus* species, especially *mutans, sanguis, salivarius* and *milleri* which have a major role in both caries initiation and progression (Fitzgerald, 1968; Druker and Green, 1978; Loesche *et al.,* 1975). Other species, such as *lactobacillus acidophilus* and *casei* and also *actinomyces* can also be associated with the caries process (Syed *et al.,* 1975).

1. 5 The progression of dental caries:

All four elements of this process are equally essential for the initiation and progression of the demineralising process of dental hard tissue. The progression of carious activity takes place as a result of subsurface demineralisation, leaving a relatively narrow but unaffected layer of surface enamel (Darling, 1958). Under the correct circumstances, demineralisation will continue in the subsurface area and spread towards the amelo-dentinal junction, and eventually into dentine. The structural characteristics of enamel will dictate that once a certain degree of demineralisation is reached, the tissue becomes weak, the surface enamel breaks down and an open cavity is produced. Further progression of demineralisation into the dentine causes a reactional activity of odontoblasts, by the secretion of so-called reparative dentine at the pulpo-dentinal junction.

1.5.1 Active and arrested caries:

The progression of dental caries will depend on a number of different factors, including the pH of the saliva, which in turn is related to several factors already discussed in Section 1.3.2. This process has been divided into two distinct types in terms of its activity with respect to acute or active caries, where the carious lesion is in either an active phase of destruction, or arrested caries, where progression of the carious lesion has been interrupted and the process of demineralisation is no longer occurring. Epidemiological studies have shown that active caries is more common in children, whilst arrested caries can be found mainly in adults. Treatment of acute caries is clearly more important as any failure to treat such lesions could lead to spread of the disease, whilst arrested caries may stay relatively innocent for some time without treatment (Trowbridge, 1981; Silverstone *et al.,* 1981).

1.5.2 Structural changes of the dental hard tissue during the caries process:

Since both the chemical composition and the ultramicroscopic orientation of the molecules varies a great deal between enamel, dentine and cementum, so their reactions to acid attack will differ to a varying degree. Dentine is, however, covered by the other two structures, an initial loss of enamel or cementum being essential to expose dentine to caries risk.

In general, carious lesions have been categorised in terms of stages of development as: 1. initial caries, which includes white and brown spot lesions,

2. enamel caries commencing with decalcification of the superficial layer of enamel followed by breakdown of the enamel matrix and the formation of a cavity, 3. dentine caries, which can be associated with minimal enamel involvement, or no involvement of enamel, up to the stage of actual cavitation of the tooth.

1.5.3 Enamel Caries:

The carious process is a gradual destruction of the tooth structure with loss of both inorganic and organic components. Organic acids, responsible for demineralisation of the tooth, are believed to be produced within the dental plaque from dietary carbohydrates, especially polysaccharides (Geddes, 1991). The first stage of the demineralisation appears in the form of a white spot lesion, where enamel mineral density is lost. Such early lesions may be remineralised if proper and effective measures are implemented (Kidd, 1984). The process of demineralisation of enamel will continue to the stage where a cavity is formed by massive destruction of the crystals of enamel eventually involving the underlying dentine (Silverstone *et al.,* 1981). The carious lesion in enamel has been described histologically using polarised light as having a surface zone, a body of the lesion, a dark zone and a translucent zone (Kidd and Joyston-Bechal, 1987). Both primary and permanent enamel have been shown to exhibit these histological features (Kidd and Joyston-Bechal, 1987).

1.5.4 Dentine caries:

Carious dentine has been described as consisting of two distinct layers of firstly, infected soft denatured dentine, showing the presence of micro-organisms, and secondly, affected, discoloured but hard dentine with the presence of only endotoxins of the bacteria (Fusayama, 1979; Fusayama, Okuse and Hosoda, 1966; Ohgushi and Fusayama, 1975). The outer layer is irreversibly denatured, infected by bacteria and not remineralisable, whilst within the inner layer the process appears to be reversible. In the latter, the dentine is not infected, it is remineralisable and can be preserved (Miauchi, Iwaku and Fusayama, 1978). Caries activity within dentine is also believed to be associated with a series of reactions in the pulpo-dentinal complex. These reactions include features such as tubular sclerosis, reactionary dentine and finally inflammation of the pulp (Kidd and Joyston-Bechal, 1987).

Fusayama and co-workers in several electron microscopic studies of the outer layer of carious lesions, have reported a decrease in cross-bands and inter-bands, whereas the inner layer demonstrated dense, regularly arranged collagen fibres similar to those found in intact sound dentine (Ohgushi and Fusayama, 1975; Kuboki, Ohgushi and Fusayama, 1977; Sato and Fusayama, 1976).

The second (inner) layer of carious dentine contains physiologically remineralisable collagen fibres and living odontoblast processes (Kurosaki *et al.,* 1977). One of the reasons why physiological remineralisation occurs in the second layer of carious dentine could be due to the presence of odontoblastic processes. The character of the collagen fibres as the basis for precipitation of calcium and metallic elements may be another reason to explain this phenomenon (Kurosaki *et al.,* 1977). This latter finding was discovered following electron microscopic observations of the second layer of carious lesions, which indicated that the metallic elements of tin and zinc, (but not mercury or silver dissolved from amalgam restorations), simply passed through the first layer, which had sparsely scattered collagen fibres without definite cross bands. These metallic elements accumulated in the second layer, which were associated with dense, regularly arranged fibres with characteristic cross bands similar to those in the sound dentine (Kurosaki and Fusayama, 1973).

Collagen fibres play an important role in the process of remineralisation of carious dentine. A histochemical stainability, in addition to electron microscope cross-bands and inter-bands, are described as characteristics of collagen fibres in the second layer of carious lesions and not in the first layer (Kuboki, Ohgushi, and Fusayama, 1977). No significant difference has been reported in the amino acid composition of carious and sound dentine. In the first layer, destruction occurs, not only in the cross-links, but also involves intramolecular degradation within the collagen molecules (Kuboki, Ohgushi, and Fusayama, 1977).

In 1975, Ohgushi and Fusayama reported that collagen had a partially degraded fibrillar structure in carious lesions. The decalcified, superficial carious layer with degraded collagen is fuchsin-stainable, whereas the slightly demineralised dentine nearest to the sound dentine, containing unchanged collagen, does not stain (Fusayama and Terachima, 1972). Micro-organisms can occasionally invade the deeper portions of mineralised dentine adjoining the lesion (Dorphman, Stephan, and Muntz, 1943). A remineralisation process is believed to take place within the dentine beneath the carious lesion during its active phase as a reaction to initial dentine attack (Johnson, Taylor and Berman, 1969).

1.6 Differences between dentine caries in primary and permanent teeth:

The pathology of the carious process in dentine of primary teeth, and the defence mechanisms of the tissue, are similar to those described for permanent teeth. Determination of the speed of caries progression on the developing defence changes between primary and permanent teeth is not known (Johnson, Taylor and Berman, 1969).

Since the thickness of enamel and dentine in primary teeth is considerably less than that of permanent teeth, and also that the area occupied by the pulp in primary teeth is relatively larger than that in permanent teeth, the chance of caries progress to pulpal involvement is much higher in primary teeth (Silverstone, 1970; Johnson, Taylor and Berman, 1969).

Featherstone and Mellberg (1981) reported that the progress of artificial carious lesions in enamel of primary teeth was faster than that of permanent teeth.

Extensive demineralisation of the intertubular dentine was reported in histological assessment of deciduous dentine caries with the presence of micro-organisms within the mineralised areas (Lester and Boyde, 1968, Johnson, Taylor and Berman, 1969). Work carried out some time ago indicated the presence of bacteria remaining on the floor of the dentine cavity, after caries removal, was higher in primary teeth than permanent teeth (Whitehead, McGregor and Marsland, 1960). However, the fundamental features of carious lesions in both primary and permanent teeth are described as being very similar (Kidd and Joyston-Bechal, 1987).

1.7 The reaction of the Pulpo-dentinal complex to the carious process:

The intensity of the disease and the period of time the pulpo-dentinal complex has been exposed to microbial activity defines the level of defence and possible damage. However, the defensive reaction starts quite early, probably when enamel is undergoing demineralisation. Changes in dentine represent the reaction of the pulpo-dentinal complex to acid challenges on enamel and its transmission through the interprismatic region to the amelo-dentinal junction (Arends *et al.,* 1987). Different levels of reaction to carious stimuli can be seen in the pulpo-dentinal complex which include: 1. Changes within dentine (tubular sclerosis, dead tracts) 2. Changes at the pulpo-dentinal junction (reparative/reactionary dentine formation, atubular calcification, odontoblastic degeneration), 3. Changes within the pulp (inflammation which appears as the effect of bacterial products, pulpitis, necrosis of the pulp) (Levine, 1974; Reeves and Stanley, 1966).

1.8 Epidemiology and assessment of dental caries:

Since dental caries is now considered a socio-economically associated disease, the need for detailed epidemiological assessment of the disease has become mandatory. This will involve both the study of prevalence and the incidence of the disease. Prevalence is used to define the quantity and the extent of the disease at a particular time, while incidence refers to the changes of the rate of the disease within a certain period of time.

The prevalence of dental caries within a population has been examined for many years using one of the most commonly used index systems first introduced by Klein, Palmer and Knutson, (1938). This index measures the sum of decayed, missing, filled teeth or surfaces as DMFT/S for each individual member of the population. The prevalence of the disease within the population can be presented by the mean value of these sums. To become more sensitive, these indices have been modified from a tooth to a surface assessment for individual subjects. A modification to the indices for primary teeth can be used to eliminate exfoliated teeth, the DEFT/S (Decayed, Extracted, Filled, Teeth/Surface) (Doherty, 1988). For a root caries, more specified index described as the Root Caries Index (RCI), has also been used to assess dental caries in exposed root surfaces (Katz, 1980).

Several methods of assessment are commonly employed in clinical dentistry to examine teeth with regard to the different degrees of demineralisation, preoperatively. The examination of a dried, clean tooth surface with a good operating light is probably the most common initial method of caries detection at the occlusal pit and fissure regions. Electronic detectors (Rock and Kidd, 1988), and laser beams (Benedetto and Antonson, 1988) are the most recent techniques which are under continued investigation for their reliability and clinical applicability. Pitts and Rimmer (1992) reported considerably higher caries rate in teeth with tight interproximal contacts. They suggested the use of orthodontic separators as a means of obtaining a better direct, clinical view of proximal surfaces.

The diagnosis of the initial stages of dental caries and also hidden approximal caries has always been of great concern to clinicians. The increased prevalence of diagnosed hidden caries under the fissure-sealed, sound occlusal surfaces has been reported as 19%, using bitewing radiographs as an adjunct to caries diagnosis (Weerheijm *et al.,* 1992). Bitewing radiographs are employed to aid the diagnosis of approximal caries in posterior teeth, while fibre optic transillumination (FOTI) is used mainly for the assessment of interproximal caries of the anterior teeth (Pitts, 1984; Mitropoulos, 1988; Kidd and Pitts, 1990). Bitewing radiographs are generally accepted as the most reliable assessment technique for assessing the presence and also the degree of progress of interproximal caries (Kidd and Pitts, 1990). The technique is, however, only an estimation as to the depth of the lesion (Espelid and Tveit, 1986). A bitewing positioning device has also been introduced for use with children, to allow accurate placement of the x-ray film intra-orally (Pitts *et al.,* 1991).

1.9 Caries prevention:

1.9.1 Introduction:

Prevention is implemented in three stages based on the progress and severity of the disease including: 1. primary prevention, before the disease occurs, 2. secondary prevention, elimination of the disease during its initial stage, 3. tertiary prevention, the actual treatment of a well established disease in order to prevent further destruction. As with many other infectious human diseases, for example bacterial infection of the respiratory system, dental caries can be prevented by removing one or more of the initiating factors. The prevention of dental caries is an achievable goal which can save considerable amount of time and effort for both patient and clinician, in addition to the removal of the need for restoring carious teeth.

Different methods of prevention have been investigated to define their ability to prevent demineralisation of hard dental tissue with the most common techniques routinely used, including: 1. altering the surface structure and chemistry of the enamel using fluoride ions (Ogaard, Arends and Rolla, 1990; Murray, Rugg-Gunn and Jenkins, 1991), 2. covering the anatomical pits and fissures of the tooth, using resin-based sealant materials (Bowen, 1982), and finally 3. altering the level of the carbohydrate content of the diet (Nikiforuk, 1985b). Bibby (1970) has argued, however, that the role of carbohydrates on caries activity is considerably less effective than the others.

1.9.2 Fluoride:

Fluoride is commonly acknowledged as the most effective natural element which can influence dental caries before its initiation by altering the enamel structure. Only Fluoride, in certain concentrations, 75 to 100 parts per million (ppm) at neutral pH, can produce such favourable chemical changes on enamel through the production of calcium fluoride (Leach, 1959; Ogaard, 1990). This ion, in excess, can cause irreversible damages to the tooth enamel during its formation, commonly known as dental fluorosis (mottling). Fluoride is believed to have its effect on hard dental tissue both pre- and post-eruptively. It can be administered, therefore, at the required concentration at each stage of tooth development (Murray, Rugg-Gunn and Jenkins, 1991).

Fluoride is available in several forms including: drops, tablets, mouthrinses and toothpastes. The most effective means of delivering fluoride is, however, by its addition to the water supply. Milk and salt are two other vehicles for fluoride delivery. It is believed that the fluoride concentration of 0.7 to 1 parts per million in drinking water is sufficient to reduce the level of dental caries by 50% (Dean, Arnold and Evolve, 1942).

The exposure of enamel to fluoride is believed to strengthen the chemical structure of the enamel through a series of chemical bonds changing the enamel hydroxyapatite to a new chemical structure called fluoroxyapatite (Murray, Rugg-Gunn and Jenkins, 1991; Kidd and Joyston-Bechal, 1987). The exact mechanism of fluoride's anticaries activity is, however, still not clear.

Precipitation of compounds such as calcium fluoride are believed to create a barrier against acid diffusion and act as a nidus of free fluoride, since calcium fluoride is sparingly soluble (ten Cate and Duijsters, 1982).

Ogaard *et al.* (1986) reported that the level of mineral loss in enamel and cementum has been reduced by 80% after fluoride rinsing (Ogaard, Rolla and Arends, 1988). Blinkhorn, Hosting and Leathar (1983) investigated the level of dental caries experience between secondary school children in Scotland and its relation to dental care. A 22% reduction of the level of the DMFT in those who used fluoride rinsing during the period of the study was reported when compared to the control group.

For some considerable time it has been clear that patients with fluorosed teeth have a relatively high resistance to caries attack, even taking into account the relatively poorly mineralised surface layer of the enamel. This is explained by both the presence of a high level of fluoride and a low level of salivary protein adsorption on the enamel surface, reducing the deposition of dental plaque (Kidd and Joyston-Bechal, 1987). It has been suggested that a remineralised white spot lesion on enamel may be more resistant to a caries attack than sound enamel (Koulourides, Cueto and Pigman, 1961). It has been shown that fluoride-releasing restorative materials have the potential of inducing remineralisation to early enamel lesions by their fluoride exchange capacity (Creanor *et al.,* 1994). However, the presence of pellicle and plaque, which is considered as a diffusion barrier and is known to cover the glass ionomer surface soon after placement, may reduce the fluoride exchange level (Creanor *et al.,* 1995).

1.9.3 Other methods of caries prevention:

Several other possibilities have been investigated to prevent both the initiation and progression of dental caries including: 1. immunisation (Challacombe, Guggenheim and Lehner, 1973; Cohen, Colman and Russel, 1979; Aaltonen *et al.,* 1985), 2. Alteration of the enamel surface structure using high energy laser radiation (Nammour, Renneboog-Squilbin and Nyssen-Behets, 1992; Nelson *et al.,* 1986; Nelson, Jongebloed and Featherstone, 1986; Franquin and Salomon, 1986; DeRadd, Paschoud and Holz, 1988), 3. The eradication of enamel fissures (Bodecker, 1929), 4. Covering the crown using stainless steel crowns, usually following an initial repair, (Curzon, Roberts and Kennedy, 1996), 5. The use of Chlorhexidine as an antimicrobial agent with an inhibitory effect on the demineralisation of enamel (Regölati, König and Muhlemann, 1969), 6. Increasing the level of metal ions such as Copper (Cu^{++}), Iron (Fe^{++}), Zinc (Zn^{++}) (Emilson and Krasse, 1972; Giertsen, Bowen and Pearson, 1991).

As a conclusion, it is clear that prevention of dental caries can be performed by elimination of any one of the four essential factors involved in caries development as the easiest approach in practice. However, any attempt to do this should be planned carefully.

1.10 Treatment of dental caries:

1.10.1 Introduction:

The treatment of dental caries involves the removal of the degraded part of the dental hard tissue followed by repair of the prepared cavity by an appropriate restorative dental material. Several caries removal techniques have been studied in dental research which have included both mechanical and non-mechanical approaches (Anderson and van Praagh, 1942; Goldman and Kronman, 1976; Melcer *et al.,* 1984). The next three sections will discuss about those caries removal methods which will include the more recent conventional method.

1.10.2 Conventional caries removal technique:

The most commonly used technique for the removal of dental caries is the use of rotary instruments, that is slow and high speed handpieces. Drilling is considered as highly efficient, fast, and reliable in its ability to remove caries. Discomfort during the application of such equipment, especially for anxious patients, however, may be a problem. Rotary instruments were introduced to dentistry in 1870, as before that date cleaving of the enamel and excavation of carious dentine were undertaken with hand instruments alone (Stephens, 1986). The conventional mechanical technique, using rotary instruments for caries removal, can cause considerable discomfort, and in some cases results in an unpleasant experience, particularly for young patients. In addition, such methods are not selective in their ability to remove caries. Rotary instruments, due to their friction action on dental hard tissue, will produce heat on the surface to which they are applied. This heat can then be transmitted to the deeper layers of the tooth, and eventually to the pulp and may, therefore, cause pulpal damage. Coolants, supplied with these instruments, are designed to limit the heat created by this frictional force (Stanley and Swerdlow, 1960), with this effect being confirmed as an important factor for pulp safety during conventional drill application (Goodis, Schein and Stauffer, 1988a, Goodis, Schein and Stauffer, 1988b).

Local anaesthesia is routinely prescribed to reduce the discomfort and pain produced by the action of the drill during caries removal. The technical design of drills over recent decades has changed, to provide a more efficient and easy cutting instrument (Stephens, 1986). But, the removal of sound dental tissue remains one of the disadvantages when rotary instruments are being used for cavity preparation.

1.10.3 Laser Caries Removal:

The concept behind the use of lasers as a possible substitute for conventional rotary instruments for drilling hard dental tissues was first introduced by Kinersly *et al.* (1966). Lasers have been introduced as an optical drilling technique and a possible alternative to conventional treatment (Goldman *et al.*, 1964; Stern, Vahl and Sognnaes, 1972).

The major concern of using lasers as a means of dental hard tissue removal, is the effect of the procedure on vital pulpal tissue below the cutting surface. It has been reported that most of the present lasers available for dental application, including the Nd:YAG, have the potential for producing heat during their application to the dental hard tissues (Adrian, 1977; Melcer, Chaumette and Melcer 1985). Even the Er:YAG laser, advocated as a non-thermal laser, has been reported as producing some degree of temperature rise at the surface of the irradiated area (Frentzen and Koort, 1990). Since laser caries removal is the subject of this study, further details and different aspects of laser applications in dentistry, including caries removal, will be discussed later in this Chapter.

1.10.4 Other techniques of removing dental caries:

There have been several other reports on possible alternative techniques for removing carious tissues which have had varying degrees of success. The following is a brief description of some of these techniques:

a- Air abrasive technique:

An air abrasive was created through the kinetic energy of a high velocity stream of fine abrasive particles (crystals of aluminium oxide) in a stream of carbon dioxide gas). This mixture of abrasive and gas was delivered through a dental handpiece which has a tube with a contra-angle shape designed to ease access to different angles of the cavity (Black and Christi, 1955). The technique was introduced some years ago, supposedly as an easy, rapid and biologically accepted method. The use of rotary instruments continued to be used, however, to complete cavity preparation (Nielson, Richards and Wolcott, 1955; Black and Christi, 1955). The air abrasive technique for cavity preparation was reported as acceptable to the patient but was limited to those teeth which could only be viewed by direct vision; also, the technique had the added disadvantage of preventing tactile sensation during the cutting procedure (Black and Christi 1955).

b- Ultrasonic technique:

An ultrasonic method for cutting hard dental tissue was evaluated by Oman and Applebaum (1955). This method was believed to produce smooth cutting edges on enamel or dentine (Nielson, 1955; Oman and Applebaum, 1955). Ultrasonic energy was produced by a variable frequency oscillator which supplied a high frequency alternating current to the magnetostrictive handpiece through a power amplifier. Rapid vibration movement produced the vibration of the dental instrument which in turn transmitted an effective cutting action to the abrasive liquid mixture (aluminium oxide and water) which was in contact with the tooth structure (Oman and Applebaum, 1955). Nielsen, Richards and Wolcott (1955) stated that the ultrasonic system was unable to remove soft carious tissue and was only effective on cutting surfaces with a hard structure.

c- Chemomechanical Caries Removal:

Chemical caries removal was first introduced by Goldman and Kronman in 1976. The chlorination of denatured collagen disrupts secondary hydrogen bonding resulting in removal of the so-called infected layer of the carious lesion (outer layer) (Kronman *et al.,* 1977). Chemical caries removal reagents are claimed to be effective only on the denatured collagen in the outer layer of the carious lesion, with no effect on the inner layer which may, therefore, be considered as a technique which has a selective caries removal effect (Goldman and Kronman, 1976).

Several clinical and laboratory studies have been carried out to evaluate the efficacy of the technique in its ability to remove dental caries, in addition to its acceptability for anxious individuals (Ansari, 1994; Zinck *et al.,* 1988). Results of both *In vitro* and *in vivo* studies on the efficacy of the technique have indicated high success rates of 98% and 76% in removing carious tissue (Mcnierney and Petruzillo, 1989; Robbins and Ragan 1988), particularly in primary teeth (Yip, Beeley and Stevenson, 1991a; Yip, Stevenson and Beeley, 1995). Patient's acceptance rate has been reported as being as high as 87% by Zinck *et al.* (1988) and 89% by Ansari, Beeley and Reid (1994). The potential ultrasonic effect of the ultrasonic scaling unit supplied by Caridex chemical reagent was also tested and resulted in a higher efficacy for caries removal in a shorter time (Ansari *et al.,* 1995). However, the clinical feasibility of the ultrasonic machine for this purpose is still under investigation.

1.10.5 Caries removal assessment techniques:

It can often prove difficult to estimate the amount of carious dentine that should be removed clinically from a cavity. Studies carried out on caries detection using different dyes following the removal of caries, as judged by visual and tactile criteria, demonstrated the stainability of remaining dentine to some degree (Anderson, Loesche and Charbeneau, 1985). The deeper the carious invasion into dentine, the greater the possibility of basic fuchsin 0.5% staining the dentine after caries removal was assessed clinically (Anderson and Charbeneua, 1985). To date, several different types of caries detection dyes have been tried in an attempt to consistently and accurately detect carious dentine especially at the ADJ. These include: 0.5% Basic Fuchsin in propylene glycol (Anderson, Loesche and Charbeneua, 1985), 1.0% Acid Red (Boston and Graver, 1989; Kidd, Joyston-Bechal and Beighton, 1993), Sodium Fluorescein (Van-der-veen and Ten-Bosch, 1993) and Tracer Dye (O'Brien, Vazquez and Johnston, 1989).

Fuchsin in propylene glycol solution has been shown to stain the soft carious material better than erythrosin solution (Anderson, Loesche and Charbeneua, 1985). It is important to remember that only erythrosin can be used clinically due to the now established carcinogenicity of fuchsin (Brännström, Johnson and Friskopp, 1980). There was no difference reported in the level of infection between stained and non-stained dentine following clinical caries removal judged with visual and tactile criteria (Kidd *et al.,* 1989; Kidd, Joyston-Bechal and Beighton, 1993). It has been suggested that conventional tactile and visual senses are, therefore, satisfactory means of assessments for caries removal and that the use of caries detectors dyes on hard and stain free dentine may cause unnecessary removal of sound structure (Kidd *et al.,* 1989; Kidd, Joyston-Bechal and Beighton, 1993; Yip, Stevenson and Beeley, 1994).

1.11 Lasers in Dentistry:

1.11.1 Introduction:

The word "laser" is an acronym for Light Amplification by the Stimulated Emission of Radiation. The laser has been considered for use in many areas of science and technology, including medicine and dentistry. Maimen (1960) initiated the idea of light amplification based on a similar idea of microwave amplification of stimulated emission of radiation (Maser) introduced by Schawlow and Townes (1958). When lasers appeared in the 1960's, the world of dentistry had great hopes that this new technology would remove caries more precisely than drilling instruments without vibration, usually responsible for most of the patient's discomfort. If this goal were achieved, the need for the use of local anaesthesia would be reduced and, therefore, access to this method of caries removal could encourage dental phobic patients to accept routine restorative dental treatment.

1.11.2 Laser sources (types):

To date more than 600 laser media are known, with varying wavelengths with 10 different types used in medicine. The first laser introduced to medicine was a Ruby laser made by a crystal of Ruby (Maiman, 1960). Javan, Benet and Herriott (1961) introduced the first gas medium laser from a continuously operating machine. Next was the CO_2 laser (Patel, McFarlane and Faust, 1964) followed by the Nd:YAG laser introduced by Geusic, Marcos and Van Uitert (1964). Goldman, Reuben and Sherman (1964) were the pioneers of laser application on human dental hard tissues by applying early engineering lasers to enamel. Dental and medical lasers have been designed to have specific effects on tissues, and the reaction of the tissue to the laser beam determines the clinical suitability of the particular treatment. Currently, there are several types of laser used in dentistry, amongst which four most commonly used are namely: 1. Carbon dioxide (CO_2), 2. Argon ion, 3. Neodymium Yttrium Aluminium Garnet (Nd:YAG) and 4. Erbium Yttrium Aluminium Garnet (Er:YAG).

Different laser wavelengths are produced by excitation of the emission in different laser medium. The laser medium, in the case of the Nd:YAG, is a crystal whilst the CO_2 and Argon lasers are both produced by excitation of gas. There has been no report on any alteration in atomic structure of the tissues exposed to any of the three laser radiation causing, for example, genetic mutation. The ultraviolet range, on the other hand, has demonstrated such a potential risk (Pick, 1993). Table 1.1 shows some specifications and details of the current lasers.

1.11.3 Nd:YAG laser characteristics:

The Nd:YAG laser which is in the infra red range, 1.06 microns, can not be seen and therefore care is required during its application. A Neodimum-Helium laser light is supplied by the Nd:YAG lasers as the aiming beam. The Nd:YAG laser wavelength is attracted to the darkened pigmented tissue surfaces, resulting in varying degrees of optical scattering and penetration with minimal absorption and no reflection (Pick, 1993). The laser is available in both

Type of laser	component elements	mode of energy delivered	method of excitation
ArF-excimer	Argon-fluorine	pulsed	High voltage
XeCl-excimer	Xenon-Chlorine	pulsed	High voltage
Nd:YAG	Neodymium yttrium aluminium garnet	pulsed/ continuous	Xenon lamp
Ho:YAG	Holium yttrium aluminium garnet	pulsed/ continuous	Xenon lamp
Er:YAG	Erbium yttrium aluminium garnet	pulsed/ continuous	Xenon lamp
ErCr:YAG	Erbium, Chromium, yttrium aluminium garnet	pulsed	Flash lamp
CO_2	Carbon dioxide	pulsed/ continuous	Tube current flow

Table 1.1: presentation of the source, mode, and excitation method of most commonly used laser types in hard tissue research.

continuous and pulsed modes, with the main advantage being its ability to be delivered through an optical fibre. The Nd:YAG laser delivery system has been designed for two different modes of application, including: contact and non-contact modes, with different indications. Depending on the mode of laser energy delivery, the Nd:YAG laser wavelength can penetrate into depths of 0.5 to 4 mm into oral soft tissues (Pick, 1993). Continuous wave Nd:YAG laser irradiation, particularly with a non-contact mode, is known to penetrate deeper into the tissue causing tissue damage (Miserendino, Levy and Miserendino, 1995).

The absorption peak of the Nd:YAG laser for enamel and dentine has been stated as being 9.6 μm and 2.9 μm respectively (Hibst and Keller, 1989). The Nd:YAG laser has a wavelength (1.06 μm) near the infrared part of the electromagnetic spectrum, which penetrates the tissue readily and at the same time, due to its scattering and reflection properties, may easily damage the tissue (Launay *et al.,* 1987; Hillenkamp, 1989). Black initiator dyes have been found to provide a sharp demarcation between coated and non-coated areas irradiated with the Nd:YAG laser, suggesting a more controlled cut when these dyes are used (Hess, 1990).

1.11.4 Mechanism of tissue interaction:

The effect of laser energy on the target tissue is based on the absorptivity of the tissue medium and the laser wavelength used (Yellin *et al.,* 1976). As the laser energy hits the target tissue, it will either be scattered, reflected, absorbed or transmitted. Tissue interaction of the laser is based on three important characteristic factors in laser radiation including: 1. wavelength, 2. energy density, and 3. mode of application (Yamamoto and Sato, 1980). Interaction between the laser and the tooth divides into: 1. photochemical, 2. photothermal, 3. photoablative, and 4. photodisruptive mechanisms. Of the four possible mechanisms, only the two latter mechanisms are considered suitable for removing caries. These actions are produced by 30 pulses per second (pps) or less at power densities of at least 1 mJ (Minderman and Niemz, 1993).

a- Ablation and photodecomposition:

The higher the energy of the light photons (shorter wavelengths), the more efficient is the photoablation process of dental tissue (Frentzen, Koort and Thiensiri, 1992). As the wavelength of radiation increases, direct dissociation of molecular bonds may not occur and instead stimulated lattice vibration can lead to heat, resulting in thermal decomposition of weaker molecular bonds. Thermal decomposition of these molecular bonds will cause vaporisation and expansion of the localised tissue superficially. Tissue vaporises as a result of thermal interaction with an increase of internal lattice vibration, ending in a thermal destruction process (Frentzen, Koort and Thiensiri, 1992). Miserendino, Levy and Miserendino (1995) described the thermal effect of the laser on the target tissue as either photoablation or removal of tissue by vaporisation. Photoablation means dissociation of molecules.

b- Photochemical decomposition:

Photochemical interaction occurs when long irradiation time and low energy densities are employed, which subsequently changes to photothermal action by increasing energy densities (Miserendino, Levy and Miserendino, 1995). A photochemical process occurs when molecules absorb laser energy; in other words, it includes biostimulation by stimulating the normal biochemical and molecular processes happening in tissues, for example the healing process. The thermal or thermomechanical process happens through absorption followed by vibration of rotation bands, which converts light to heat which because of its high level, leads to carbonisation of the dental tissue (Minderman and Niemz, 1993).

c- Photodisruption:

It has been suggested that short pulsed laser irradiation, with high energy densities, causes material ionisation by producing a plasma, which dissipates the tissue explosively at a very high pressure, also called mechanical destruction (Berlien and Muller, 1989). Photoelectrical interaction or so-called photoplasmolysis, which happens following an electrical charge of ions and particles of the gas surrounding the target tissue. Plasma has been considered as the fourth state of matter in all three types of solid, liquid, and gas (Miserendino, Levy, and Miserendino, 1995). Short pulses and high power densities are necessary to enable multi-photon absorption. In excess of these two characters, photodisruption takes place by generation of a microplasma with temperatures of 6,000-10,000°C at the focal point of the laser.

Photodisruption or photomechanical interaction is described as the breaking apart of structure following laser application (Minderman and Niemz, 1993).

Several other factors have an influence on the laser-tissue interactions, such as the absorption rate of individual laser wavelength by water and other chromophores in the irradiated tissue, photoacoustics and photothermal capacity of the target tissue (Dederich, 1993). Because of the nature of the wavelength, Nd:YAG laser has a high penetration rate with a high absorption on pigmented or darkened tissues (Absten, 1990; Yamamoto and Kayano, 1988), while the CO_2 laser radiation is quite different, having a high absorption coefficient in water-containing tissues with small penetration potential (Pogrel, McCracken and Daniels, 1990)

Dederich (1993) stated that as soon as charring occurs at the surface of the target tissue, the absorption rate will be increased due to darkening of the tissue surface. In other words, the charred dentine will play the role of an initiator and, thereby, improves the absorption of the specific laser wavelength (Dederich, 1993). A combination of the different interactions can appear at the same area, especially at high pulse energies (Frentzen and Koort, 1990). An example of this combined interruption has been reported in cases irradiated by Excimer lasers (Melcher, 1984; Srinivasan, 1986).

It can be summarised, therefore, that factors involving the actual reaction of the tissue to the laser light are: 1. power density, 2. exposure duration, 3. nature of the tissue 4. wavelength, each of which should be considered carefully and selected properly before any laser application.

1.12 Laser effects on dental hard tissues

Dental hard tissues are considered as compound materials consisting of mineralised and organic elements which exhibit varying degrees of optical and material properties (Frentzen and Koort, 1990). Laser irradiation of dental hard tissue causes varying degrees of structural alteration on enamel and dentine including: cratering, melting and recrystalisation and finally carbonisation as the result of charring (Kantola, 1972; Kantola, Laine and Tarna, 1973; Kantola, 1973). Every laser has its particular effectiveness on cutting hard dental tissues which is also depend on the laser energy level as well as the exposure time. In addition, the absorption coefficient of the tissue at the particular wavelength of the laser is an important factor in the process of laser/tissue interaction (Paghdiwala, 1991). Since the physical properties of enamel and dentine are different, lasers will inevitably have differing effects on dentine compared to enamel. On the other hand, the crater depth is directly proportional to the amount of laser radiation delivered to the target tissue (Stern, Renger and Howell, 1969). More details of these effects on enamel and dentine are discussed below.

1.12.1 Effects of lasers on enamel:

Different effects of lasers on enamel have been investigated, including its effect on acid resistance (Fox *et al.,* 1992a; Fox *et al.,* 1992b), enamel etching

(Nelson, Jongebloed and Featherstone, 1986; Renneboog-Squilbin *et al.*, 1989), bleaching of enamel (Kinersly *et al.*, 1965) and more importantly, the laser's ability to cut through enamel (Launay *et al.*, 1987; Hillenkamp, 1989). Meurman *et al.* (1992) investigated the effect of different laser radiations, including: 1. Nd:YAG, 2. CO_2, 3. Nd:YAG - CO_2 combination on the crystalline structure changes of synthetic hydroxyapatite. It was concluded that enamel acid resistance reduced due to melting of enamel following the rise of surface temperature when the tissue was exposed to high energy densities (Meurman *et al.*, 1992).

Both Nd:YAG and CO_2 lasers are shown to be capable of producing alteration in enamel structure, resulting in a higher resistance to acid attack and subsequent subsurface demineralisation (Yamamoto and Ooya, 1974; Yamamoto and Sato, 1980; Boran, Zakariasen and Peters, 1991; Sognnaes and Stern, 1965). The enamel acid resistance achieved by a continuous Nd:YAG laser radiation was less than that achieved from the pulsed Nd:YAG laser radiation (Yamamoto and Kayano, 1988). Quintana *et al.* (1992) suggested that improved enamel resistance to acid attack following laser irradiation could be due to microfusion and loss of the surface prismatic structure. The best result of increased enamel resistance to acid attack was reported to be achieved by irradiation of enamel using acoustooptically Q-switch Nd:YAG laser with 10 W output energy for 0.8 sec (Yamamoto and Sato, 1980).

Phase changes in inorganic material (Fowler and Kuroda, 1986; Lobene, Bhussry and Fine, 1968), permeability changes of enamel (Stern, Vahl and Sognnaes, 1972), and finally reduced enamel solubility by chemical changes (Nelson *et al.,* 1987), in irradiated areas of the teeth by the CO_2 laser are among some of the explanations given for the reduction of demineralisation rate of subsurface enamel. The nature of recrystalisation of melted enamel eliminates the prism boundaries and produces homogenous and non-homogenous crystals of apatite with larger particles, resulting in reduced acid reactivity (Ferreira *et al.,* 1989). The level of fluoride uptake of the irradiated area of enamel, using a pulsed Nd:YAG laser with energy density of 750 mJ 20 pps for 0.5 sec was reported to be higher than non-lased area of the tooth (Bahar and Tagomori, 1994).

Willenborg (1989) described the Nd:YAG laser as being an effective tool for caries removal and preventive fissure sealant therapy. The water content of the target area should be boiled off before the laser energy can attain the destructive threshold of the tooth structure. As dentine contains almost six times more water than enamel (Sicher, 1986), more laser energy is, therefore, required for dehydration of dentine compared to enamel (Peck and Peck, 1967). The laser penetrated enamel more easily than dentine, causing frank destruction in enamel which could be related to the structural and biochemical differences between dentine and enamel (Peck and Peck,1967).

1.12.2 Effects of lasers on dentine:

The effects of lasers on dentine varies from no effect, disruption of the smear layer, to actual melting and resolidification of dentine. Each of these effects will be based inevitably on energy densities, exposure time and the degree of darkening of the dentine. Another example of recrystalisation as an important feature is the observation that lasing of the dentine of the root canal wall reduced the level of its permeability to fluids with the presence of needle-like crystals as the indication of non-porous dentine (Dederich, Zakariasen and Tulip, 1984).

During laser application, a great deal of energy is delivered to a reasonably small area, which is converted to heat following absorption in that area. The tissue's reaction to heat will vary depending on a number of different factors, which includes the level of the temperature rise. High temperatures produced by laser radiation of dentine causes varying features from: burning to melting and, more favourably, ablation of the dentine by vaporisation of the organic matrix. This former effect is believed to be the most favourable outcome of laser radiation with regard to the removal of carious dentine (Melcer *et al.,* 1984). Pashley *et al.* (1992) reported the effect of laser radiation of dentine as sealing the surface and, therefore, reducing the permeability of dentine, in addition to removal of the smear layer.

The natural opacity of intact dentine ranges from 50-91 per cent, while the equivalent thickness of intact enamel has an opacity ranging from 21 to 67 per cent (Souder and Paffenbarger, 1942). It is clear, therefore, that dentine (due to its greater opacity) will absorb more laser radiation and will demonstrate a more extensive effect than enamel (Dederich, 1993). The exposure time, in addition to the energy density applied to the tooth, will determine the ultimate effects of the laser on the tissues (van Breugel and Dop Bar, 1992). Application of a dark dye is believed to enhance laser absorption (Yamamoto and Kayano, 1988), therefore, increasing its caries removal efficacy, which, perhaps, reduces the level of energy travelling through the lesion (Bassie, Chawla and Patel, 1994). Cox, Pearson and Palmer (1994) stated that once the threshold level for dentine damage has been exceeded, further increases in the energy density augments tissue loss and increases the depth of cratering.

Wavelengths between 320 and 500 nm are suggested to provide optimum selective ablation of carious lesions, which is about four times less than the energy needed for ablation of sound dentine (Clarkson, 1992). Therefore, proper laser energy settings might be considered safe for sound, adjacent dentine during a caries removal procedure. The procedure of vapourisation of dentine is based on the different properties of dentine, including the level of water and the collagen content (Cox, Pearson and Palmer, 1994). Laser irradiation of dentine has been described as producing three distinct zones of destruction: 1. central zone of complete dentinal destruction; 2. a surrounding zone of partial dentinal destruction; and 3. a scattered zone of dark speckling beyond the first two zones. When dentine is vaporised by laser energy, the surface of the dentine becomes darkened by the procedure of carbonisation. It has been recommended that this superficial discoloured layer be removed, due to its potentially poor aesthetic side effect on the colour of restorations (Peck and Peck, 1967).

1.12.3 Nd:YAG laser and dentine:

The Nd:YAG laser beam is capable of being transmitted through an optical fibre and is absorbed more readily by a dark dentine surface, as stated earlier, compared to the CO_2 laser beam (Schultz *et al.,* 1986; Yamamoto and Kayano, 1988). This particular wavelength (1.064 μm) is not absorbed by sound enamel but it may be absorbed by intact cementum and dentine (Bassie, Chawla and Patel, 1994).

White *et al.* (1991a) suggested that superficial carious dentine was removed successfully using a pulsed Nd:YAG laser of 0.3 to 3.0 W and provided a suitable dentine surface for restoration via micromechanical retention. Bassie, Chawla and Patel (1994) reported that post-operative sensitivity of laser-treated teeth was much less compared to conventionally treated teeth, which could be due to the fusing effect of the laser on dentine, thereby closing the open dentinal tubules. This resulted in a reduction in dentine permeability and thus, reduced tooth sensitivity.

Microscopic assessment of the laser's effect on carious tissue revealed a selective deep destruction of coloured carious mass by laser irradiation (Goldman, Gray and Goldman, 1965). Scanning electron microscopic views of the specimens revealed that the Nd:YAG laser punched out the craters irregularly followed by the production of melted and recrystalised masses of dentine giving an appearance of glazed interconnected droplets, in addition to a normal dentine appearance in the areas between droplets (Cernavin, 1995).

Opaque sclerotic dentine, because of its colour and structural quality, absorbs the Nd:YAG laser energy in a similar fashion to pigmented tissues. Translucent sclerotic dentine, however, is less able to absorb any energy and transmits the light through to the underlying structure (Dederich, Zakariasen and Tulip, 1984; Dederich, Zakariasen and Tulip, 1988). Even partial absorption of the Nd:YAG laser, following a continuous radiation of opaque dentine will eventually heat the dentine to its melting point (600-800 °C) (Komrska, 1972) which with further exposures, this heat will be transmitted to the deeper points of dentine (Dederich, 1993). The clinical point where the tissue effect is noticeable would begin when the colour of the surface of treated dentine turns dark, thus increasing the absorption rate of the Nd:YAG laser beam. (Dederich, Zakariasen and Tulip, 1984; Dederich, Zakariasen and Tulip, 1988).

1.12.4 Other dental hard tissue applications of laser technology:

As the FDA has only approved the clinical use of lasers for soft tissue applications, their usage as a means of hard tissue application having not yet been granted, research on different aspects of this new approach to dentistry is still under investigation. In addition to those discussed earlier, there has been several other laser applications on dental hard tissues since its introduction to dentistry including: a- reducing dentine hypersensitivity (Ronten-Harper and Midda, 1992; Stobholz *et al.*, 1995); b- caries detection (Benedetto and Antonson, 1988; Longbottom and Pitts, 1993), c- pulp therapy (Zakariasen *et al.,* 1986), d- removal of subgingival calculus (Radvar *et al.,* 1995), e-sterilisation (Burns, Wilson and Pearson, 1994; Hooks *et al.,* 1980; Adrian and Gross, 1979), f- fusing dental porcelain (Peacocke *et al.,* 1988), g- cavity restoration by fusing the porcelain powder packed into the prepared cavities into the enamel and dentine (Stern and Sognnaes, 1965) and h- polymerisation of the light activated dental resins (Potts and Petrou, 1991). It is important, however, to consider the problems associated with the use of lasers in any of the above applications including potential pulpal damage (see below).

1.13 Side effects of lasers on the dental pulp and periodontal tissues:

Different laser wavelengths have different effects on biological tissues and, therefore, behave to a varying extent when they are applied to these tissues. The likelihood of a laser affecting underlying tissues depends on its ability to be penetrated and transmitted into the underlying tissue (Miserendino, Levy and Miserendino, 1995).

Inevitably, lasers have disadvantages including, the possible detrimental effects on the dental pulp. Different laser wavelengths have been reported to cause varying degrees of pulpal changes. Amongst those, the Nd:YAG laser may cause irreversible pulpitis, followed by a sterile necrosis of the pulp tissue. This could be due to high temperature rises at the depth of the tissue which directly effects the pulp (Wigdor *et al.,* 1993). Miserendino *et al.* (1989) believed that pulpal damage usually occurs following either inappropriate power levels or exposure times. This concept is supported by Melcer (1986), who suggested that a short exposure with low energy laser radiation to an unfocused area would not damage the irradiated tissue. Damage of a thermal nature is possible during laser cavity preparation of deep cavities. In this respect, a minimum of 3 mm thickness of the remaining dentine is necessary, between the floor of the cavity and the pulp, to avoid pulpal damage during optimal laser irradiation (Jeffrey *et al.,* 1990).

Results of an *in vivo* investigation, using a pulsed Nd:YAG laser radiation on enamel surface of dogs' teeth, revealed an acute haemolytic necrosis of the pulp which were reported to return to normal within a month following irradiation (Bahcall *et al.,* 1993). Serebro *et al.* (1987) suggested that the duration of exposure was significantly more important than the power of the laser energy used as shown by the reaction of the dental pulp observed in histological assessments. More recent studies on the histology of the pulp following laser irradiation of the tooth, using a pulsed Nd:YAG laser, for 2 min (150 mJ at 20 pps) indicated no pathological changes to indicate any damage the vital pulp (Goodis, White and Harlan, 1992; White, Goodis and Daniels, 1991).

1.14 Aims and Objectives:

This study was designed to investigate the effect of a pulsed Nd:YAG laser on dental caries, both in primary and permanent teeth. The clinical acceptability of the laser technique was also investigated for treating anxious children. The aims of these investigations, therefore, were as follow:

a- Assess the efficacy of the laser on removing carious tissues in comparison to conventional drilling both *in vitro* and *in vivo*.

b- Assess any potential temperature changes in the pulp chamber during different treatment applications using an *in vitro* model.

c- Make an assessment of the microleakage in restored cavities.

d- Assess any changes in patients' anxiety towards dental treatment following laser caries removal.

e- Evaluate the long term response of the pulp to laser radiation for caries removal.

CHAPTER II

MATERIALS AND METHODS - GENERAL

CHAPTER 2: MATERIAL AND METHOD - GENERAL

2.1 Introduction

In this Chapter, the methods, equipment and materials employed in the *in vitro* studies (Chapters 3,4,5), and the *in vivo* trial of the laser (Chapter 6) are described. A brief description of general methodology for *in vitro* and *in vivo* trials will be discussed, also. Further details of these studies will be given in the related chapters.

2.2 Methods and materials employed for the *in vitro* studies:

2.2.1 Tooth selection and preparation

Extracted primary and permanent carious teeth were obtained from the Oral Surgery unit at the Glasgow Dental Hospital and School NHS Trust and stored in 0.12% thymol at 4 °C before and after experiments. Selected teeth were categorised into three groups, based on a clinical judgement on the diameter of the carious cavity openings:

1= Small, less than 1 mm (S),

2= Medium, 1 to 2 mm (M),

3= Large, more than 2 mm (L).

This classification was further confirmed using radiographs. A transportable Philips Oralix 65 kV, 7.5 mA machine, with a 20 cm cone, was used mounted on an adapted Atomscope stand. The radiographs were taken on Kodak Ultra Speed dental film DF-56 (Kodak, USA) using a parallel technique of radiation.

Carious lesions were scored radiographically, according to the following criteria (Creanor *et al.,* 1990):

0: Sound surface

2: Radiolucency in enamel, up to amelodentinal junction

3: Radiolucency in dentine, but not involving pulp

4: Radiolucency involving dentine and pulp

5: Restored surfaces

The score 1 is considered as inapplicable, as the lesion, i.e. superficial enamel spot lesions will not normally be seen on radiographs (Creanor *et al.,* 1990). The principle behind pre-operative radiographic scoring was to assess the accuracy of the initial clinical categorisation of the cavities and also to assess the relationship between the pulp and the carious lesion.

The class of the carious lesion on individual sample teeth was recorded based on Black's classification of cavities. This was carried out to provide an epidemiological assessment. Teeth with clinical or radiographic pulpal involvement were not included in any of the experiments.

2.2.2 Laser caries removal protocol

A pulsed Nd:YAG laser (American Dental Laser, dLase 300, Sunrise Technology, Birmingham, MI) at wavelength of 1.06 μm was employed throughout the different studies (Figure 2.1). It has the following specifications:

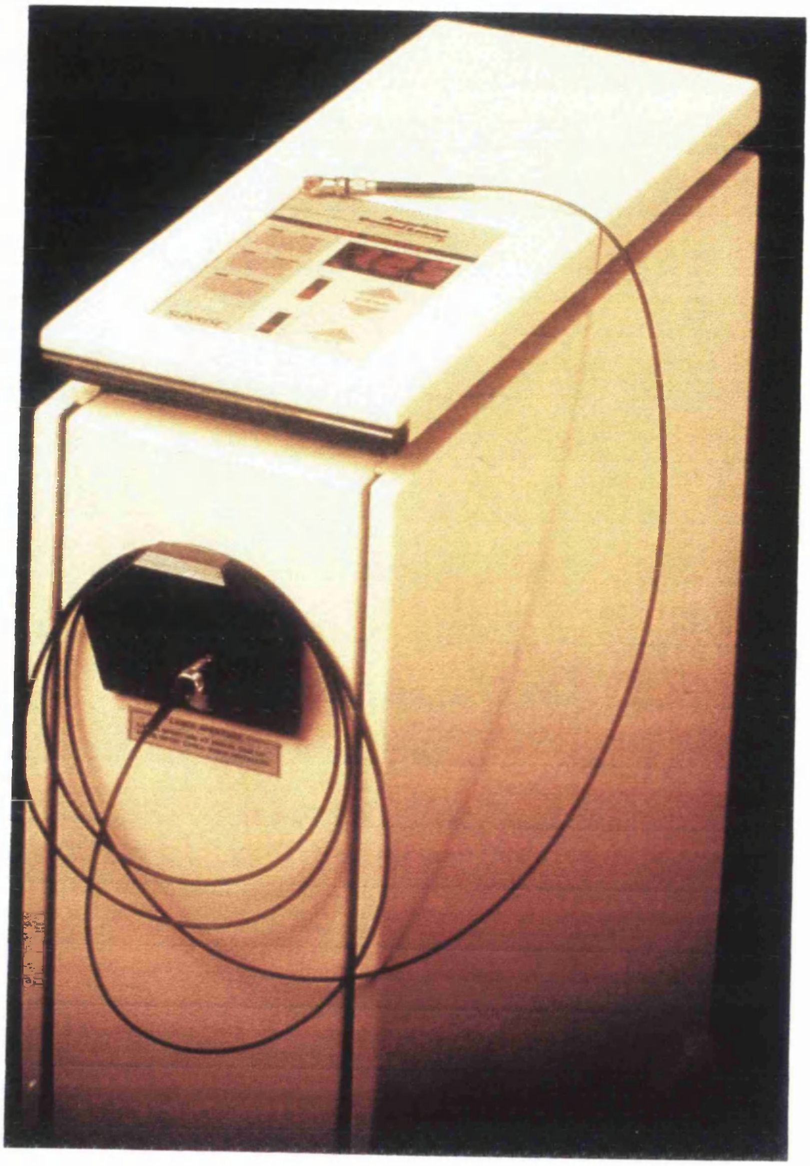


Figure 2.1: The pulsed Nd:YAG laser (American Dental Laser, dLase 300, Sunrise technology, Birmingham, MI) employed throughout the different studies of this thesis is illustrated above.

1. A power range of 0.3 to 3.0 Watts (W) with an energy range of 30 to 150 millijoules (mJ) per pulse.
2. Number of pulses per second ranged from 10 to 30 Hertz (Hz) and the pulse duration was 150 ns.
3. Pulse width of 150 microseconds (allowing the transmission of high energy levels for short periods).
4. A flexible quartz fibre optical cable system terminated in a handpiece with changeable angulated tips. Two fibre optic sizes (diameter of 200 and 320μm) are available depending on the area to be irradiated. The 320μm fibre was used in the following studies.
6. A red helium-neon laser with emission at 0.63 μm as an aiming beam for controlling the laser to the treatment area.

The selected power of laser energy is shown on a control panel of the laser machine. Available power outputs, produced by the combination of different energy levels at different pulse frequencies of this particular laser, are listed in table 2.1.

a- Laser caries removal method:

The laser energy was set between 1 to 1.5 W output, depending on the particular experiment. The carious lesion was removed by exposure to a maximum of 30 sec bursts of laser irradiation for each episode, until the cavity was found to be clinically caries-free (see below). Based on the size of the cavity and the nature of carious tissue, i.e. consistency and colour, the number

Power position↓/ pulse rate(pps)→	10	15	20	25	30
1	**30 mJ** 30 mJ	**0.50 W** 33 mJ	**0.75 W** 37 mJ	**1.00 W** 40 mJ	**1.00 W** 33 mJ
2	**40 mJ** 40 mJ	**0.75 W** 50 mJ	**1.00 W** 50 mJ	**1.25 W** 50 mJ	**1.25 W** 42 mJ
3	**50 mJ** 50 mJ	**1.00 W** 67 mJ	**1.25 W** 62 mJ	**1.50 W** 60 mJ	**1.50 W** 50 mJ
4	**60 mJ** 60 mJ	**1.25 W** 83 mJ	**1.50 W** 75 mJ	**1.75 W** 70 mJ	**1.75 W** 58 mJ
5	**70 mJ** 70 mJ	**1.50 W** 100 mJ	**1.75 W** 87 mJ	**2.00 W** 80 mJ	**2.00 W** 67 mJ
6	**80 mJ** 80 mJ	**1.60 W** 107 mJ	**2.00 W** 100 mJ	**2.25 W** 90 mJ	**2.20 W** 73 mJ
7	**85 mJ** 85 mJ	**1.70 W** 113 mJ	**2.25 W** 112 mJ	**2.50 W** 100 mJ	**2.40 W** 80 mJ
8	**90 mJ** 90 mJ	**1.80 W** 120 mJ	**2.50 W** 125 mJ	**2.75 W** 110 mJ	**2.60 W** 86 mJ
9	**95 mJ** 95 mJ	**1.90 W** 127 mJ	**2.75 W** 137 mJ	**2.85 W** 114 mJ	**2.80 W** 93 mJ
10	**100 mJ** 100 mJ	**2.00 W** 133 mJ	**3.00 W** 150 mJ	**3.00 W** 120 mJ	**3.00 W** 100 mJ

Table 2.1 : The outcome energy level of American Nd:YAG laser in different conditions are illustrated. (Top: displayed power, bottom: energy out put)

of exposures varied from 1 to 5 bursts. The whole surface was treated by moving the fibre across the entire carious surfaces of the cavity in a sweeping manner. The fibre tip was held about 1 mm from the surface of the target area.

Approximately 10 mm of the laser fibre optic tip was cleaved after each application (Figure 2.2) to ensure consistent radiation. This was checked by visually evaluating the sharpness of the aiming beam. The output of the laser was checked regularly by the laser safety officer.

b- Laser health and safety parameters:

All laser operations were carried out under the direct supervision of the laser safety officer of the Glasgow Dental Hospital and School NHS Trust. Local rules for safe laser application were met for these operations, details of which are presented in Appendix A.

2.2.3 Conventional caries removal protocol

Caries removal was carried out on the control teeth using a conventional slow speed handpiece, running on an air motor at 40000 rpm (Kavo Dental Ltd, UK). A new sterile round tungsten carbide bur (size 3 to 5) was employed for each cavity, in a similar fashion as to routine clinical use. Caries removal was stopped when the cavity was found to be caries-free, as tested by conventional visual and tactile assessment techniques recommended as efficient for this purpose by Kidd, Joyston-Bechal and Beighton (1993). Since the prepared

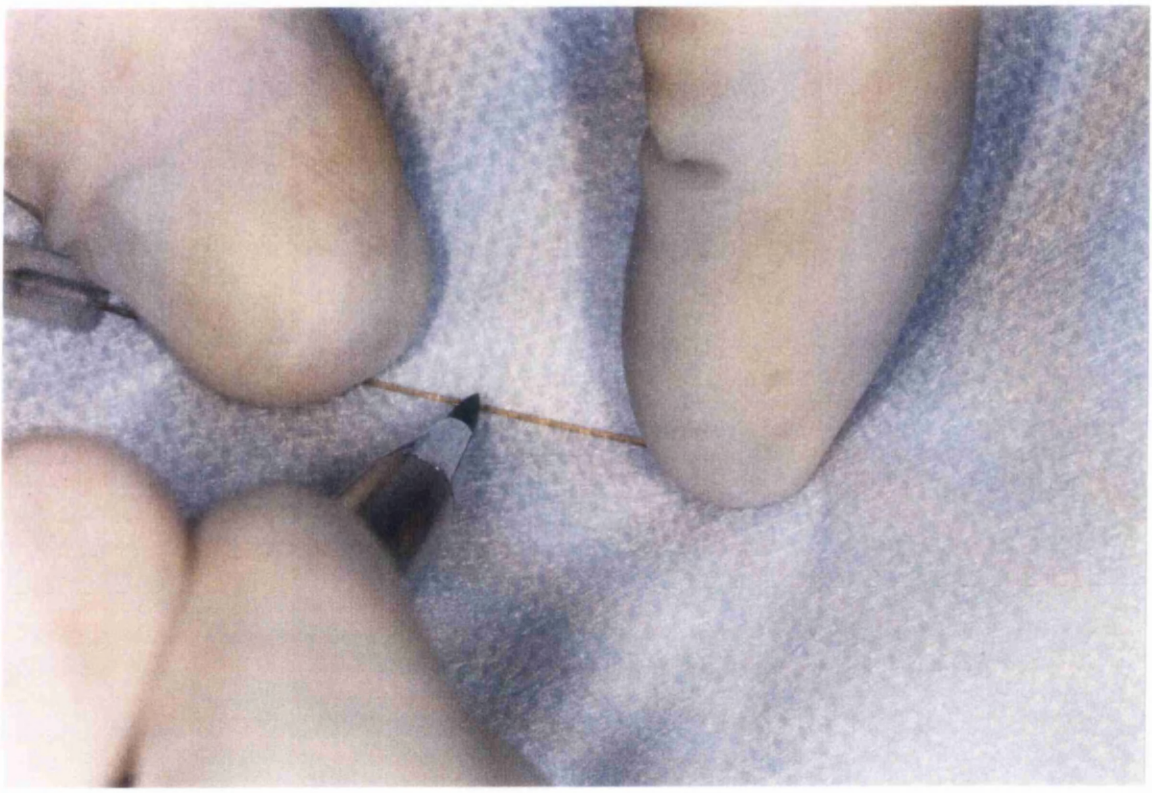


Figure 2.2: The method of cleaving the laser fibre optic tip is demonstrated here (about 10 mm from the tip).

cavities were to be restored with an adhesive restorative material, no further cavity preparation was undertaken.

An air turbine (Siemens 4000 MS, Germany), operating at 275,000 rpm, and a diamond fissure bur of size 8 was used in cases where wider access to the carious tissue was necessary prior to the laser or drill application.

2.2.4 Caries removal assessment technique:

After the completion of the caries removal procedure, a clinical assessment was carried out using conventional visual and tactile criteria. This technique was suggested by Kidd, Joyston-Bechal and Beighton (1993) as being both efficient and reliable. In this technique, the cavity surface is examined under a conventional chair side light source, using a straight blunt probe after the cavity is dried.

2.2.5 Histological assessments of *in vitro* prepared dentine surfaces:

The aim of these histological assessments were to investigate microscopic changes of the remaining dentine following caries removal using either laser or drill. Four different methods of assessment were employed, including:

1. Microscopic assessment of the ground sections prepared from treated teeth.
2. Microscopic assessment of the demineralised sections prepared from treated teeth.
3. Assessment of microradiographs prepared from the ground sections of the treated teeth.

4. Scanning electron microscopic assessment of the dentine surface treated by either of the techniques.

a- Preparation and assessment of the ground sections:

Teeth were sectioned into two halves using a diamond saw (Microslice 2, Malvern, UK). Ground sections with a thickness of 250 μm were prepared from one half to examine the characteristics of the dentine structure remaining after caries removal. This was carried out as follows:

1. Treated teeth were embedded in tan wax and mounted on the chuck of the Microslice hard tissue saw (Figure 2.3).
2. Longitudinal sections were prepared in such a way as to cut the tooth passing through the floor of the cavity towards the pulp and displaying the structure between the pulp and the prepared dentine surface.

Prepared sections were hand lapped to a thickness of about 145 μm, using an aluminium oxide containing abrasive powder (White Bauxlite 2000, Honing abrasive, UK) (Figure 2.4). This process, removed the cutting marks produced by the cutting wheel and produced planoparallel section with uniform thickness. An electronic micrometer (Digimatic Indicator, Mitutoyo, Japan) was used to assess the thickness of different regions of the sections during the procedure (Figure 2.4).

The sections were dehydrated using xylene and alcohol with different degrees of concentrations and then mounted on microscope slides using Hyolanic

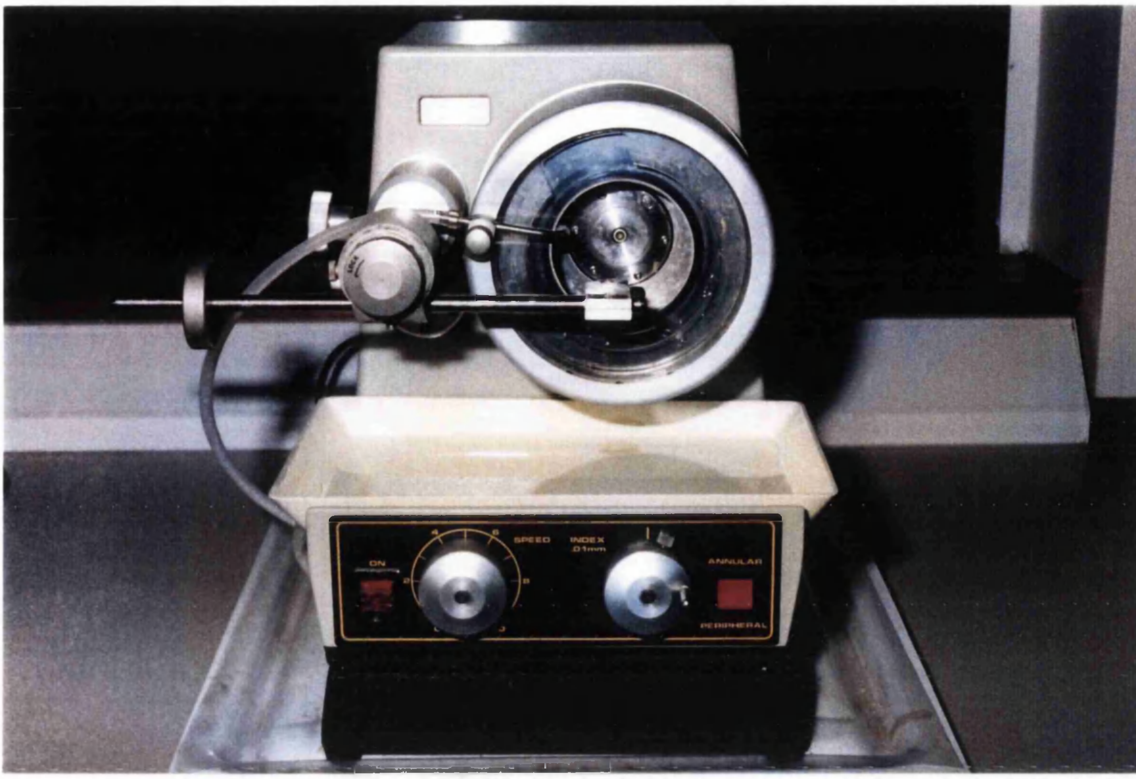


Figure 2.3: Microslice hard tissue saw used for the ground sections preparation is illustrated.

Figure 2.4: The glass pad with the handle used for lowering the thickness of the ground sections are shown in addition to the electronic micrometer used for thickness measurments.

Synthetic Resin (HSR). Sections were examined under the light microscope using x2.5 and x6.3 magnifications. Details of dehydration and mounting procedures will be discussed in Chapter 3.

b- Preparation and assessment of Microradiographs:

The purpose of this assessment was to examine the degree of opacity of the remaining dentine at the floor and walls of the prepared cavity when compared to the surrounding sound dentine. To prepare a microradiographic view, ground sections were prepared as described earlier in this Section. Each specimen was ground to approximately 150 μm in order to achieve a standard thickness for further assessment. Sections were placed between two layers of clingfilm (Figure 2.5) to prevent dehydration, as well as permitting easy and safe handling during the radiographic procedure. A modified high resolution radiographic film (Kodak, USA) was used for this purpose. The film, with specimens mounted, was placed in a specially designed plate holder, for microradiographic purposes (Figure 2.6). The sealed plate holder including the film and sections, was placed inside the Diffractus 582 x-ray unit (Enraf Nonius Delft, Holland) set at 20 kV, 30 mA and exposed to the x-ray beam for 20 min (Figure 2.7). Films were processed and finally subjected to assessment under the light microscope (Leitz, Switzerland). Details of these assessment processes are described in Chapter 3.

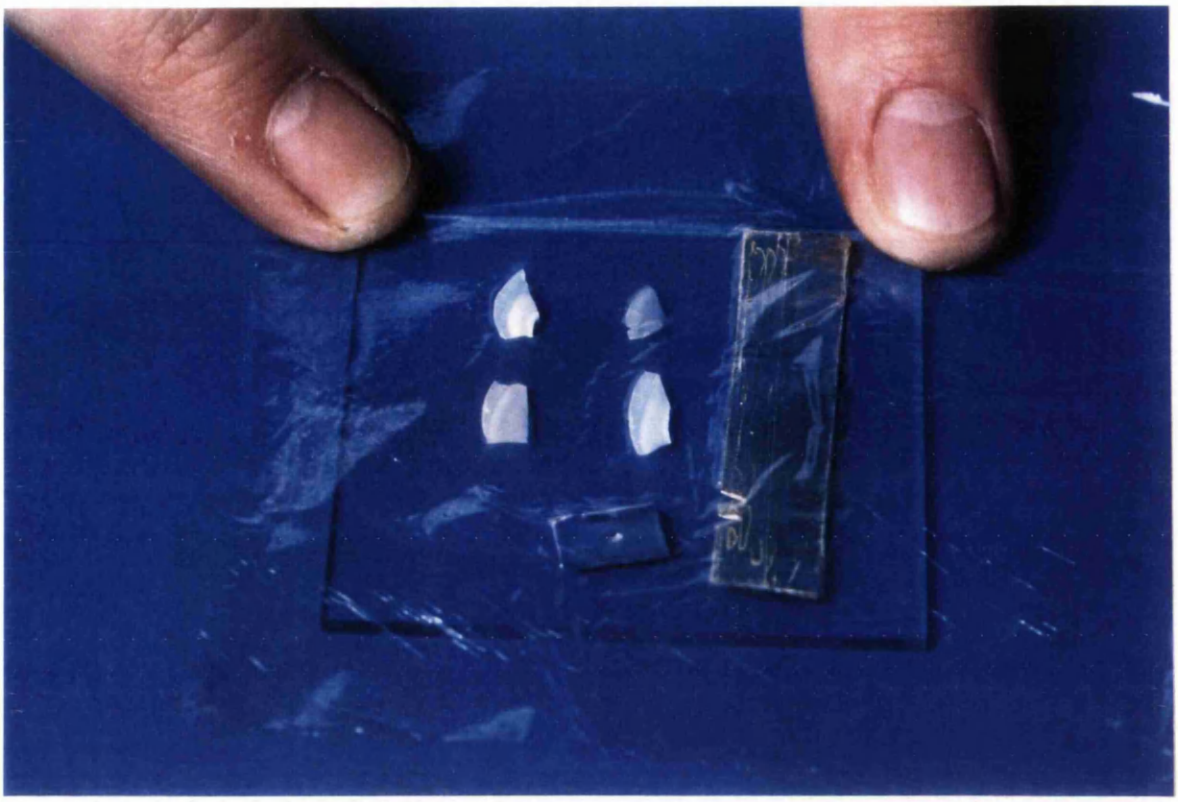


Figure 2.5: The prepared sections are placed between two layers of clingfilm prior to microradiography.

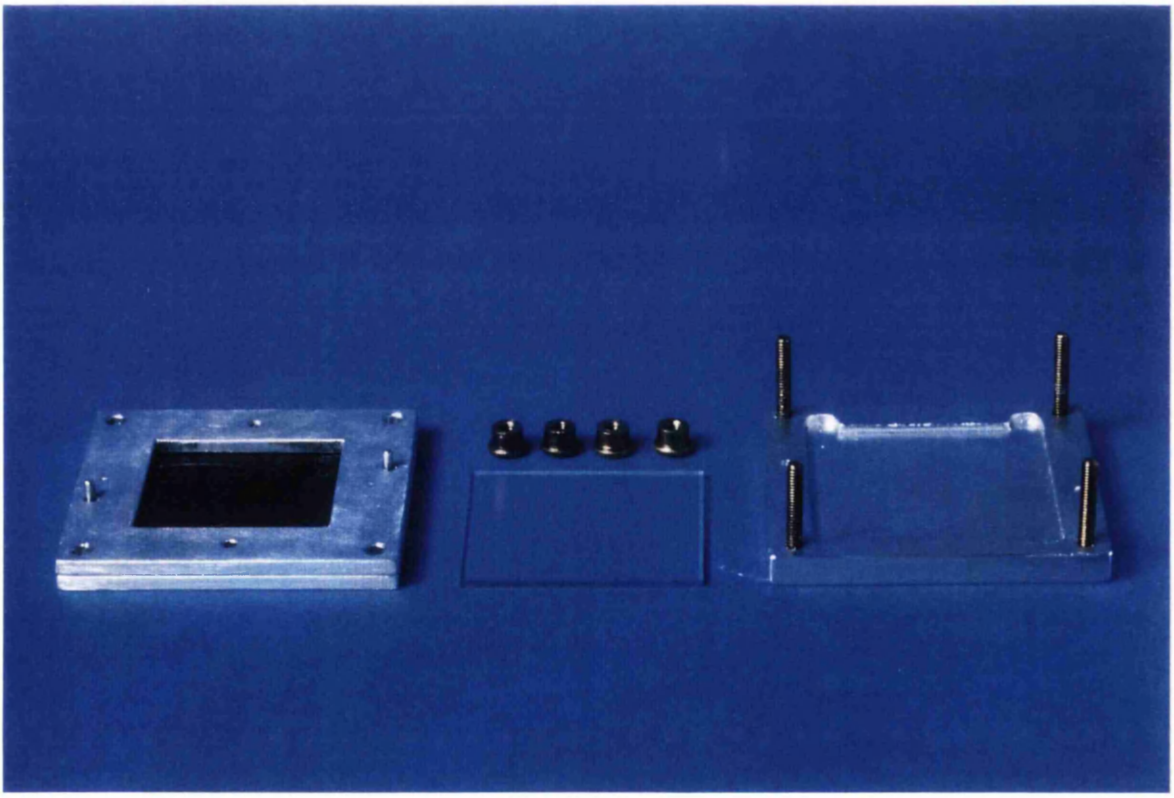


Figure 2.6: The film, with specimens mounted on, are placed in this specially designed plate holder for microradiographic purposes.

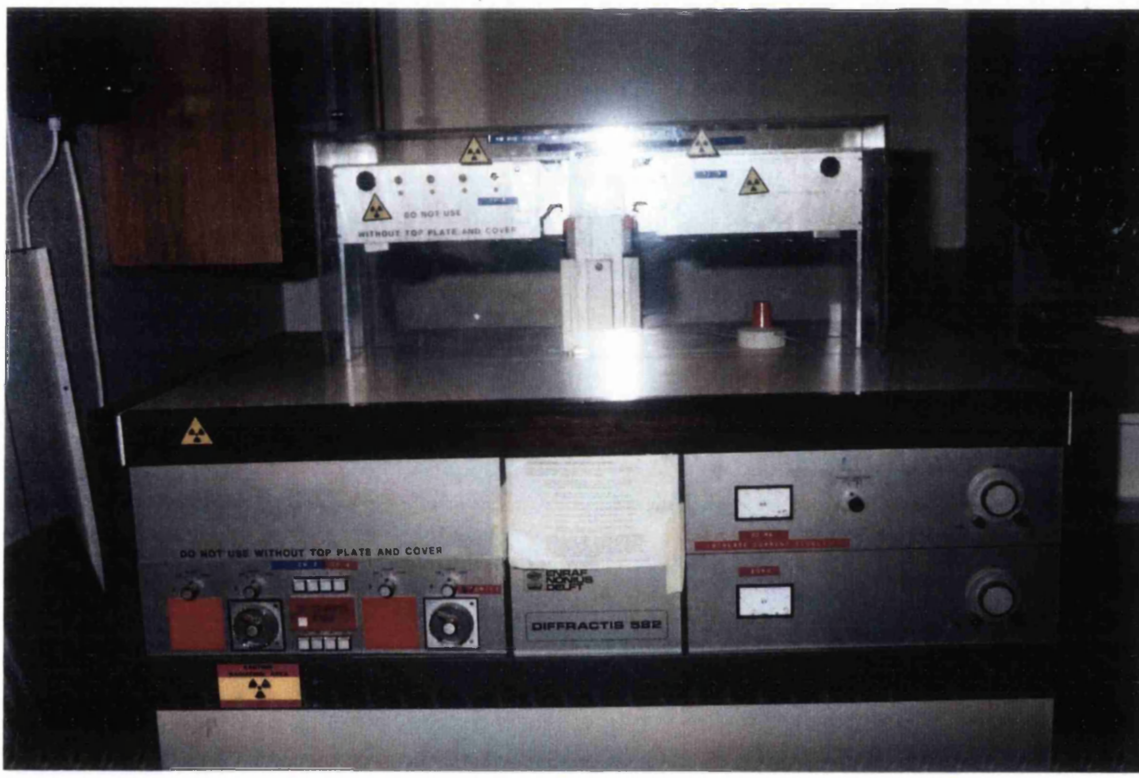


Figure 2.7: Microradiographic machine used for radiographic assessments of the sectioned specimens.

c- Preparation and assessment of demineralised sections:

The aim of this microscopic investigation was to examine the condition of the remaining collagen fibres following the use of laser radiation. Demineralisation was carried out using the second half of the teeth, the first half being used for ground sections. In this way specimens for the different assessments would be correlated. The thickness of prepared sections was approximately 5μm with cutting line through the centre of treated cavities. Each section was then processed, stained and then mounted on microscope slides for assessment. Sections were then examined under a light microscopic with magnifications of x6.3, x10, and x40. Details of the preparation techniques and their assessment methods will be discussed further in Chapter 3.

d- Preparation and assessment of SEM specimens:

This investigation was carried out to enable the assessment of the surface shape and configuration of the treated dentine surfaces. Sample teeth were immediately fixed after laser/drill application using 2.5% glutaraldehyde buffered in 0.1M cacodylate. The procedure was followed by dehydration of the teeth using ethyl alcohol which took about 5 days for primary teeth and 7.5 days for permanent teeth. Details of this procedure will be discussed more in Chapter 3. The prepared specimens were mounted on aluminium stubs (Agar Scientific Ltd) and coated with a thin film of gold using a sputter coating machine (Polaron E 5000). The prepared specimens were assessed using a scanning electron microscope (Jeol T 300, SEM) at an accelerating voltage of 30 kV. Photomicrographs of the specimens were taken from the treated cavities at the following magnifications: x35, x500, and x1000, using Kodak TP120 film type 6415 (Kodak Ltd. Manchester).

2.2.6 Restoration of prepared cavities and their assessment:

To assess the level of adaptation of the restoration to differently prepared cavity walls, restored teeth were subjected to a microleakage investigation. All treated teeth were restored by a single restorative material, to eliminate any other factor than the effect of the cavity preparation technique on adaptation level. The material used was a light cured compomer filling material i.e. Dyract® (Dentsply, UK). The main reason for the use of this material was that less tissue removal is required, due to its adhesive property, in addition to its fluoride releasing property. Dyract®-PSA Prime/adhesive is a single component visible light cured cavity primer, sealer and adhesive, which was first applied to the prepared surfaces and cured. This was followed by the immediate placement of the Dyract® restorative component which was subsequently light cured, according to the manufacturers instructions, using an Aristolite curing light (Litema halogen, Pluraflex HL 150, Germany).

- Assessment of the restorations:

In order to assess the quality of the restorations different studies were set up, including the measurement of the gap size and microleakage level at the interface between the restoration and the cavity wall. All the experimental teeth were subjected to a series of thermal shocks to simulate temperature change in the oral cavity. A thermocycling machine (Figure 2.8) was used for 350 cycles with temperatures of 4, 37, and 55 °C as described by Scott, Saunders and Strang (1993). The specimens were stored at each temperature for approximately 10 sec.

To measure the gap size at the margins of the restoration, each tooth was subjected to two separate impressions. Impressions were taken immediately before and after the thermocycling, to record the changes caused by thermal stimulation of the material. A resin replica was constructed from each of these impressions to provide samples of the restored teeth before and after thermal cycling. These samples were then subjected to assessment and measurement under the light microscope, details of which will be discussed in Chapter 5.

The experiment was continued by the application of a dye (buffered 0.2% Methylen Blue, ,UK), to the tooth specimens, to evaluate the microleakage resistance of the tooth/restoration interfaces in each cavity. Teeth were, therefore, dissected through the centre of the restoration and examined immediately under the light microscope with a magnification of x10. The level of microleakage was estimated based on the level of dye penetration. Details of these measurements will be explained latter in Chapter 5.

2.2.7 Assessment of temperature changes at the pulpodentinal junction

The laser irradiation of the dental structure produces heat which can be easily transferred through the bulk of the dentine to the pulp (Arcoria and Miserendino, 1995). Due to the dangers involved with a temperature rise of the pulp, an experiment was designed to measure the amount of this temperature rise at the pulpodentinal junction. Nickel/Copper thermocouple wires were inserted into the pulp chamber of carious teeth through the apices of their roots, while these were connected to a digital thermometer and a chart recorder.

Temperature rise at the PDJ was recorded during both laser and drill caries removal procedures. An additional temperature recording was carried out while the visible curing light was applied to the treating teeth before and after caries was removed. The effect of remaining dentine thickness between the floor of the cavity and the pulp on temperature rise was also considered as an important factor. This was assessed by measuring this thickness using a radiographic view, in addition to the direct examination of dissected teeth under the light microscope at a magnification of x6.3. More details of these measurements and the methodology will be discussed in Chapter 4.

2.3 Methods and materials employed for the *in vivo* trial:

2.3.1 Sample selection and preparation:

Patients were selected from the Consultant clinic at the Child Dental Health Unit, Glasgow Dental Hospital and School NHS Trust, based on the following criteria:

1. Patients aged between 3 and 12 with at least two primary carious teeth
2. Patients with some degree of dental anxiety
3. No medical condition influencing the patient's behaviour

Teeth were selected based on the following criteria:

1. Fresh carious teeth with no clinical or radiographic sign of pulpal involvement
2. Less than one third of the root resorbed, as assessed radiographically
3. Similar teeth with roughly the same size cavities

2.3.2 Initial assessment and categorisation

Two scoring systems were used for the anxiety assessment of patients prior to the treatment including: 1. operator's judgement using Frankl scoring system (Frankl, 1962), 2. Patient's scoring using a modified assessment technique to the pictorial assessment technique suggested by Venham (1979). The pictorial form was used with modification on its interpretation for use with laser treatment and patient's feeling towards the technique before and after the treatment. Instructions given to patient's were standardised, taking patient's age to account. This modified Venham's pictorial form, is demonstrated in Appendix B. To examine the effect of the method of caries removal on the patient's reaction, treatment was started randomly with either of the techniques.

A radiographic assessment was conducted pre-operatively, for all proposed cases to enable an initial assessment of the extent of the carious lesion with a similar fashion as was used for the *in vitro* specimens. A standard bitewing view was used as the radiographic view of choice for posterior teeth and periapical view for the anterior region. In cases of poor co-operation for intra-oral radiographs, extra oral radiographic views were obtained, including orthopantomograph and lateral oblique views. However, no radiographic assessment was performed for class V carious lesions and the radiographs were used for the assessment of the periapical areas. Individual clinical scoring of the cavity sizes was also recorded for further comparison as described in Section 2.2.1. Teeth were also examined clinically, for the condition of soft tissue surrounding the teeth to be treated, to eliminate those with any pathological sign of pulpal involvement.

In addition, patients were assessed for the following:

1. The dmfs score for each patient was checked.
2. Any previous dental experience was recorded.
3. Parent's views on laser caries removal system was evaluated using a questionnaire (Appendix C).

2.3.3 Laser caries removal

A similar protocol to the *in vitro* application of the laser was adopted, in terms of the method of laser application. A power of 1.25 W, produced by 60 mJ energy at 15 pps, was employed for the clinical trial. This was based on the results of the *in vitro* experiment by testing different energy levels detailed in Chapter 3. In order to reduce the chance of damaging the pulp due to heat production, a high velocity aspirator was used to reduce the temperature rise of the tooth surface during laser irradiation and also to remove smoke produced by charred dentine. A second precautionary measure was considered by limiting the laser exposures to 30 sec maximum for each with a minimum of 30 to 60 sec rest before the second application. The laser fibre optic tip was cleaved after each exposure and the contrast of the radiation beam was tested subsequently, as described earlier in Section 2.2.2. Caries removal was stopped when the cavity was found to be clinically caries-free using conventional tactile and visual criteria.

2.3.4 Conventional caries removal protocol

Conventional caries removal was conducted on control teeth using a slow speed handpiece on an air motor (Kavo Dental Ltd, UK). A new sterile round tungsten carbide bur (size 3 to 5) was employed for each tooth, as necessary. The procedure of caries removal was continued until the cavity was found to be clinically caries-free, again using tactile and visual criteria. No further modifications were performed on the shape of the prepared cavities as an adhesive restorative material was to be used. Hand excavation was used as necessary, Section 6.7.4.

2.3.5 Caries removal assessment

Prepared cavities were assessed clinically using a conventional straight probe under conventional dental chair lighting. Caries removal was considered as complete based on clinical judgement using visual and tactile criteria (Kidd, Joyston-Bechal and Beighton, 1993). In addition, prepared cavities were randomly subjected to an extra caries removal assessment by independent calibrated clinicians.

2.3.6 Restoration of prepared cavities:

All prepared teeth were restored with a light cure compomer as the restorative material of choice as described in Section 2.2.6. The restoration placement and its light exposure time for curing were carried out as recommended by the manufacturer. Compomer restorations are suggested as a suitable restorative material for restoration of prepared cavities with no additional modification to the outline of the cavity, particularly in primary teeth (Croll, 1993), as this avoided unnecessary tissue removal which would have been required for non-adhesive restorations (Elderton, 1986; Kidd, Joyston-Bechal and Beighton, 1993). Compomers, as a modified formula of glass ionomer, could perhaps provide similar bond strength in addition to fluoride releasing capacity (Manufacturer's data).

Each prepared cavity was isolated using rubber dam or cotton wool rolls. To achieve maximum wetness of the bonding surface of the dentine, single component primer/adhesive was applied to the dentine surfaces following the completion of caries removal. The primer was air thinned and then light cured for 20 sec. This was followed by the placement of a suitable shade restorative material into the cavity and light cured using Visilux™ 2 (3M Dental Products, Germany) for 40 sec.

2.3.7 Scanning electron microscopic assessment of clinically prepared dentine surfaces:

To allow a more precise assessment of the dentine surface of the *in vivo* specimens following caries removal, teeth with laser/drill prepared cavities were subjected to an impression using light body President impression material (Coltex®, Switzerland) (Figure 2.9) loaded in nickel chromium crowns as special

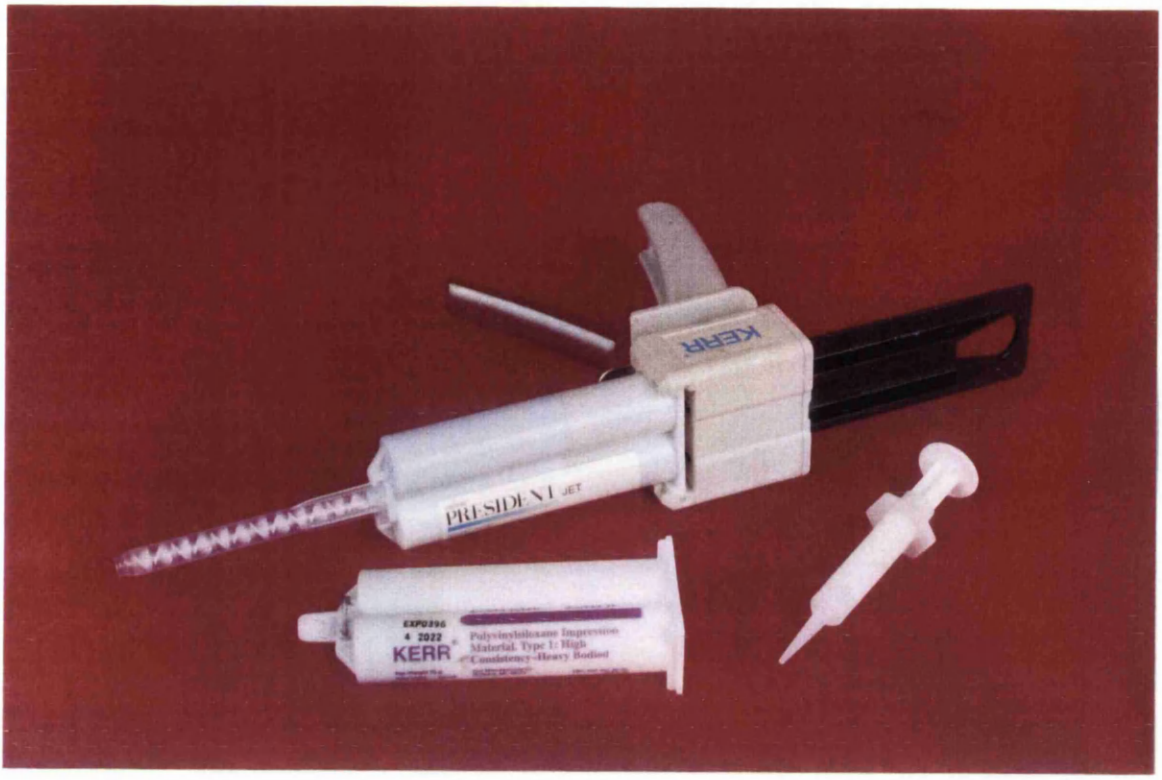


Figure 2.9: President impression material (Coltex®, Switzerland) used is shown with a fine syring used to inject the material into the prepared cavities.

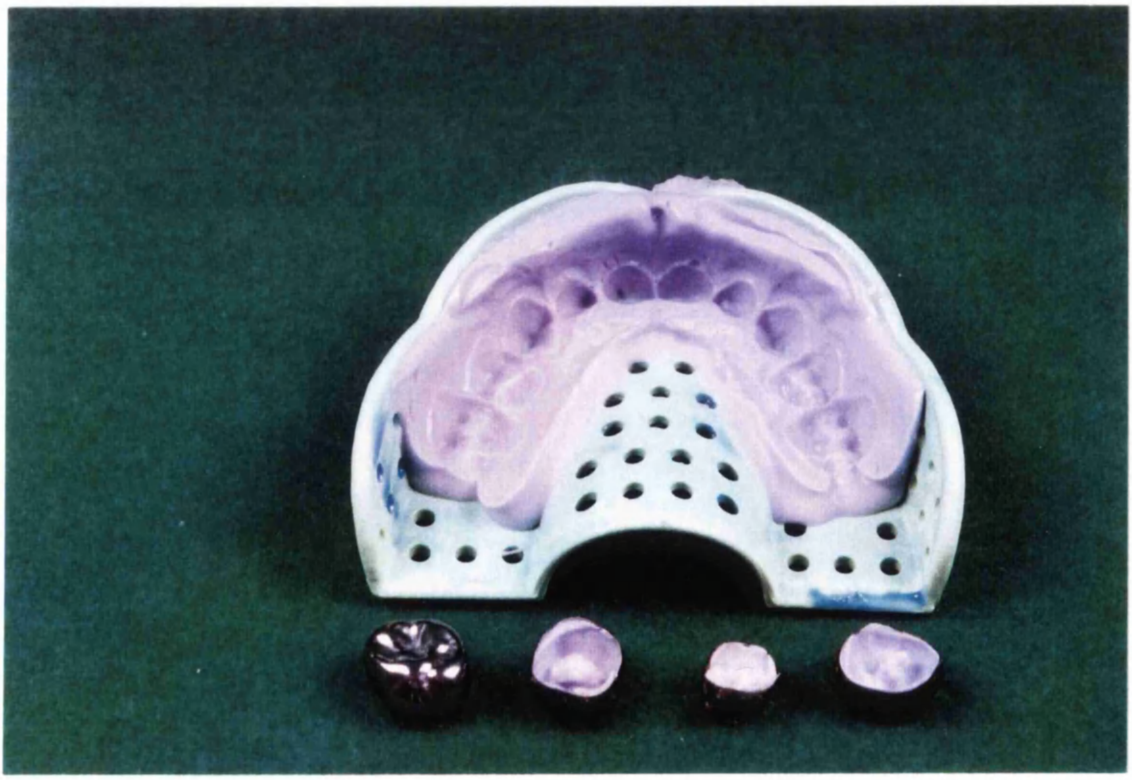


Figure 2.10: Impressions taken from prepared cavities using custom trays of nickel chromium crowns are shown, with an impression after restoration.

trays (Figure 2.10). Resin replicas were provided by pouring the impressions with epoxy resin (Epofix, Struers tech, Denmark). Resin specimens were then subjected to a gold coating process using a sputter coater (Polaron E 5000), details of which have been discussed earlier in Section 2.2.5. The duplicated surfaces were examined under the scanning electron microscope to evaluate any differences in the dentine surface following laser and drill application.

CHAPTER III

LASER CARIES REMOVAL EFFICACY

CHAPTER 3: Laser effect on carious and sound dentine, comparing three different energy densities

3.1 Introduction:

Most of the currently available lasers have the capacity to produce a range of energy output to enable a variety of different applications. A minimum laser energy is required for ablation of a subject which will differ between different materials. It is, therefore, essential to define the minimum effective level of the laser energy to be used for ablation of carious tissue. At the same time it is important to make sure that it does not exceed the safe limit for sound dentine. This effectiveness depends on several factors, including the optical properties of the carious mass i.e. colour, laser energy at the tissue surface, and the length of the exposure time (Koorts and Frentzen, 1995; van Breugel and Dop Bar, 1992).

The effect of laser irradiation on dental hard tissue can vary from no effect to carbonisation of the tissue, perhaps resulting in cracks and even complete loss of the inorganic component. This effect depends mainly on the amount of energy delivered to the tissue, a function of the laser's power and duration of exposure (Koorts and Frentzen, 1995). The effects of different laser energy densities on dental hard tissues have been examined, the major concern being the possibility of overheating of the tissue, especially when higher powers and longer periods of radiation are employed (van Breugel and Dop Bar, 1992; White *et al.,* 1993).

Laser power of 3 W has been suggested as the highest safe limit for enamel and 1.5 W for dentine, during caries removal for periods of up to 1 min (Cernavin, 1995). However, vital dental pulp, which is obviously in close association when the tissues are subjected to laser radiation, can only tolerate a certain level of energy which will ultimately result in the production of heat (Wigdor *et al.,* 1993).

3.1.1 Factors influencing the laser tissue interaction:

Laser energy acts differently when it is exposed to different structures. The effects are influenced by: 1. laser absorption properties of the material, 2. laser energy characteristics and 3. exposure time.

Different materials have demonstrated varying degrees of response to a single laser wavelength. For example, laser energy penetrates enamel much more easily than dentine, causing more severe destruction in the latter tissue (Peck and Peck, 1967). The amount of water contained within a tissue has been suggested as having an important role on the response of the target tissue to certain laser radiations, including CO_2 laser, whilst this effect is minimum in the case of the Nd:YAG. Liesenhoff *et al.* (1989) showed a higher tissue removal ratio in dentine compared to enamel, indicating a higher cutting efficacy of the laser radiation in dentine, probably due to the differences in composition of the two structures.

The amount of laser energy delivered to the target surface was shown to have a direct influence on the degree of change within the tissue, including the crater's width and depth (Peck and Peck, 1967). Whether the laser beam is pulsed or continuous may also cause variation in how the tissue will react, pulsed lasers usually causing less damage. The duration of exposure is also an important factor, since this effect is directly dependent on the length of exposure. The longer the exposure time, then the greater the cutting effect of the laser (Koorts and Frentzen, 1995). The effect of laser radiation on hard tissue is thought to be unpredictable, in contrast to its effect on soft tissue, which is described as predictable due to its high absorption rate (Koorts and Frentzen, 1995).

Generally, low intensity laser exposure for a long period is described as less destructive with only some photochemical effects. Higher energies using shorter exposure times cause a photothermal interaction, the basis of most surgical lasers (Koorts and Frentzen, 1995). Tissue dehydration, as a natural sequela of heat generated in the bulk of the tissue, is considered as an initiator to thermal interaction. The degree of this thermal damage can be reduced by choosing the proper laser parameters, including: spot size, exposure duration, pulse repetition rate, and the duration of the pulses (Koorts and Frentzen, 1995).

Dederich (1991) described the reaction of the laser when it hits the target tissue as being in one of the following four major forms:

1. absorption which converts the light directly to heat,
2. scattering which distributes the light over a large volume of tissue, thereby reducing any thermal effects,
3. reflection, which by reducing the amount of light entering the tissue produces the minimal thermal effect,
4. Transmission of the light through the bulk of tissue with minimal effect on the target tissue.

In addition to the main factors involved in laser/tissue interaction, including: wavelength, pulse length, peak power and power density, secondary factors include reflecting capacity, degree of opacity and the colour of the irradiated tissue (Peck and Peck, 1967). It can be concluded, therefore, that the effect of the laser on the target tissue will vary from tissue to tissue and from laser to laser.

3.1.2 Surface temperature and its effect on surface morphology:

Since the physical properties of enamel and dentine are different; the laser's effect on dentine will vary considerably when compared with enamel (Stern, Renger and Howell, 1969). Charred areas of dentine can indicate a high surface temperature sufficient to produce carbonisation of the organic matter of dentine (Anic *et al.,* 1992). Hard tissue changes, including cratering and recrystalisation have been reported following laser irradiation of enamel and dentine, resulting from a rise in surface temperature (Kantola, 1972; Kantola, Laine and Tarna, 1973; Kantola, 1973). Excessive heat production at the irradiated surface during laser application will cause carbonisation and cracks of the surrounding parts of the irradiated cavity (Stern and Sognnaes, 1972; Sugawara, 1974; Adrian, Bernier and Sprague, 1971; Launey *et al.*, 1987).

A range of lasers have been investigated as to their ability to raise the temperature at the dentine surface. These include Nd:YAG, CO_2 and Excimer lasers with Excimer lasers having a significantly reduced thermal injury-inducing effect on enamel and dentine (Liesenhoff *et al.*, 1989; Frentzen *et al.*, 1989; Matsumoto, Nakamura and Wakabayashi, 1990). However, Arima and Matsumoto (1993) reported surface temperature rises of 19 °C after 3 min caused by 0.12 W energy ArF:Excimer laser application on the dentine surface. In addition, the ultraviolet range laser wavelengths are believed to have the potential of DNA and RNA alteration (Frentzen *et al.*, 1989).

3.1.3 Changes at the dentine surface following laser irradiation:

Dentine, which has been irradiated by a laser will inevitably undergo some degree of surface morphology alteration. Microscopic examinations, including SEM assessment of the treated dentine was recommended as the most reliable technique of assessment of the alterations within the tissue.

As discussed earlier, different laser wavelengths behave differently on tissues which will then produce varying degrees of damage to the tissue as explained by histological examination. With regard to tissue porosity, Stabholz *et al.* (1995) have reported a marked reduction in the penetration depth of dye applied to specimens following laser irradiation. This indicated that the laser, under the conditions used in that study, was capable of reducing dentine permeability and, therefore, probably hypersensitivity (Stabholz *et al.,* 1995). The mechanism for this could have been by occlusion of the dentinal tubules after resolidification of melted material.

Bassi, Chawla and Patel (1994) used an Nd:YAG laser with the power of 1 W to remove carious dentine and reported a higher micromechanical retention at the irradiated dentine surface. Dederich, Zakariasen and Tulip (1984) reported varying degrees of laser effects on sound dentine, from no effect, to disruption of the smear layer to melting and recrystalisation of surface dentine using an Nd:YAG laser with powers of 10 to 90 W for one group and 0.1 to 0.9 W for a second group. However, there was no indication of how long the exposure time to these different laser energies.

The crater depth is believed to be directly proportional to the amount of laser energy delivered to the target surface. Interestingly, some degree of alteration in dentine subjacent to the lased enamel has been reported demonstrated by dark, pinpoint speckling or a denatured pattern microscopically (Peck and Peck, 1967). Droplets of resolidified melted dentine covering the lased area of dentine is a common appearance which can be observed following Nd:YAG laser application with a power of 1.5 W (Cernavin, 1995). Wigdor *et al.* (1993) reported that a glazed dentinal surface was produced following the irradiation of the teeth with a 12.5 W continuous wave Nd:YAG laser. This was suggested as being the result of high temperature and melting of the surface structure following laser radiation. The clinical appearances of those teeth were reported as charred surrounded by a basophilic band on the irradiated dentine surface.

The production of a charred dentine surface has been reported following exposure to a pulsed carbon dioxide laser radiation of 3 W supplied by a water coolant spray, but with no reference to the exposure time (Stabholz *et al.*, 1992). Dederich (1993) believed that the effect of the Nd:YAG laser wavelength on dentine was unpredictable and inconsistent when applied to different parts of the dentine because of the variation in tissue colour.

Cox, Pearson and Palmer (1994) have suggested that once the threshold level for dentine damage is passed, increasing the energy density of the laser beam results in an increase in both tissue loss and depth of cratering. The melting and vaporisation process will start as soon as the organic content of dentine has disappeared (Cox, Pearson and Palmer, 1994). Scanning electron microscopic examination of teeth irradiated by the Nd:YAG laser revealed appearances of irregular punched out craters with the presence of melted and recrystalised masses of dentine. The appearance of glazed interconnected droplets was noted at the irradiated surfaces. The presence of normal dentine structure, however, between droplets was also noted indicating no alteration of sound dentine (Cernavin, 1995). Further laboratory investigations using x-ray diffraction of lased dentine has indicated a higher concentration of minerals at the lased area, which was concluded as being due to the formation of tricalcium phosphate during recrystalisation (Vahl, 1968).

3.1.4 Microscopic changes of prepared dentine following laser irradiation:

There are several methods of assessment for examination of tissue change, with histological examination being the most reliable and accepted, particularly for changes at the deepest portion of the tissue. The prepared dentine surface can be monitored microscopically using the scanning electron microscopy (Koort and Frentzen, 1992; Stabholz *et al.,* 1992). In addition, microradiographic evaluation of the remaining tissues can be carried out, to estimate and measure the mineral content of the remaining tissues (Angmar, Carlstrom and Glas, 1963).

To examine the degree of tissue change within the deeper portions of the dentine, it is necessary firstly to prepare sections of the specimens, both ground and demineralised sections; This permits examination of changes to both the organic and inorganic components of the tissue. Generally, among the dental hard tissues, dentine will be expected to absorb more laser energy, due to its greater opacity compared to enamel and should, therefore, demonstrate a more efficient cutting effect (Peck and Peck, 1967). Three different histological zones of destruction are described for laser irradiated dentine. These include: 1. a central zone of complete destruction; 2. partial destruction of the immediately surrounding tissue to the centre of destruction; 3. partial destruction with isolated foci beyond the first two zones. The depth of these laser-produced craters seems to be directly proportional to the level of laser energy delivered to the target (Peck and Peck, 1967).

The presence of microcracks have been reported during Nd:YAG laser irradiation of dentine when employing powers above 100 mJ. However, areas of carbonisation, surrounded by necrosed tissue were produce associated with microcracks in specimens of teeth irradiated by all four types of laser tested by Koort and Frentzen (1992). High temperatures, however, will produce tissue melting, which in turn occludes the dentinal tubules during caries removal (Nammour, Renneboog-Squilbin, and Nyssen-Behets, 1992). However, the laser caries removal technique is believed to prepare a non-smeared surface which may produce a better adhesion potential for restorative materials (Pashley *et al.,* 1992).

Microscopic examination of sectioned laser-irradiated carious teeth showed a selective deep destruction of carious tissues (Goldman, Gray and Goldman, 1965), in addition to a higher level of calcium and phosphorous compared to non-lased surfaces, assessed through microradiographic and electron probe microanalysis examinations (Kantola, 1972).

3.2 Aims:

The major aim of this Chapter is to identify the most effective and least damaging power of the Nd:YAG laser to remove dentine caries. The aims of this Chapter can be summarised, therefore, as follows:

1. to examine, using various methods, the dentine surface irradiated using different power settings on the Nd:YAG laser
2. to examine the effect of these powers on sound dentine
3. to evaluate the efficacy of individual powers in removing dentine caries.
4. to assess the condition of the smear layer and melted material produced using different power settings.

3.3 First preliminary study - Efficacy of different laser energies for removing dentine caries:

3.3.1 Introduction:

A pilot trial was designed which involved an assessment of carious dentine removal using a series of laser energies, in the range recommended earlier (Miserendino *et al.,* 1993; White, Fagan and Goodis, 1994), and to identify which range of laser energies of the American Dental Laser (Nd:YAG), will remove carious dentine efficiently, without damage to surrounding tissue.

3.3.2 Methods and Materials:

Twenty freshly extracted primary carious teeth were selected randomly, which included both anterior and posterior teeth with roughly the same size of carious cavities. The teeth were stored in 0.12% thymol at 4 °C before and after treatment. Four different laser energy levels were tested in this pilot study, ranging from 1 to 1.6 W. The experimental teeth were divided into four groups, each of which was treated using one of the four energy settings. The laser energy settings were:

1. 50 mJ at 15 pps (1.00 W)
2. 60 mJ at 15 pps (1.25 W)
3. 70 mJ at 15 pps (1.50 W)
4. 80 mJ at 15 pps (1.60 W)

The operating time was limited to a maximum of 2 min. Depending on the size of the cavities, some of the teeth required further laser irradiation to achieve a caries-free status. Half of the carious lesion was irradiated by the laser beam while the other half was left untreated to allow a direct assessment of the amount of tissue removed.

Ground sections and demineralised sections were prepared from treated teeth, and included both treated and untreated parts on the same tooth. Demineralised sections were stained with two routine stains. These were Haematoxylin and Eosin (H&E) and van Gieson stains. The ground sections were examined under the light microscope (Leitz, Germany) under ×2.5 and ×6.3 magnifications while the demineralised sections were assessed under ×6.3, ×10 and ×40. The ground sections were then demounted and microradiographed for further microradiographic assessment using the technique described in detail in Section 2.2.5.

3.3.3 Results:

Assessments were made from both the ground and demineralised sections. H & E was used as a general stain, with van Gieson as a special stain to examine the degree of change to the collagen fibres.

a- Findings of the light microscopic assessment of prepared sections:

From the ground sections, the extent of caries removal was assessed. These indicated that, when compared with the untreated half of the tooth, carious material was completely removed, leaving only carbonised remnants on the cavity floor (Figure 3.1).

Examination of the stained, demineralised sections showed widespread invasion of the tissue by micro-organisms in the area directly below the carious surface of the cavity, accompanied by areas of altered collagen. However, this appearance was reduced considerably in the irradiated site of the carious dentine, with the major part of the carious tissue being removed completely. There were no major differences between the three different energy levels, although teeth treated with low energy still demonstrated occasional carious material remaining on the irradiated margins, even after several exposures. Teeth treated with the high power laser energy showed a continuous band of carbonised tissue adjacent to the irradiated surface. A yellow coloured band close to the surface of the irradiated dentine was noted in almost all the experimental teeth (Figure 3.2).

Figure 3.1: Microscopic view of the ground section of a sample tooth from the pilot study treated by laser power of 1.25 W (60 mJ at 15 pps), note the carbonised layer covering the surface of treated dentine (x6.3).

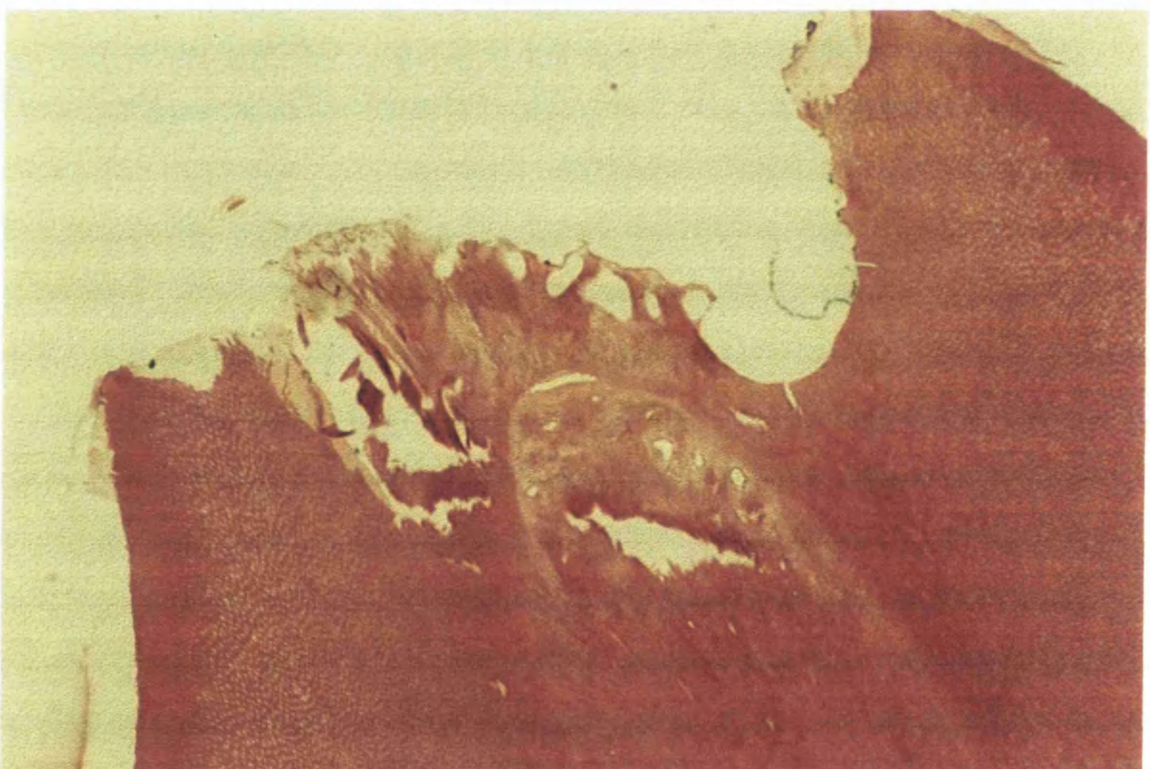


Figure 3.2: Demineralised section of the same tooth, demonstrating the alterations in the carious control site with a relatively normal dentinal structure at the irradiated site (van Giesen staining) (x6.3).

b- Microradiographic assessment:

The lased area was clearly defined on the microradiographic film (Figure 3.3), with the cavity borders (hole shaped) with untreated carious control site immediately adjacent to the irradiated area of the cavity. The laser-treated surface of the dentine did not show a similar appearance to the carious area, with the carious mass being quite clearly radiolucent when compared to the sound parts of the dentine. The opacity of the remaining dentine was relatively similar to the non-carious, sound dentine. Figure 3.3 illustrates a micro-radiographic view of a sectioned tooth treated by the laser energy of 1.25 W.

3.3.4 Discussion and conclusions:

Results of this preliminary investigation have shown the potential ability of the laser to remove carious dentine with all the powers tested, and a tendency to have a higher efficacy when the energy output is increased. However, the exposure time has played an important role in caries ablation. This is clearly seen in cases where caries was partially removed in short exposures. It would appear from this pilot study, however, that the high powers may have caused some damage to the sound, underlying dentine. In addition, there is also the possibility that such laser power could well be potentially hazardous to the vitality of the pulp. The microradiographic evaluation of the sections showed a higher opacity of the dentine at the irradiated site compared to the control site, similar to that of the sound, unaffected dentine. These findings confirmed the efficacy of laser in removing dentine caries and a further confirmation of the results obtained by examination of the related ground and demineralised sections. The laser's ability to remove dentine caries was shown to be directly related to the energy level employed.

It is difficult to suggest whether the changes observed at the remaining dentine at the floor of the cavity were caused by the carious process or as a result of the effect of the laser exposure. Since the carious process involves alteration of collage fibres by affecting the organic matrix of dentine, it is possible that the changes may have occurred prior to laser irradiation, and were caused, instead, by microbial products. To establish which was more likely, a second preliminary investigation was designed by assessing the effect of the laser on sound dentine of non-carious teeth employing similar power parameters.

3.4 Second preliminary experiment - Laser effect on sound non-carious dentine:

3.4.1 Introduction:

The aim of this part of the study was to assess the extent of any changes at the sound dentine surface when exposed to a similar range of laser energies as employed in the previous pilot experiment. The fourth laser energy was abandoned, since it was found to be destructive and clearly exceeded the safe limit for dentine.

3.4.2 Methods and materials:

Nine primary human extracted caries-free teeth, including canines and both first and second molars, were divided into three groups. Three energy levels were employed: 1 W, 1.25 W, and 1.5 W. The same protocol was employed for laser irradiation of the cavities as in the previous pilot test, following an access opening through the sound enamel and into dentine, if necessary, irradiating only one half of the cavities. Similarly, all teeth were examined using the same three methods of investigation, as discussed in Section 3.2.2.

3.4.3 Results:

Broadly, assessment of the teeth post-irradiation indicated no obvious clinical effect on the dentine surface when the first two powers were employed. However, the 1.5 W for 30 sec exposure was considered enough to initiate dehydration and carbonisation of sound dentine.

a- Findings of the microscopic assessment using ground sections:

Microscopic assessment of the ground sections revealed no obvious effect of the low and medium powers on dentine surface while a continuous layer of carbonisation was present at the surface of the treated site when the high power (1.5 W) was used. Figures 3.4 (a), 3.5 (a), and 3.6 (a) illustrates photomicrographs of the ground sections prepared from the sound specimens irradiated with each individual laser energies.

b- Findings of the assessment of demineralised sections:

Microscopic assessment of the demineralised sections, which had been prepared from the other half of each tooth, revealed no noticeable changes at either the dentine surface or deep to the lased areas, when the first two laser

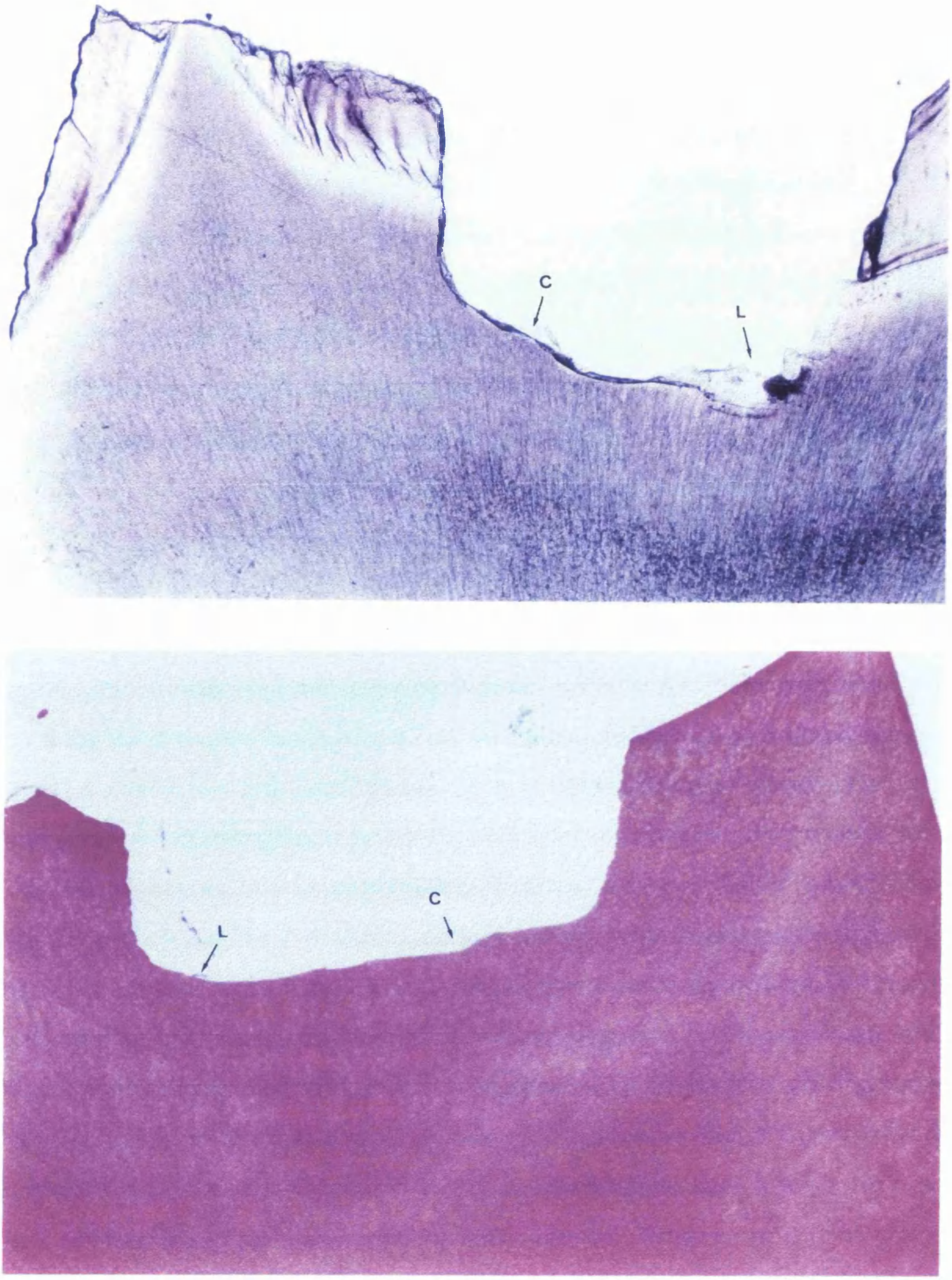
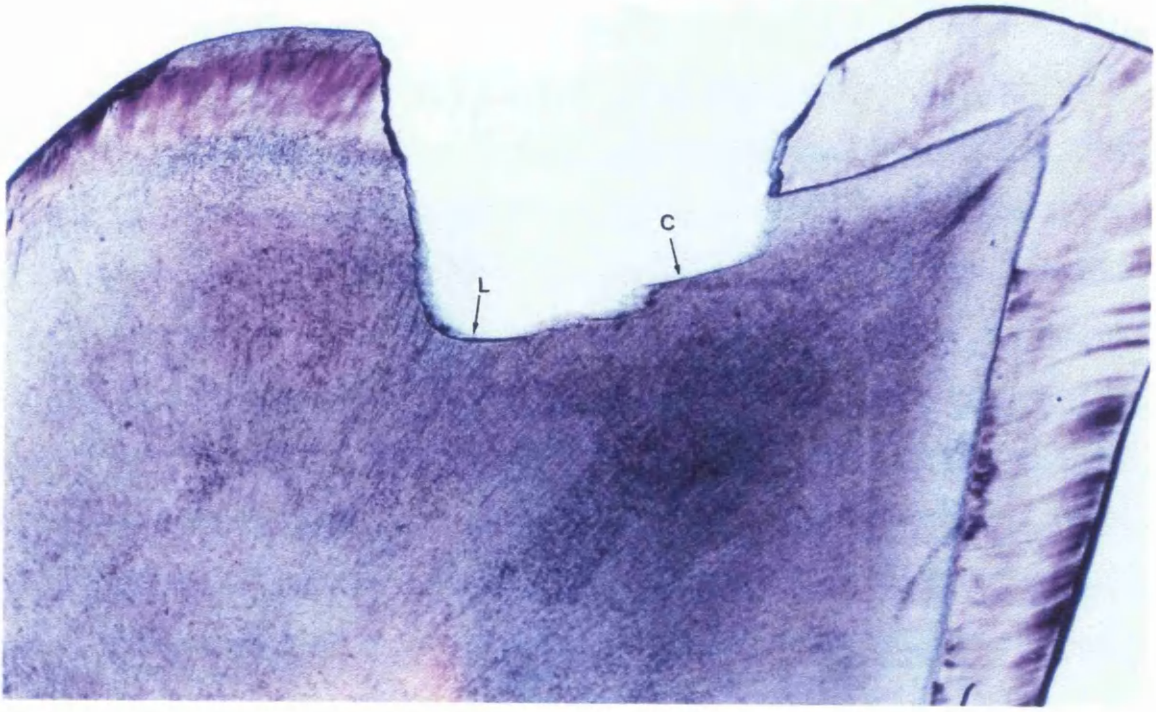


Figure 3.4: Illustrating the lased (L) and non-lased control (C) areas of sound dentine prepared from specimens irradiated with low power laser energy (1 W): **a.** Ground section (x6.3) **b.** Demineralised section of the same specimen (van Giesen staining, Mag. x10).



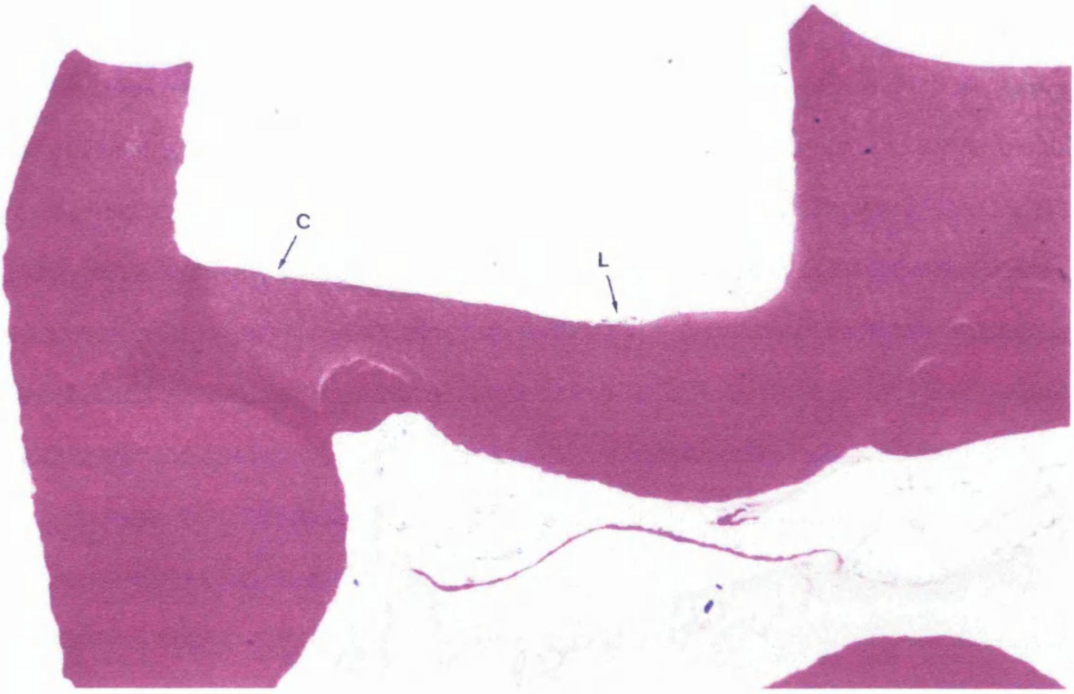


Figure 3.5: Illustrating the lased (L) and non-lased control (C) areas of sound dentine prepared from specimens irradiated with medium power laser energy (1.25 W): **a.** Ground section (x6.3) **b.** Demineralised section of the same specimen (VG staining, Mag. x10).

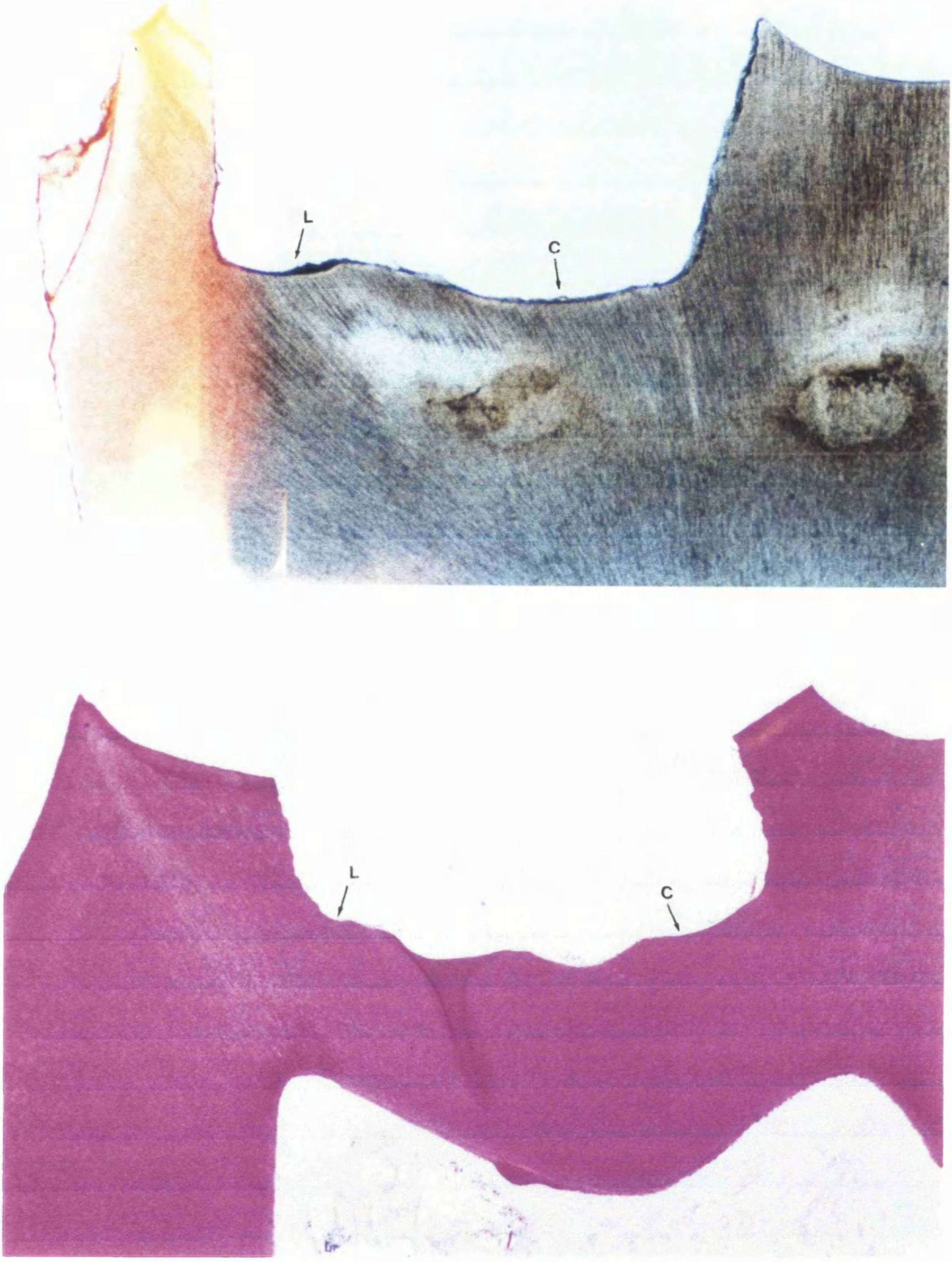


Figure 3.6: Illustrating the lased (L) and non lased control(C) areas of sound dentine prepared from specimens irradiated with low power laser energy (1.5 W): **a.** Ground section (x10) **b.** Demineralised section of the same specimen (VG staining, Mag. x10)

energies were employed. There was, however, a carbonised layer, which appeared to be detached from the surface using the higher power (1.5 W) laser energy. Both lased and non-lased halves of the prepared cavities showed a normal dentine structure with intact dentinal tubules. Examination of the van Gieson specimens showed no signs of collagen modification, as had been observed in the laser-treated carious dentine, seen as an amber band close to the surface. Figures 3.4 (b), 3.5 (b), 3.6 (b) illustrate photomicrographs of the demineralised sections prepared from the sound specimens irradiated with the different laser energies.

c- Microradiographic findings:

Microscopic assessment of the microradiographs of the laser irradiated sound teeth revealed no general pattern of change, appearing very similar to the untreated site in all three groups of teeth irradiated by the different laser energies (Figures 3.7 a,b,c).

d- Findings of the assessment of scanning electron microscopy:

SEM evaluation was carried out on these sound teeth in order to enable the assessment of any possible surface alteration that may have been caused by laser radiation. The SEM photomicrographs of the irradiated surfaces (Figures 3.8 a,b,c) revealed some degree of surface melting and occlusion of dentinal tubules when the highest laser power (1.5 W) was used.

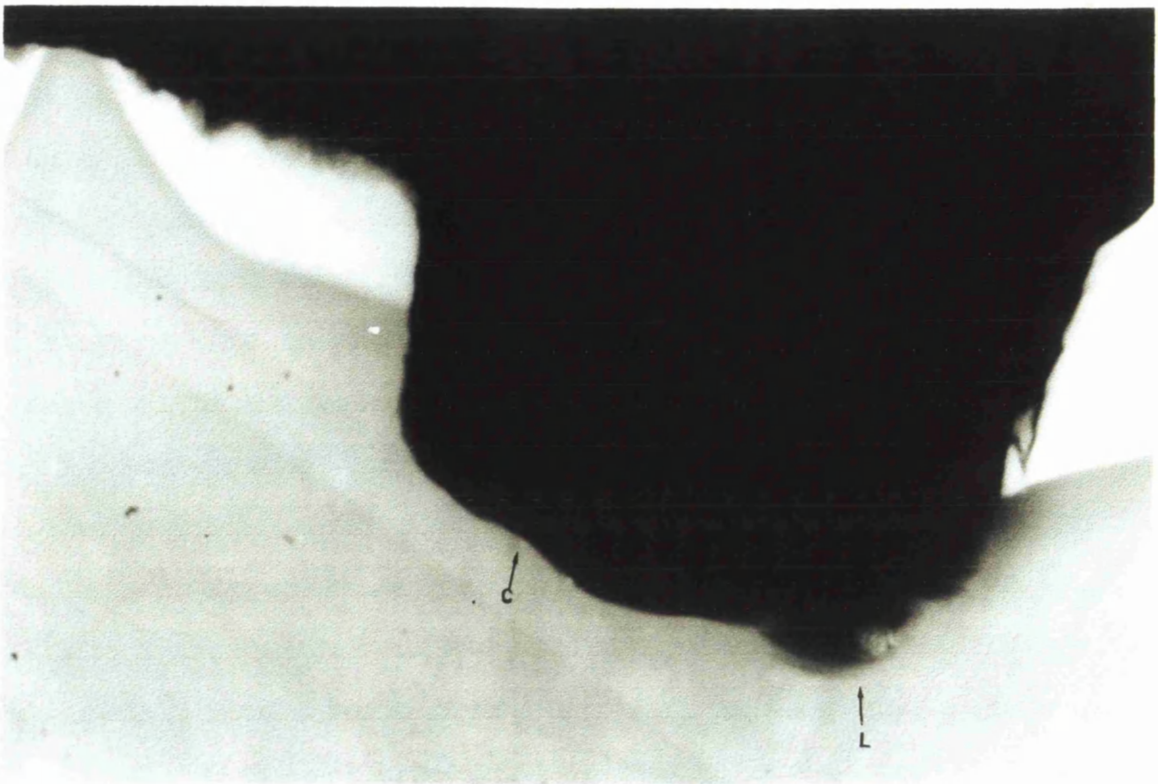


Figure 3.7 a: Microradiographs of the specimens as figures 3.4, illustrating the lased (L) and non-lased control (C) areas of sound dentine irradiated with low power laser energy (1 W) (x6.3).

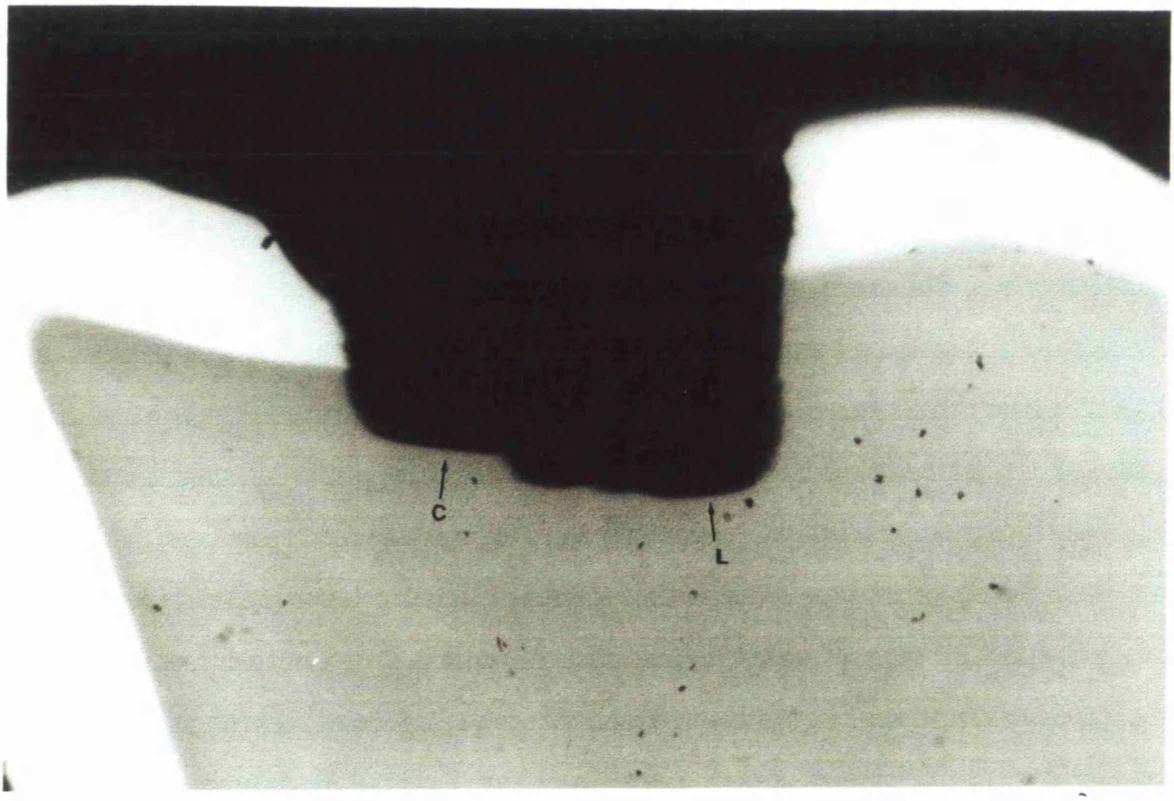


Figure 3.7 b: Microradiographs of the specimens as figures 3.5, illustrating the lased (L) and non-lased control (C) areas of sound dentine irradiated with medium power laser energy (1.25 W) (x6.3).

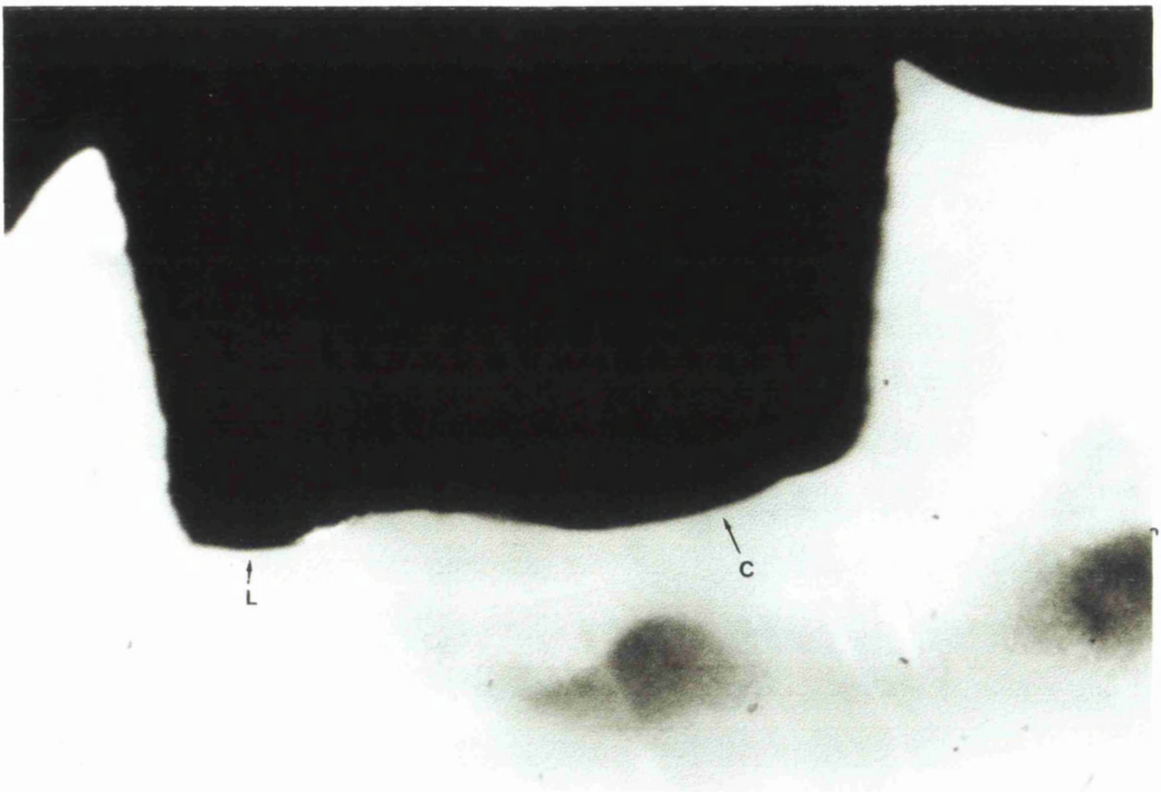


Figure 3.7 c: Microradiographs of the specimens as figure 3.6, illustrating the lased (L) and non-lased contrl (C) areas of sound dentine irradiated with high power laser energy (1.5 W) (x10).

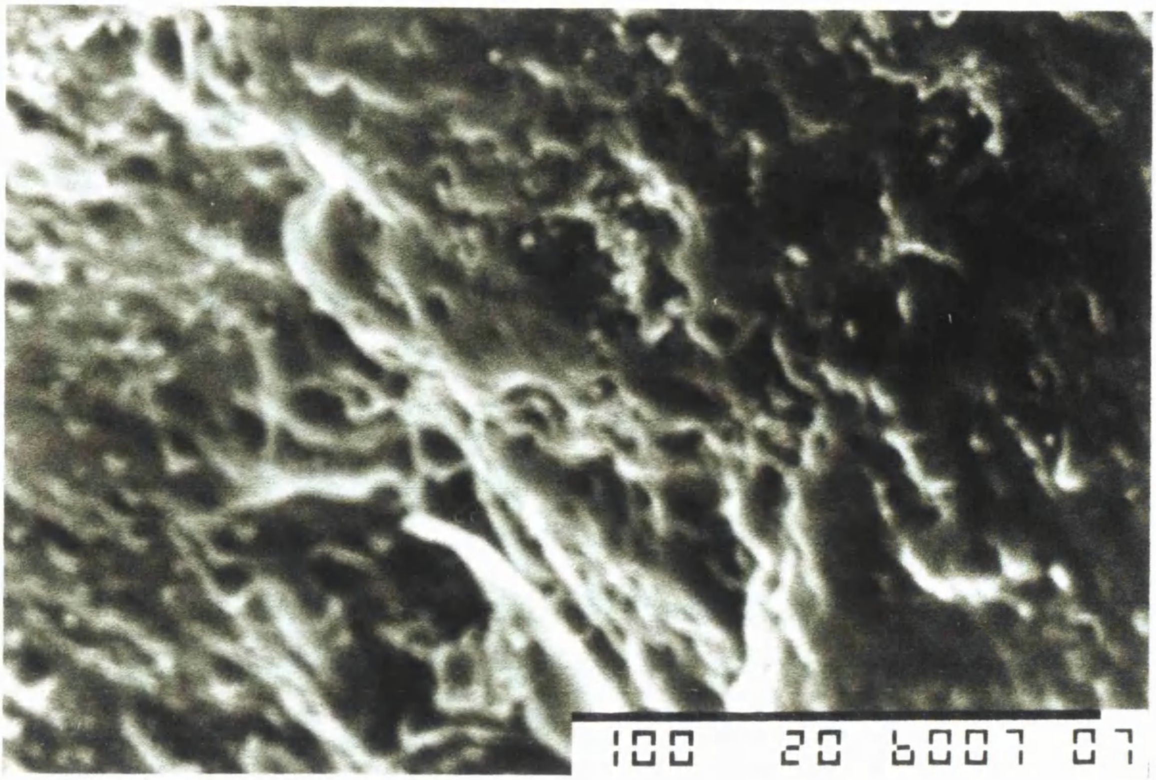


Figure 3.8a: SEM views of the specimens as figure 3.4, illustrating the lased area of sound dentine irradiated with: low power laser energy (1 W) (x270).

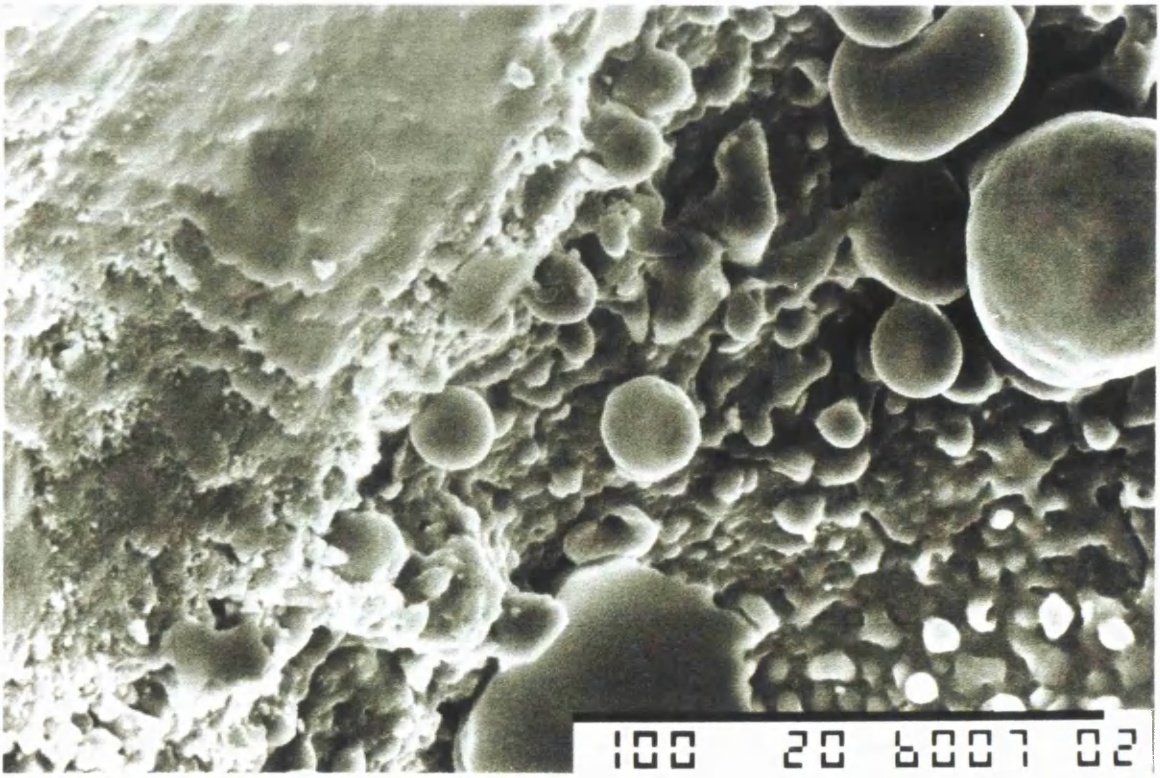


Figure 3.8b: SEM views of the specimens as figure 3.5, illustrating the lased area of sound dentine irradiated with medium power laser energy (1.25 W) (x270).

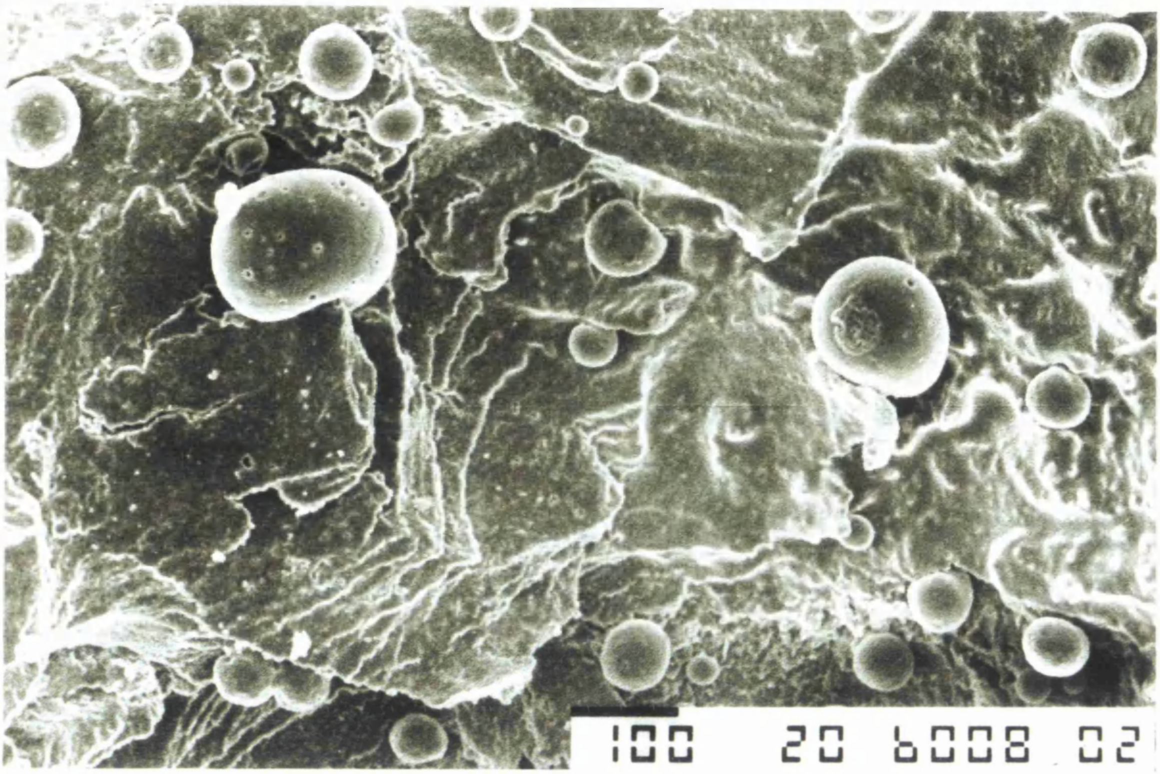


Figure 3.8c: SEM views of the specimens as figure 3.6, illustrating the lased area of sound dentine irradiated with high power laser energy (1.5 W) (x500).

3.4.4 Discussion and conclusion:

Results of this further pilot experiment revealed some degrees of thermal damage to the sound dentine surface following 30 sec laser exposure with a laser power of 1.5 W. The carbonised tissue was observed in teeth treated with the high energy level by all three methods of investigation. There were no obvious changes in the dentine irradiated by the other two lower laser energies.

Examination of the van Gieson-stained specimens showed no signs of the amber coloured band immediately below the prepared dentine surface, as was observed previously in the carious dentine cases. It may be concluded, therefore, that the affected layer of carious dentine was partially altered prior to laser exposure. However, in higher magnifications (×10 and x40), cases irradiated with the high power presented some degrees of staining at the superficial layers, with accompanying disruption at the dentine surface.

3.5 Principal study - Evaluation of the effect of laser energies on removing dentine caries:

The aim of this experiment was to assess in greater detail at both the dentinal surface and subsurface regions when irradiated by the three laser energies of 1, 1.25, and 1.5 W. Based on the results achieved from the first two preliminary experiments, these laser energies were concluded as being the most appropriate range of energies produced by this laser for the principal experiment.

3.5.1 Methods and materials:

3.5.1.1 Tooth preparation and assessment:

Thirty extracted human carious primary teeth were selected randomly, and included incisors, canines and molars. Teeth were placed into three groups based on their cavity size, as determined by clinical and radiographic assessment techniques described previously in Section 2.2.1. Each tooth was then mounted in modelling wax blocks as shown in figure 3.9 for safe and easy handling. Only half of the cavity was irradiated by the laser, leaving the other half untreated as control.

3.5.1.2 Laser parameters:

Three different power settings of 1 W (50 mJ 15 pps), 1.25 W (60 mJ 15 pps), 1.5 W (70 mJ 15 pps) were applied to the teeth, in a similar fashion to the pilot studies. Local Health and Safety rules were adhered to strictly, as detailed in Appendix A.

3.5.1.3 Caries removal protocol:

The laser was applied in a sweeping manner to the experimental half of the cavity, whilst the laser probe being held in close association to the tissue. Each episode of laser application did not exceed 30 sec, since this was recommended as being in the range of safe application for adjacent normal structures (White, Fagan and Goodis, 1994). The fibre tip was cleaved after each application (Figure 2.2), to achieve the desired radiation beam contrast.

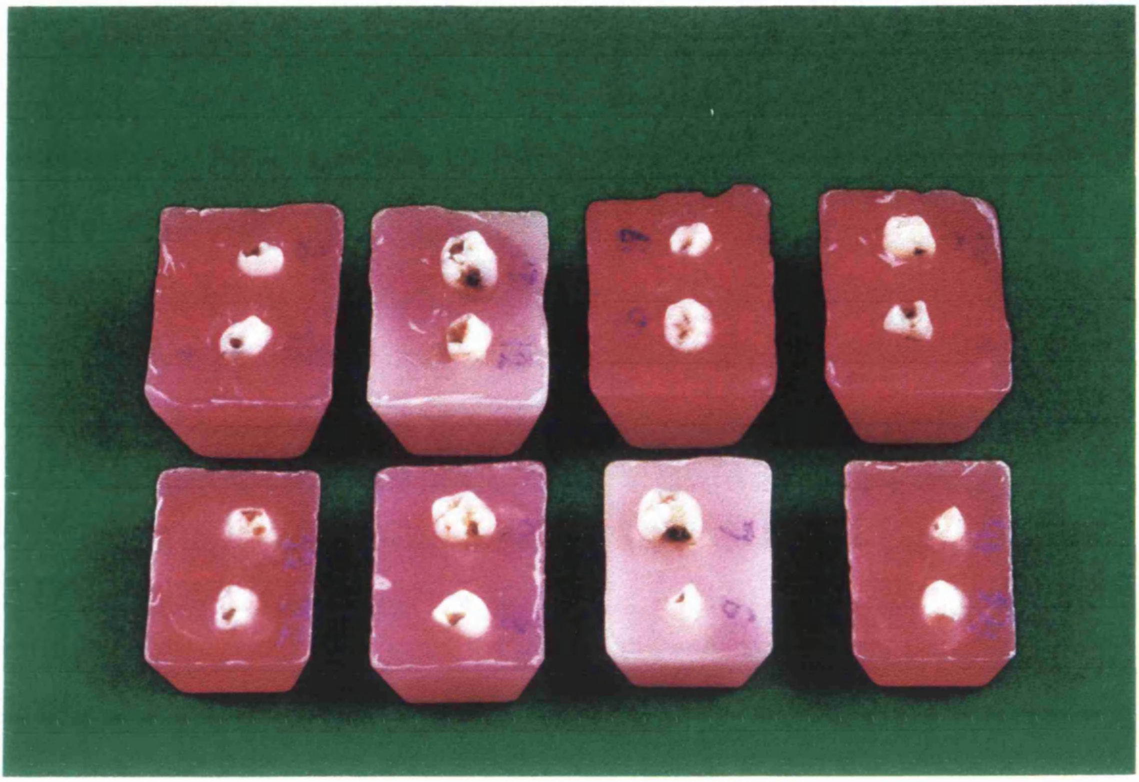


Figure 3.9: Experimental teeth were held in modelling wax during the cavity preparation stage as shown above.

3.5.1.4 Clinical assessment of the cavities pre and post operatively:

Clinical assessment of the cavities was carried out prior to the treatment, both by evaluation of radiographs, and a clinical judgement of the size of the cavities (Table 3.1) as detailed in Section 2.2.1. The anatomical tooth type was also recorded (Table 3.2). Assessment of the prepared cavities was performed using conventional tactile and visual criteria described in detail in Section 2.2.4. The time taken for each individual cavity preparation was recorded in seconds.

3.5.1.5 Ground section preparation:

Ground sections were prepared as described previously in Section 2.2.5. Sections were examined using a light microscope, to assess any differences between lased and unlased sites of the specimens, and between the three different power settings.

Ground sections were prepared from each specimen based on the technique described in Section 2.2.5. The thicknesses of the sections were then measured using a digital micrometer (Digimatic Indicator, Mitutoyo, Japan) (Figure 2.4), in three areas surrounding the floor and walls of the cavity in each section. Sections were subsequently ground to 150 μm thickness, using an aluminium oxide abrasive powder (White Bauxlite 2000, Honing abrasive, UK) (Figure 2.4). The thickness of each specimen was measured intermittently throughout the grinding procedure to avoid excessive tissue removal. Sample sections were then selected for microradiographic assessment using the

Table 3.1: The distribution of the number of teeth in each cavity class based on Black's classification of the cavities for both experiments.

Experiment		Cavity class I	II	III	IV	V
Different powers	No. of teeth	12	11	6	0	1
	percentage	40%	37%	20%	0	3%
Different cavity sizes	No. of teeth	6	18	5	0	1
	percentage	20%	60%	17%	0	3%

Table 3.2: The distribution of the number of teeth in each category based on their anatomical classification, for both experiments.

Experiment		Type of teeth A	B	C	D	E
Different powers	No. of teeth	1	1	3	16	9
	percentage	3.33%	3.33%	10%	53.33	30%
Different cavity sizes	No. of teeth	1	2	4	16	7
	percentage	3.33%	6.67%	13.33%	53.33%	23.33 %

Diffractus 582 (Enraf Nonius Delft, Holland) (Figure 2.7) with exposure settings set at 20 kV, 30 mA, and an exposure time of 20 min.

3.5.1.6 Demineralised section preparation:

The other half of each tooth was demineralised, using a similar procedure to that employed in the pilot experiments. This was carried out as follows:
Each specimen was fixed initially in phosphate buffered formalin (10%). The procedure was continued by decalcification of the specimens in a 20% formic acid for a period of 3 to 4 days for the primary teeth (This period was longer, up to a maximum of 7 days, for permanent teeth). The specimens where then radiographed using a modified laboratory x-ray machine (Philips, UK) to examine whether the decalcification process has been complete. This examination stage would also help to avoid over exposure of the tissue to the decalcification process, which may inadvertently cause damage to the specimen. A processor machine (Tissue Tek Vip 1000, Bayer Plc, UK) was employed to prepare the tissue for mounting in wax blocks for sectioning. The stages of tissue processing are given in detail in Appendix D.

Specimens were then sectioned using a microtome (Leitz 1512, Leitz GMBH, Austria) set on 5μ thickness. Sections were placed on microscope slides and stained immediately using two methods of staining, namely: 1. Haematoxyllin and Eosin (H&E) as a general purpose staining and 2. van Gieson (VG) specific for staining collagen fibres.

Since sectioned specimens may pull off the slide, subslides were used. Slides, for this purpose were placed on a rack (holds 25) and immersed in a strong commercial cleaning solution (i.e. Neodisher) overnight. The slides were removed from the cleansing solution after 12 hours and washed for another 12 hours in running water. This was followed by immersing the slides in distilled water for another 24 hours. Specimens were finally dried at 40 °C using a dust free rack. The subbing solution, 0.5% Gelatine in 0.05% Chrome Alum (Chromic Potassium Sulphate) was prepared as follows: Gelatine was first dissolved in a hot oven and then Alum added, allowed to cool, and then filtered into a Coplin Jar. At this stage, slides were dipped into the solution for 2 to 3 sec followed by wiping the back of the specimen with a paper towel to leave only one side covered. Finally, the specimen was allowed to dry in a dust free cabinet. Sections were then mounted on microscope slides using HSR mounting medium as described in detail in Section 2.2.1. The demineralised sections were then examined under a light microscope (Leitz, Switzerland) using objectives x6.3, x10, and x40 magnifications.

3.5.1.7 Method of preparation for microradiographic examination:

As described previously, sections were grounded to a thickness of between 145 to 165 microns. Thickness measurements were carried out on three points of dentine surrounding the cavity, approximately 1 mm distant from the cavity surfaces using an electronic micrometer (Digimatic indicator, Mitutoyo, Japan).

This measurement was repeated frequently, during the grinding process, to avoid excessive tissue removal.

Sections were then dried using a paper pad and placed between two layers of clingfilm. This prevented dehydration of the specimens and also permitted easier handling (Figure 2.7). The Clingfilm with the sections included were then placed over a piece of microradiographic film (Kodak, USA); this was then placed within the film holder and sealed (Figure 2.6). The film was subsequently exposed to x rays of 20 kV and 30 mA for 20 min. The films were then assessed under the light microscope with similar magnification to the ground sections.

3.5.1.8 Scanning Electron Microscopy:

Three treated teeth were selected from each group for SEM investigation. All specimens were immediately fixed after laser application in ice-cold 2.5% glutaraldehyde buffered in 0.1 M cacodylate, with a pH of 7.4 for a period of 2 hours. The specimens were then subjected to a dehydration procedure, initiated with a rinse through a 0.1 M sodium cacodylate buffer followed by the actual dehydration procedure using different degrees of ethyl alcohol, with gradually increasing concentrations. The procedure took about 7.5 days (33% for 4 hours, 50% for 4 hours, 67% for 12 hours, 95% for 48 hours and 100% for 72 hours). Lastly, specimens were immersed in hexamethyldisilazane for 36 hours. This procedure was followed by air drying for 24 hours.

The specimens were then mounted on aluminium stubs (Agar Scientific Ltd, UK) using a conductive carbon cement (Leit C, TAAB Laboratories Equipment Ltd, UK). At this stage, each specimen was individually subjected to sputter coating (Polaron E 5000, UK), by placing the specimen inside a vacuum chamber. An Argon beam, which is electrochemically neutral with a lesser chance of interrupting the gold coating procedure, was aimed at the specimen, while the chamber was still pumping down to the desired vacuum level. A thin film of gold was placed on the surface of the specimen after it was evaporated from its source, at a voltage of 1.2 kV. for a period of 5 min.

Specimens were examined under the scanning electron microscope (Jeol T-300 SEM, UK), at an accelerating voltage of 30 kV. Photomicrographs of the all specimens were taken at the following magnifications: x35, x250, and x500 using Kodak TP 120 film type 6415 (Kodak Ltd., UK).

3.5.2 Results:

3.5.2.1 Findings of the clinical assessment of prepared cavities:

Clinical examination of the teeth treated with different laser energies demonstrated varying degree of carbonisation at the irradiated site of the cavities in all three groups. Clinical signs of tissue ablation were noticed slightly later than the actual start point of the irradiation when low energy was employed. This was followed by shrinkage of the superficial layer of carious tissue without smoke production. Further irradiation of the tissue caused a burning reaction associated with ablation of carious tissue. The ablation process was started much quicker in the other two groups treated by medium and high powers.

The mean time recorded for individual groups of teeth with different laser energy densities demonstrated a direct relationship between the level of laser energy and the time required to achieve a caries free cavity. The higher the level of laser energy, the quicker the process of caries ablation. Clinical evaluation of the treated dentine surface by the power of 1.5 W exposure revealed generalised charring and carbonisation appearances at the irradiated dentine surface. Application of the low power (1 W) revealed initial shrinkage of the irradiated tissue followed by eventual ablation. The laser appeared to produce a crater by removing carious tissue, leaving sound dentine covered with products of evaporation and carbonisation.

- Time taken for a complete caries removal:

Caries removal required a shorter exposure time (mean = 93 sec ± 49) in cases treated with the high power, compared with the other two energy settings. In this respect, those cases treated by the low power laser energy still required a longer period of exposure to achieve a caries-free cavity (mean = 137 sec ± 70) than those treated by the medium power (mean = 130 sec ± 47). Figure 3.10 demonstrates the relationships between the laser power and the time taken to complete caries removal process, and figure 3.11 represents the

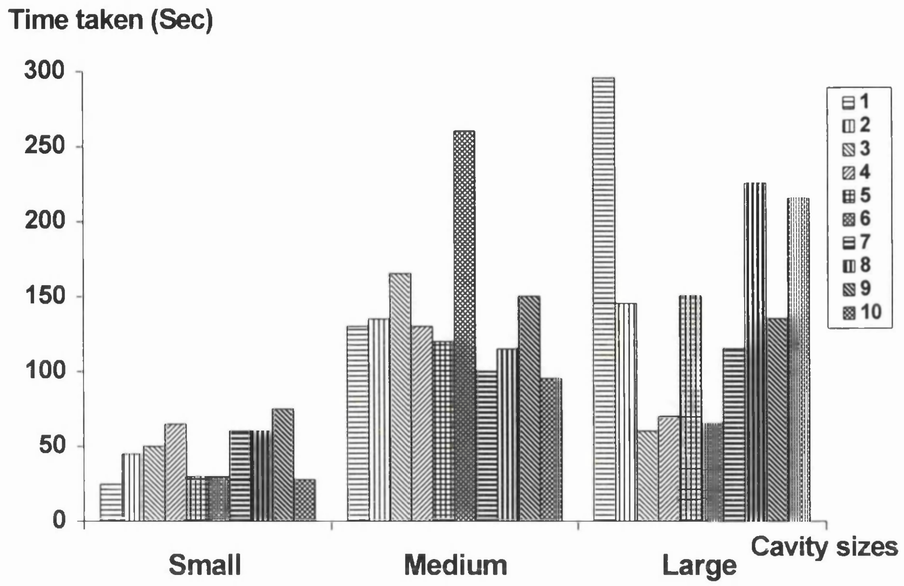


Figure 3.10: The length of time taken to achieve caries free cavities in three groups of cavities,(Bars indicate individual teeth).

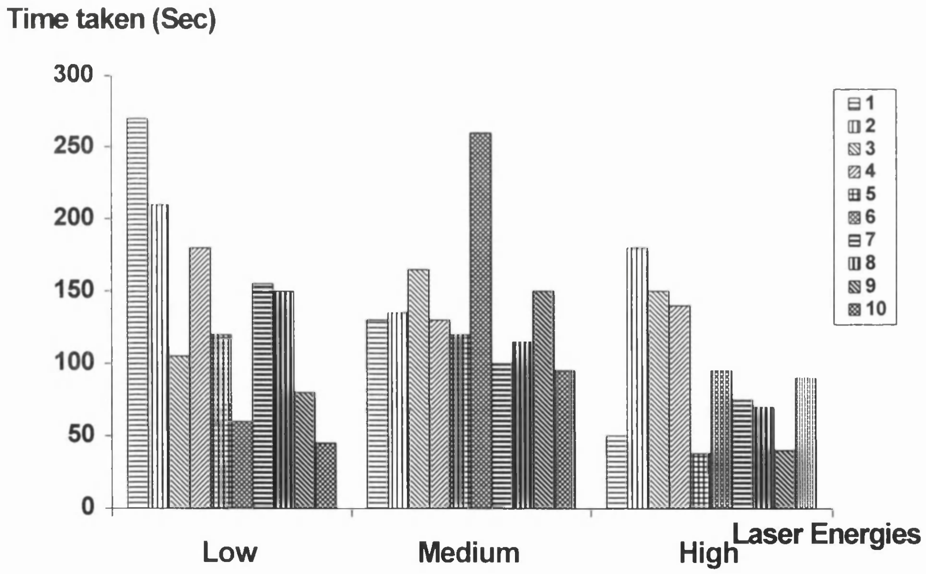


Figure 3.11: The length of time taken to achieve caries free cavities in three groups of teeth are presented using different levels of laser energy, (Bars indicate individual teeth).

sum of the time taken to achieve caries-free cavities in the three different cavity size groups.

A One-way ANOVA test was carried out to examine whether there was any significant difference between the time taken by the three different laser energies for ablation of carious tissue. Findings of this comparison showed that there was no significant differences (p=0.128) between the length of time required to achieve a caries-free cavity using these different laser powers (Table 3.3). A similar test was carried out between the three groups of teeth with different size cavities while they have been all treated by medium power (1.25 W). The result of this comparison indicated a highly significant difference (p=0.000) between the three groups of teeth for the time required to remove all caries (Table 3.4).

3.5.2.2 Light microscopic assessment:

a- Microscopic assessment of the prepared ground sections:

The ground sections were examined under the light microscope, using x2.5 and x6.3 magnification. Varying degrees of caries removal success were demonstrated in teeth treated by the low power laser energy. This included a few cases where the remaining carious tissue was seen to be associated with a superficial carbonised layer, covering the remaining carious tissue. Complete caries removal was observed in those specimens exposed to the high power (1.5 W), again with some degree of carbonisation close to the prepared floor of the cavities. The group treated with the medium power also demonstrated

Table 3.3: The mean value time recorded to achieve caries free cavities when three different laser energies were used, with the result of a One-way ANOVA test on their differences.

Different Laser powers	No. of teeth	Mean time taken (sec), (SD)	p	F
1	10	137.5 ± 70.17	0.128	2.22
2	10	140 ± 47.14		
3	10	92.80 ± 48.96		

SD= Standard Deviation

Laser Powers:
1= Low (1.00 W),
2= Medium (1.25 W),
3= High (1.50 w)

Table 3.4: The mean value time recorded to achieve caries free cavities in three different cavity sizes scored clinically with the result of a One-way ANOVA test on their differences (Medium power laser energy).

Cavity size	No. of teeth	Mean time taken (sec), SD	p	F
1	10	46.80 ± 17.89	0.000	11.05
2	10	140 ± 47.14		
3	10	147.5 ± 77.47		

SD= Standard Deviation

Cavity sizes:
1= Small,
2= Medium,
3= Large

complete caries removal, with the presence of some carbonised tissue close to the surface of the irradiated dentine.

Figures 3.12 (a), 3.13 (a), 3.14 (a) are photomicrographs of ground sections of the teeth treated by the three different energy settings. Of note, is the degree of tissue removal in the lowest power and the level of carbonisation produced in the highest power.

b- Results of microscopic examination of demineralised section:

Haematoxylin and Eosin staining is routinely used for general purpose illustration of organic material. Micro-organisms were present in some of the specimens of this study, which were disclosed by the H&E staining method. The extent to which they had invaded the dentinal tubules could be estimated using these sections (Figures 3.12 b, 3.13 b, 3.14 b).

Two distinct halves of the cavities were clearly defined through the examination of the demineralised sections, which corresponded well with the ground sections. The crater produced by laser irradiation adjacent to the carious half of the cavity was obvious by its characteristic punched-out appearance. The remaining dentine under the lased area was relatively normal with comparable structural features to the sound areas of dentine. The pattern of dentinal tubules and collagen fibres of the irradiated sites represented a normal appearance when compared to the non-lased carious area (Figure 3.13 b).

The presence of invaded micro-organisms associated with massive destruction of the dentinal structure in the controlled, untreated carious half of the cavity is clearly demonstrated in figure 3.12 (b). Occasional particles and bundles of disrupted collagen fibres were still present at the irradiated site of the teeth treated by the low power, which appeared similar to features of the remaining carious dentine at the control site. In comparison, no such structural pattern was found in dentine of the irradiated surface in teeth treated by either medium or high powers. Micro-organisms were not present in the dentine remaining at the irradiated site, treated by the medium and high powers.

Examination of the van Gieson-stained sections showed a band, amber in colour, close to the surface of the irradiated site in all three groups of teeth irradiated by different laser energies. The presence of altered collagen, an indication of remaining carious tissue, was clearly visible in these sections at the irradiated site of teeth treated with the low power laser energy (Figure 3.12 b). An apparently intact collagen structure was present at the laser irradiated site of dentine in those teeth treated with the medium power (Figure 3.13 b). The presence of the amber coloured tissue close to the irradiated surface of dentine was observed in sections of most of the specimens irradiated by the high power (Figure 3.14 b).

Massive destruction of the collagen matrix of the control carious site can be seen in all specimens. Enlargement of intertubular spaces on the carious mass left at the control half of the cavity may be explained by the effect of acid produced by the micro-organisms within these targeted dentinal tubules. Colonisation and multiplication of these micro-organisms involved in the process of dentine destruction during caries development can be seen clearly in figure 3.15 (a,b).

c- Microradiographic findings of the prepared sections:

The level of radio-opacity on the lased dentine was considerably higher when compared to that of the carious tissue at the control site from an assessment of the microradiographic films. The level of opacity of the remaining dentine at the lased area was found to be close to the opacity of sound, unaffected dentine. The carious lesion (Figure 3.16 a,b,c) appeared to exhibit a higher degree of radiolucency when compared with the sound dentine. This radiolucency reduced gradually closer to sound underlying dentine. Some defused radiolucent areas were found at the irradiated site of the dentine irradiated by the low power (Figure 3.16 a). However, this appearance was not found in the other two groups of teeth treated with the medium and high powers. The remaining dentine surface was found to be radiographically similar to the sound, unaffected part of the dentine.

3.5.2.3 Scanning electron microscopy:

The SEMs indicated that there was variation between the appearances produced at the dentine surfaces irradiated by the different laser energies. The presence of recrystalised, melted material on the surface of all three groups indicated degrees of effect and surface temperature. Examination of those

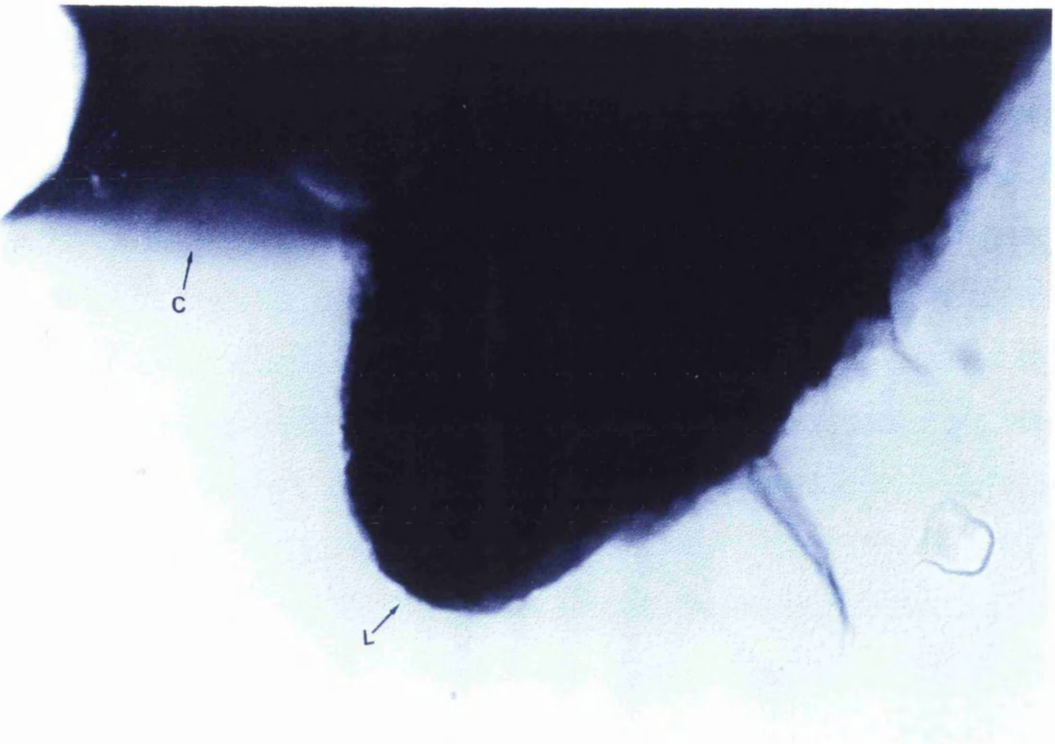


Figure 3.16a: Illustrating the microradiographic view of the specimen as figure 3.12, note the lased (L) and non-lased control (C) areas of the specimen irradiated with low power laser energy (1 W) (x10).

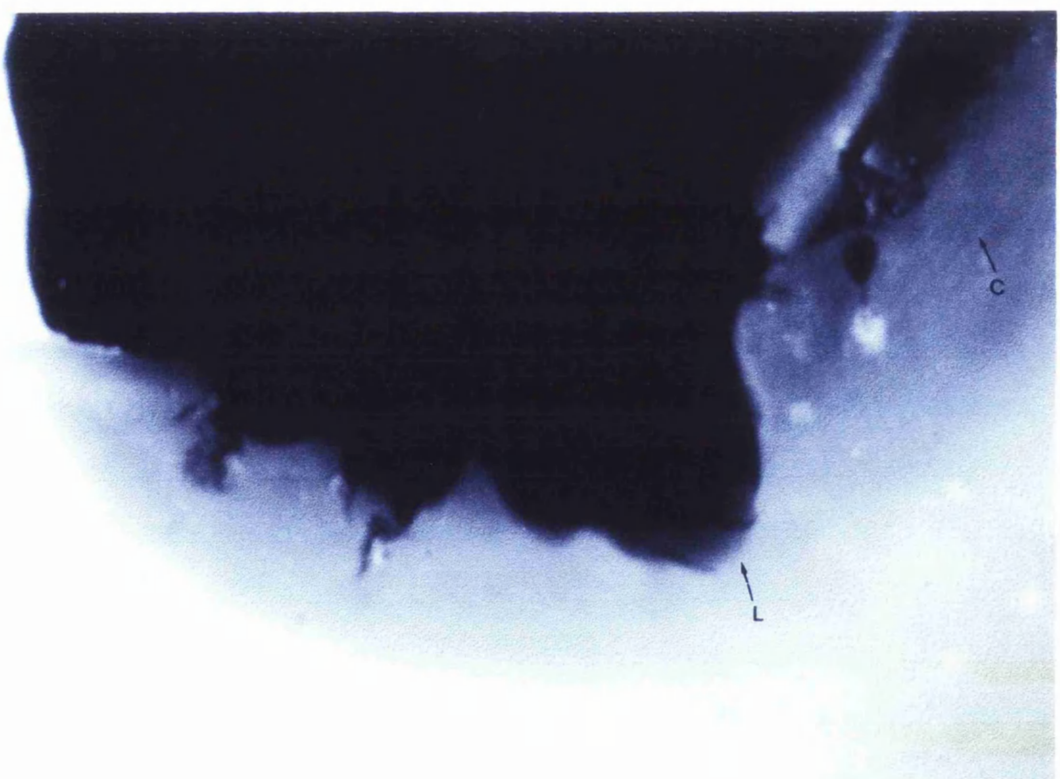


Figure 3.16b: Illustrating the microradiographic view of the specimen as figure 3.13, note the lased (L) and non-lased control (C) areas of the specimen irradiated with medium power laser energy (1.25 W) (x10).

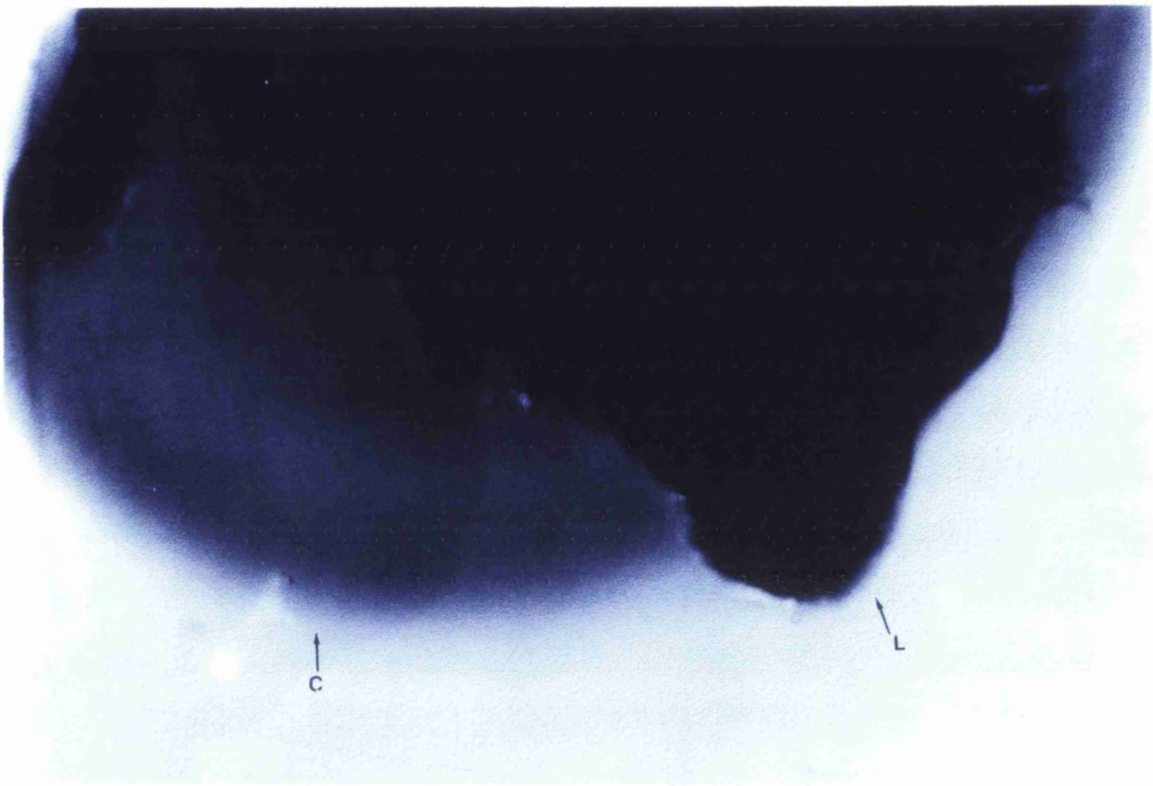


Figure 3.16c: Illustrating the microradiographic view of the specimen as figure 3.14, note the lased (L) and non-lased control (C) areas of the specimen irradiated with high power laser energy (1.5 W) (x10).

teeth treated with the high power revealed the presence of a higher level of melting material, which covered almost all the irradiated dentine surface. In the case of those samples treated with the high laser energy, large globules of resolidified melted material were seen to occlude the openings of the dentinal tubules. The extent of this coverage was reduced in specimens exposed to the lower powers, having areas with open dentinal tubules and gaps present between the droplets of resolidified materials. Figure 3.17a is an SEM view of the carious site of the same sample as figure 3.17b. Figures 3.17 b,c,d are photomicrographs of the SEM observations from the dentine surfaces prepared with the three different laser energies (x500).

It is clear, therefore, that specimens exposed to all three laser energies produced varying levels of caries removal, with some degree of accompanying recrystalisation. There were more open dentinal tubules in cases treated with the medium power, indicating a lower temperature rise at the surface with less melted products. Cracks observed on the specimens were due to the preparation procedure as these were found to be present in all the specimens.

3.5.3 Discussion:

Removing carious tissue selectively, whilst leaving adjacent sound dentine undamaged is the major goal of any caries-removal technique. With the Nd:YAG laser, the energy output and the exposure time dictate the laser's effect on dentine. Before this instrument may be used clinically, both its safety and efficacy have to be assured.

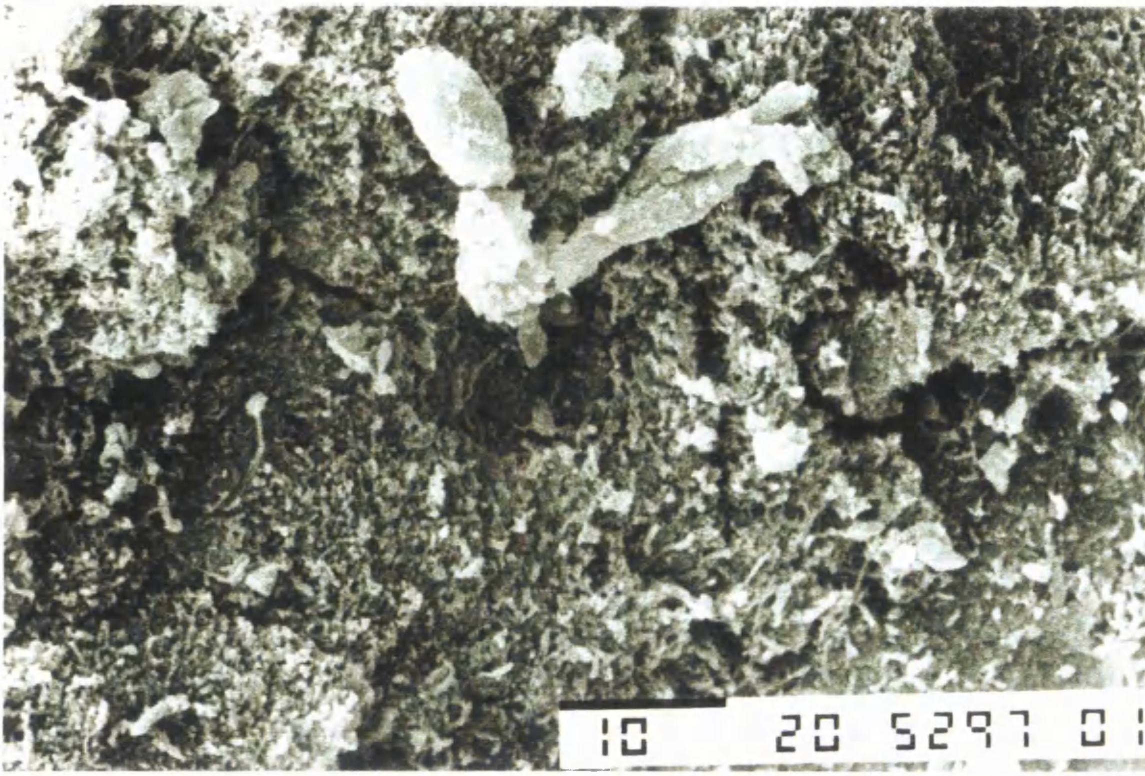


Figure 3.17a: SEM view of the carious lesion from the specimen as figure 3.12 (x500).

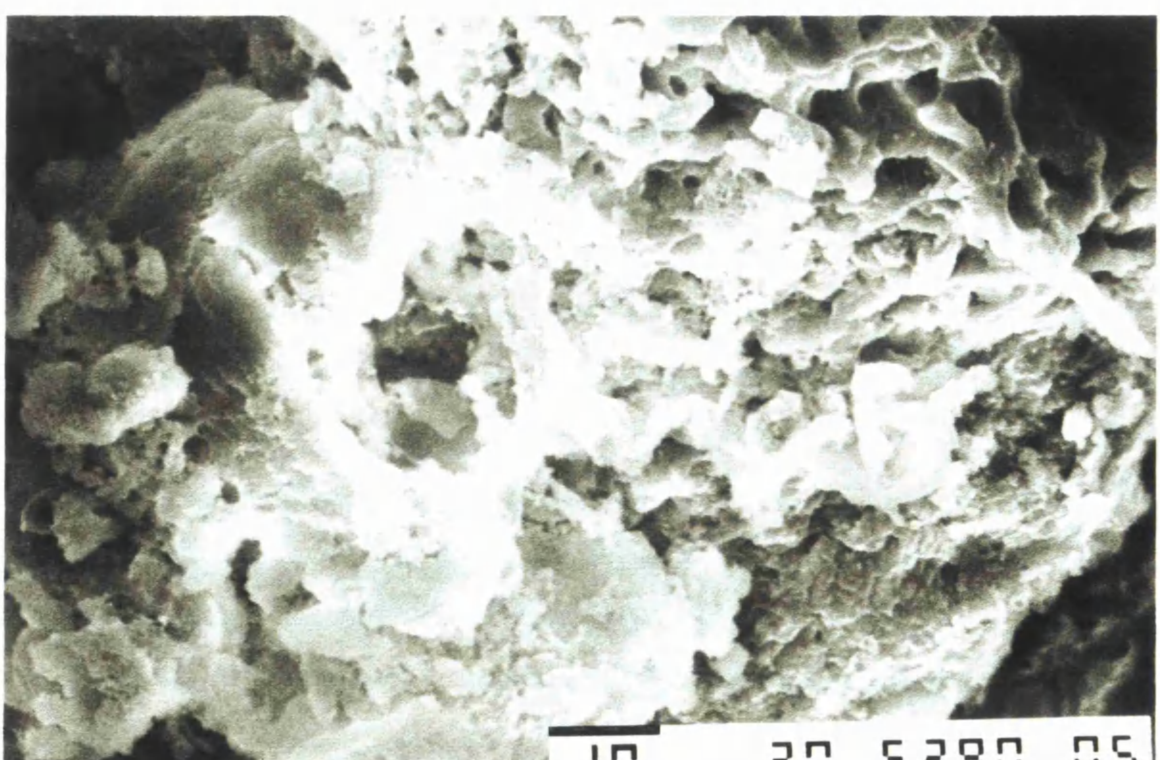


Figure 3.17b: SEM views of the specimen as figure 3.12, illustrating the lased area of sound dentine irradiated with low power laser energy (1 W) (x500),

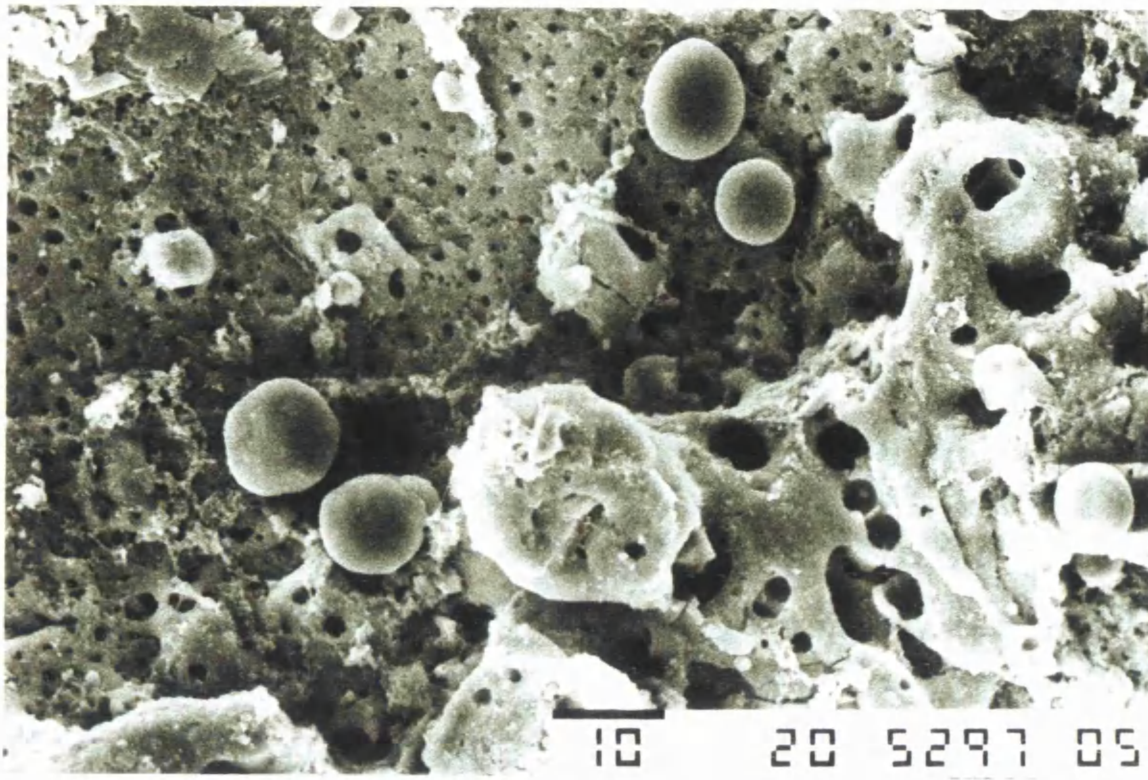


Figure 3.17c: SEM views of the specimens as figure 3.13, illustrating the lased area of sound dentine irradiated with low power laser energy (1.25 W) (x500).

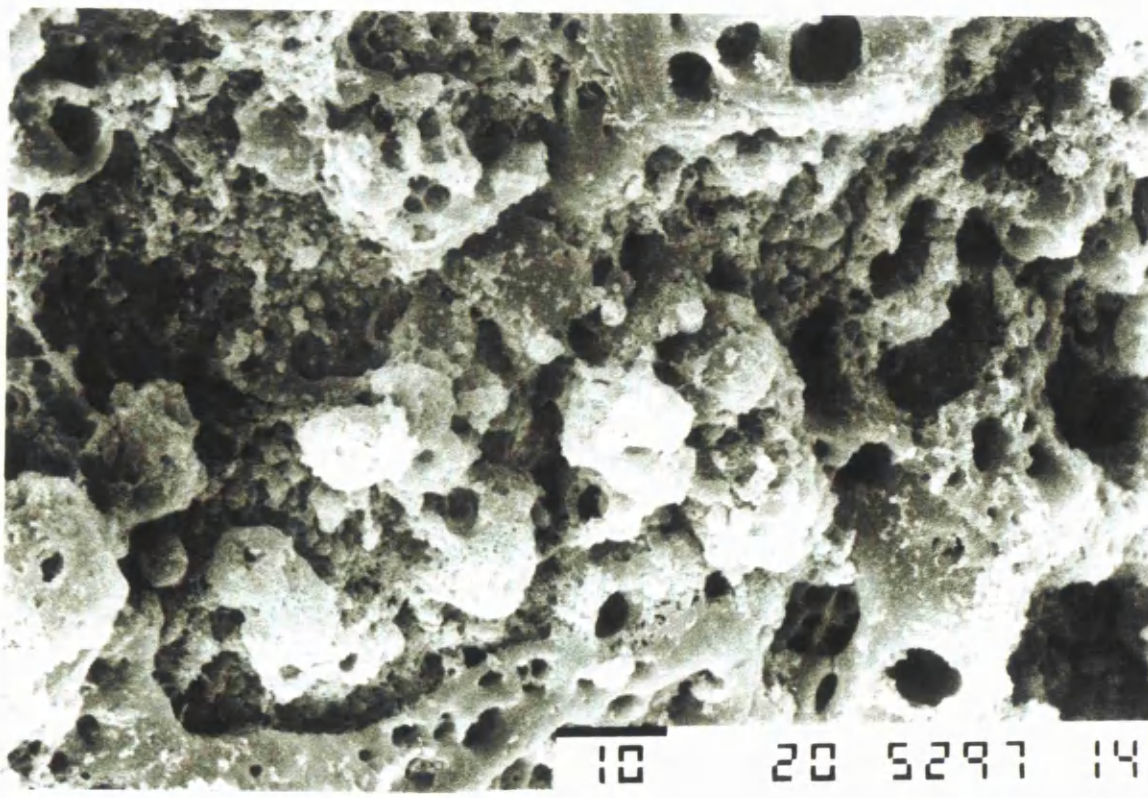


Figure 3.17d: SEM views of the specimens as figure 3.14, illustrating the lased area of sound dentine irradiated with high power laser energy (1.5 W) (x500).

In this study, the lowest power (1 W) appeared to be unable to remove carious tissue effectively. However, the teeth treated by the high power (1.5 W), demonstrated complete caries removal, with an accompanying thick layer of carbonised tissue at the prepared surface of dentine. It is not easy to assess whether sound dentine has also been removed merely from the clinical appearance of the specimens. When the ground sections were viewed, however, the interface between the carious and sound tissue, could be viewed (Figures 3.12 a, 3.13 a, 3.14 a). These indicated that the higher power had been quite effective in removing carious tissue as well as having uncontrolled ablation effect on the underlying sound dentine.

Varying degrees of caries removal were observed in microscopic examination of the ground sections, with a lower caries removal efficacy of the lowest laser energy tested in this experiment. This was demonstrated by the presence of some remaining carious tissue, even after several laser applications. Examination of the prepared sections from the treated teeth with the other two laser energies, revealed complete efficacy of the medium and high powers which was shown by the absence of any remaining carious tissue at the irradiated site of the treated teeth.

The presence of the carbonised layer at the surface of almost all specimens treated with the high power was quite remarkable, when compared with those specimens treated with the medium power. The medium power produced a caries-free surface with only occasional elements of carbonised tissues on the treated surface. The result of a single laser exposure on sound dentine for 30 sec, discussed earlier in Section 3.3.3, indicated that only the high power produced charring of the dentine. In this respect, Koort and Frentzen (1992) stated that the production of a carbonised layer at the operating surface may increase the absorption level of the laser energy which in turn causes an increase in its cutting effect with the production of higher temperature rises, leading to unwanted side effects.

Microradiographic evaluation of the teeth treated in this experiment showed a similar opacity at the irradiated site of the treated cavities in both medium and high powers. This opacity was comparable to that of sound, unaffected dentine. It was also noted that sections of the irradiated cases by the low power laser energy had some degree of radiolucency at the irradiated site indicating the presence of remaining carious tissue. This investigation did not show any increased radiodensity of the dentine surface reported earlier (Kantola, 1973), presumably the result of deposition of condensed, resolidified material at the irradiated surface. This is due, probably, to the laser's inability to produce resolidification and recrystalisation as such when using the energy levels tested in this study.

The stained demineralised sections showed some interesting features. On the van Gieson stained specimens, a basophilic yellow band covering the lased half of the sections was considered as being a representation of the thermal side-effect of the laser on the remaining dentine surface. This was not confirmed, however, when the laser was exposed to sound, non-carious teeth. It was concluded that this appearance was due, in part, to the layer of carious dentine that is not soft, but is partially decalcified.

SEMs of the three different powers showed a remarkable difference in the level of coverage at the surface of irradiated dentine by melted products. This was probably the result of the degree of temperature rise at the surface produced by the three laser energies. A higher degree of covering of the surface was achieved as a result of higher melting production when the specimens were exposed to the high power when compared to the other two powers. Surface melting did occur in both the other laser powers, but not to the same degree. Interestingly, there was no smear layer present at the lased area of the cavity, as is commonly seen in the case of mechanical cavity preparation using a conventional bur. This could perhaps be due to the lack of any physical contact with the surface of the dentine. In some of the cases it was noted that the low power laser energy used in this experiment may only cause melting of the superficial carious tissue, without ablating. This layer may then become resolidified at the superficial aspect of the carious mass, giving a false sensation of complete caries removal on probing the irradiated surface.

Cracks observed on the SEM specimens were due to the preparation procedure and not because of the laser, since they were seen to extend over the entire tooth and were even seen in non-lased areas. This conclusion has been confirmed by other work carried out within this laboratory (Radvar *et al.*, 1995).

3.5.4 Conclusions:

1. The optimal laser power for effective caries removal was found to be 1.25 W.
2. This power also produced a lower level of damage to the sound dentine.
3. The prepared dentine surface did not have a smear layer, but was covered to a considerable extent with melted products.
4. The length of time required for complete caries removal was not significantly different ($p= 0.128$) between the three powers tested in this study, but there was a significant difference ($p<0.001$) between the time required for the completion of caries removal in different cavity sizes.

Further investigation is required to assess if this surface would effect the bond strength at the interface of tooth/restoration using adhesive restorative materials and it is this question which forms the basis of Chapter 5.

CHAPTER IV

PULP TEMPERATURE CHANGES FOLLOWING LASER/DRILL CARIES REMOVAL

CHAPTER 4: Temperature changes at the pulpodentinal junction during laser/drill caries removal

4.1 Introduction

The potentially harmful effects of heat on dentine and the dental pulp in vital teeth during restorative procedures are well known, and precautions such as water-cooled handpieces are routinely employed in clinical practice. Heat generated at the superficial layers of the tissue is usually transmitted to the deeper tissues. The speed of this process is dependent on the thermal conductivity of the tissue. In the case of dental hard tissues, heat generated at the surface of enamel or dentine following routine cutting procedures passes through the bulk of dentine to the pulp (Taylor, Shklar and Roebor, 1965) and concern relating to heat transfer has been expressed ever since lasers were introduced as a means of removing carious tissue (Adrian, Bernier and Sprague, 1971). It has been suggested that measuring the temperature by using the time-temperature relationship can be used to identify possible changes within the dental pulp (Fanibunda, 1986).

4.2 Current techniques for the assessment of the dental pulp sensitivity:

4.2.1 Clinical pulpal sensitivity techniques:

There are several techniques used currently for the assessment of the pulp. These include: 1. Thermal test, 2. Electric pulp test, 3. Laser doppler flowmetery, 4. Soft tissue examination, 5. Radiographic examination. The pulp's response to thermal stimuli, such as cold (ethyl chloride) or hot (heated gutta perchae) are commonly used pre-operatively to indicate the pulpal condition. Electric pulp testing has also been used, although there has been concern as to its reliability (Fuss *et al.,* 1986). The concept of assessing pulpal blood flow is a relatively new method and involves measuring the speed of blood flow passing through the pulp (Aars *et al.,* 1993).

The indications for a cavity test as a means of assessing sensitivity are strictly only before the placement of a restoration, and where caries is involved. Finally, radiographic assessment of the surrounding structure of the tooth is considered a complementary aid to the assessment of the condition of the pulp and is used mainly when there is severe damage to the pulp, as in pulpal necrosis.

4.2.2 Laboratory assessment techniques of the dental pulp pathology:

4.2.2.1 Pulp histology assessment:

Clearly, histological examination of the pulp is the most reliable technique for the evaluation of the pulp cells following any stimuli, including restorative procedures. Unfortunately, the tooth requires to be extracted before this method can be employed. To avoid any changes in the pulp condition, this examination should be carried out immediately after the completion of the procedure. Like any other method of pulp assessment, pulp histology has limitations including: lack of reproducibility, not being quantitative, and only applicable to clinical conditions. In this respect, measurement of the temperature within the pulpodentinal complex can be used as an indicator of events happening within the pulp (Beveridge and Brown, 1965; Van Hassel and Brown, 1969).

4.2.2.2 Measurement of the pulp temperature rise:

There have been several studies which have evaluated the level of pulpal damage following routine restorative dental procedures which resulted in an increase in pulpal temperature (Smail *et al.,* 1988; Goodis, White and Watanabe, 1991; Hansen and Assmusen, 1993). Although the measurement of pulpal temperature is unable to indicate serious damage to the pulp, it can indicate the risks and possible injuries which may occur. Like other restorative procedures, laser irradiation of the tooth will produce heat within the tissue and may well effect the pulp.

The critical threshold for pulpal temperature rise has been suggested as 5.6 °C. A rise of this level is thought to initiate a pulpal reaction (Zach and Cohen, 1965), whilst a temperature rise of 8.3 °C is thought to cause irreversible changes (Shoji, Nakamura and Horiuchi, 1985). There were no indications given in those studies as to the duration of the temperature rise. In contrast, destruction of odontoblasts and oedema after 24 hours with healing of the lesions 2 months later with the formation of irregular dentine has been reported following a rise in pulp temperature caused by the application of a hot metal probe (Lisanti and Zander, 1952).

4.3 Methods of assessing temperature changes of the pulp

A range of equipment has been used for assessing the level of temperature changes of the dental pulp during routine restorative procedures. These include: 1. thermocouple wire (Goodis *et al.,* 1989) 2. thermistor (Neiburger and Miserendino, 1988) 3. photothermal camera (Marchesini *et al.,* 1985) 4. infrared camera (Anic *et al.,* 1993), 5. digital thermometer (Anic *et al.,* 1993), and 6. Thermovision (Arima and Matsumoto, 1993). Of these techniques, the thermocouple wire has been used most commonly (Goodis *et al.,* 1989; Anderson and van Praagh, 1942).

4.4 Common causes for pulp temperature changes:

During routine dental procedures, heat is produced either by physical frictional forces, particularly in dry conditions, or following the absorption of light from either a polymerising light unit or a laser beam. Temperature rises of the pulp has been investigated both *in vitro* and *in vivo* to estimate the level of damage to the pulpal structure (Marchesini *et al.,* 1985; Goodis *et al.,* 1993; Miserendino *et al.,* 1993).

4.4.1 Pulp temperature rise during conventional cavity preparation:

Excessive heat, produced by the cutting action of the drill, is more likely to occur when sound, healthy tissues are being removed to provide, for example, mechanical retention (Anderson and van Praagh, 1942). The amount of pulp temperature rise during conventional caries removal will depend on: 1. the sharpness of the bur, 2. proximity of the cavity to the pulp, 3. The use of air/water coolants, 4. Pressure applied to the bur during cutting procedure (Walsh and Symmons, 1949; Peyton, 1955; Peyton, 1958; Hudson and Sweeney, 1954). A temperature rise of 10 °C has been reported within the pulp after 1 min of continuous dry drilling of dentine without the use of a coolant (Goodis, Schein and Stauffer, 1988). A sharp decline in pulp temperature was reported as soon as the cutting procedure stopped, for about 2 min with a gradual decline thereafter (Goodis, Schein and Stauffer, 1988).

During conventional drilling, inner tooth temperatures of 5.8 °C and 10.5 °C at the pulpo-dentinal junction and dentino-enamel junction respectively have been recorded in the absence of a coolant, while temperature drops have been reported when air or water coolants have been used during conventional cavity preparation (Goodis, Schein and Stauffer, 1988). Temperature changes resulting from conventional operative procedures have been reported as within the tolerated limit of the pulp and are, therefore, considered as safe (Lisanti and Zander, 1952; Lefkowitz, Robinson and Postle, 1958).

4.4.2 Pulp temperature rise during light curing the restorative materials

Polymerisation of light activated restorative dental materials causes a rise in temperature of the material which in turn, will be conducted to the rest of the tooth. This temperature rise is due to both exothermic reaction processes and the absorption of energy during irradiation (McCabe, 1985; Lloyd, Joski and McGlynn, 1986; Masutani *et al.*, 1988). Heat produced in the dental pulp during the application of a curing light can be as high as 12.1 °C after 30 sec, which would be potentially damaging to the pulp (Smail *et al.,* 1988).

Different light sources cause varying degrees of temperature rise at the dental pulp (Hansen and Asmussen, 1993; Goodis *et al.,* 1993). The highest temperature rise of the pulp was reported as 4.8 °C after 60 sec light exposure of the tooth using a Fiber-lite machine (Dolan-Jenner Industries, Rochester, NH) (Goodis *et al.,* 1989). The shade and colour of the restorative material may also influence the degree of temperature rise, with darker shades tending to take longer to set. In addition, the time required for full setting of the material has been shown to be a major factor in the production of heat (McCabe, 1989; Watts, Amer and Combe, 1984). The thickness of the material will also dictate both the exposure time of the irradiation and, therefore, the temperature rise within the bulk of the material (Lloyd, Joski and McGlynn, 1986). However there remains a possibility for pulpal damage with the present polymerising light sources as the temperature produced could be sufficient to affect pulp vitality (Strang *et al.,* 1988; Goodis *et al.,* 1989).

4.4.3 Laser irradiation and the pulp temperature changes:

Laser energy, either pulsed or continuous, will produce different levels of heat with a higher temperature being produced when continuous wave lasers are applied and, therefore, with a higher potential to cause pulpal damage (Serebro *et al.,* 1987; Miserendino *et al.,* 1989; Jeffrey *et al.,* 1990). In a pulsed system, the beam energy is high, but since it is intermittent, less heat is produced

(Lanzafame *et al.,* 1988). In pulsed lasers, the total heat energy produced within the irradiated tissue is calculated as the sum of the energies of the pulses. The temperature distribution, therefore, depends on both the energy level and the number of pulses (Hibst and Keller, 1990).

The Nd:YAG laser beam is described as being able to be transmitted through enamel and dentine and into the pulp, as a result of the low absorption coefficients of these structures. This was thought to cause an increase in the level of heat near the pulp (Launay *et al.,* 1987). Also, the deposition of charred debris during laser application (as witnessed in Chapter 3) has been reported to reduce the temperature rise within the pulp (Marchesini *et al.,* 1985). The use of an air flow for removing smoke and debris from the irradiated area, has been shown to cause a slight reduction in heat production (Marchesini *et al.,* 1985).

4.5 Factors influencing temperature rise of the pulp during laser irradiation:

Several factors are believed to influence the accuracy of temperature measurements within the dental pulp. One of those factors is clearly the presence of pulpal tissue during the measurement. There have been few *in vivo* trials assessing the level of changes within a vital pulp (Schuchard and Watkins, 1961; Zach and Cohen, 1962; Bhaskar and Lilly, 1965; Carlton and Dorman, 1969). Apart from the ethical issue, measurement of a vital pulp is not recommended, as the tissue itself will prevent the thermocouple tip to come into proper contact with the pulpal wall of the dentine (Goodis, Schein and Stauffer, 1988b).

The extent of a thermal effect of laser irradiation on different dental structures is dependent on the absorption coefficient of the tissue, thermal diffusivity, and thermal expansion of the target tissue. Of these factors, the absorption coefficient of the irradiated material is considered to be a major factor influencing the extent of temperature rise (Lobene, Bhussry and Fine, 1968). Dental tissues, which are heterogeneous in structure, react differently to thermal stimuli (Lobene, Bhussry and Fine, 1968). Light intensity distribution has also been suggested as being responsible, in part, for temperature rises of the irradiated tissue (Marchecini *et al.,* 1985).

The remaining dentine thickness and the length of the laser exposure will determine the level of temperature rise within the dental pulp. Since frequent laser irradiation is believed to cause substantial temperature rise, due to summation of the energies (Jeffrey *et al.,* 1990).

In conclusion, the exposure time, as well as the energy delivered to the tooth are considered major factors which will influence pulpal response to laser irradiation. The clinical application of pulsed lasers has been advocated as more reliable than the continuous wave lasers. The thickness of the remaining dentine at the floor of the cavity will also have an influence on the degree of temperature rise.

4.6 Suggested techniques for pulp protection from thermal damages:

Like other dental cutting instruments, some of the laser manufacturers have also supplied their products with a cooling system (Launey *et al.,* 1987). The use of an air/water spray, has been shown to reduce effectively the heat produced within the dental tissues and, therefore, reduces the possibility of thermal damage to the vital pulp (Miserendino *et al.,* 1993).

4.7 Lasers and pulp histology:

Different lasers will have varying effects on the pulp. For example, the first generation laser, the Ruby laser (over 2 kJ/cm^2), has been shown to cause coagulative necrosis of the pulp following caries removal (Adrian, Bemier and Sprague, 1971), while controlled energies of a pulsed neodymium laser, up to 6.5 KJ/Cm^2, was reported as causing no thermal damage to the pulp (Adrian, 1977).

4.7.1 CO_2 laser and pulp histology:

Coagulative necrosis was reported as a consequence of the high temperature rise caused by direct irradiation of the pulp, using a CO_2 laser (Shoji, Nakamura and Horiuchi, 1985). New dentine formation was detected on the pulpal wall of the dentine adjacent to the irradiated area when a CO_2 laser radiation of less than 20 W for maximum of 0.5 sec was used. No cellular deformity of the pulp tissue one month after laser irradiation was detected (Serebro *et al.,* 1987).

4.7.2 Nd:YAG and pulp histology:

Shoji and Horiuchi (1989) described the effects of Nd:YAG laser irradiation of 5.0 W for 0.3 sec on the pulp. These were described as mild dilatation of vessels with some calcified tissue formation 4 weeks after laser irradiation. However, temperature rise of the pulp following laser irradiation of enamel, using an Nd:YAG laser of 1-3 W for 12 sec, was considered high enough to cause localised pulpal inflammation with possible irreversible damage, occurring only at the site of irradiation (von Fraunhofer and Allen, 1993). Bahcall *et al.* (1993) reported that irradiation of dog's teeth with a pulsed Nd:YAG laser beam (100 mJ at 10 pps for 30 sec), caused acute haemolytic changes of the pulp 24 hours after laser irradiation. However, a return to normality was reported 15 to 30 days later.

It can be concluded that short laser exposures, with controlled energy levels may cause only localised changes in the pulp and that these changes are reversible and will return to normal a month after treatment.

4.8 Aims and Objectives

The aims of this experiment were:

1. To evaluate the influence of the remaining dentine thickness between the floor of the cavity and the roof of the pulp on temperature rises of the pulp.
2. To assess the level of temperature rise at the pulpodentinal junction following laser irradiation of the dentine caries using an *in vitro* model.

3. To assess the level of temperature rise at the pulpodentinal junction following conventional caries removal.
4. To estimate the degree of temperature rise at the pulpodentinal junction following the application of a curing light before and after caries removal.

4.9 The effect of thickness of dentine slices on temperature reading - A preliminary investigation:

4.9.1 Introduction:

A preliminary investigation was carried out initially, to assess the influence of dentine thickness, using dentine slices, on the amount of heat produced and transferred through varying thicknesses of tissue.

4.9.2 Methods and Materials:

Dentine slices with a thickness of 1 mm, 2 mm, 3 mm from both primary and permanent teeth were prepared using a LabCut 1010 hard tissue microtome (Agar Scientific Ltd, UK). The thickness of all prepared sections was measured using an electronic micrometer (Digimatic Indicator, Mitutoyo, Japan) to ensure reproducibility of specimen thickness. Those specimens which were excessively thick were hand lapped to reduce the thickness of the specimens to the desired level. This technique was described in detail in Section 2.2.5.

Prepared specimens were stored in 0.12% thymol. A Polymerising blue light (Aristolite, Germany) was used to measure the differences of temperature rise of the dentine surface at the opposite side to that which was irradiated. A

Copper / Copper / Nickel thermocouple wire (type T, RS Components Ltd, UK) was employed for these measurements (Figure 4.1). The fibre tip of the polymerising unit was in direct contact with the tooth surface .

The exposure time for all experimental teeth was 60 sec, and the irradiation was carried out while the tip of the thermocouple was in contact with the other side of the dentine slab. Temperature rises were recorded for each group of dentine specimens using a digital thermometer (Comark Electronics Ltd, UK) and a chart recorder (Bryans Southern Instruments, Mitcham, England). Figure 4.2 illustrates the temperature measurement set up.

4.9.3 Results:

There were varying degrees of temperatures recorded at the dentine surface which were primarily based on the thickness of the slabs. The lowest temperature was recorded with the 3 mm thick specimens (3.8 °C for the case of dentine slice of permanent teeth and 1.75 °C for dentine slice of primary teeth). However, the rise in temperature recorded from the 1 mm thick dentine slices was slightly higher in the permanent teeth (4.5 °C), this change was quite obvious when the curing light passed through the dentine slice of 1 mm from a primary tooth (6.25 °C). Table 4.1 demonstrates the mean temperature values recorded for the 3 dentine specimens, with the different thickness of slices, for both primary and permanent teeth.

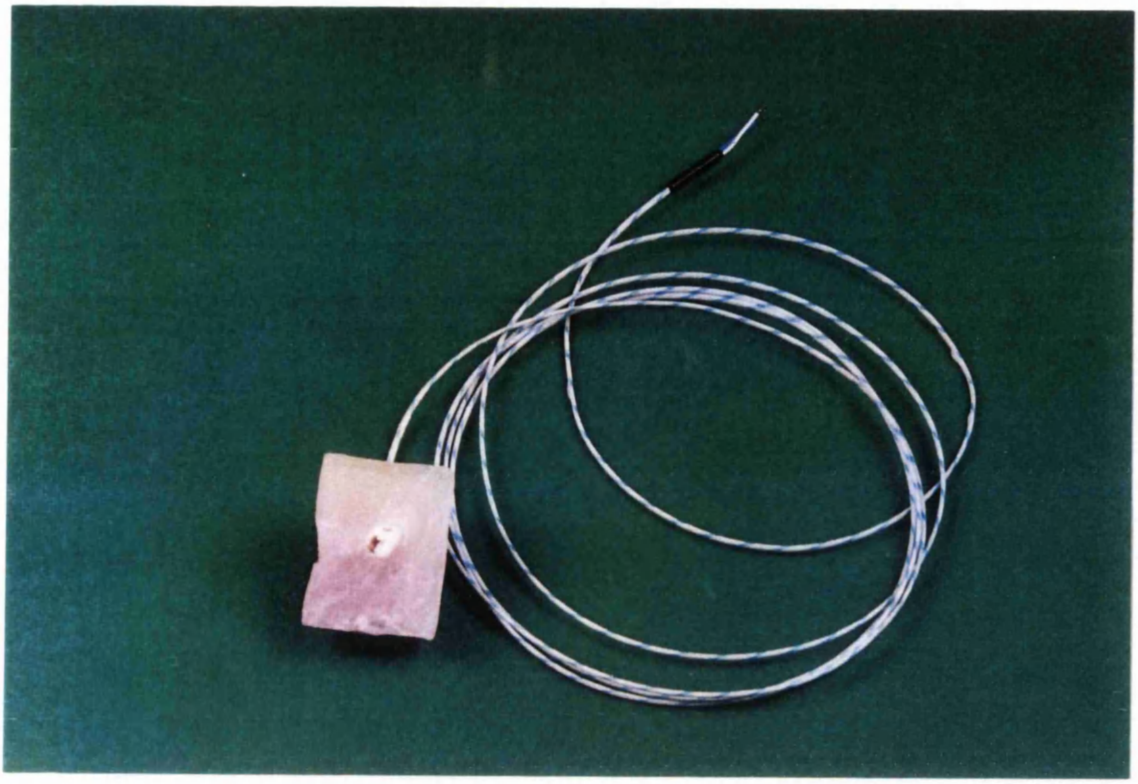


Figure 4.1: The thermocouple wire used in this experiment for measuring the temperature changes at the PDJ is illustrated while it is inserted into the pulp of a deciduous molar, fixed in a wax block.

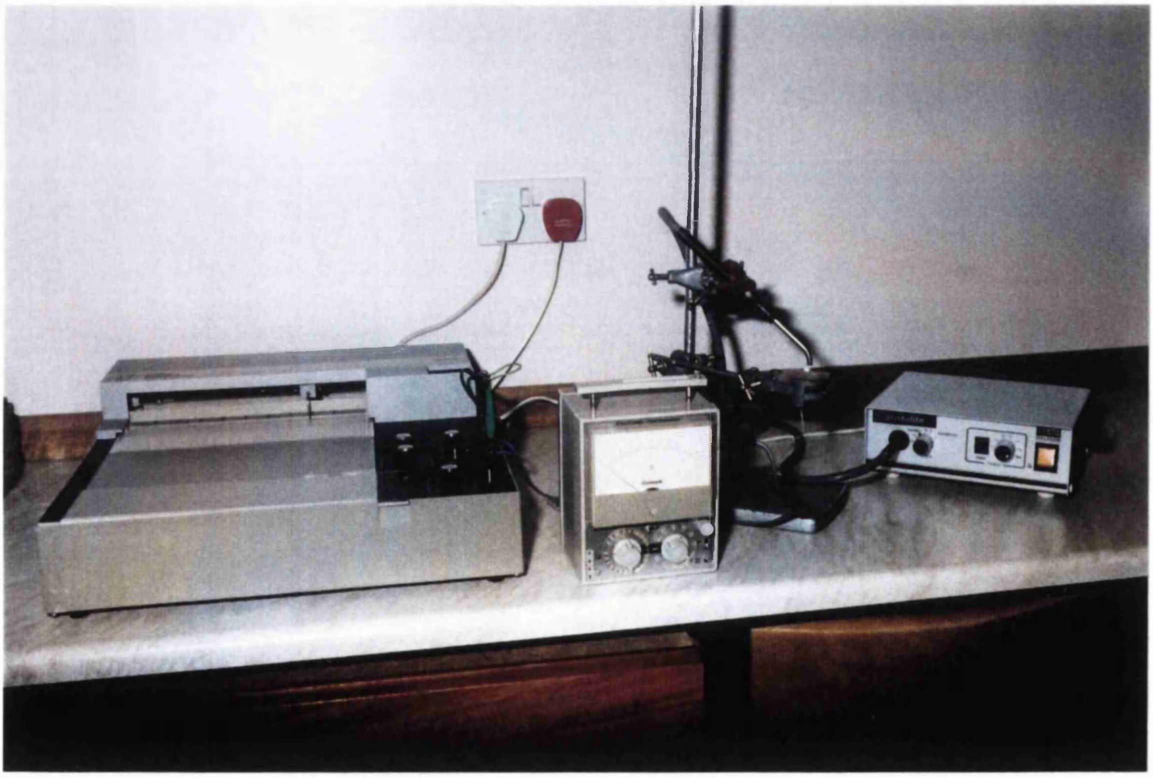


Figure 4.2: Illustrates the temperature measurement set up with chart recorder (left), electrical thermometer (middle), the curing light source (right) and the specimen on laboratory stand.

Table 4.1: Mean peak temperature rises recorded following the PBL application on dentine slices with different thickness, from both primary and permanent teeth.

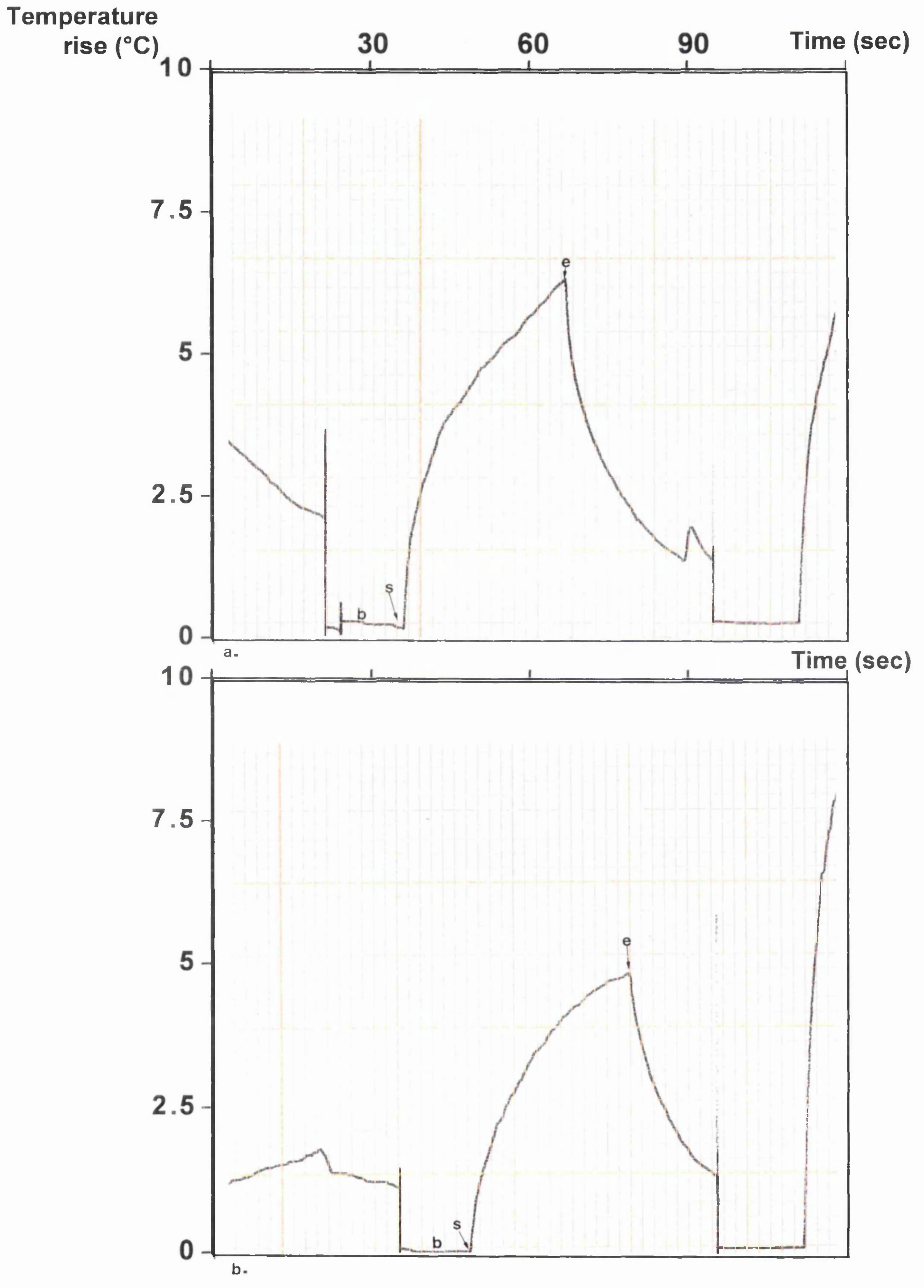
Type of the sliced dentine	thickness of dentine slices		
	1 mm	2 mm	3 mm
Primary	6 °C	2.5 °C	1.8 °C
Permanent	4.5 °C	5 °C	3.8 °C

PBL = Polymerising Blue Light

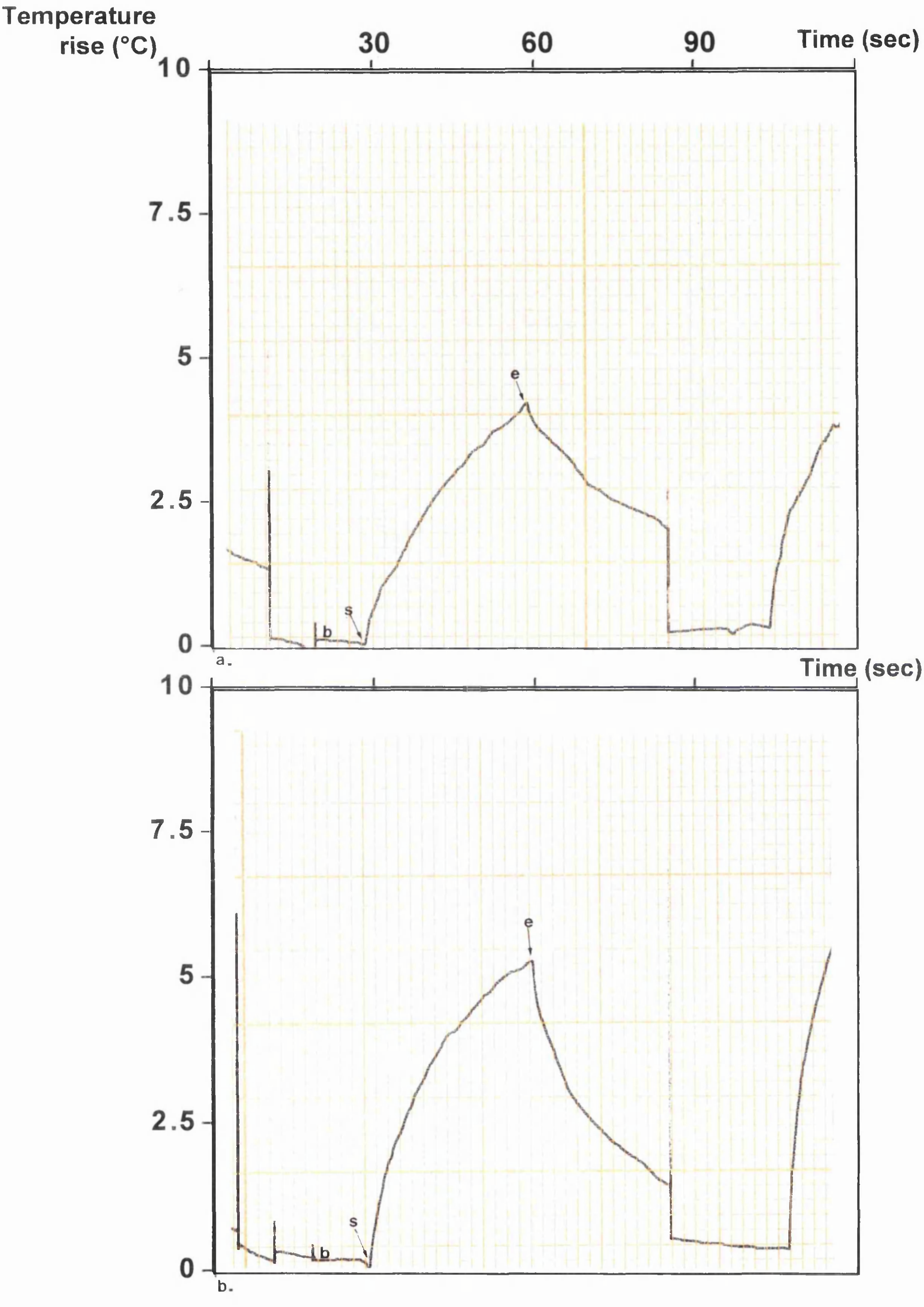
Figure 4.3 (a,b) shows the temperature rises recorded during the light exposure of the dentine specimens of primary teeth with 1 and 3 mm thicknesses. Figure 4.4 (a,b) represents the level of temperature rises recorded for the dentine specimens of permanent teeth with 1 and 3 mm thicknesses.

4.9.4 Discussion and conclusion:

The distance between the heat source and the subject was shown to be well correlated with the degree of temperature rise. Based on the results of this preliminary investigation, the thickness of the dentine is now thought to play a crucial role in the amount of energy passing through dentine. There was only a slight difference between the recorded temperature rises following the exposure of dentine slices of similar thicknesses from primary and permanent teeth by the curing blue light. The readings of temperature rise from the dentine slices of permanent teeth demonstrated, by and large, a smaller degree of change than the dentine slices of primary teeth within the different thicknesses. However, it is not clear as to why the primary dentine specimens exhibited a higher temperature rise under identical conditions. In conclusion, it is clear that the thickness of remaining sound dentine between the floor of a prepared cavity and the pulp has a crucial role in reducing the chance of pulpal overheating. This thickness seems to be more important in the case of primary teeth. The mean peak temperature for specimens of primary teeth fell as the dentine thickness increased. There was no difference in the mean peak temperature for permanent teeth between RDT of 1mm and 2mm. This could be possibly due to the increased calcific content of permanent teeth.



Figures 4.3: Show the temperature rises recorded during the PBL exposure of the dentine specimens of primary teeth with **a.** 1 mm (top) and **b.** 3 mm thickness (bottom) (b=baseline, s= starting point of PBL application and e= end of application).



Figures 4.4: Represents the level of temperature rises recorded for the dentine specimens of permanent teeth **a.** 1 mm (top) and **b.** 3 mm thickness (bottom) (b=baseline, s= starting point of PBL application and e= end of application).

4.10 Methods and Materials - Principal study:

4.10.1 Tooth selection and preparation:

Forty primary and 40 permanent carious human teeth were stored in 0.12% thymol prior to any experimental procedure being carried out. Teeth were selected based on the cavity size of '2' (medium size), using the clinical scoring system described previously in Section 2.2.1. A radiographic assessment, using the scoring system described in the same Section (2.2.1), was carried out for further evaluation as to the extent of the carious lesions within the dentine before treatment. Teeth were included in the experiment if they exhibited carious lesions with a radiographic score of '3'. Teeth were divided into 4 groups of 20 teeth: 20 primary and 20 permanent teeth were laser treated, while another 20 primary and 20 permanent teeth were treated using the conventional drill.

It was decided that the thermocouple tip had to be in direct contact with the pulpal wall of the dentine. No medium, such as gel, etc. was employed as an intermediate medium. To facilitate this in a reproducible manner, access was obtained from the apical area of the largest root of each tooth using a high speed handpiece (Siemens 4000 MS, Germany) fitted with a fissure diamond bur. Since the roots of primary teeth are generally narrow, access was gained through the furcation area of these teeth. For permanent teeth, the apical third of the root was amputated and the pulp canal subsequently enlarged using the same bur, to provide easy access to the pulp chamber to facilitate insertion of the thermocouple. Pulpal tissue was extirpated using a barbed broach.

4.10.2 Thermocouple insertion:

The thermocouple (type T, RS components Ltd., UK) was inserted into the pulp chamber from the prepared radicular access until it came into contact with the roof of the pulp chamber. The root portion of the tooth, with the thermocouple in place, was then embedded in red wax to ensure the whole set-up remained stable and secure during the caries removal and temperature recording procedures. The other end of thermocouple was connected to a calibrated digital thermometer (Comark Electronics Ltd, UK), and a chart recorder (Bryans Southern Instruments, Mitcham Ltd, England). Teeth embedded in wax blocks were held by a laboratory clamp on a stand (Figure 4.5) during all subsequent procedures. Temperature changes at the pulpodentinal junction (PDJ) caused by the application of a polymerising blue light (PBL) (Aristolite, Germany) was also measured when caries removal had been completed. This ensured that firstly, the position of the thermocouple tip had not changed and secondly, to measure the temperature during carious removal.

4.10.3 Calibration of the thermocouple positioning:

To ensure stability of the position of the thermocouple and its contact with the surface of the dentine in the pulp chamber, the temperature rise at the PDJ was recorded in two stages using the light produced from a conventional PBL. Firstly, the thermocouple was fixed in wax block following its initial insertion into the pulp chamber and temperature changes were recorded as the index. The thermocouple was then removed from the tooth completely followed by

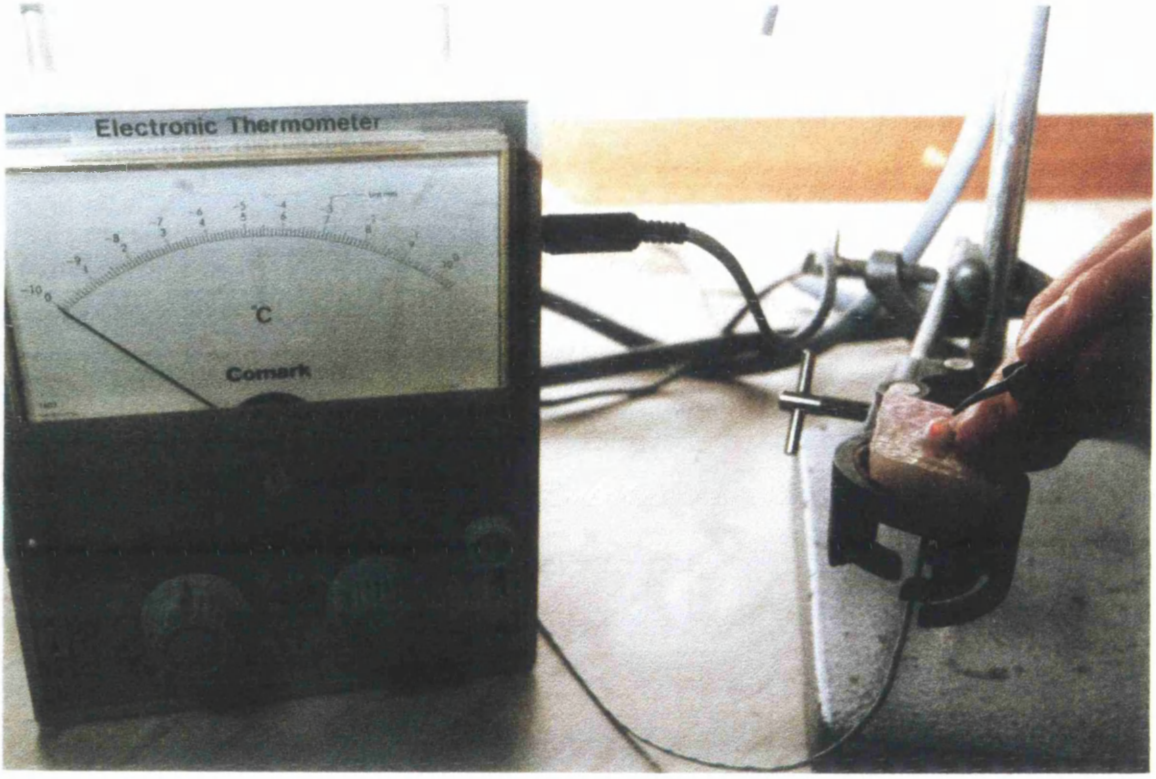


Figure 4.5: The position of teeth, embedded in wax blocks, while fixed on the laboratory stand during all subsequent procedures is demonstrated.

insertion of a second thermocouple into the pulp chamber. A second temperature rise was recorded which was compared to the initial reading.

Where there was considerable differences between the two measurements, a third temperature assessment was carried out. It was decided that the highest reading within the recorded temperature values was considered as the value representing the peak temperature.

4.10.4 Caries removal protocol

Carious tissue was removed from the experimental teeth using a pulsed Nd:YAG laser (American Dental laser, USA), specifications detailed in Section 2.2.2 (Figure 2.1), with an energy level of 60 mJ at 15 pulses per second (1.25 W). The laser fibre optic tip was held in close contact to the surface and moved across the cavity in a sweeping manner in close contact with the cavity surface. The exposure time of 30 sec was employed for each application and repeated as necessary. Any further application of the laser was carried out at least 60 sec after the completion of the previous exposure, to achieve, once again, a stable baseline temperature for further recording.

Experimental teeth were exposed to the laser on a varying number of occasions depending on the extent of caries within the cavity, ultimately to achieve a clinically caries-free cavity. The fibre was cleaved after each application as described in Section 2.2.2. The accuracy of this procedure was assessed by checking the sharpness of the aiming beam on a clean, flat white surface, about 3 cm away from the fibre tip. This cleaving procedure was considered essential as scattered light will result in diminution of the laser energy at the cutting surface. In addition, there may be damage to adjacent tissue.

Carious tissue was removed in the control group using a conventional slow speed handpiece acting on an air motor with a rotational speed of 40,000 rpm (Kavo Dental Ltd, UK) supplied with an air spray. To ensure reasonable consistency, all teeth were prepared by the same operator (GA), on all occasions with the use of a new bur for each cavity. Each cavity was prepared for a maximum of 30 sec, with further drilling being performed after a 60 sec rest period, similar to the experimental group. Caries removal assessment was carried out as described in Section 2.2.3. The temperature measurement set up is illustrated in figure 4.2. The chart recorder, used in this study, provides graphs, examples of which are illustrated in figures 4.6 (a,b,c,d,e).

4.10.5 Measurement of remaining dentine thickness (RDT):

As the size of the cavities, based on their proximity to the pulp, were different radiographically, it was decided to categorise the cavities by measuring the remaining dentine thickness. Two methods of assessment were carried out as follows: 1. Microscopic assessment of the remaining dentine thickness (RDT) using radiographic views, 2. Microscopic measurement of RDT using sectioned teeth directly.

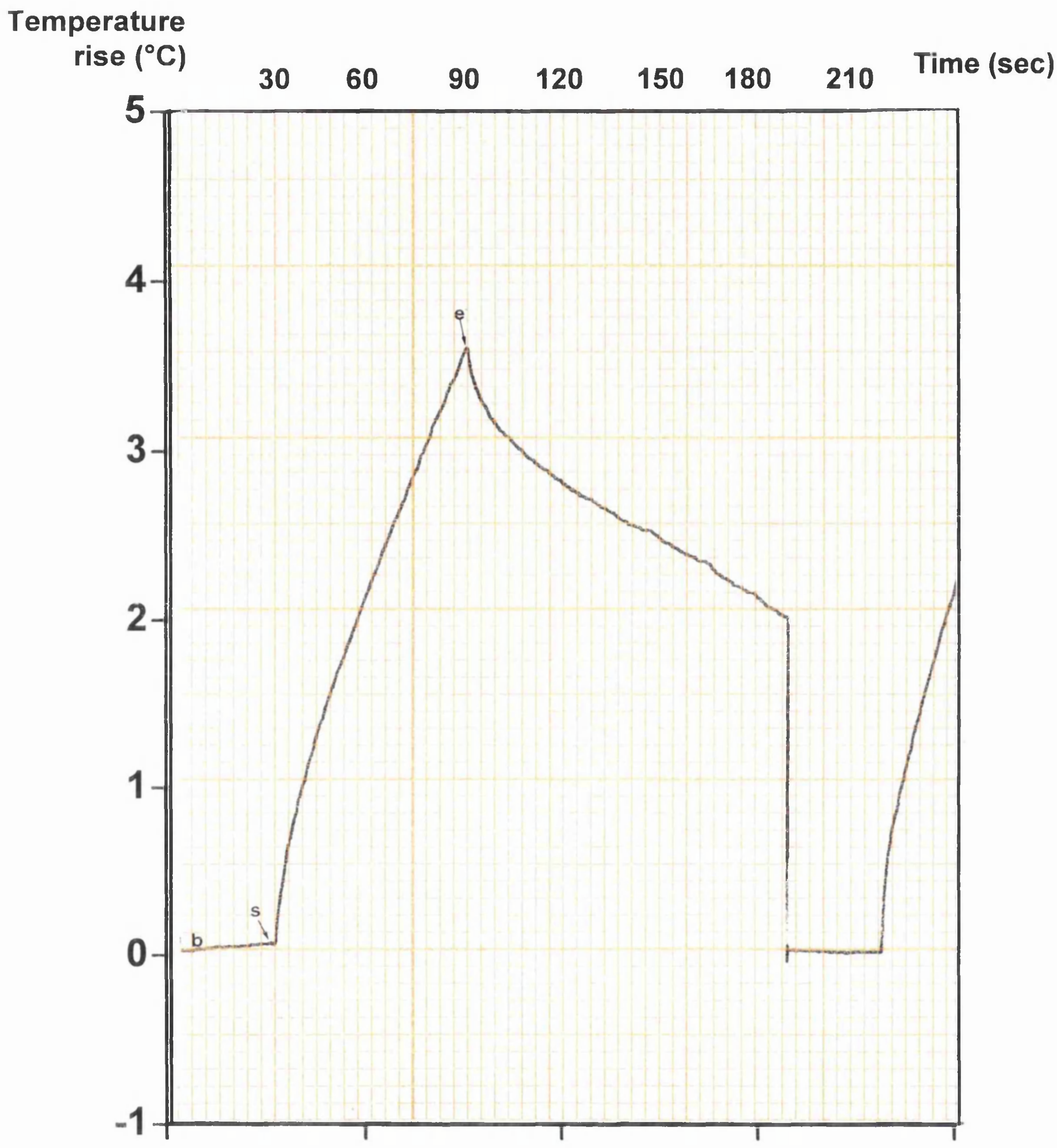


Figure 4.6 a: Sample graph from the temperature rise of the PDJ caused by the polymerising blue light application on carious tissue, (b=baseline, s= starting point of PBL application and e= end of application).

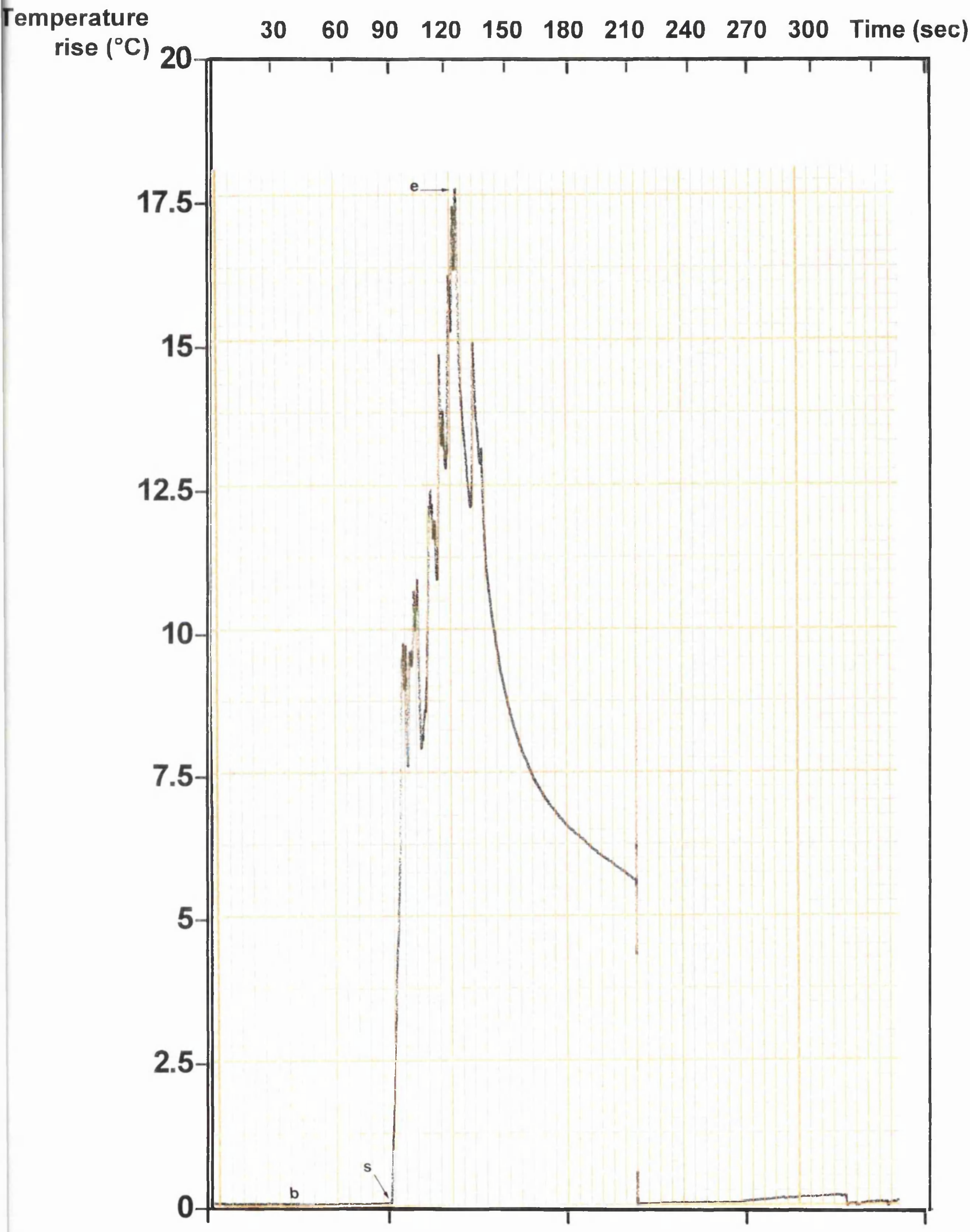


Figure 4.6 b: Sample graph from the temperature rise of the PDJ caused by the laser irradiation of carious tissue, (b, baseline, s= starting point of Laser application and e= end of application).

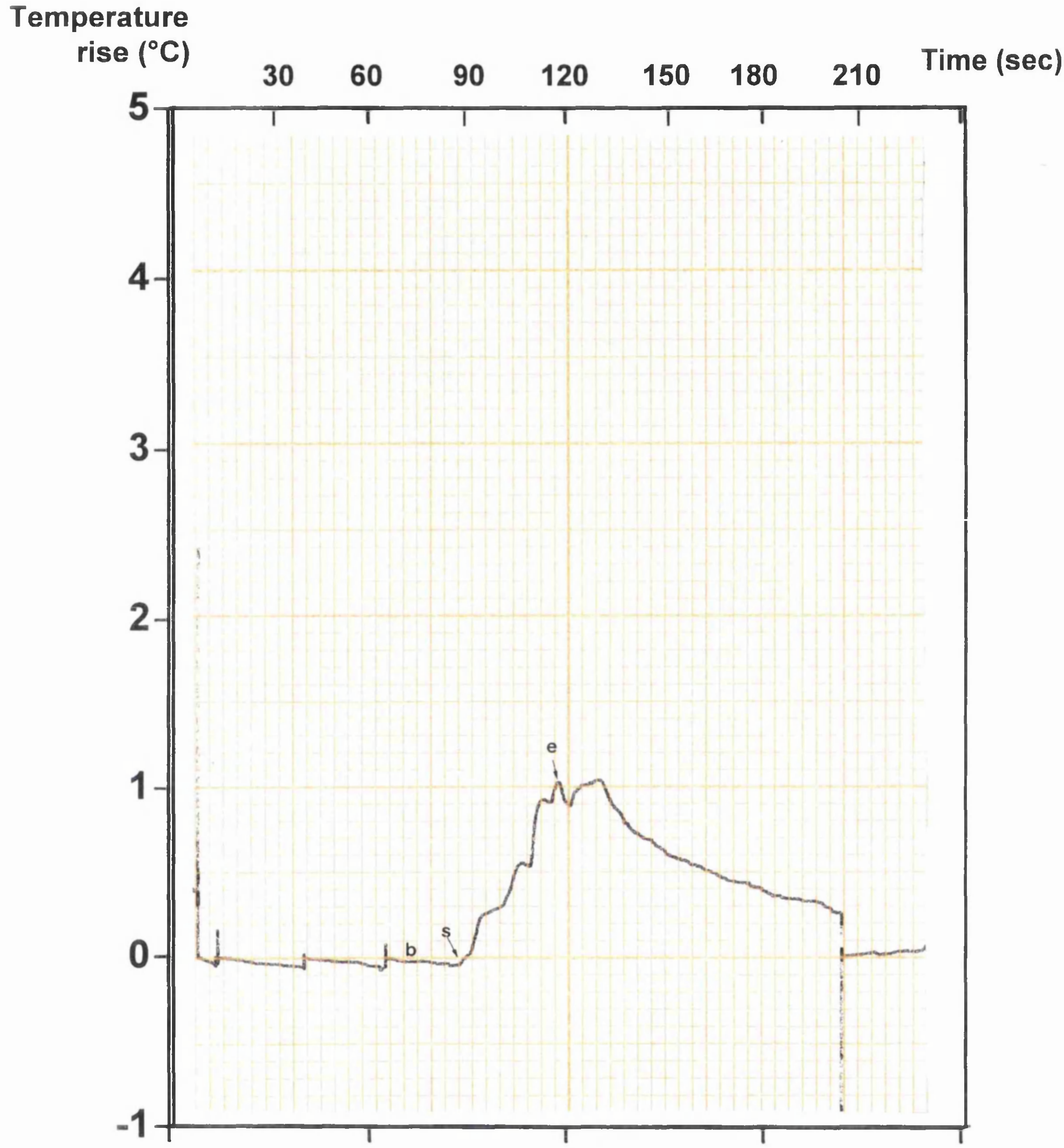


Figure 4.6 c: Sample graph from the temperature rise of the PDJ caused by the conventional drilling of carious tissue, (b= baseline, s= starting point of Drill application and e= end of application).

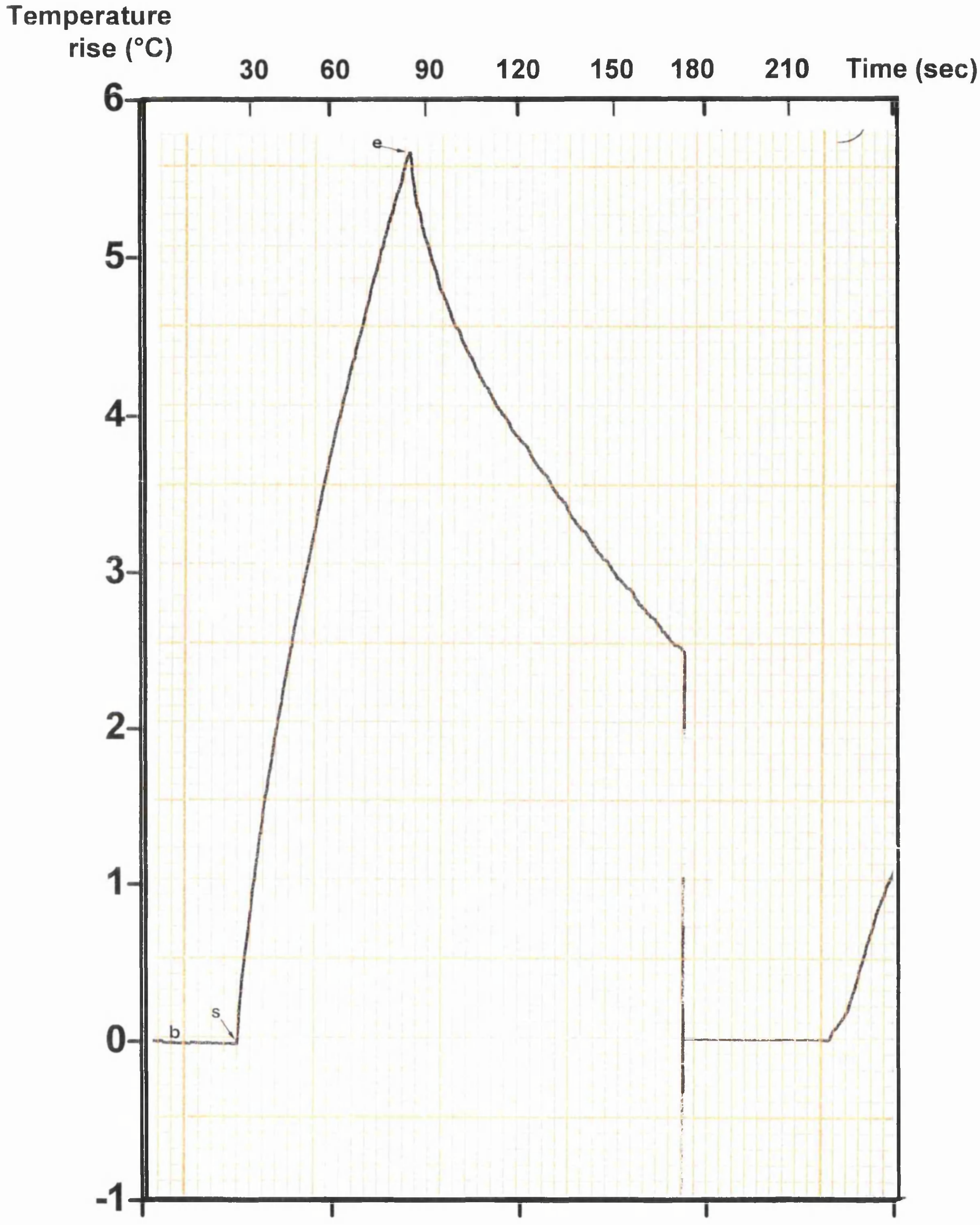


Figure 4.6 d: Sample graph from the temperature rise of the PDJ caused by the polymerising blue light after caries being removed, (b=baseline, s= starting point of PBL application and e= end of application).

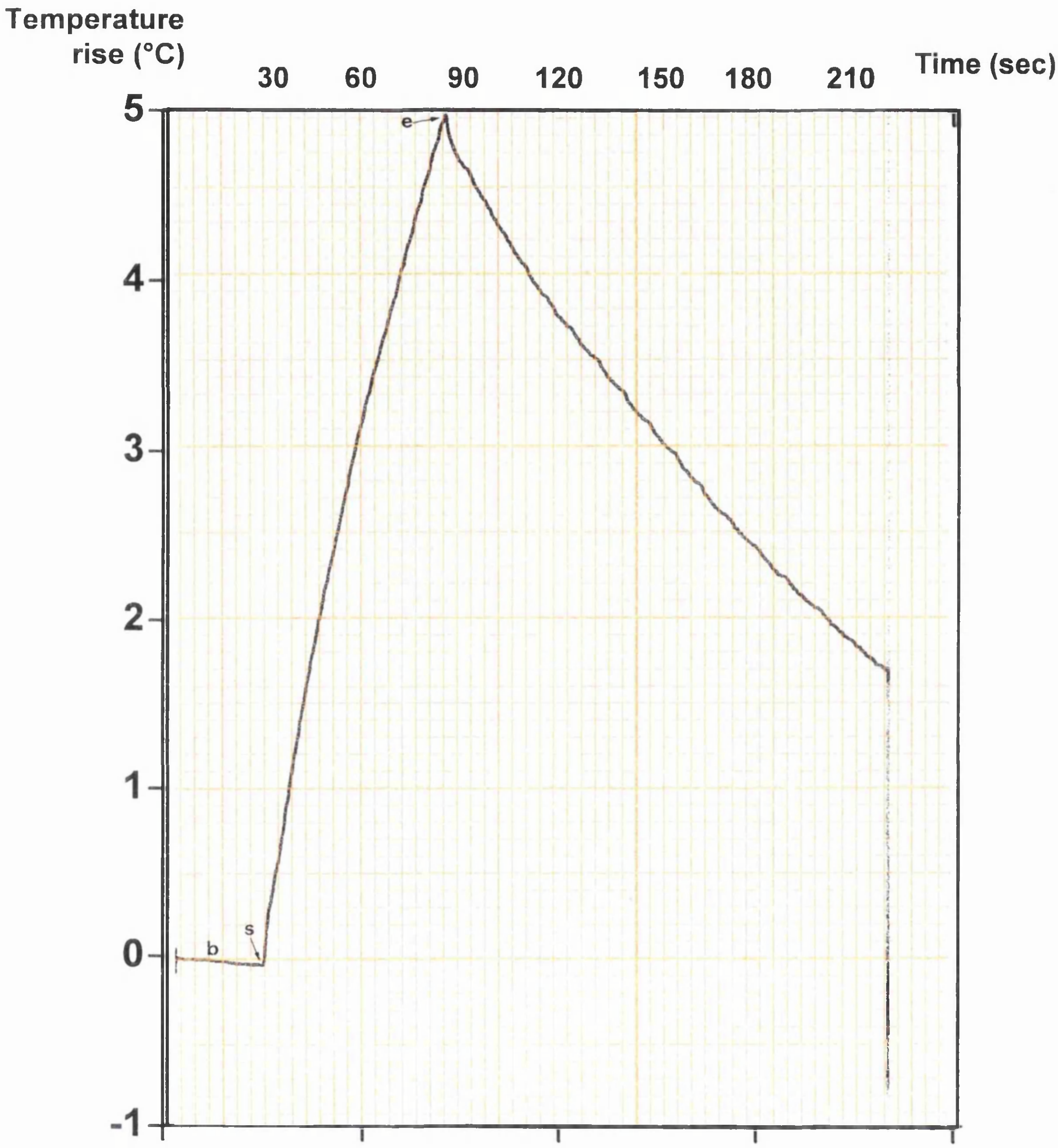


Figure 4.6 e: Sample graph from the temperature rise of the PDJ caused by the polymerising blue light after restoration was placed, (b=baseline, s= starting point of PBL application and e= end of application).

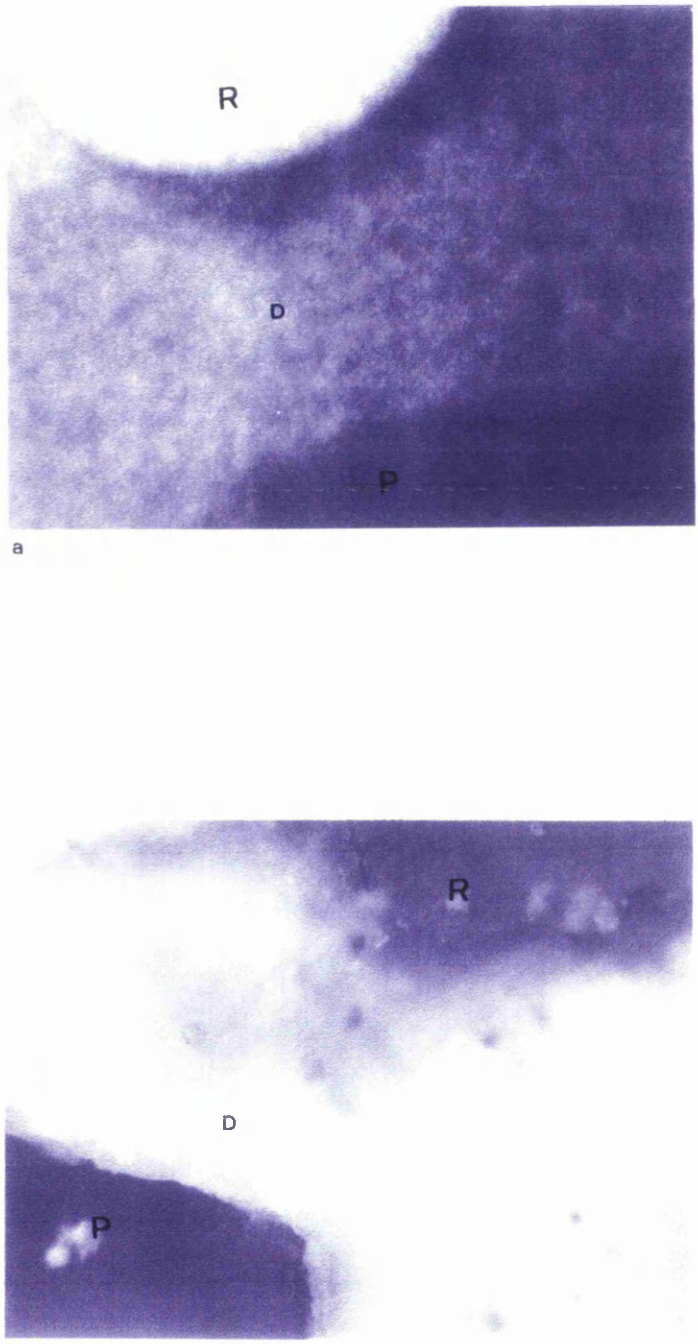
Radiographic views (RG) were prepared from each tooth before and after caries removal as described in detail in Section 2.2.1. Radiographic views were assessed under a light microscope (Leitz, Germany) connected to an IBM computer using a custom made image analysis programme. A calibration process was carried out using a stage micrometer (Leitz, Germany) before the measurement of the RDT in microns. Figure 4.7 shows an example of the computer image imported from the radiograph.

Accuracy of the RDT measurements using RG's was further confirmed by the second measurement using the direct assessment of the sectioned teeth. Teeth were sectioned using a LabCut machine (Agar Scientific ltd, UK), through what was considered to be the deepest part of the cavity. The RDT measurement was assessed as the distance between the pulp and the deepest part of the cavity as assessed by both direct and radiographic procedures.

Teeth were placed into three groups, based on their RDT level. Teeth with RDT of less than 1 mm (Group 1); Group 2 had between 1 to 2 mm and the third Group had more than 2 mm thick. This enabled a comparison to be made between the influence of the RDT and the temperature rise at the PDJ.

4.10.6 Methods of statistical analyses:

Statistical advice was sought from Mr Harper Gilmour from the Department of Public Health and Statistics. Two statistical tests were employed for these test conditions: One-way ANOVA and the students t-test. Results of the of the RDT



1000 μm

Figure 4.7: Examples of computer image achieved from **a.** the radiograph **b.** sectioned tooth, used for RDT measurement, (R=Restoration, D=Dentine and P=Pulp).

measurements were compared between the two techniques including the use of radiographic views and direct measurement, using the sectioned teeth, with a two sample t-test. The differences were tested between the pulp temperature caused by laser, the drill and the curing light with different RDT's, using One-way ANOVA. The differences between primary and permanent teeth were compared using both One-way ANOVA and two sample t-tests. Finally, the differences between the level of temperature rises caused by each application of the curing light, in the presence and absence of caries and a restoration, were tested using One-way ANOVA test.

4.11 Results:

In general, temperature changes at the pulpal surface of the dentine in laser irradiated teeth were found to be considerably higher than those treated by the drill. An appreciable temperature rise was also recorded during the application of the polymerising blue light. Details of the results are described below:

4.11.1 Findings of the RDT measurements:

Table 4.2 represents the number of teeth within different ranges of RDT, which were measured using radiographic and direct measurements. The mean values for the RDT's are presented in table 4.3. The mean value of peak temperature rises of the PDJ measured in primary and permanent teeth while irradiated by different heat sources are presented in table 4.4.

Table 4.2: Distribution of the number of primary and permanent teeth with different RDT, measured radiographically using the periapical radiographs and direct using the sectioned teeth.

		Remaining Dentine Thickness			
measurement	teeth type	< 1 mm	1-2 mm	> 2 mm	total No. of teeth
Radiograph	Primary	19	18	3	40
	permanent	11	15	14	40
Direct	Primary	6	23	11	40
	permanent	2	18	20	40

RDT= Remaining Dentine Thickness

Table 4.3: Comparison between two methods of measuring RDT (μ), Radiographically and Direct (see text for details), in primary and permanent teeth, in addition to the test and control groups, using two sample t-test.

Teeth type	Measurement	No of teeth	Mean RDT (μ)	p	DF
Primary	Radiographic	40	1697 ± 693	0.014	36
	Direct	40	1042 ± 553		
Permanent	Radiographic	40	2377 ± 1141	0.046	37
	Direct	40	1774 ± 1159		
Laser group	Radiograph	40	2231 ± 1135	0.013	77
	Direct	40	1594 ± 1100		
Drill group	Radiograph	40	1842 ± 809	0.0009	77
	Direct	40	1222 ± 802		

RDT= Remaining Dentine Thickness
DF= Degree of Freedom

Comparison between the findings of the two methods of measuring the RDT showed a significant difference (p= 0.014) between the values achieved radiographically and those achieved following the direct measurement, using two sample t-test. Generally, it was noted that a higher level of reading was achieved when the radiographic views were used for estimation of the RDT (i.e. 1697 ± 693 μm from radiographic assessment of primary teeth while 1042 ± 553 μm from direct measurement of the same specimens). The mean of the recorded values from the remaining dentine thickness are presented in table 4.3 with the p value of the differences between the two techniques of measurement using two sample t-test. These results indicated that the direct measurement is more reliable and realistic.

4.11.2 Temperature rise of the pulpodentinal junction (PDJ) following the application of a polymerising blue light (PBL):

Figure 4.6 (a,d,e) illustrate example curves recorded following the exposure of the polymerising blue light on carious dentine, after caries had been removed and finally, during the polymerisation of the restoration. Mean temperature rises of 4.4 °C ± 0.28 for primary and 2.8 °C ± 0.22 for permanent teeth were recorded when the polymerising blue light was applied before removing carious tissue. Temperature rises of the PBL were 4.7 ± 1.9 °C and 2.6 ± 1.7 °C after removing caries for primary and permanent teeth, respectively. Table 4.4 demonstrates the mean values of peak temperature rises in each individual group of cavities, based on their different RDT.

Table 4.4 : Relationship between the RDT and temperature rise using different heat producing sources, (*P* value from One-way ANOVA test).

Heat Source	RDT (Direct)	No. of teeth	Mean peak temp (°C), SD	p	F
Laser	<1 mm	12	18.85 ± 6.7	0.017	4.55
	1-2 mm	16	14.06 ± 6.7		
	>2 mm	12	10.32 ± 7.4		
Drill	<1 mm	18	0.06 ± 0.7	0.133	2.13
	1-2 mm	17	0.08 ± 0.9		
	>2 mm	5	0.9 ± 0.7		
C. Light before CR	<1 mm	30	3.71 ± 1.7	0.131	2.09
	1-2 mm	33	3.74 ± 1.7		
	>2 mm	17	2.75 ± 1.8		
C. Light after CR	<1 mm	30	4.58 ± 1.6	0.15	4.47
	1-2 mm	33	4.37 ± 2.0		
	>2 mm	17	3.03 ± 1.7		

RDT= Remaining Dentine Thickness
SD = Standard Deviation
C. Light = Curing Light
CR = Caries Removal

One-way ANOVA-test showed a highly significant difference ($p<0.001$) between the temperature rise caused by the polymerising blue light in primary and permanent teeth. However, these differences were not statistically significant ($p= 0.17$) before and after caries being removed.

Results of the recorded temperatures during the polymerisation of restorative materials showed smaller values compare to the values prior to the restoration. This may have been due to the thickness of the restoration which absorbed some of the light before it reached the cavity floor. The mean value temperature rises of 4.16 ± 1.7 °C was recorded for primary teeth and 2.99 ± 1.4 °C for permanent teeth. One way ANOVA test showed that there was a highly significant difference between these temperature rises of primary and permanent teeth irradiated with the PBL following the placement of the restorative material (Table 4.5). The overall comparison of the temperature rises of the PBL showed an increase from the light application prior to caries removal compared to after caries was removed, while it was associated with a further decrease when the restoration was placed into the prepared cavities.

4.11.3 Temperature rise of the pulpodentinal junction (PDJ) during laser radiation:

Figure 4.6 (b) illustrates a typical curve produced by the chart recorder following laser radiation of carious dentine. High values of temperature rises (ranging from 1.7 °C to 28 °C in primary teeth and 3.25 °C to 30 °C in permanents) at the PDJ were recorded following caries removal using the laser. However, the

Table 4.5: Mean peak temperature rise of the PDJ following the application of curing light in four different occasions are presented, with the differences between the two groups of primary and permanent teeth (p value from One-way ANOVA test).

Heat source	Tooth type	No. teeth	Mean peak temperature (°C),SD	p	F
C Light 1	Primary	40	4.47 ± 1.7	0.000	16.24
	Permanent	40	2.98 ± 1.6		
C Light 2	Primary	40	4.44 ± 1.8	0.000	20.47
	Permanent	40	2.80 ± 1.4		
C Light 3	Primary	40	4.72 ± 1.9	0.006	7.84
	Permanent	40	3.61 ± 1.7		
C Light 4	Primary	40	4.16 ± 1.7	0.001	11.66
	Permanent	40	2.99 ± 1.4		

C Light= Curing Light
SD= Standard Deviation

C light 1= initial curing light application,
C light 2= immediately before caries removal,
C light 3= after caries removal,
C light 4= after restoration was placed

mean temperature rise was higher in primary teeth compared to the permanent teeth (mean values of 17 ± 1.5 °C and 12 ± 2 °C, respectively) (Table 4.6). The remaining dentine thickness (RDT) was found to have an influence on the degree of temperature rise at the PDJ, when the laser was applied. This was shown by a One-way ANOVA-test which indicated a significant difference ($p = 0.017$) between the three groups of teeth with different RDT thickness (Table 4.4). The differences between the primary and permanent teeth was tested using One-way ANOVA, results of which revealed a significant difference ($p = 0.04$) between the two groups of teeth (Table 4.6).

4.11.4 Temperature rise of the pulpodentinal junction (PDJ) during drill application:

Temperature rises were small and in some cases negative temperatures were recorded. The latter may be explained by the cooling effect of the air flow from the handpiece on the prepared dentine surface, which could then be transferred through the dentine to the thermocouple tip. The temperature continued to rise a little after the conventional caries removal procedure had stopped and then it started to return to the baseline, an example of which is demonstrated in figure 4.6 (c).

One way ANOVA test on the effect of different remaining dentine thickness revealed no significant difference ($p=0.133$), between the three groups, both in primary and permanent teeth, treated by the conventional drilling. The temperature changes of the PDJ caused by conventional drill was not

Table 4.6 : Mean peak temperature rises of the pulp in primary and permanent teeth using different heat producing sources.

Heat source	Tooth type	No. of teeth	Mean peak temp (°C)	P t-test	DF	p ANOVA	F
C. L before CR	Primary	40	4.44 ± 1.8	0.000	25	0.000	21.61
	Permanent	40	2.80 ± 1.4				
Drill	Primary	20	0.29 ± 0.6	0.36	28	0.363	0.85
	Permanent	20	0.05 ± 1.1				
Laser	Primary	20	16.82 ± 6.6	0.039	36	0.039	4.58
	Permanent	20	11.93 ± 7.8				
C. L after CR	Primary	40	4.72 ± 1.9	0.006	76	0.006	7.84
	Permanent	40	3.60 ± 1.7				
C. L after Res.	Primary	40	4.16 ± 1.7	0.001	75	0.001	11.66
	Permanent	40	2.99 ± 1.4				

C.L= Curing Light,
CR= caries removal
Res= Restoration
SD= Standard Deviation
DF= Degree of Freedom

significantly different between primary and permanent teeth (p=0.363), using two sample t-test (Table 4.6).

4.11.5 Comparing the level of temperature rises at PDJ caused by laser, drill and the polymerising blue light:

Results of a student t-test revealed a highly significant difference between the two methods of caries removal (p= 0.000), with the drill producing only a minor rise in temperature (mean of 0.29 °C and 0.05 °C in primary and permanent teeth, respectively). The differences between the temperature rises caused by the laser and the PBL on the same series of teeth was found to be statistically significant (p= 0.000) using a two sample t-test. The mean value of the peak temperature rises recorded at the PDJ, produced by all three potential sources of heat, including the polymerising blue light before and after removing caries, are presented in figure 4.8 in the form of a histogram. The results of the two sample t-tests with mean values of each test group are presented in table 4.7.

The differences in temperature rise detected at the PDJ caused by the application of the PBL were not significantly different before or after caries removal (p= 0.41) when caries was removed by laser radiation. These differences, however, were significant in the drill treated teeth (p = 0.04), using a two sample t-test (Table 4.8). A One-way ANOVA-test, on the effect of the remaining dentine thickness (RDT) following laser/drill caries removal showed that the temperature rises at the PDJ, had no significant differences between

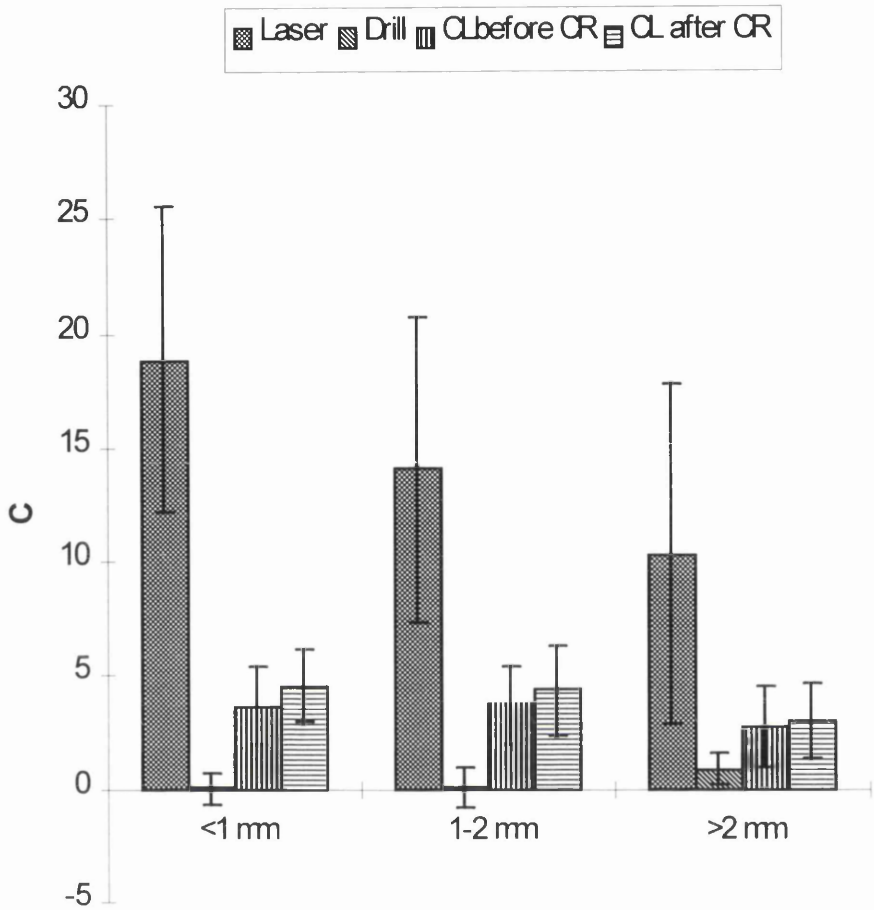


Figure 4.8: Histogram of peak temperature increases measured at the pulpal level of the teeth exposed to different heat sources with three different RDT.

Table 4.7: The mean peak temperature rise of the PDJ caused during laser and drill caries removal in addition to the overall application of the curing light before and after caries removal is presented with their differences using two sample t-test.

Heat Source	No of teeth	Mean peak temperature (°C), SD	p	DF
Laser	40	14.38 ± 7.6	0.000	39
Drill	40	0.17 ± 0.8		
Laser	40	14.38 ± 7.6	0.000	45
Light after caries removal	40	3.95 ± 2.23		
Light before caries removal	80	3.62 ± 1.8	0.062	157
Light after caries removal	80	4.16 ± 1.9		

DF= Degree of Freedom
SD= Standard Deviation

Table 4.8: The mean peak temperature rise of the PDJ caused by the application of a curing light before and after caries removal is presented for each group of laser and drill treated teeth. The differences of the temperature rise in presence and absence of carious layer was tested using a two sample t-test.

Experimental group	Light application time	No of teeth	Mean peak temperature (°C), SD	p	DF
Laser	before caries removal	40	3.55 ± 2.1	0.41	77
	after caries removal	40	3.95 ± 2.2		
Drill	before caries removal	40	3.69 ± 1.5	0.036	77
	after caries removal	40	4.38 ± 1.4		

DF= Degree of Freedom
SD= Standard Deviation

Wheater *et al.* (1991) described three main patterns of pulp tissue necrosis, including: 1. Coagulative, Colliquative and 3. Caseous. Within those, coagulative necrosis of the pulp is described when much of the cellular structure and tissue architecture is retained histologically, though the cell contents are dead. This condition was reported to be produced by 25 °C temperature rise at the PDJ following laser irradiation of the teeth (Marchesini *et al.,* 1985). Coagulative changes of the soft tissues have also been reported in oral mucosa, following the production of excessive heat caused by biting the current cable (MacDonald, Avery and Lynch, 1987). In the case of the present study, the mean temperature rise caused by laser radiation was recorded as 14 °C which is well below the level reported by Marchesini *et al.* (1985). It is clear that with the dry laboratory conditions used for these measurements, still higher temperature are produced than what can be expected in a clinical condition, where other factors, including pulpal blood flow, influence the temperature rise of the pulp.

Any heat produced at the tooth surface will be reduced as it conducts through the enamel and dentine, (15 °C at the DEJ compared to 4.5 °C at the PDJ) (Renneboog-Squilbin *et al.,* 1989). Also, the duration of exposure is known to be more important than the level of laser energy in producing heat in the dental pulp (Miserendino *et al.,* 1989; Shoji, Nakamura and Horiuchi, 1985; Serebro *et al.,* 1987). In this respect, a surface temperature rise of over 1000 °C has been reported to be associated with only 2 °C temperature changes at the pulpal level (Boehm, Chen and Blair, 1976).

The remaining dentine thickness beneath the cavity floor is a very important factor to control the degree of pulpal temperature rise during any operative procedure (Stanley and Swerdlow, 1964; White, Goodis and Daniels, 1991). However, findings of the present study have revealed that only high temperature changes, caused by laser have a statistically significant difference between the three RDT's, and not significant in the other test groups (Table 4.4).

The direct effect of the laser on the thermocouple tip has been suggested to be a possible cause for a false rise in temperature reading (Lobene and Fine, 1966; Nowak *et al.,* 1964), however, von Fraunhofer and Allen (1993) believed that since the temperature rise continues for a few seconds after the end of laser radiation, it is therefore clear that the thermocouple itself has not been directly affected by the laser radiation and the actual heat transmitted through the tooth substance was the only recorded temperature.

The rise in temperature within the dental tissue will return to a baseline very slowly, and further exposures may produce further temperature rises. It is, therefore, essential to apply short laser exposures with reasonable resting periods between exposures (Lenz Von, Gilde and Walz, 1982; Launay *et al.,* 1986). A minimum of 60 sec appears to be essential as the resting gap, to allow the heated tissue to cool down before any further temperature recording can be made accurately. This indicates that in a clinical situation, insufficient resting periods may cause pulpal overheating, even with controlled energy levels as the accumulated heat will go above the tolerating limit of the pulp.

By comparison, very small temperature rises were recorded during conventional drilling of the cavities in the control group with no differences also between primary and permanent teeth. The temperature continued to rise for a short period after drilling had stopped, indicating thermal conductivity of dentine by continuation of the heat transference to the thermocouple. This was more evident in small cavities, where there is a thicker layer of sound dentine between the floor of the cavity and the roof of the pulp chamber. It may be that the greater the dentine thickness, the greater the chance of thermal diffusion throughout the entire tooth structure and, therefore, consequent reduction in the amount of energy reaching the pulp.

The application of the PBL as the standard basic heat source on the primary and permanent teeth revealed a highly significant difference in temperature rise which may be explained by smaller thickness of enamel and dentine in the primary dentition with a larger size pulp chamber (Figure 4.9). This higher temperature rise in primary teeth indicates the higher risk of this group to pulpal overheating. Interestingly, comparison between the recorded values of temperature rise at the PDJ, caused by the blue light, before and after removing caries showed no significant differences. Slight differences were noted in individual cases, suggesting that the carious layer may act as an insulator in these individuals.

It has been suggested that controlled laser exposures may result in merely minor temperature rises, which fall within the physiological limits of pulpal tolerance (Miserendino *et al.,* 1989). Thermal conductivity of enamel and dentine may, however, delay the process of heat transferring to the pulp (Miserendino *et al.,* 1989). It is concluded, therefore, that controlled laser exposures may be used safely since temperature rises were shown to fall within the tolerance limit of the pulp. It is important to note, however, that the temperature rises measured within this model were produced under dry conditions and in the absence of any coolants during laser exposure. Such conditions will vary considerably in an *in vivo* model, as the presence of blood circulation and dentinal fluid, for example, would compensate the heating effect on the pulp.

The laser radiation, due to its higher absorption rate compared to the PBL produces a greater degree of heat within the dental hard tissue, but this temperature rise returns to baseline very quickly. The effect of heat is directly related to the length of its exposure on the biological tissues, including the dental pulp. In the case of pulsed lasers, this exposure duration is calculated from the width of each individual pulse over the period of exposure (Miserendino *et al.,* 1989). It can, therefore, be concluded that the laser irradiation of hard dental tissues for short fragments of a sec, even with the temperatures recorded in this study, can be carried out with minimum damage. In the case of PBL, used routinely in clinical practice, also seems that the temperature rises could not effectively influence the pulp status and, therefore, no evidence of any adverse effect of this temperature producing source has been reported. However, no histological study has been reported on the effect of the PBL applications on pulp of the irradiated teeth, to indicate the exact pulpal status following the rise in temperature of the pulp.

4.13 Conclusions:

1. A dramatic temperature rise at the pulpo-dentinal junction was recorded following laser irradiation of dentine carious.
2. There was, by comparison, only a minimal increase in temperature at the pulpo-dentinal junction following conventional caries removal.
3. A considerable rise in temperature, particularly in primary teeth, was observed at the pulpo-dentinal junction, when a polymerising blue light was applied.
4. The extent of the temperature rise caused by the polymerising blue light at the pulpo-dentinal junction did not vary with the presence or absence of caries.
5. Overall, there was a significant difference between the laser- and drill-produced temperature rises, as well as between the laser and the PBL.

CHAPTER V

RESTORATION ASSESSMENT FOLLOWING LASER CAVITY PREPARATION

CHAPTER 5: An *in vitro* valuation of restorations of cavities prepared by laser/ conventional drilling

5.1 Introduction:

Most restorative materials have the common complication of microleakage at their cavosurface margins (Bergenholtz *et al.,* 1982). This is mainly related to the physical properties of the restorative materials, including their adaptability to the prepared walls of the cavity. The method of cavity preparation can play an important role on the level of retention and adaptation of the material at the tooth/restoration interface, by producing surface features including: undercuts and a smear layer which may influence bond strength (Pashley *et al.,* 1983; Boyer and Svare, 1981).

The presence of a smear layer at the prepared dentine surface has been shown to reduce the level of adaptation of the restorative material to this surface, which is particularly important for resin-based restorations as it reduces the bond strength. Therefore, chemical treatment of these surfaces is recommended prior to restoration placement (Buonocore, 1955; Hotz *et al.,* 1977; Levine, Beech and Garton, 1977 Munksgaard *et al.,* 1984). By comparison, little concern has been stated for this problem in glass ionomer restorations, perhaps due to the potential of these materials to adhere by a chemical mechanism to the untreated dentine surface (Hotz *et al.,* 1977; Levine, Beech and Garton, 1977).

5.2 Classification of currently used restorative materials:

There are several restorative materials used in dental practice, including dental amalgam, composite resins, gold (inlay), porcelain (inlay), glass ionomer and compomers. These materials can be divided into two general groups of adhesive and non-adhesive as detailed below:

5.2.1 Non-adhesive conventional restorative materials:

Non adhesive restorative materials have been used to restore hard tissue defects of dental structures for many years. Amongst these, amalgam is still the most commonly used restorative material for restoration of posterior teeth both in primary and permanent dentitions. However, like any other restorative material, amalgam has its limitations, including: 1. Excessive tissue removal required for mechanical retention (Elderton, 1986), 2. High marginal leakage due to the lack of any adhesion property (Elderton, 1975; Chan and Glyn Jones, 1994), 3. Corrosion and its soft tissue effect (causing Oral Lichen Planus) (Molin, 1992), 4. Mercury release and its potential hazards including toxicity and allergic reactions (Eley and Cox, 1993; Bruce, MacDonald and Sydiskis, 1993; Koppel and Fahron, 1995) and finally 5. unacceptable for restoration of anterior teeth due to poor aesthetics. In this respect, adhesive restorative materials have been suggested for use as an alternative material to amalgam (Chan and Glyn Jones, 1994).

5.2.2 Adhesive restorative materials:

Two types of adhesive restorative materials are available for use in dental practice, including: a. those which require the use of an additional bonding agent, i.e. composite resins, b. Materials with a direct chemical bonding property, i.e. glass ionomers.

5.2.2.1 Composite resin restorations and dentine bonding agents (DBA):

Acrylic resin restorative materials are categorised into three generations: 1. unfilled resins as generation I, 2. filled resins as generation II, and finally 3. microfil, macrofil and hybrid as generation III (Curzon, Robertz and Kennedy, 1996). Between these, only generation I and II, which contain filler particles, can be termed composite. Acid etching of enamel margins can improve the retention of these restorations and also reduces the chance of microleakage (Buonocore, 1955; Erikson and Pears, 1978). Present composite resins are either chemically polymerised or photopolymerised.

Dentine bonding agents (DBA's) are mainly used to enhance the retention of composite resin restorations by bonding to the particles of composite from one side and to the dentine or enamel surface from the other side. DBA's have been used for many years with the main concern on adaptability of the material at the tooth/restoration interface. Despite the wide usage of composites in operative dentistry, their common complications of Shrinkage during the polymerising phase (Donly *et al.,* 1987), excessive wear (Harrison and Draught, 1976), discolouration and marginal leakage (Derkson, Richardson and Waldman, 1984) still remain.

5.2.2.2 Glass ionomers:

Today's restorative dental materials should posses ideal properties, strength, durability and compatibility, while also adhering to tooth structure. Glass ionomer cement, which is a mixture of calcium aluminosilicate glass and polyacrylic acid, is capable of bonding to dentine by its free hydrophilic carboxyl groups, promoting surface wetting to hydrogen bonds at the tooth surface. Glass ionomer cements are described as being very vulnerable to water, especially in their initial setting stage (Donly, 1994). The hydrogen ions are produced by ionisation of the calcium aluminosilicate glass, which also contains fluoride, resulting in fluoride release (Skartveit *et al.,* 1990). Light cure glass ionomers, also known as resin-modified glass ionomers, are claimed to have a better marginal adaptation with a more acceptable colour match, in addition to their reduced problems with water (Barnes *et al.,* 1995). It is, perhaps, more advisable to use these materials for the restoration of primary teeth in patients with poor co-operation. Within these materials, compomers are suggested as the improved formula of glass ionomer materials which are shown to have acceptable clinical survival rates (Peters, Roeters and Frankenmolen, 1995).

5.2.2.3 Compomers:

Compomers are newly introduced restorative materials recommended for use in restoring primary teeth (Croll, 1993). It contains the essential components of a glass ionomer cement, but below the level required to activate acid-base cure reactions in the absence of light and considered as a poly-acid modified composite resin (McLean, Nicholson and Wilson, 1994). Compomers were developed to improve the physical properties and clinical handling of glass ionomers. Compomers are also designed to be light-activated and used as restoratives or liners. This new generation of restorative materials provide clinical results comparable to those recorded for composite resins after 12 months (Barnes *et al.,* 1995).

Compomer, which is a combination of composite and glass ionomer, is demonstrated to have the capability of chemical bonding to dentine. Cortes, Garcia-Godoy and Boj (1993) studied the bond strength of two glass ionomers, namely Fuji II LC (GC American, USA), Photac-Fil (Espe, Germany) and a compomer, Dyract (Dentsply, Germany), with and without acid etching and showed that Dyract had a significantly higher bond strength than the other two, with no significant differences between the etched and non-etched groups (Cortes, Garcia-Godoy and Boj, 1993).

5.3 Advantages and disadvantages of compomers:

Compomer restorative material, like any other restorative material has been tested for its properties with the following results: fast and easy to use, good colour match with tooth, single component primer/adhesive, available in compule/ syringe system, high wear resistance, good finishing and immediate polishing capacity, fluoride release and finally enhanced shelf stability (Clinical

Research Association, News Letter, 1995). This material is water resistant compared to other glass ionomer materials and does not require any protective cover immediately after it is set. It has a primer/adhesive component which reduces the time required for restoration of teeth in children.

Compomers have also some fluoride releasing capacity, in high levels which helps protect both the immediate and surrounding tooth structure from carious attack (Swartz, Phillips and Clark, 1984; Skartveit *et al.,* 1990). The maximum level of fluoride release after the placement of restoration in the prepared cavity, has been reported as being mainly during the first day of its placement (El Mallakh and Sarkar, 1990; Creanor *et al.,* 1994) but this process may continue for about 2 months (Cooley and McCourt, 1991) and even until one year after restoration was placed (Swartz Phillips and Clark, 1984; Hatibovic-Kofman and Kock, 1991). However, no significant difference has been reported between the level of fluoride release from light activated and conventional chemically activated materials (Momio and McCabe, 1993).

Limitations of compomers can be listed as: a. Limited stress tolerance, only suitable for non-stress bearing areas, b. Instability of prime/bond component during application, c. Unknown long-term prognosis, only studied for maximum of two years, d. limited range of colour. Overall, the limitations of this material can be ignored in certain cases, including restoration of primary teeth in uncooperative young patients where an easy and quick technique of restoration is required.

5.4 Choice of material:

Glass ionomer base restorative materials including the latest generation, compomers, have been demonstrated to be effective as an alternative to conventional amalgam and composite resin bonding systems particularly for restoring carious primary teeth (Croll, 1993; Peters, Roeters, and Frankenmolen, 1995). To select any material it is essential to assure the physicochemical properties of the material including its shrinkage and expansion potential causing microleakage. It has been demonstrated that poor adaptation of the restoration to the margins of the prepared cavity leads to a gap between the wall of the cavity and the body of the restoration. This defect, known as microleakage, allows the bacteria to ingress and subsequently activate a demineralisation process of dental structure, considered as a major factor in the failure of restorations (Kidd, 1976).

5.5 Common causes and the prevalence of the failure of restorations:

One in every three existing restorations has been reported to meet the criteria of failure. This high prevalence indicates that every individual restoration can be considered as a possible failure within a few years of restoration placement (Elderton, 1976a). Several factors have been described as being responsible for these failures and the long-term prognosis of restorations, including:

1. Cavity design (Healey and Philip, 1949; Elderton, 1975; Elderton, 1976b)
2. Properties of the restorative materials (Elderton, 1975)
3. Faulty restorative techniques (over/under filled) (Gilmor and Sheiham, 1971)
4. Residual/recurrent caries (Allan, 1969)

5. Traumatic occlusion (Healey and Philip, 1949)

Scientists and manufacturers have been attempting to improve the quality of restorative materials by changing the properties of the materials as well as improving the prepared surface by altering the cavity preparation technique. As the method of cavity preparation and its effect on the property of the restoration was of interest of this study, it will be discussed in further detail in the following sections.

5.5.1 Effect of the method of cavity preparation on the marginal adaptation of restoration:

Different cavity preparation techniques have been reported to produce different features on the prepared enamel or dentine surfaces. For example, rotary instruments cut thoroughly even sound enamel and dentine and leave a rough, uneven surface with undercuts (Boyer and Svare, 1981). A smear layer forms immediately after the completion of the cavity preparation procedure as a result of the cutting action of the bur on dentine, regardless of the type of material, carbide or diamond (Boyer and Svare, 1981). Cutting dentine with different rotary instruments produces generalised blockage of the dentinal tubules with debris, which in turn considerably reduces the permeability of the dentine (Boyer and Svare, 1981). Removal of carious tissues using hand excavators leads to the formation of a smear layer as in the case of rotary instruments (Gwinett, 1984).

5.5.2. The smear layer and its role on a restoration's failure:

The smear layer is believed to be responsible for excluding bacteria from dentinal tubules by occluding the surface and reducing the surface area available for the diffusion of micro-organisms (Vojinovic, Nyborg and Brännström, 1973; Pashley and Livingston, 1978). As it has been suggested that the smear layer hinders the achievement of optimum dentine bonding, the current bonding agents are designed to either modify, remove or partially remove and modify the smear layer.

In comparison, laser irradiation of carious dentine produces different features on the surface of prepared dentine, including resolidification of melted tissue with the absence of such a smear layer as in the case of conventional drilling. However, occasional pieces of debris from carbonisation of the irradiated tissue may be seen in temperatures higher than the safe limit (Koort and Frentzen, 1995). Laser irradiation causes melting of the surface by producing excessive heat, followed by a resolidification process. The organic material of the smear layer, irradiated by CO_2 laser radiation, has been reported to have been vaporised with fusion of the mineral components, and therefore improving the cohesive strength (Pashley *et al.,* 1992). Earlier studies had indicated that the shear bond strength of composite to dentinal surface treated with a CO_2 laser radiation had significant improvements compared to the bond strength of non-lased areas of dentine (Cooper *et al.,* 1988; Featherstone and Nelson, 1987).

It is concluded, therefore, that the laser prepared surface could have a potential advantage to the conventionally prepared surfaces by providing more suited surface characteristics for bonding to adhesive restorative materials, including glass ionomer group.

5.6 Current methods of assessing restorations:

To ensure achievement of maximum properties of restorations, any newly introduced material should be approved through a series of tests prior to its clinical use. In general, several tests have been suggested for assessment of the properties of restorations, including: 1. Bond strength to dental hard tissue (Aboush and Jenkins, 1986; Scott, Strang and Saunders, 1992), 2. Wear resistance (Lutz *et al.,* 1984), 3. Compressive and tensile strength (Harrison and Draught, 1976), 4. Marginal adaptability and integrity (Chan and Glen-Jones, 1994). In addition to the assessment of microleakage level on restored teeth, a complementary assessment technique has also been carried out by means of measuring the gap sizes at the margins of restorations as an indication of microleakage and restoration failure (Reid *et al.,* 1994). As cavity preparation technique could only influence the level of adaptation at the tooth/restoration interface, measurements were carried out of microleakage and gap size, in this experiment.

Several laboratory methods have been introduced to investigate the presence and the extent of microleakage at the interface between the tooth and the restoration, including: 1. Dyes and radioactive isotopes (Grossman, 1939;

Going, Massler and Dute, 1960), 2. Air pressure (Harper, 1912), 3. Bacteria (Fraser, 1929), 4. Neutron activation analysis (Going, Myers and Prussin, 1968), 5. Artificial caries (Ellis and Brown, 1967), and finally 6. Scanning electron microscopy (Boyde and Knight, 1969).

Thermal cycling has been suggested, in conjunction with the use of the dye, to simulate conditions within the oral cavity, during the *in vitro* experiments (Nelsen, Wolcott and Paffenbarger, 1952; Saunders, Strang and Ahmed, 1991; Crim, Swartz and Phillips, 1985, Wendt, McInnes and Dickinson, 1992). In recent years thermal cycling has been used routinely as an essential part of microleakage studies. It is suggested that the thermocycling machine, by producing a series of thermal shocks, as occurs in the mouth (Michailesco *et al.*, 1995), produces such alterations, at the tooth/restoration interface, detectable by the dye penetration depth (Crim, Swartz and Phillips, 1985).

In this experiment, restorations of laser- and drill-prepared cavities were evaluated by means of their microleakage level, using a disclosing dye following thermocycling. This enabled the evaluation of the potential quality of laser prepared cavity surfaces for bonding to the adhesive restorative material used, i.e. Dyract®. In addition, a further microscopic investigation for the presence of a gap at the margins of restorations was performed by means of measuring the size of the gaps before and after thermocycling.

5.7 Aims and objectives:

The suitability of laser cavity preparation for a higher adhesive strength of restorative materials was tested by means of:

1. Assessing the level of microleakage on both primary and permanent teeth.
2. Comparing the level of microleakage between laser- and drill-prepared cavities.
3. Assessing the gap size at the tooth/restoration interface for both primary and permanent teeth.
4. Assessing the gap size at the tooth/restoration interface of laser- and drill-prepared cavities.

5.8 Methods and Materials:

5.8.1 Introduction:

Restorations of laser- and drill-prepared cavities were assessed in this experiment by means of investigating the presence and size of the gaps at the restoration margins, in addition to the assessment of the level of microleakage around the restorations.

5.8.2 Tooth selection and preparation:

40 primary and 40 permanent human extracted teeth were stored in 0.12% thymol before and after caries removal procedure. Teeth with medium size occlusal cavities, based on the clinical scorings detailed in Section 2.2.1, were selected for this experiment. This allowed the elimination of any of other factors

than cavity preparation technique which could influence the restoration's behaviour during the experiment.

5.8.3 Caries removal protocol:

Carious tissue was removed in test teeth using the pulsed Nd:YAG laser as detailed in Section 2.2.2. Control teeth were treated using a conventional slow speed handpiece on an air motor (Kavo Dental Ltd, UK) with a new round tungsten carbide bur (size 3-5) for each cavity. Caries removal was stopped when the cavity was found to be caries-free, using visual and tactile criteria, details of the techniques having been described earlier in Section 2.2.4. To avoid any disturbance of the prepared surfaces, cavity shape and outline was not altered further. In any case, the use of an adhesive restorative material, obviated the need for further cavity preparation.

5.8.4 Restoration protocol:

All test and control teeth were restored using a light cured compomer i.e. Dyract® (Dentsply, UK). The commercial Dyract® restorative material package, used in this experiment, is illustrated in figure 5.1.

Each cavity was thoroughly washed and air-dried using an air/water spray prior to restoration. Adhesive/primer was applied to the prepared dentine surface and then air-dried for 15 sec. This was followed by a 20 sec light application using the Aristolite blue light source (Pluraflex HL 150, Germany). A single compomer, shade A2, was used for all restorations to eliminate influences of

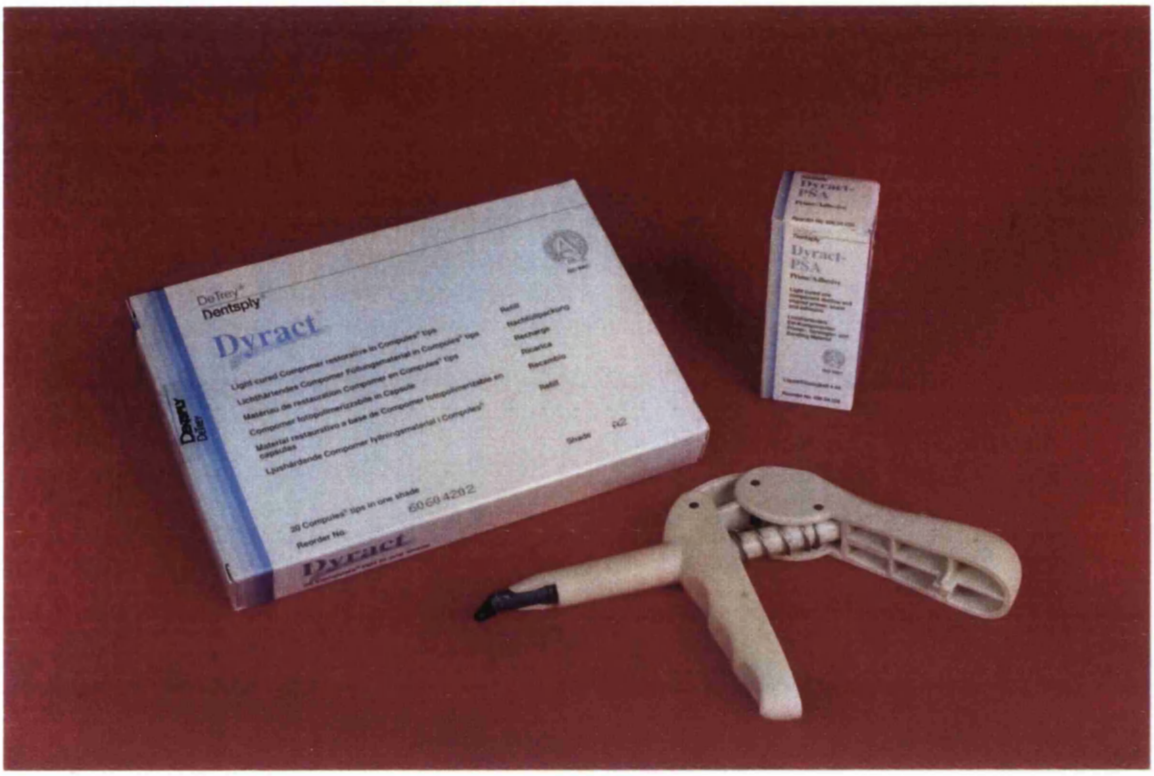


Figure 5.1: The commercial Dyract® restorative material package, used in this experiment.

colour and opacity. The restorative material was then inserted into the prepared cavities and light cured for 60 sec in a routine manner.

5.8.5 Thermal cycling method:

To simulate the clinical situation in this *in vitro* study, all restored teeth were thermal cycled to apply a series of thermal stress to the restoration as occurs in the mouth (Michailesco *et al.,* 1995), using a thermocycling machine (Figure 2.8) with the following set up:

1. The temperatures of the baths were set at 4 °C, 37 °C and 55 °C which then provided the following series of temperatures: 5 °C, 37 °C, 55 °C, and 37 °C.
2. The number of cycles was set for 350 cycles.
3. The period of time for the specimen to remain in each bath was 10 sec.

5.8.6 Methods used for the assessment of restorations:

Two techniques were employed to assess the tooth/restoration interface: 1. gap size measurement, if present, 2. microleakage evaluation by assessing the penetration depth of the dye.

5.8.7 Sample preparation for gap size measurement:

The presence of any gap at the tooth/restoration interface was assessed using light microscopic assessment of the specimens. As the same teeth should be assessed regarding microleakage study, impressions of the restored teeth were taken to make resin replicas of each specimen. Impressions were taken in two stages, with the initial impression being taken immediately after the restoration was set, using a two stage impression technique, employing a polyvinylsiloxane impression material (heavy & light body President, Dentsply, UK). A second impression was taken following the completion of thermal cycling, to allow the measurement of the gap size at the restoration margins, following thermal cycling. Impressions were poured with epoxy resin (Epofix, Struers tech, Denmark).

The resin replica was prepared from specimens as follows:

Two segment resin liquids were mixed immediately before use and mixed until a homogenous texture was achieved. Each impression was filled with the resin liquid and left for at least 48 hours to set. Care was taken to avoid any contact with the restored surface of the tooth replica, in order to keep the model as close to the original specimen as possible. Samples of resin replica were then assessed using light and scanning electron microscopy. Figure 5.2 shows sample impression from the experimental teeth with its corresponding resin replica.

5.8.8 Gap size assessment techniques:

5.8.8.1 Light microscopy:

To enable microscopic assessment of these prepared resin samples, it was essential to choose a suitable microscope to provide sufficient light for transillumination through the bulk of the resin specimen to produce an accurate microscopic image. Each resin replica was positioned on the slide of the microscope used (Leitz, Germany), and investigated as usual. A video camera

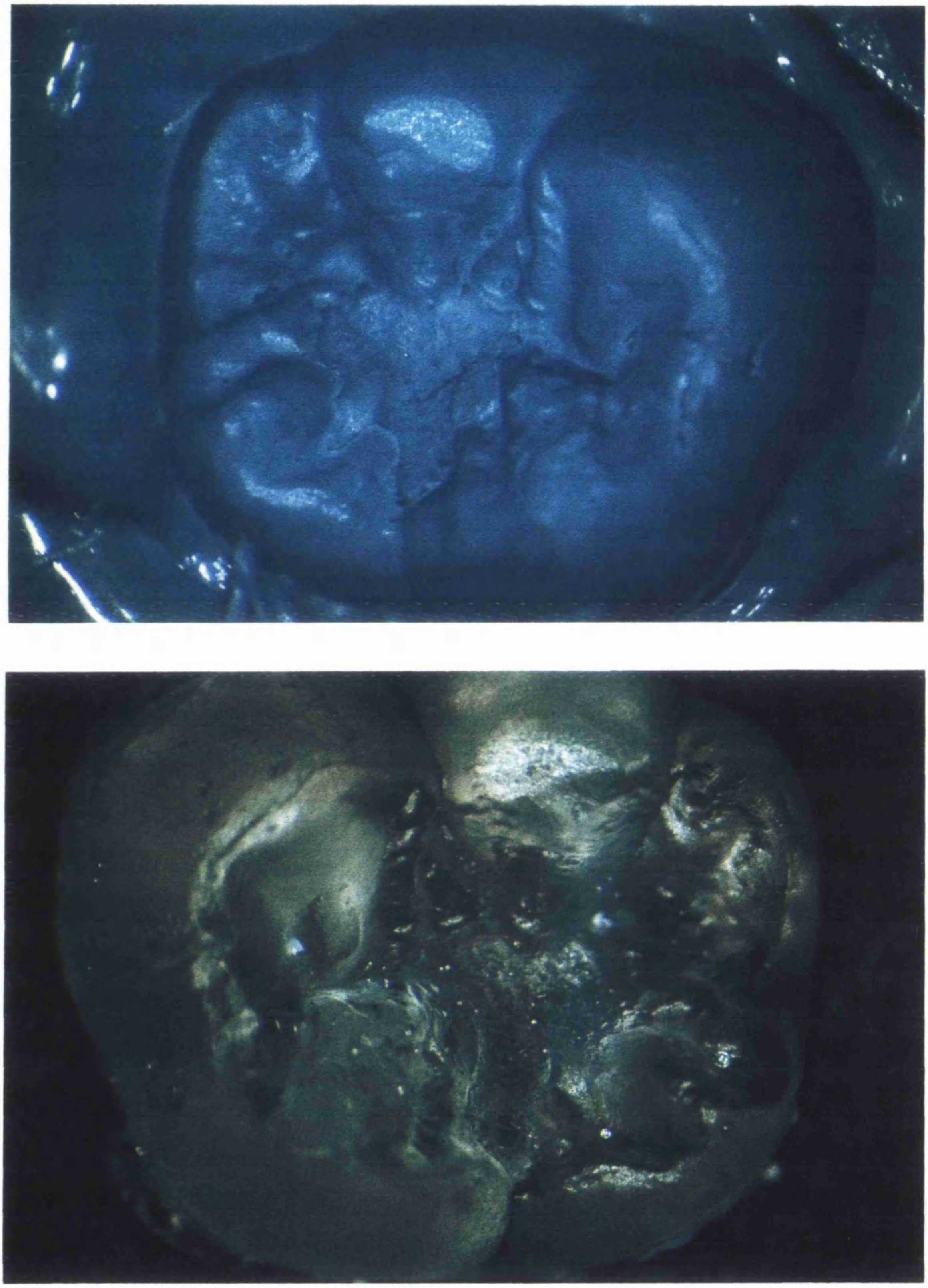


Figure 5.2: Illustrates the impression taken from a restored tooth (a) with its related resin replica (b) used for the assessment of the gaps at the restoration margins.

mounted on the microscope allowed images to be shown in an IBM compatible PC (Figure 5.3) using the method described in Section 4.9.5. An Image Analysis programme was used for measuring the gap distance. Calibration was achieved using a stage micrometer (Leitz, Germany). The imported picture on the computer screen was printed using a video graphic printer (EU-850, Sony, Japan) samples of which are presented in figures 5.4 (a,b). An estimation as to the border of the restoration was considered as the first point of measurement at the widest area of the gap. The second point was at the edge of the cavity surface, on the cavosurface line, in a butt joint angle. As only the maximum gap size was measured, these measurements were recorded only at the highest values achieved following repeated measurements.

5.8.8.2 Scanning electron microscopy:

Resin replicas were first mounted on Aluminium stubs (Agar Scientific Ltd) using a conductive carbon cement (Leit C, TAAB Laboratories Equipment Ltd.) and coated with a thin layer of gold using a sputter coating machine (Polaron E 5000). Details of the coating procedure are given in Section 2.6.4. Specimens were then examined using the scanner (Jeol T 300 SEM) to estimate the gap size at the restoration margins of replicas from before and after thermocycling. Figures 5.5 (a, b) and 5.6 (a,b) demonstrate sample SEM views of the existing gap on the specimens before and after thermocycling, in both experimental and control groups. The anatomical landmarks of the crown were used to re-establish the location of the gap.

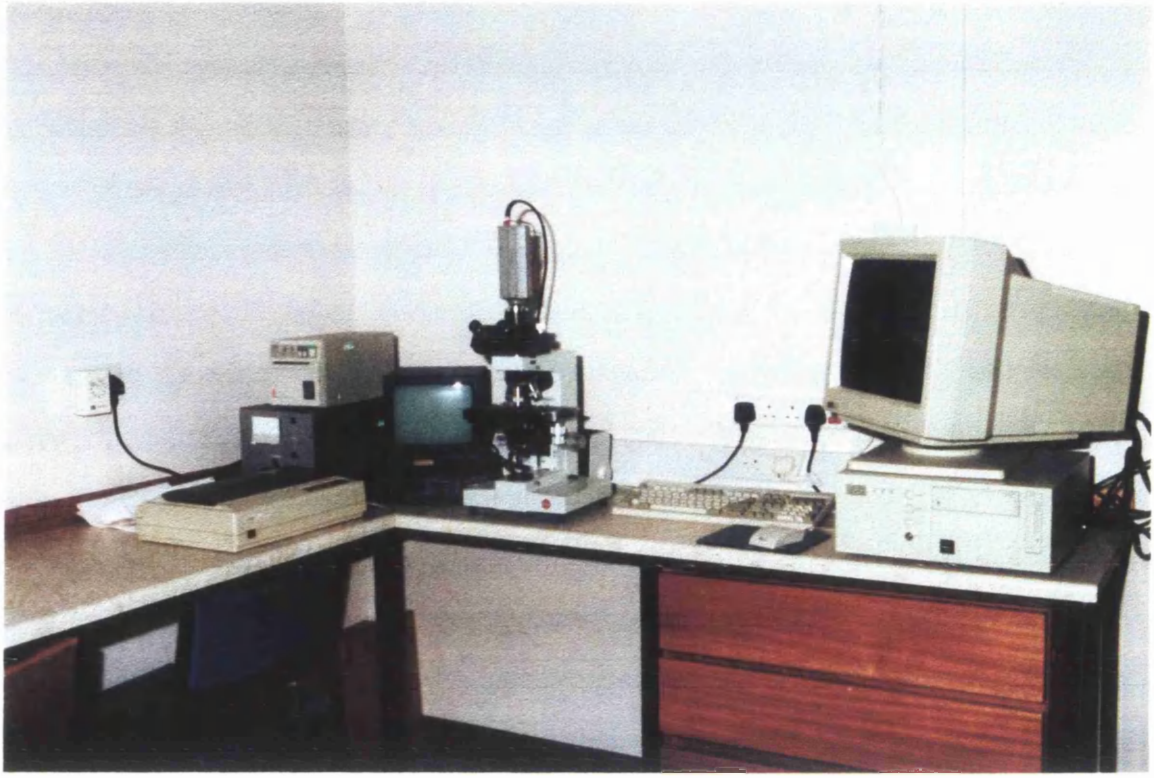


Figure 5.3: Computer measurement set up for assessing the gap size.

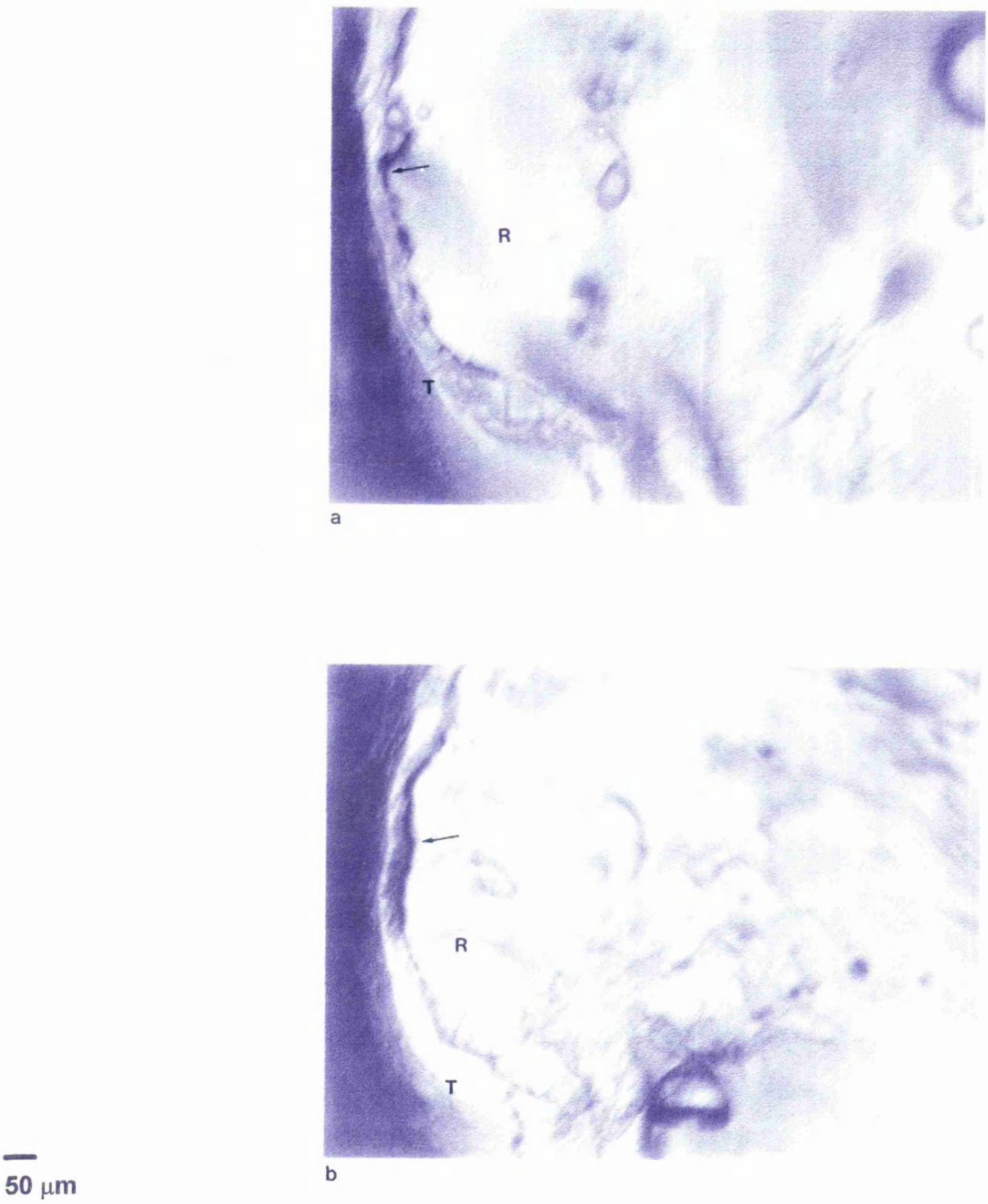


Figure 5.4: A sample print of the restoration margin of the specimen provided by the PC printer **a.** before and **b.** after thermocycling (Arrow points to the existing gap, R= Restoration, T= Tooth).

5.8.9 Sample preparation for microleakage assessment:

To prevent the dye penetration from any routes other than the restoration margins, which was left uncovered, all specimens were sealed using two layers of nail varnish (Diamond Hard, 829, Maxfactor International, UK). The apical foramen, which is a wide path to the pulp chamber, was initially sealed with a layer of Cyanoacrylate adhesive prior to the application of nail varnish. The varnish was applied to the whole tooth surface leaving 2 mm around the restoration margins (Figure 5.7).

5.8.9.1 Dye application:

In order to allow the dye solution to travel through the potential gap existing between the restoration and the wall of the cavity, if any, teeth were immersed in 2% aqueous solution of buffered Methylene Blue for a period of 15 hours. Specimens were washed thoroughly under running water, for 5 min, to remove excess dye. Teeth were now ready for sectioning.

5.8.9.2 Teeth dissection:

A diamond disk on a laboratory microtome (Agar Scientific Ltd, UK) (Figure 5.8) was used to cut through the restored tooth. Only one longitudinal cut was made on each tooth, with the cutting line being located as near as possible to the centre of the restoration. Figure 5.7 demonstrates the cutting line through the centre of the restoration.

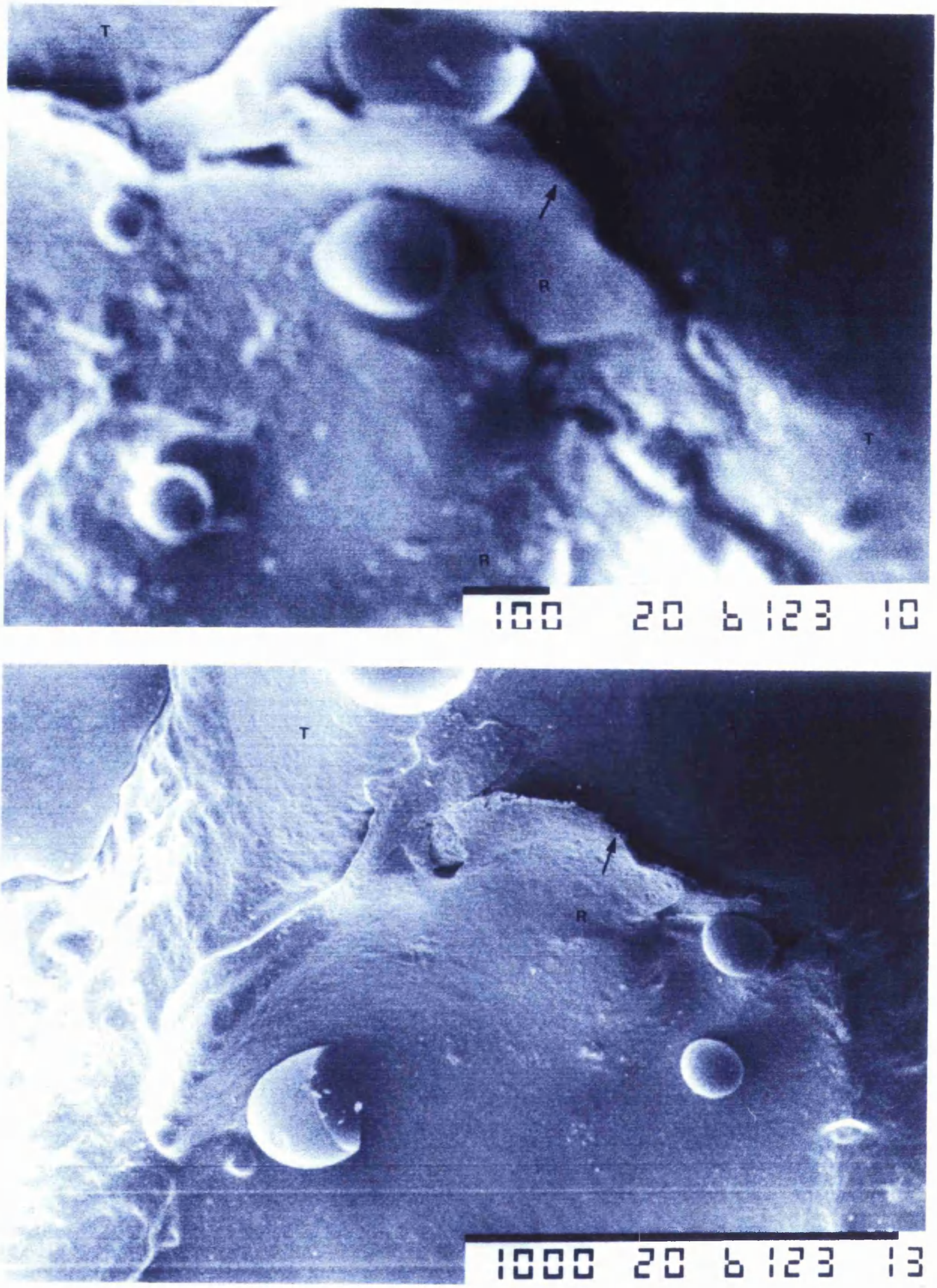


Figure 5.5: Photomicrograph of the existing gap on the margin of a restoration: **a.** before (Mag. x500) and **b.** after thermocycling (Mag. x22) (SEM), sample from laser treated group (Arrow points to the existing gap, R= Restoration, T= Tooth).

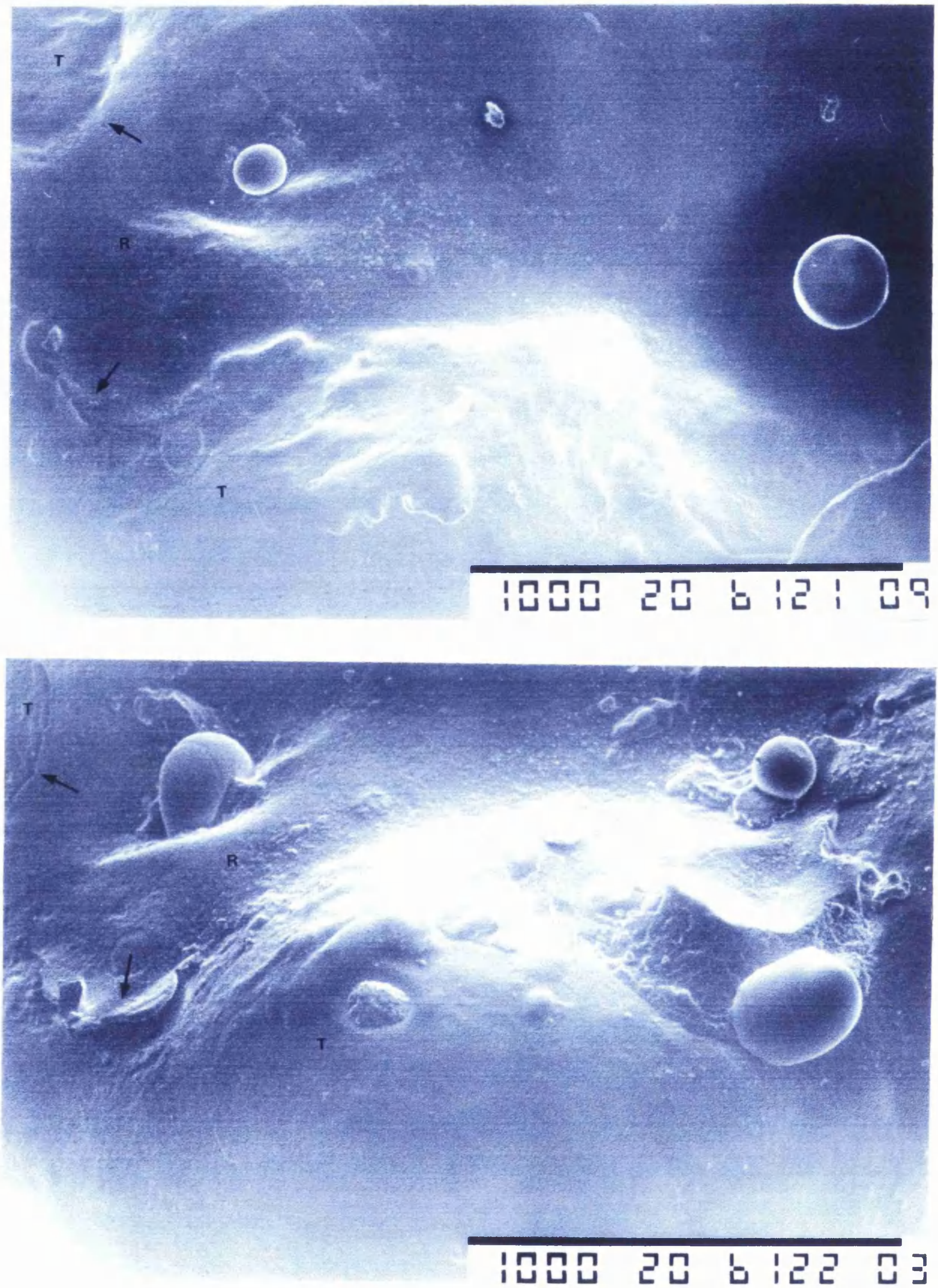


Figure 5.6: Photomicrograph of the existing gap on the margin of a restoration: **a.** before (Mag. x22) and **b.** after thermocycling (Mag. x22) (SEM), sample from drill treated group (Arrow points to the existing gap, R= Restoration, T= Tooth).

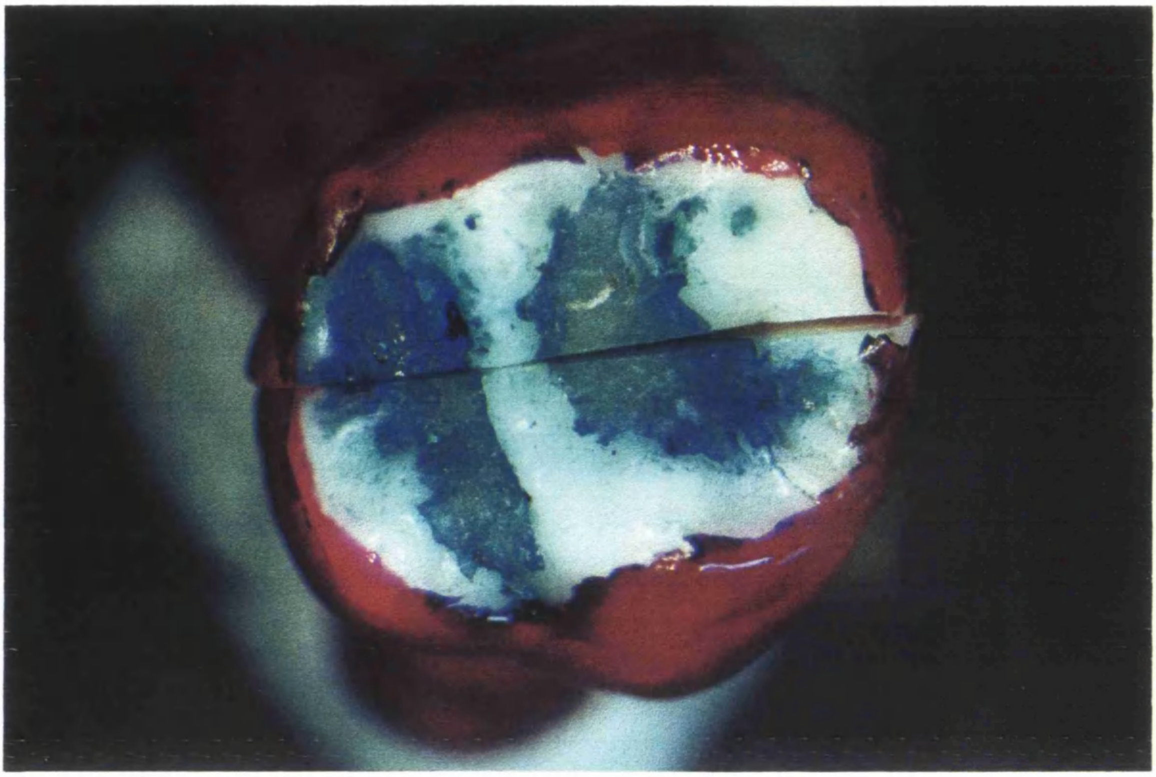


Figure 5.7: Demonstrates the cutting line through the centre of the restoration.

Figure 5.8: The microtome with diamond saw used for dissecting the restored teeth for the assessment of the dye penetration depth (microleakage level) around the restorations.

5.8.9.3 Assessing the penetration depth of the dye:

Sectioned teeth were assessed using a light microscope (Zeiss, Germany) with 10 and 20 times magnifications. The degree of dye penetration was scored based on the following criteria (Saunders Strang and Ahmed, 1991):

0 = No leakage

1 = Dye penetration up to half way along the wall of the cavity

2 = Dye penetration to full depth of the wall of cavity

3 = Dye penetration on pulpal floor

4 = Extensive dye penetration towards pulp

Different scores of microleakage of restorations are illustrated in figures 5.9 (a,b,c,d,e).

5.8.10 Statistical analysis :

A two sample t-test was carried out to assess the differences of the gap size before and after thermocycling. Mann-Whitney tests were carried out to compare the level of microleakage in primary and permanent teeth of both laser- and drill-treated groups.

5.9 Results:

Findings of measurements on the gap size changes, in addition to the levels of microleakage following thermocycling are described below:

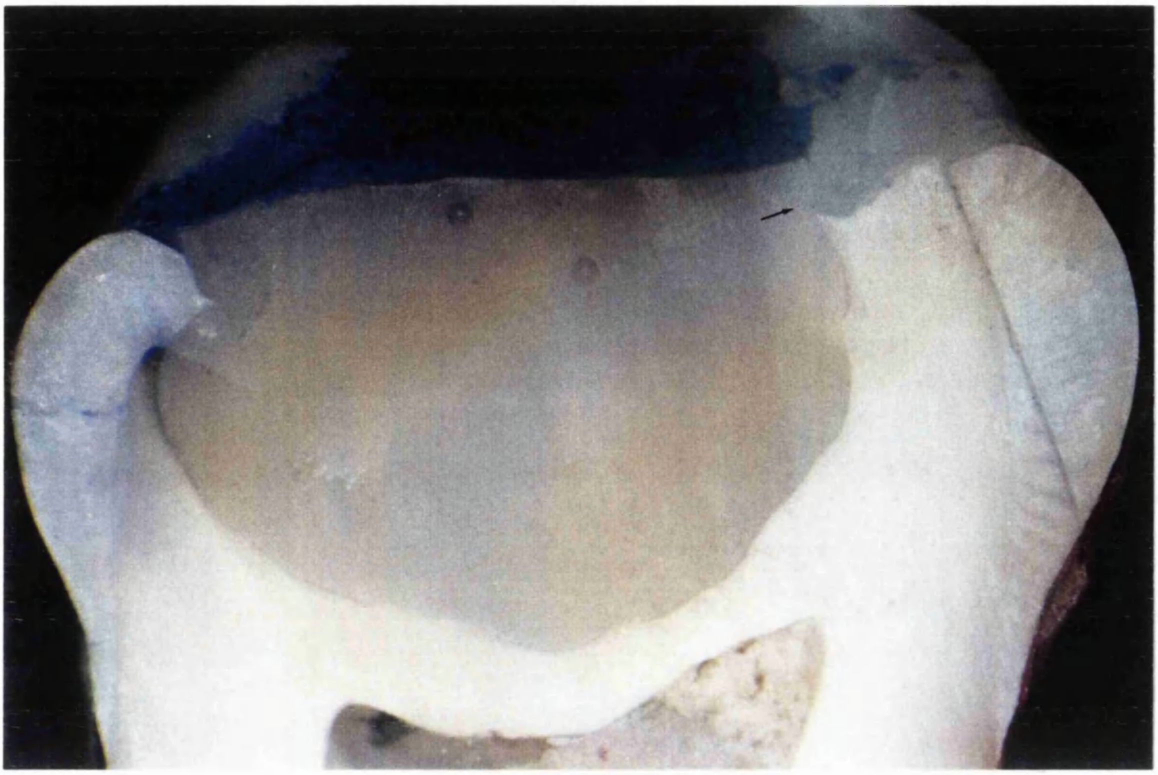


Figure 5.9a: Score 0 of microleakage around the restoration (right side of the restoration) (see text for details).

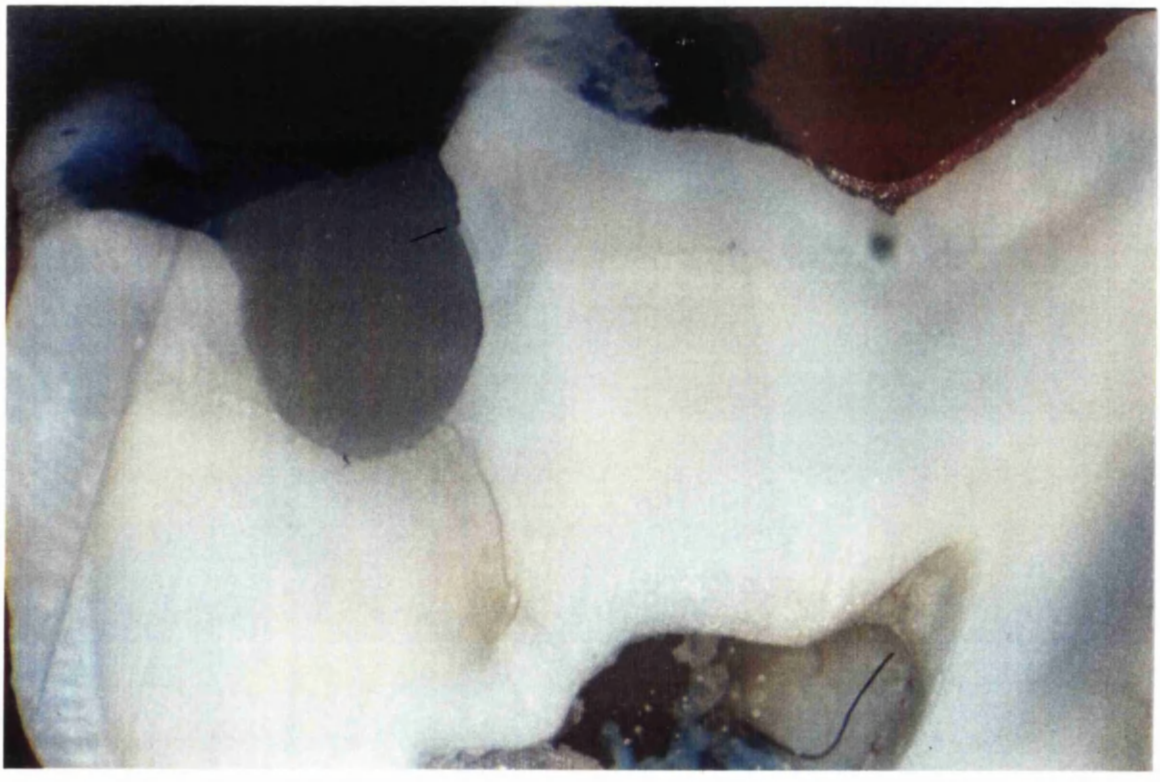


Figure 5.9b: Score 1 of microleakage around the restoration (right side of the restoration) (see text for details).

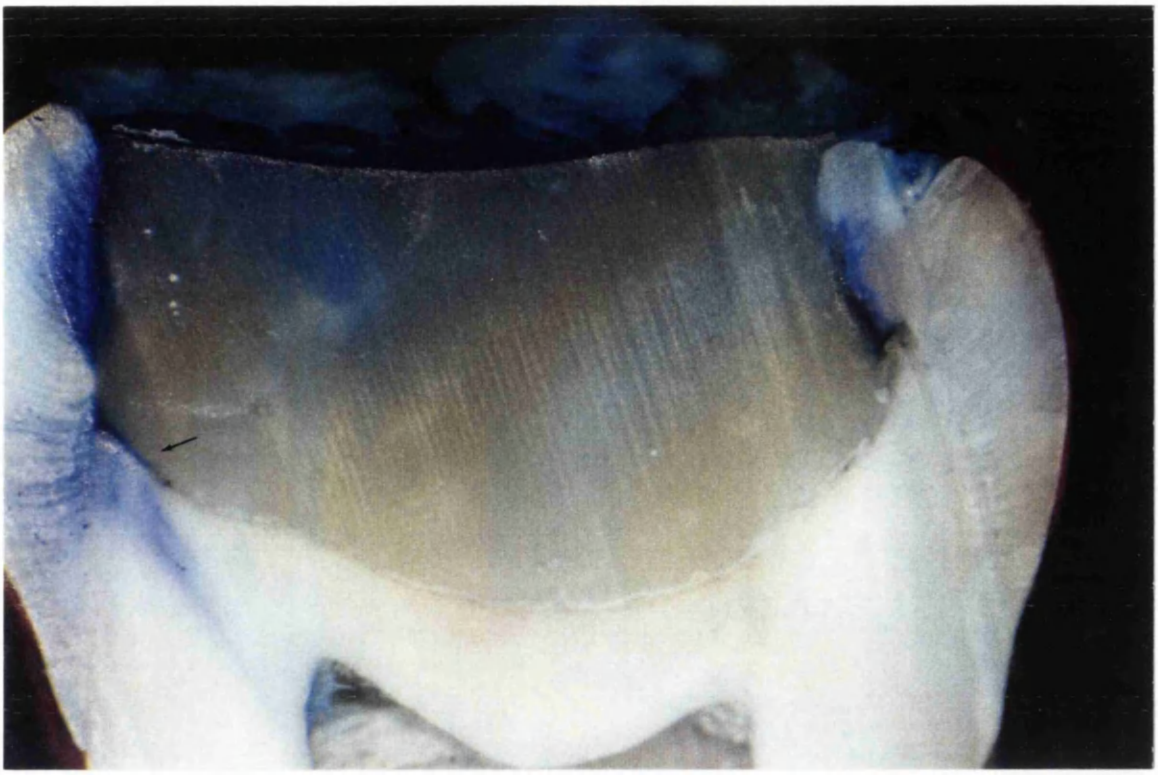


Figure 5.9c: Score 2 of microleakage around the restoration (left side of the restoration) (see text for details).

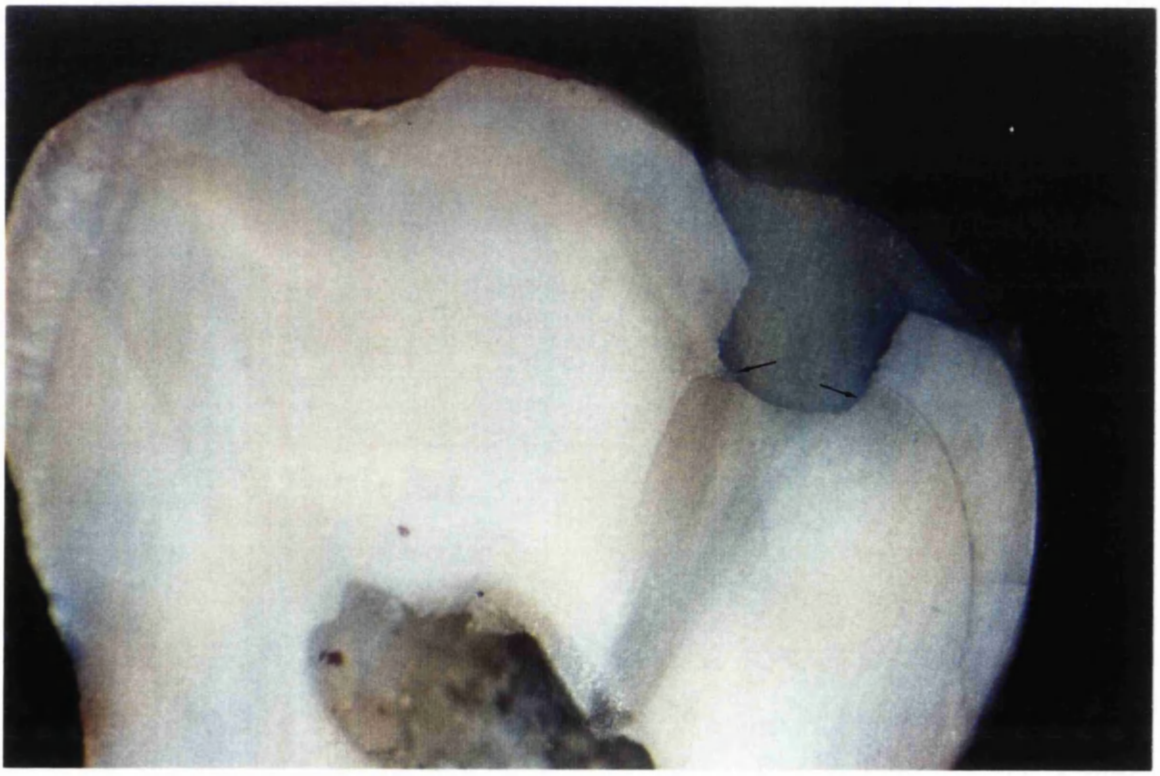


Figure 5.9d: Score 3 of microleakage around the restoration (both sides) (see text for details).

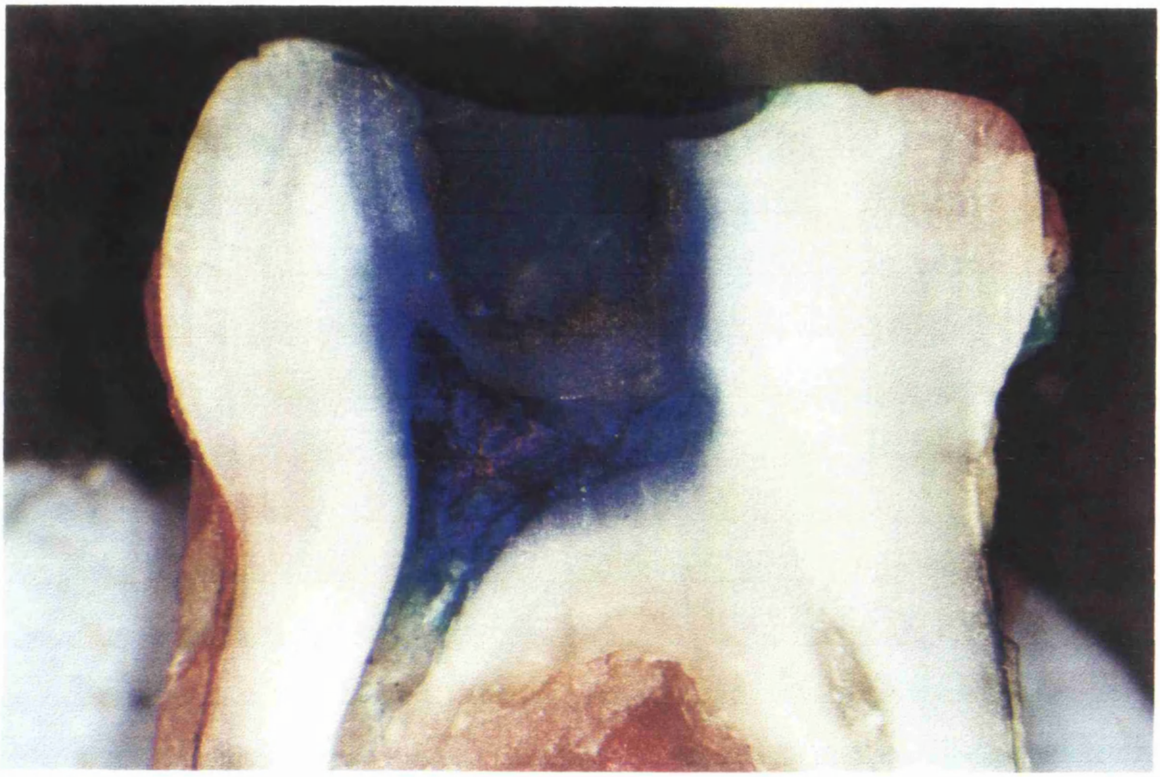


Figure 5.9e: Score 4 of microleakage around the restoration (see text for details).

5.9.1 The effect of thermocycling on the gap size:

The mean maximum gap size before and after thermocycling for both primary and permanent teeth are presented in table 5.1, in addition to the differences from before and after thermocycling. The changes of mean maximum gap size (Δ) were calculated from data achieved for each sample before and after thermocycling. The measured gap sizes showed a wide range between groups and even within each group. The mean maximum gap size of the restorations of laser and drill prepared cavities (Table 5.2) were 90.3 ± 45.3 μm and 62.2 ± 56.3 μm, respectively, prior to the thermocycling. These values were 75.8 ± 28.1 μm and 78.9 ± 56.2 μm after thermocycling, indicating a reduction in gap sizes of restoration in the laser-treated teeth while these values showed an apparent increase in the conventionally treated teeth. However, statistically no significant difference was found between the gap sizes of restorations of laser and drill prepared cavities following thermocycling (Table 5.3).

5.9.1.1 Differences of the gap size on restored teeth treated by laser or drill:

Comparing the results of the gap size measurements in the two groups of laser- and drill-treated teeth (Table 5.2) revealed that restorations in the laser-treated group had a higher score of gap size compared to that of the control group, both in primary and permanent teeth. However, this difference was more marked in primary teeth than in permanent teeth. The mean maximum gap sizes measured on samples before and after thermocycling, presented in tables

Table 5.1: The mean maximum gap size at the restoration margins, before and after thermocycling, for different treatment methods, both in primary and permanent teeth with the differences from before to after thermocycling.

caries removal method	type of teeth	No. of teeth	mean MGS before Tc. (μ)	mean MGS after Tc. (μ)	Δ (μ)
Laser	primary	5	80 ± 41	91 ± 32	11 ± 13
	permanent	5	75 ± 79	100 ± 74	-40 ± 42
Drill	primary	5	100 ± 52	60 ± 14	26 ± 60
	permanent	5	49 ± 22	57 ± 22	8 ± 33

MGS= maximum gap size
Tc. = thermocycling
Δ= Differences in means

Table 5.2: The mean maximum gap size of the tooth/restoration margins for different treatment methods, both before and after thermocycling (p value from two sample t-test).

Measurement point	Caries Removal Method	No. of teeth	Mean MGS (μ),SD	p	DF
Before Thermocycling	Laser	10	90.3 ± 45.3	0.24	17
	Drill	10	62.2 ± 56.3		
After Thermocycling	Laser	10	75.8 ± 28.1	0.88	13
	Drill	10	78.9 ± 56.2		

MGS= maximum gap size
Tc. = thermocycling
DF= Degree of Freedom

Table 5.3: The mean maximum gap size of the tooth/restoration margins for two treatment methods, both before and after thermocycling (p value from two sample t-test).

Caries Removal Method	Measurement point	No. of teeth	Mean MGS (μ), SD	p	DF
Laser	Before Thermocycling	10	90.3 ± 45.3	0.40	15
	After Thermocycling	10	75.8 ± 28.1		
Drill	Before Thermocycling	10	62.2 ± 56.3	0.52	17
	After Thermocycling	10	78.9 ± 56.2		

MGS= maximum gap size
SD = Standard Deviation
DF= Degree of Freedom

5.4 and 5.5, were found to have no significant difference between primary and permanent teeth treated by either laser or drill.

Results of two sample t-tests on the overall gap size values measured before and after the thermocycling showed no significant difference in any of the two control and test groups ($p = 0.40$ and $p = 0.52$, respectively) (Table 5.3). The same test was carried out on the effect of treatment method and the type of teeth on gap size. Results showed no significant differences ($p = 0.24$) between the gap size of restorations of laser and drill prepared cavities, prior to the thermocycling, with larger mean maximum gap size recorded in the laser group (Table 5.2).

5.9.1.2 Differences in the existing gap sizes in restorations between primary and permanent teeth:

The mean maximum gap size of restorations of primary and permanent teeth, before thermocycling, were 78 ± 59 μm and 75 ± 46 μm, respectively (Table 5.6). These values were increased to 83 ± 57 μm in primary teeth while decreased to 54 ± 18 μm, in permanent teeth (Table 5.6). Two sample t-tests showed no significant differences between the two groups of primary and permanent teeth, both before and after thermocycling ($p = 0.90$ and $p = 0.17$, respectively) (Table 5.6). These results indicate that perhaps both primary and permanent teeth, with similar histochemical structures, have a similar level of adhesion and adaptation properties to the restoration used in this study.

Table 5.4: The mean maximum gap size at the restoration margins for laser and drill treated teeth with the *p* value of the differences between the MGS before thermocycling, in primary and permanent teeth (p value from two sample t-test).

caries removal method	type of teeth	No. of teeth	mean MGS beforeTc. (μ)	p	DF
Laser	primary	5	80 ± 41	0.52	7
	permanent	5	75 ± 79		
Drill	primary	5	100 ± 52	0.52	4
	permanent	5	49 ± 22		

MGS= maximum gap size
Tc. = thermocycling
DF= Degree of Freedom

Table 5.5: The mean maximum gap size at the restoration margins for laser and drill treated teeth with the differences between the MGS, measured after thermocycling, in primary and permanent teeth (p value from two sample t-test).

caries removal method	type of teeth	No. of teeth	mean MGS after Tc. (μ)	p	DF
Laser	primary	5	91 ± 32	0.10	5
	permanent	5	100 ± 74		
Drill	primary	5	60 ± 14	0.28	5
	permanent	5	57 ± 22		

MGS= maximum gap size
Tc. = thermocycling
DF= Degree of Freedom

Table 5.6: The mean maximum gap size of the tooth/restoration margins for two groups of primary and permanent teeth, both before and after thermocycling (p value from two sample t-test).

measurement point	teeth type	No. of teeth	Mean MGS (μ)	p	DF
Before Thermocycling	primary	10	77.7 ± 59.4	0.90	16
	permanent	10	74.8 ± 46.1		
After Thermocycling	primary	10	83.1 ± 57.3	0.17	10
	permanent	10	54.9 ± 18.4		

MGS= maximum gap size
Tc. = thermocycling
DF= Degree of Freedom

Gap size in Micrometers

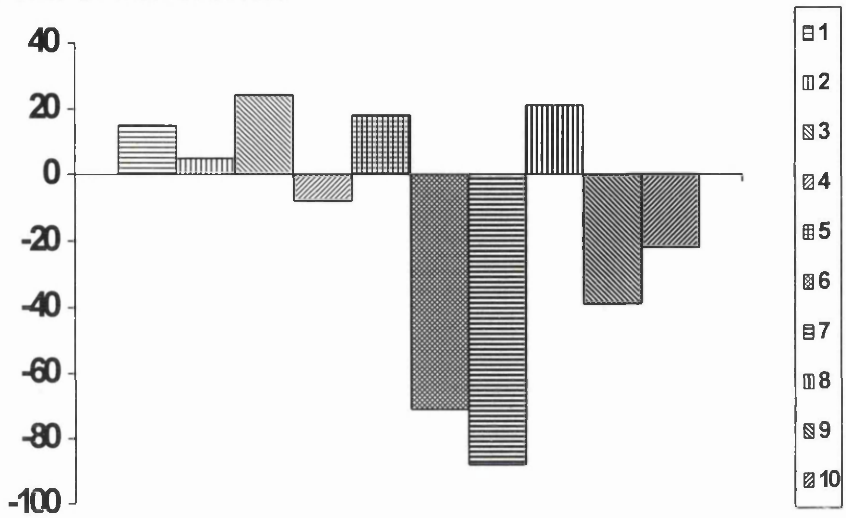


Figure 5.10: The differences of maximum gap size measured before and after the thermocycling are presented for restorations of laser treated teeth.

Gap size in Micrometers

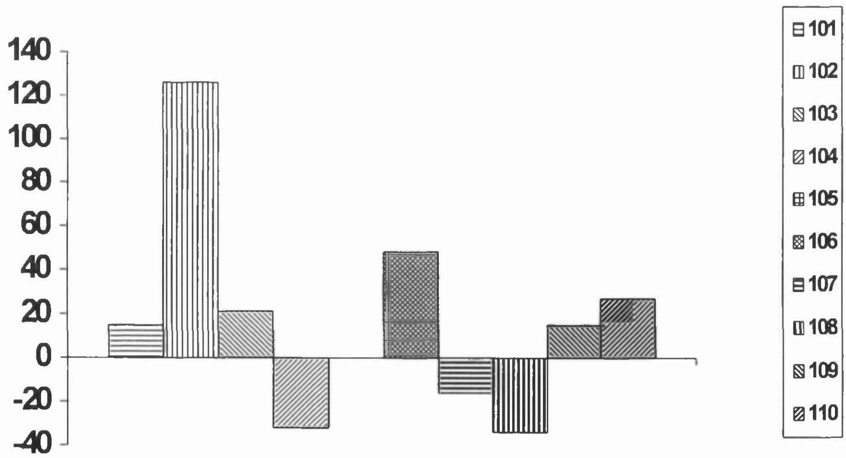


Figure 5.11: The differences of maximum gap size measured before and after the thermocycling are presented for restorations of drill treated teeth.

5.9.1.3 Differences in the gap sizes before and after thermocycling:

Comparison between the gap sizes measured before and after thermocycling revealed that there was an overall tendency of reduction in the size of the gap of the restorations in laser treated group (Table 5.3). However, this difference was tested for its statistical significance using a two sample t-test, the results of which indicated that there was no significant differences between the changes in gap size of restorations before and after thermocycling in two groups of differently prepared cavities ($p = 0.40$ in laser group and $p = 0.52$ in drill group) (Table 5.3). Figures 5.10 and 5.11 show the individual values of the gap sizes following thermocycling, in the form of histograms.

5.9.2 Findings of microleakage assessments:

The level of microleakage was found to be generally higher in the case of drill-treated primary teeth than those treated with the laser. While these results were contrary to those found in permanent teeth with the laser-treated teeth showing higher microleakage of restorations (Table 5.7). Details of the comparisons between these groups of differently prepared cavities and the differences between primary and permanent teeth, after thermocycling, are presented in the following sections:

5.9.2.1 Finding the level of microleakage in differently prepared cavities:

Comparing the results of microleakage in primary teeth between the two groups of laser and drill treatment revealed no significant difference ($p = 0.933$) using a Mann-Whitney test. However, in permanent teeth this comparison between the

Table 5.7: Presents the number of primary and permanent teeth with their relevant degree of microleakage in both laser and drill prepared cavities.

			Microleakage Score				
type of teeth	Treatment method	No. teeth	0	1	2	3	4
Primary	Laser	20	4	5	9	0	2
	Drill	20	4	8	1	3	4
Permanent	Laser	20	4	5	1	5	5
	Drill	20	6	9	4	0	1

Table 5.8: The differences between the level of microleakage of restorations in laser and drill treated teeth were tested in individual groups of primary and permanent teeth, using Mann-Whitney test for the degree of microleakage.

type of teeth	Treatment method	No. teeth	Mean MLS Score, (SD)	Median MLS	CI	p
Primary	Laser	20	1.55 ± 1.15	2.00	-1.00,1.00	0.933
	Drill	20	1.75 ± 1.48	1.00		
Permanent	Laser	20	2.10 ± 1.55	2.50	0.00,2.00	0.039
	Drill	20	1.05 ± 0.99	1.00		

MLS= Microleakage Score
CI= Confidence Interval

Table 5.9: The differences between the level of microleakage of the restorations following laser/drill caries removal (p value from Mann-Whitney test).

Treatment method	No. of teeth	Median MLS	CI	p
Laser	40	2.00	0.00,1.00	0.137
Drill	40	1.00		

MLS= Microleakage Score
CI= Confidence Interval
Mann-W= Mann-Whitney

two groups of laser and drill was found to be significant ($p= 0.0176$) using the same test (Table 5.8). Permanent teeth showed a lower level of microleakage when they were treated conventionally compare to those treated by the laser with a reverse result in primary teeth. An overall comparison was carried out between the level of microleakage of restorations in laser- and drill-treated teeth, the results of which indicated no significant differences between the two techniques (Table 5.9). This could perhaps indicate that the laser caries removal method might be as efficient as conventional drilling.

5.9.2.2 Comparing the level of microleakage in two groups of primary and permanent teeth:

Comparison between the level of microleakage of restorations in primary and permanent teeth treated by laser or drill revealed no significant difference between primary and permanent teeth treated by drill ($p= 0.176$) using a Mann-Whitney test. The difference was also not significant ($p= 0.286$) between the lased groups of primary and permanent teeth (Table 5.10). Similar results were achieved when these differences were tested by a Kruskal-Wallis test (Table 5.11).

5.10 Discussion:

The use of a microleakage assessment technique, in addition to a microscopic evaluation of the margins of restorations for the presence of any gap was performed for this part of the study, since this was the most common technique for this purpose. Other techniques for assessing restoration properties e.g.

Table 5.10: The differences between the level of microleakage of restorations in primary and permanent teeth, treated by laser or drill are presented with the p value from the Mann-Whitney test.

Treatment method	type of teeth	No. teeth	Mean MLS Score, (SD)	Median MLS	CI	p
Laser	Primary	20	1.55 ± 1.15	2.00	-2.00,1.00	0.286
	Permanent	20	2.10 ± 1.55	2.50		
Drill	Primary	20	1.75 ± 1.48	1.00	0.00,1.00	0.176
	Permanent	20	1.05 ± 0.99	1.00		

MLS= Microleakage Score
CI= Confidence Interval

Table 5.11: The differences between the level of microleakage of the restorations in primary and permanent teeth following laser/drill caries removal using Kruskal Wallis test.

Treatment method	type of teeth	No. teeth	Median MLS	p	df
Laser	Primary	20	2.00	0.280	1
	Permanent	20	2.50		
Drill	Primary	20	1.00	0.172	1
	Permanent	20	1.00		

MLS= Microleakage Score
CI= Confidence Interval
df= Degree of Freedom

wear and compressive strength, were not within the limit of this experiment. The use of thermocycling was decided to be included as it has been supported strongly in the literature to be able to simulate closely the environment of the mouth (Crim, Swartz and Phillips, 1985). It has been shown that the degree of dye penetration does not appear to differ significantly between specimens subjected to 100 or 1500 thermal cycles and, therefore, within this range the effect would not be different (Crim and Garcia-Godoy, 1987). It was decided, therefore, to set the thermocycling machine on 350 cycles which was within the recommended range.

The complementary microscopic investigation of the margins of restorations for the presence of marginal gap was to identify any technical failure during the restoration stage. This was shown by comparing the presence of the gap prior to thermocycling, which in certain situations can be the main cause of microleakage (Reid *et al.,* 1994). Bearing in mind that each fast setting restorative material including the light cured series, have the problem of shrinkage during polymerisation (Donly *et al.,* 1987), it is, therefore, important to evaluate the changes in the gap size following thermal shocks similar to those within the mouth.

Since Buonocore (1955) first introduced the acid etch technique for enhancing the retention of resins, most research has concentrated on formulating a material which will give a strong and permanent bond to calcified tissues.

Dentine, due to its higher water and organic content, provides a more problematic bond than enamel. An initial shrinkage occurs as the result of polymerisation of resin-containing restorative materials which produces gaps at the tooth/restoration interface (Torstonson and Brännström, 1988). These gaps allow an ingress of micro-organisms, bacterial products, ions, enzymes, a process known as microleakage (Kidd, 1976). Elderton (1976a) in a literature review, reported the result of overall assessment of the existing restorations as showing a high prevalence (one third) of unsatisfactory restorations. It is, therefore, necessary to improve both the quality of restorative materials and the method and quality of cavity preparation to improve bonding. Poor adaptation of the restoration to the margins of the prepared cavity leads to a gap between the wall of the cavity and the body of the restoration. This defect allows bacteria to ingress and subsequently activate a demineralisation process (Kidd, 1976).

Different factors may influence microleakage, including: 1. Cavity design (Healey and Philip, 1949; Elderton, 1976b), 2. Properties of the restorative materials (Elderton, 1975), 3. Faulty restorative techniques (over/under filled) (Gilmor and Sheiham, 1971), 4. Residual/recurrent caries (Allan, 1969), 5. Traumatic occlusion (Healey and Philip, 1949).

Based on the findings of the present investigation, there was no statistically significant difference (p= 0.933) between the level of microleakage in the groups of laser- and drill-treated primary teeth. However, the difference was significant (p= 0.039) between the two groups of laser- and drill-treated permanent teeth with laser group showing higher microleakage levels. This may suggest that only laser caries removal in primary teeth may be capable of producing a similar result to that of the drill. In conventional drilling, results demonstrated a varying degree of dye penetration, indicating a difference between the structure of dentine and enamel of primary and permanent teeth. Comparison of the microleakage result in the laser-treated teeth indicated similar surface characteristics with no obvious difference between the two groups of primary and permanent teeth.

It is believed that the process of melting causes the dentinal tubules to occlude (Stabholz *et al.,* 1995; Pashley *et al.,* 1992) and, therefore, after resolidification the resultant surface would not have any undercuts to hold the restoration in place. Changes in the dentine surface due to high temperature, causing melting of the surface, may also affect the crystalline structure of this surface and, therefore, reduce the bonding property of the treated surface (Kantola, 1973; Cernavine, 1995).

The presence of a microscopic gap was common in both groups of treated teeth. The restorations of the laser-treated teeth presented a higher mean maximum gap size at their margins compared to those of the conventionally prepared teeth. However, this difference was not found to be significant and, therefore, it is possible to conclude that the laser technique tested in this experiment is capable of producing a prepared surface similar to that of the conventional method. No differences were also found between the two groups of primary and permanent teeth, indicating that perhaps with a similar material and similar tooth structure, cavity preparation technique, as the only difference, did not have a significant influence on the presence and change of gap size following thermocycling. However, comparing the individual groups showed that gap sizes were reduced after thermocycling in laser-treated teeth while these values were increased in conventionally treated teeth. It is not quite clear why the thermocycling process produced these different effects on the two groups. Further investigations with larger number of samples are required to clarify the differences and reasons for these differences.

5.11 Conclusion:

The following conclusions can be made from the results of this study:

1. There were no significant differences in the gap sizes of restoration margins between primary and permanent teeth following either laser/drill cavity preparation.
2. Microscopic gaps were present around the restorations of both laser- and drill-treated teeth, with no significant differences between the mean maximum gap sizes of the two groups.
3. A significant difference was observed between the level of microleakage of restorations in permanent teeth following laser/drill treatment with higher microleakage evident in lased teeth.

4. No significant differences were found between the level of microleakage in restorations in primary teeth following laser/drill treatment with slightly higher microleakage in drilled teeth.

CHAPTER VI

CLINICAL TRIAL: LASER EFFECT ON PATIENT'S ANXIETY AND THE DENTAL PULP

CHAPTER 6: Clinical applicability of the laser for removing dental caries in anxious children.

6.1 Introduction

Treatment of dental caries has always been one of the major concerns for patients attending dental practices. Dental fear can appear both in childhood and adulthood. Uncertainty and stress prior to the dental appointment will automatically influence the patient's attendance and behaviour during the course of treatment. In paediatric dentistry, a child's first impression is very important, as this can build up and establish a good relationship between patient, dentist and even parents which will then provide an adequate level of co-operation (Kent and Blinkhorn, 1992). It is well acknowledged that unpleasant experiences from past dental treatment, particularly the painful application of rotary instrument, affects directly the future behaviour of the young patient, which may result in avoidance of further treatment. In this Chapter, the clinical applicability of an Nd:YAG laser radiation will be discussed as an alternative method of caries removal. Patients' acceptance level of this technique is tested in a young population in addition to its long-term effects on the pulp status of irradiated and control primary teeth.

6.2 Importance of restoration in primary teeth:

There are several reasons why primary teeth should be preserved until their natural physiologic exfoliation, including: the physiological growth of the jaws, prevention and pain relief, chewing function, preventing malocclusion, aesthetic, phonetic, and finally the child's emotional stability. To avoid these clinical complications, primary teeth should be treated and maintained until their natural physiological exfoliation. Treatment becomes much easier to deal with if the carious defect is treated at an early stage which will save both time and material, as well as preventing pulpal involvement. The problem of speech defects caused by early loss of primary incisors has been described as temporary which will be restored spontaneously by eruption of permanent teeth (Curzon, Roberts and Kennedy, 1996). It is very important to avoid unnecessary extraction of primary teeth as early extraction can cause space loss and, therefore, crowding due to disruption in the normal eruption process (MacDonald, Henon and Avery, 1987). It can, therefore, be concluded that restoration of carious primary teeth is essential as primary teeth facilitate normal eruption of the permanent dentition.

6.3 Prevention and pain relief:

Amongst the reasons discussed earlier in Section 6.2, prevention and pain relief are considered to be the most important issues in the treatment of dental caries in children. Prevention of dental caries is a cost effective, easy, and commonly applicable approach to children which removes the need for providing active treatment services. Negligence of receiving prevention and lack of treatment due to the fear of the dental environment may result in progression and extension of caries to the pulp causing pulpal pathology and pain. Lack of sleep and distress, caused by a painful tooth, may influence a patient's behaviour and, therefore, makes any further treatment difficult. It is clear, therefore, that if pain can be relieved without any additional distress, it will result in the patient's future co-operation for dental treatment.

6.4 Dental anxiety:

Terms like anxiety, apprehension, fear and panic all indicate uncertainty and uneasiness of a forthcoming event (Sinclair *et al.,* 1994). A "phobia" is an excessive fear, which can be described as an unreasonable or an irritational fear of a subject or a place i.e. the dental surgery. Fear is an emotion and normal response which is derived from the Middle English word "Faer", meaning sudden danger (Kroeger, 1987). It seems, therefore, that "dental phobics" are those who refuse/ or hardly accept any dental visit, while "anxious" and "apprehensive" patients are those who eventually accept treatment, but are in stressful condition (Friis-Hasche and Hutchings, 1990).

Anxiety towards dental treatment is commonly expressed by most patients attending the dental surgery. About 10-12 million Americans have been reported to be dental phobic with an additional 35 million of the population suffering from excessive anxiety during the course of dental treatment (Ayre *et al.,* 1983). These figures indicate the considerable magnitude of the problem in providing dental care.

Different levels of anxiety are seen in patients, even with varying degrees on different occasions. Young patients are more easily frightened, due to their uncertainty and lack of experience of dental treatment. Painful dental treatment is one of the most common reasons why a child will refuse further treatment (Curzon, Roberts and Kennedy, 1996). Fear of dental treatment may occur in children following the reaction of another child who is receiving treatment. Mismanagement by the dentist has been described as the most common reason for fear of dental treatment, and it is believed that most of the behavioural problems in children can be managed by proper personal interactions (Ayre *et al.,* 1983). Highly anxious mothers can have a negative influence on their child's behaviour in the dental practice (Johnson and Baldwin, 1969; Wright, Alpern and Leake, 1973).

It is important to overcome the patient's anxiety and fear before treatment can be carried out. This is where the treatment of anxious patients becomes highlighted. In this respect, the origin and the nature of the fear, including childhood and adulthood anxiety, should be differentiated, as they may respond differently to varying techniques of anxiety control employed by the dentist, simply due to the level of their understanding.

6.4.1 Dental anxiety in children:

Dental phobia is more predominant in youngsters and seems to be the starting point for adulthood fear of dentistry, which in about 85% of cases follows a traumatic experience (Ayre *et al.,* 1983). In young children, the dental personnel are considered as the most important factor in establishing fear, whereas in older age groups, pain is described as the most important factor (Berggren and Meynert, 1984). Kleinknecht, Klepac and Alexander (1973) have reported that the sight of the anaesthetic needle and the sight, sound, and sensation of the drill are the main factors causing an increase in fear in a dental practice, with females rated more fearful than males. Todd and Walker (1980) reported that 43% of patients do not attend the dentist unless they were experiencing dental pain.

6.4.2 Current scoring systems for assessing dental anxiety:

In order to accurately deal with the anxiety of individuals, it is important to diagnose the aetiology of the fear with some kind of estimation as to the level of anxiety, which will, therefore, lead to the most appropriate method of behavioural management. Several anxiety assessment techniques have been suggested prior to and during the course of dental treatment. These methods involve either the operators judgement of the level of patient's anxiety at the dental visit (Frankl, Shiere and Fogel, 1962; Melamed *et al.,* 1975), or a patient's self assessment by expressing their feeling using pictorial charts (Venham, 1979), and answering questions provided on those occasions which were thought to be fearful moments and subjects, in older patients (Gale, 1972; Corah, 1969; Klenknecht, Klepac and Alexander, 1973). In addition, parents of the child may be asked to judge their child's attitudes and behaviour before or during dental treatment (Klingberg *et al.,* 1995).

6.4.3 Current techniques for management of anxious patients:

Psychologists have developed several different techniques, to overcome management problems in the dental practice. These techniques are described as behaviour modification techniques, which is achieved by using the principles of learning theory (Wright, Starkey and Fardener, 1987). Each of the currently used techniques of behaviour management has its own particular indications and also certain limitations. Following are some of the most commonly used behavioural management techniques in dental practice: 1. behavioural modification techniques including: Modelling, tell-show-do, voice control (Wright, Starkey and Fardener, 1987), 2. pharmaco-therapeutic techniques using barbiturates and relaxants (Ayre *et al.,* 1983), and 3. hypnosis (Lampshire, 1975).

If desensitisation therapy is practised by trained therapists, it can dramatically help fearful individuals to receive adequate dental treatment (Gale and Ayre, 1969). In addition, development of new drugs, such as intravenous benzodiazepines, and behavioural techniques have enlarged and improved the choice for dentists (Ayre *et al.,* 1983). These anxiety-reducing and sedation techniques can be used individually or together to decrease the patient's discomfort prior to and during the course of dental treatment (Ayre *et al.,* 1983). To avoid problems and risks involved i.e. administration of relaxant drugs, in addition to the simplicity of the technique, there remains a need to research and develop atraumatic and painless techniques for caries removal.

6.5 Laser treatment of dental caries:

The use of dental lasers as a non mechanical technique for removing caries has been advocated as a potentially pain-free technique which can be used in the absence of local anaesthetic (Bassie, Chawla and Patel, 1994), and therefore, may be considered as an alternative for treating dental caries in patients with a needle phobia. The Nd:YAG laser beam, has been shown histologically to be effective enough to remove carious dentine as efficiently as conventional drilling (Myers and Myers, 1985a). However, the potential for pulpal damage following the production of high temperatures still remains a problem (Adrian, 1977).

6.5.1 Laser analgesic effect:

Laser radiation has been advocated to be capable of inducing some degrees of analgesia during operative dental treatment, including caries removal (Parkins and Miller, 1992). In this respect, the Nd:YAG laser has been suggested to induce pulpal analgesia prior to caries removal and thus reduce the need for local anaesthetic (Bassie, Chawla and Patel, 1994). However, only a slight analgesic effect was reported to be achieved following the application of an Nd:YAG laser irradiation of enamel (Whitters *et al.,* 1995). More research is required to clarify appropriate laser parameters and the exposure times should be selected to achieve the desire level of anaesthesia of the pulp for cavity preparation.

6.5.2 Hazards of laser application in clinical dental practice:

Laser radiation is a high intensity light energy which can be damaging to the biological tissues, particularly eyes, if viewed directly. Precautionary measures should be taken for all people present in the operating room during laser irradiation. Properly selected protective glasses, suitable for use with the operating laser, should be worn during the whole procedure. It is essential to operate the laser in an isolated surgery where enough protective measures can be provided. It is also important to apply the laser beam carefully to the target area and avoid directing the laser radiation or its reflected radiation from the dental mirror or any shinny surface to the surrounding structures, as this can cause unexpected tissue damage (Miller and Truhe, 1993). Surprisingly, micro-organisms are believed to be able to remain viable in laser produced smoke, as HIV virus has been found viable within the smoke sample taken immediately after production and even after 14 days of culturing (Baggish *et al.,* 1991).

6.5.3 Effects of laser radiation on the dental pulp:

Thermal damage of the pulp is considered to be the main complication associated with the clinical use of lasers for removing dental caries. This may lead to irreversible changes of the pulp tissue. Different lasers act differently when they are exposed to the dental hard tissue, due to their varying absorption coefficients, and are directly related to the laser wavelength as well as the irradiated tissue. The Nd:YAG laser, for example, has been reported to penetrate easily through the thickness of enamel and dentine and into the dental pulp. Therefore, care should be taken during laser irradiation of a vital tooth to avoid damaging the pulp.

Pulp and periodontium can suffer from injuries caused by laser irradiation by wavelengths greater than 390 nm due to heat production or even transmission and scattering of the laser beam through enamel and dentine (Arcoria and Miserendino, 1995; Dederich, 1991). Dilation of pulpal blood vessels, as an acute haemolytic response, has been reported due to the production of extensive heat during laser irradiation of the teeth (Nyborg and Brännström, 1968).

Miserendino *et al.* (1994) examined the pulp of laser-irradiated teeth of rhesus facicularis and showed that no histological changes had occurred within the dental pulp following irradiation of dentine for removal of caries. No significant differences have been reported between the histological condition of the pulp in laser- or drill-treated teeth during the six month follow up period of the teeth (Goodis, Schein and Stauffer, 1988). This may be due to the nature of pulpodentinal complex which is dynamic and, therefore, has a potential of heat compensation due to the presence of the dentinal fluid and blood circulation. The amount of heat conducted to the pulp is considerably reduced due to the low conductivity of dentine and also the effect of blood circulation of the pulp by absorbing the generated heat (Schuchard and Watkins, 1961). It is suggested that necrosis may occur rarely in young teeth due to the low thermal conductivity of dentine, in addition to the high pulpal blood supply (Bahcall *et al.*, 1993).

6.6 Aims and Objectives

The aims of this experiment were:

1. To assess patients' acceptance level of the laser caries removal technique compared to the conventional drilling method.
2. To evaluate the long-term laser effect on the pulp of irradiated primary teeth.
3. To assess the parents' views on the suitability of the technique for their children.
4. To assess the bonding capacity of differently prepared cavities and the long term prognosis of these restorations *in vivo.*

6.7 Materials and Methods:

6.7.1 Ethical approval and laser safety considerations:

Ethical approval was obtained from the Area Dental Ethics Committee at Glasgow Dental Hospital and School NHS Trust for clinical application of the Nd:YAG laser for caries removal in primary teeth (Appendix E). Local safety rules were observed during the whole procedure of laser application as detailed in Appendix A. In addition, all parents were asked to sign an informed consent form supplied with the information sheet, prior to the treatment (Appendix F).

6.7.2 Patient selection and assessment

Fifty patients age ranged between 3 to 13 years, 22 males and 28 females, were selected over a six month period with varying degrees of anxiety. Table 6.1 demonstrates the distribution of patients in each sex group with their mean age. Patients were referred either by their General Dental Practitioner or from

Table 6.1: Distribution of the patients sex and their mean age value are shown in addition to the rate of the caries in each sex group.

sex	No. of Patients	mean age (yrs)	mean dmfs
Male	22	5.43 ± 1.7	12.05 ± 5.19
Female	28	7.14 ± 2.6	11.39 ± 6.43

Table 6.2: Percentage of patients with different degrees of anxiety before and after the treatment using laser or drill caries removal (Scores 1 to 4 from highly anxious to highly co-operative, details of each are described in section 6.10.1).

	Anxiety Scores	1	2	3	4
Laser	before treatment	12 (24%)	31 (62%)	7 (14%)	0
	after treatment	1 (2%)	12 (25%)	27 (56%)	8(17%)
Drill	before treatment	10 (21%)	32 (67%)	5 (10%)	1 (2%)
	after treatment	4 (8%)	24 (50%)	18 (38%)	2 (4%)

the Accident and Emergency Department at Glasgow Dental Hospital and School NHS Trust, for treatment of dental caries. Patients were mainly referred because of their anxiety towards dental treatment and/or lack of co-operation. Treatment of each patient was started with either the laser or drill caries removal techniques in an alternating sequence. Patients with at least two freshly carious primary teeth were selected for this trial. Either two or four teeth in each patient were selected, where available, with only the first two being used for the anxiety assessment, while all treated teeth were used for long term pulpal assessment and the survival rate of restorations. Epidemiological caries assessment of individual patients was performed using the dmfs scoring system (Table 6.1). In addition, the patient's anxiety assessment before and after the two treatment methods was recorded (Table 6.2) based on the details described below:

- Anxiety Assessment:

Patient's anxiety was assessed in two stages: 1. Prior to the treatment as the baseline for anxiety level, 2. Immediately after the completion of treatment to assess the effect of treatment method on the level of anxiety. A combination of patient, parent and operator's assessment methods of anxiety was employed in the present trial, the results of which are presented in tables 6.2 and 6.3. The results of the three anxiety assessment techniques are also presented in figures 6.1, 6.2 and 6.3. In this respect, patient's anxiety scoring was carried out by the operator (GA) using four point scoring system of anxiety, introduced by Frankl, Shiere and Fogel (1962), as detailed overleaf:

Table 6.3: Changes of the anxiety of patients towards the treatment based on the patient's self assessment using the modified pictorial chart (see Appendix B for details).

	1	2	3	4	5	6	7	8
Patient's Anxiety Score	2 (5%)	18 (41%)	3 (7%)	18 (41%)	1 (2%)	0	1 (2%)	1 (2%)

Scores 1 to 4 = reduced anxiety,
Scores 5 to 8 = increased anxiety.

Table 6.4: Number of patients with complaint during laser and drill caries removal.

		YES	NO
Complaint during treatment	Laser	27 (56.25%)	21 (43.75%)
	Drill	30 (62.50%)	18 (37.50%)

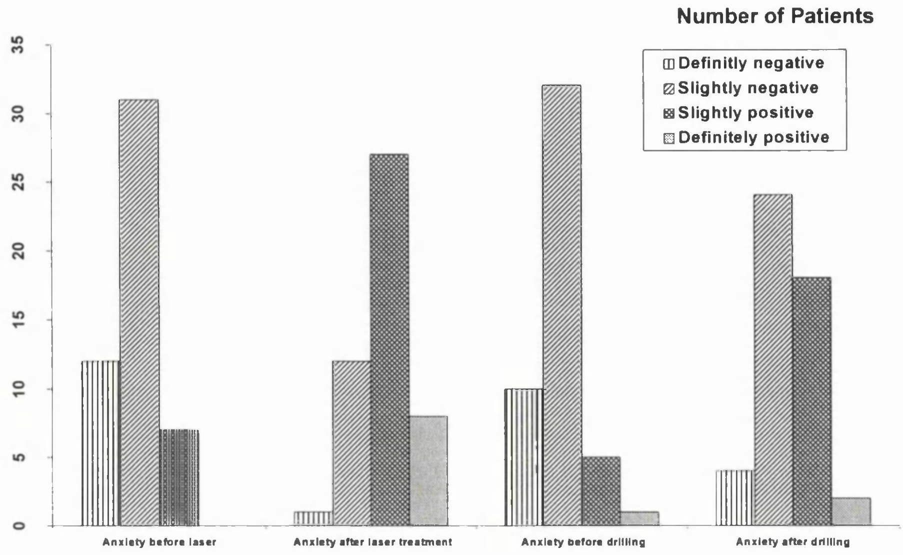


Figure 6.1: Anxiety score of patients before and after treatment using laser or conventional drilling are demonstrated in the form of histograms.

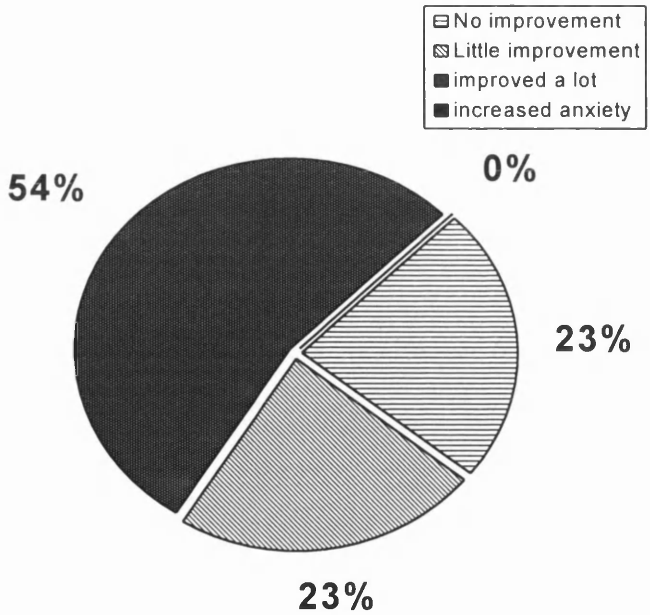


Figure 6.2: Pie chart shows the number of children with different levels of improvement in anxiety stated by parents.

1 = Highly anxious : Highly improved
2 = Moder anxious : Highly improved
3 = Slightly anxious : Moderately improved
4 = Anxious : Highly improved
5 = Anxious : Slightly improved
6 = Anxious : Moderately improved
7 = Anxious : Highly anxious
8 = Anxious : Highly anxious

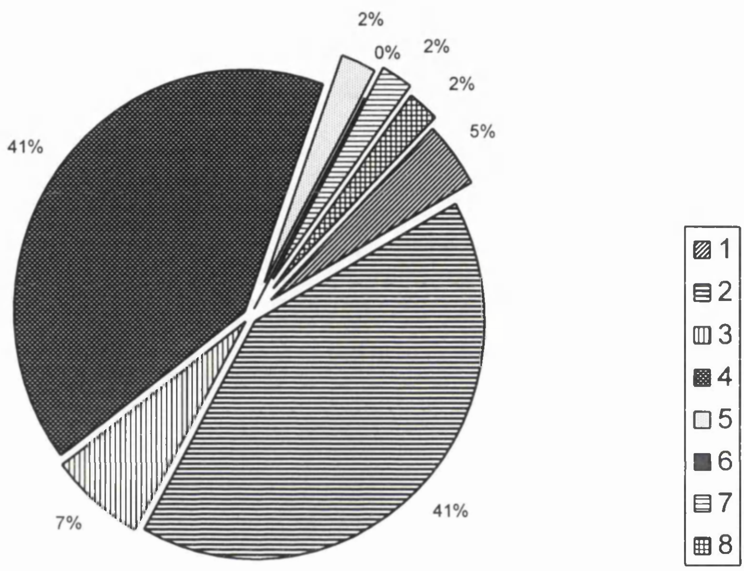


Figure 6.3: The distribution of patients with different anxiety scores.

1= Definitely negative: Refusal of treatment, over resistance, extreme fear, forceful crying, and massive withdrawal with isolation or both.

2= Slightly negative: Minor negativism or resistance and minimal to moderate reserved fear, nervousness or crying.

3= Slightly positive: Cautious acceptance of treatment, but with some reluctance, questions or delaying tactics, moderate willingness to comply with dentist.

4= Definitely positive: Good rapport with operator, no sign of fear, interested in procedures and appropriate verbal contact.

In addition to this objective assessment method, a complementary self assessment method was employed using a pictorial chart (Appendix B). This was performed, following the completion of the treatment, by asking the child to pick the most representative pair of pictures for his/her feeling towards the laser treatment. This modified pictorial assessment chart includes both the child's feeling before and after the treatment, results of which are shown in table 6.3. Parents were also asked about their impression of the laser technique for removing dental caries and its effect on their child's reaction towards the treatment, using a questionnaire (Appendix C). Patient's reaction during the cavity preparation procedure was finally recorded during treatment to enable the comparison between the frequency of reactions during laser treatment and conventional drilling (Table 6.4). All complaints were recorded including pain, smoke, heat, vibration, sound.

6.7.3 Tooth selection and evaluation:

Carious primary teeth were selected for this study, including both anterior and posterior teeth with all classes of cavities (Table 6.5). Teeth with relatively the same size cavities were selected, as judged clinically and radiographically, based on the scoring system described in Section 2.2.1 (Table 6.5). This was followed by pulpal assessment using thermal and electrical tests associated with a radiographic assessment of the periapical area. Assessment of pulpal status was carried out using: 1. Ethyl chloride (Syntex pharmaceutical Ltd, England), 2. Electric Pulp Tester (Analytic technology, USA), 3. Clinical examination of soft and hard tissue for any abnormalities, including abscesses. The level of pulpal response was recorded before and immediately after the treatment in addition to three follow up assessment stages of 1, 6 and 12 months. The clinical examination was carried out based on palpation, percussion, assessment of gingival texture and colour of the surrounding area. An initial radiographic evaluation of the periapical region and surrounding tissues was also performed to confirm the suitability of samples for this investigation.

As primary teeth have a phase of physiological root resorption which may influence the pulp response, attempts were made to choose only teeth with no or minimum root resorption. A maximum of less than two third of the original radiographic root length was considered as the limit to include the tooth for the trial, as this would also enable the proposed 24 month follow-up assessment.

Table 6.5: The distribution of different primary teeth, included in this study, class of the cavities (Black's classification), cavity size and the initial radiographic score are presented in this table (see section 2.2.1 for scoring details).

		1	2	3	4	5
Laser	Tooth	11 (14%)	12 (15%)	20 (25%)	20 (25%)	17 (21%)
	Cavity class	12 (15%)	24 (30%)	25 (31%)	1 (1%)	19 (24%)
	Cavity size	9 (11%)	48 (59%)	24 (30%)	-	-
	RG Score	0	3 (5%)	40 (62%)	21 (32%)	-
Drill	Tooth	13 (16%)	12 (15%)	18 (22%)	23 (28%)	15 (19%)
	Cavity class	14 (17%)	20 (25%)	24 (30%)	1 (1%)	22 (27%)
	Cavity size	10 (12%)	44 (54%)	27 (33%)	-	-
	RG Score	1 (2%)	5 (8%)	46 (70%)	13 (20%)	-

Type of teeth:
1=A, 4=D,
2=B, 5=E
3=C,

RG: radiographic score

Table 6.6: The number of patient's with a history of dental treatment with the radiographic views achieved for radiographic assessment.

	1	2	3	4	5
Past Dental History	12 (25%)	19 (40%)	8 (17%)	6 (13%)	3 (6%)
Radiographic technique	5 (10%)	15 (31%)	15 (31%)	1 (2%)	12 (25%)

Past Dental History
1= restoration,
2= extraction,
3= none,
4= both,
5= treatment under general anaesthesia

Radiographic view
1=Periapical
2= Bitewing
3= Orthopantomograph
4= Lateral Oblique
5= None

Teeth with history of pulpal pathology or root resorption of more than one third were not included.

The extent of the carious lesion was assessed on radiographs using the scoring system described in Section 2.2.1. Bitewing radiographs were considered as the first choice for posterior teeth and periapicals for anteriors if adequate co-operation was achieved. In cases where the patient's co-operation was poor, extraoral views, including OPT or lateral oblique were obtained. Table 6.6 demonstrates the number of different radiographic techniques employed for the patients of this study.

6.7.4 Caries removal protocol:

All treated teeth were isolated using either rubber dam or cotton wool rolls. Rubber dam, without any clamps, was used for the isolation of the anterior teeth (Figure 6.4), in association with a high velocity aspirator to remove smoke and debris from the treating area, which had an additional cooling effect on the irradiated teeth.

An access to the carious lesion was opened where necessary using a high speed handpiece (Siemens 4000 MS, Germany) with a diamond fissure bur of size 8 as detailed in Section 2.2.3. Gross caries were excavated where indicated in both experimental and control groups. The laser radiation source used in this study was a pulsed Nd:YAG laser (Sunrise Technology Inc., USA) details of which are described in Section 2.2.1. Laser radiation of the carious

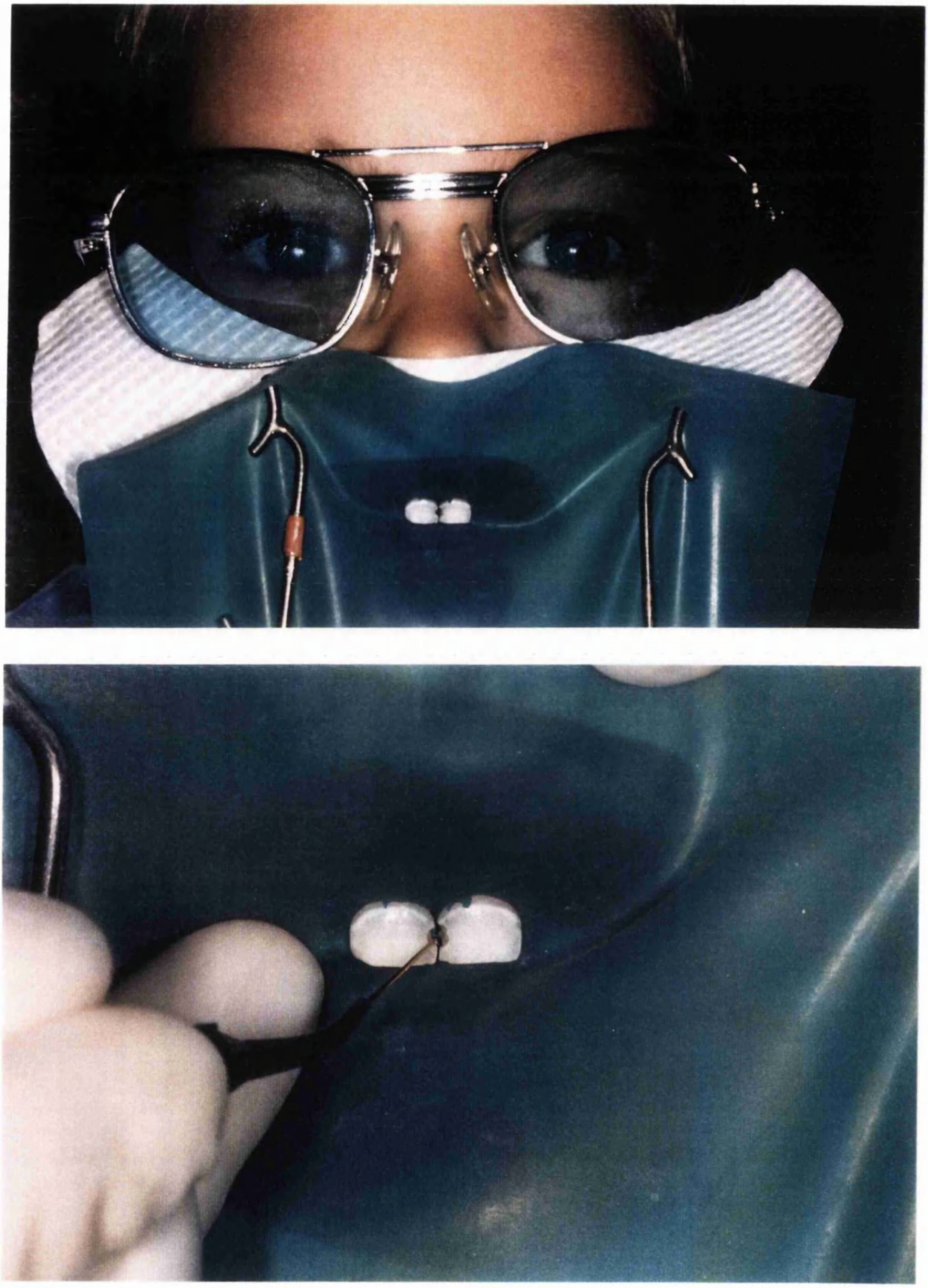


Figure 6.4 (a,b): Laser protective glasses used for the patients, with the use of rubber dam without clamp to isolate the anterior teeth is shown above.

tissue was carried out with exposures of maximum 30 sec, in a sweeping manner while the conventional caries removal was performed in a routine manner. More details of the technique and equipments, used in this study, have been described in Section 2.2.3. Time taken for the removal of caries was recorded for each technique, starting from the beginning of the caries removal procedure to its completion.

6.7.5 Caries removal assessment:

Conventional tactile and visual criteria were employed for assessment of the prepared dentine surfaces in treated cavities using a straight probe under the conventional chairside lighting while the tooth was dried. Independent clinicians were asked, on different occasions, to assess the prepared cavities as to the success of caries removal following judgement by the operator (GA).

6.7.6 Scanning Electron Microscopic examination:

Histological examination of the dentine and the pulp is the most reliable method of assessment of changes in these dental structures following an operative procedure. However, this is a destructive method which requires extraction of the tooth. In this respect, and to enable the microscopic assessment of the dentine surface without any critical tissue damage, impressions were taken of the prepared cavities using light body President impression material (Coltex®, Switzerland) loaded in Ion® Ni-Chro crowns (3M Dental Products, USA) as the special tray (Figure 2.11).

Resin replicas were produced from the prepared cavities by pouring the impressions with epoxy resin (Epofix Resin, Struers, Denmark) as described in detail in Section 2.3.7. The entire surface of the resin replica was then coated with a thin layer of gold using a sputter coater (Polaran E 5000). This early assessment technique was employed to allow the surface examination of the treated cavities before any alteration caused by restoration or development of secondary caries. Each specimen was examined under the SEM (Jeol T 300) for surface changes of dentine following laser or drill treatment, as detailed in Section 2.2.5.

6.7.7 Tooth restoration protocol and its subsequent assessment method:

Prepared cavities were restored immediately using Dyract® (Dentsply, UK), a compomer restorative material as the material of choice. A Visilux™ 2 (3M Dental Products, Germany) light cure machine was used for curing the restorative material, adjusted for 40 sec exposures. Restored teeth were then polished using enhance polishing disks (3M Dental Products, USA). Individual teeth were assessed for possible changes around the margins of restorations after 1, 6 and 12 months after placement, using the following simplified system of scoring:

1. Absence of any gap with no probe retention around the restoration margins
2. Probe retention and discoloured margins
3. Lost restorations.

Time taken for the restoration procedure was recorded for both experimental and control groups, including the time taken for the application of bonding agent and its setting.

6.7.8 Patient's follow up:

Patients were reviewed after one month, 6 months and 12 months following treatment. Treated teeth were tested at each visit for their pulpal status using conventional clinical methods of assessment, including thermal and electrical pulp tests, in addition to a soft tissue examination of the surrounding structures for any pathological changes of dental origin, as described in Section 6.7.3. At the second review visit (6 month), both experimental and control teeth were radiographed for the assessment of the possible changes at the periapical region.

Exfoliated and extracted experimental teeth were collected for further histological assessment. Teeth were placed in 10% buffered formalin as soon as they were received.

6.7.9 Assessing the parents views on laser therapy:

Parents were asked to answer a series of questions about the laser and its effect on their child's attitude to receive further dental treatment in the form of a questionnaire. Appendix C is the questionnaire given to the parents for the assessment of the parent's views on the laser and its dental applications.

6.7.10 Statistical analyses:

Two sample t-test was used for the comparison between the differences in the effect of laser and drill techniques on a patient's anxiety level. The period effect was also tested using two sample t-test to find out if the order in which each of the two techniques was given, had any effect on the patient's anxiety expressed for the second approach. A Mann-Whitney test was used to compare the level of anxiety of the patients prior to the two caries removal techniques. The differences between the time taken by each technique was tested using a two sample t-test. Pulpal response to EPT was compared between the test and control teeth using a two sample t-test on raw data. Chi-square tests were used to assess the differences in the pulp response to EC and also the results of clinical examination of the surrounding tissues, in each assessment time, between the laser- and the drill-treated teeth.

6.8 Results - Anxiety and knowledge

6.8.1 Operators assessment:

Table 6.7 illustrates the mean anxiety score of the operator's assessment of the patients before and after treatment using both the laser and the conventional drill. Taking the laser and drill results together, there was a highly significant difference (two sample t-test, p=0.001) between the level of anxiety before and after the dental treatment with a much lower level of anxiety after the completion of treatment. In addition, a student t-test showed a highly significant difference (p= 0.0009) between the effect of the two techniques of caries removal, with the laser being associated with less anxiety. Further t-tests

Table 6.7: The mean value of the operator's judgement of anxiety score of the patients prior to and following the treatment (Anxiety scores: from 1= the highest, to 4 = the lowest anxiety level, see section 6.7.2 for details).

sex	mean anxiety Score before laser	mean anxiety Score after laser	mean anxiety score before drill	mean anxiety score after drill
Male	1.86 ± 0.6	2.77 ± 0.7	1.91 ± 0.7	2.27 ± 0.7
Female	1.93 ± 0.7	2.96 ± 0.6	1.90 ± 0.6	2.46 ± 0.7

Table 6.8: Differences between the level of anxiety prior to the laser and drill, in patients with and without any history of past dental treatment (Kruskal-Wallis test).

Test group	Past Dental Treatment	Median Anxiety Score	p	df
Laser	Yes	2.00	0.718	1
	No			
Drill	Yes	2.00		
	No			

p value adjusted for ties.

indicated that the order of treatment had no effect on the results. Figure 6.1 shows the number of patients in each scoring category before and after treatment for both the laser and the drill.

6.8.2 Patient's self assessment:

Results of the data from the patients' replies to the pictorial assessment technique (Table 6.3) revealed a consistent preference towards the laser technique. This was concluded from the number of patients who had selected boxes 1 to 4, representing a reduction in anxiety, compared to those who selected boxes 4 to 8, indicating an increase in anxiety. The different anxiety scores and detailed description of corresponding pictures are explained in Appendix B.

An assessment of parents' comments also revealed varying degrees of discomfort during both techniques with a higher level during the drill application (63%) compared to that of the laser (56%) (Table 6.4). Three out of fifty patients refused treatment, two of which had to be referred for treatment under general anaesthesia. The third patient, who refused the laser because of the need for using protective glasses, accepted treatment, using appropriate protection, following two introductory visits. The main complaints during laser treatment were the production of smoke and heat. The main complaints of patients with regard to the use of conventional rotary instruments were vibration, noise and pain.

6.8.3 Patient's previous dental treatment:

Figure 6.5 illustrates the number of patients, with their range of past dental experience. No patient reported to have any previous dental laser experience. Kruskal-Wallis test of the effect of past dental experience on the level of anxiety prior to the laser and drill treatments revealed that there was no significant difference (p= 0.718) between individuals with and without a history of past dental treatment (Table 6.8). Twelve out of 48 (25%) of these patients refused any sort of radiographic examination on the first visit due to initial fear and anxiety (Table 6.6).

6.8.4 Assessment of the parents' reply:

The response rate to the questionnaire distributed between the parents of the patients treated in this study was high (89.5 %), being mainly returned at the second review visit. Results of the answers to question 1 (How much do you know about the laser?) indicated that 72 % of parents had little or no knowledge about lasers (Figure 6.6). Analyses of the replies to question 2 (How much did you know about lasers in dentistry before?) are shown in figure 6.7. More than 95 % of parents had little or no knowledge about dental lasers. Parents' responses to question 3 (How much information did you receive before treatment?) is shown in figure 6.8. Only four out of the total of forty three (9 %) respondents stated that they did not receive sufficient information prior to the treatment while 39 (91 %) said they received enough information about the dental laser. A few parents expressed concern about the safety of the laser radiation, question 4 (Did you search for more information about laser after it

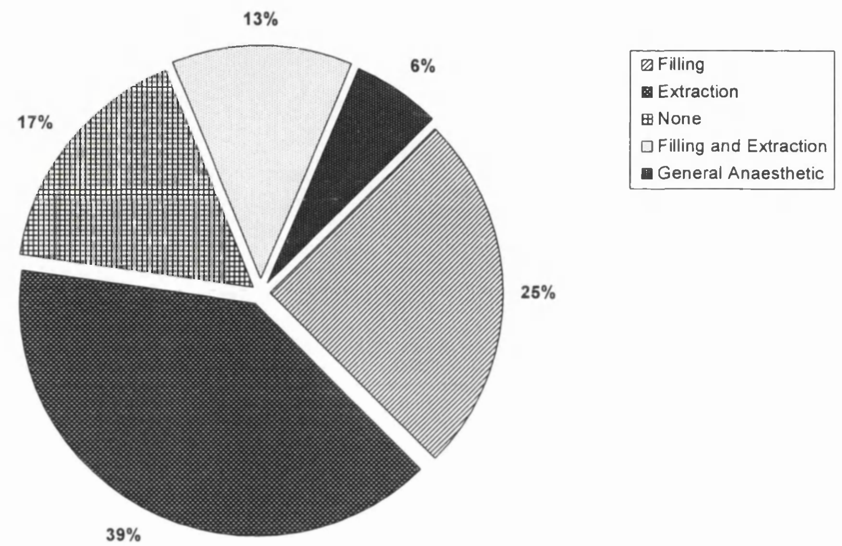


Figure 6.5: The distribution of the different past dental treatment received by patients of this study.

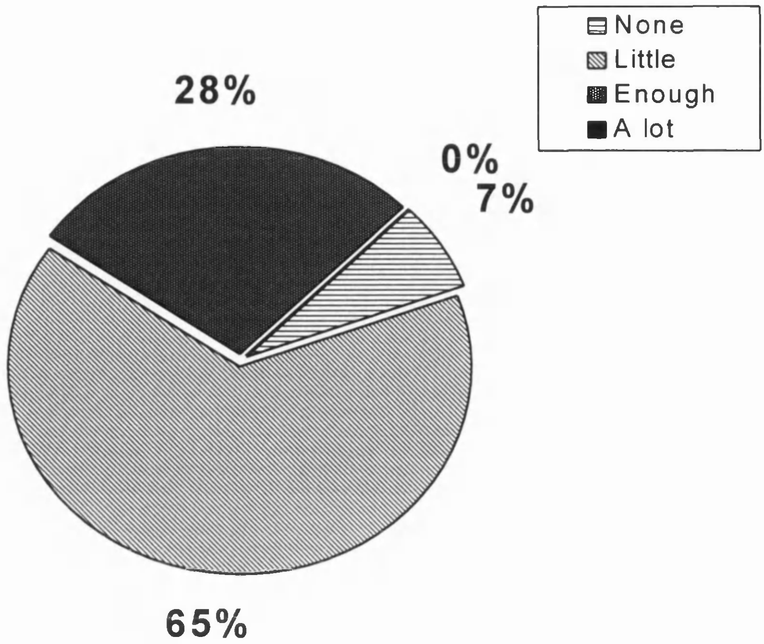


Figure 6.6: Pie chart shows the level of parents' knowledge on lasers.

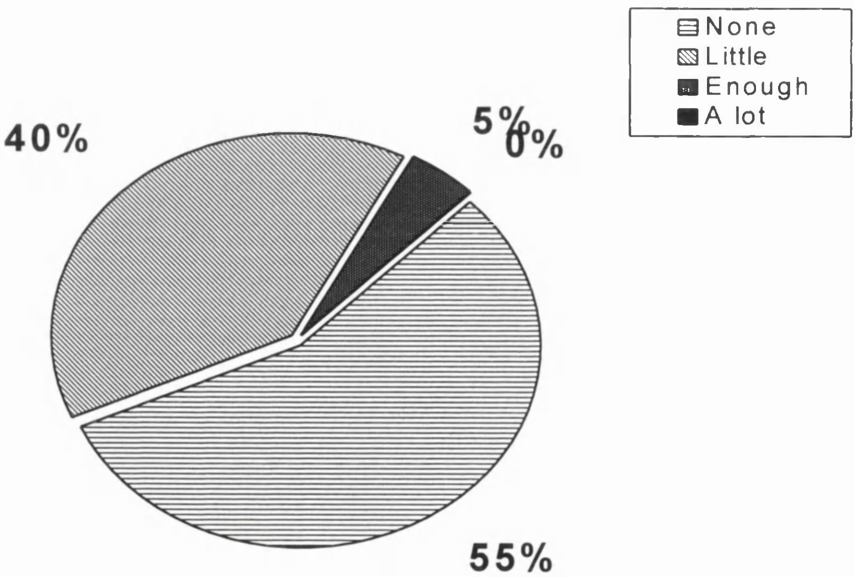


Figure 6.7: Pie chart shows the level of parents' knowledge on dental application of lasers.

was suggested for your child?). On this particular issue results indicated that 10 out of the 43 (23.26%) parents who replied, had searched for more information about dental lasers. The results of question 5 (where did you first hear about lasers in dentistry?) were the two expected sources of the operator (37%) and the consultant (44%) at the Dental Hospital. Details of these numbers are presented in table 6.9. Answers to question 9 (What was the reason for referral of your child to the Dental Hospital?) showed that the majority of patients on this trial were those who had been referred because of dental anxiety and difficulty of dental treatment (Table 6.9).

The parents' responses to questions 6 and 7 regarding the acceptability of the laser technique as an alternative technique for treatment of dental caries are presented in table 6.9 . Fifty four percent of the parents stated that the child's attitude towards dental treatment had greatly improved while 46% of them reported little or no difference (Figure 6.2). A significantly high number of parents, 38 (88 %), preferred the laser technique for treatment of the child to the conventional caries removal technique with and without local anaesthetic administration, with a high number 36 (83 %) of the total 43 respondents recommending the technique to other members of their family and friends. However, 7 parents (16%) reported that they were not sure (Figure 6.9). No post-operative pain, hypersensitivity or any other complication was reported following the use of the laser for removing dental caries. Five teeth were reported as having developed pulpal necrosis and abscessing within the first 12 months (Table 6.10).

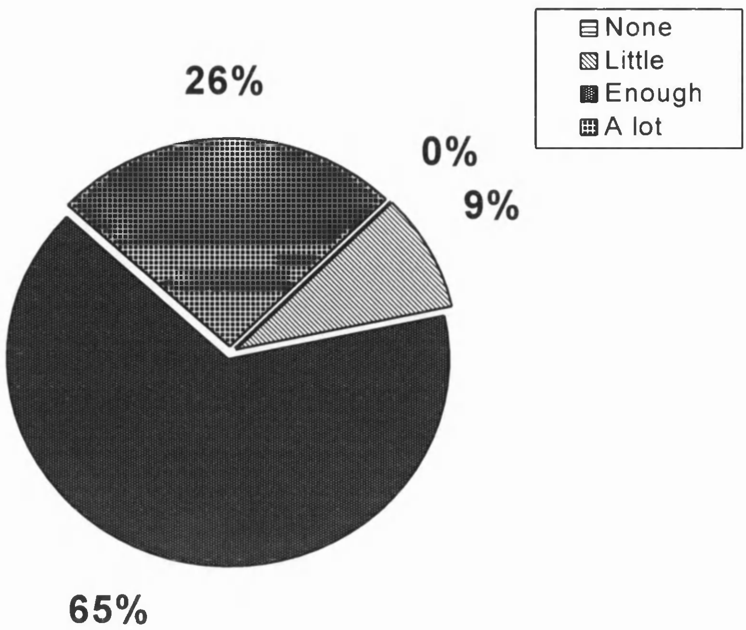


Figure 6.8: Pie chart shows the parents' idea on the adequacy of information recieved prior to the laser treatment.

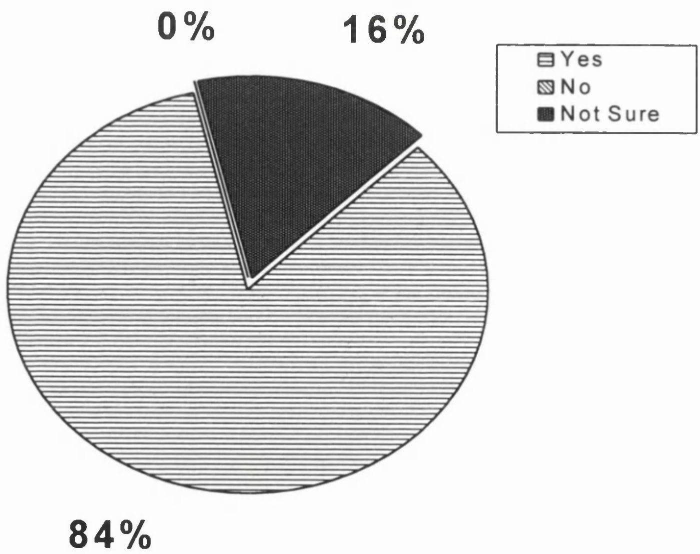


Figure 6.9: Pie chart shows the number of parents who had recommended the laser caries removal technique to others.

Table 6.9: The source of information for laser treatment and parent's preference to the treatment technique are presented here in addition to the reason for patient's referral to the Dental Hospital.

	1	2	3	4	5	6
source of information	0	2 (5%)	4 (9%)	2 (5%)	16 (37%)	19 (44%)
Preferred technique	2 (5%)	1 (2%)	38 (88%)	0	2 (5%)	0
Referral reason	13 (30%)	8 (19%)	6 (14%)	8 (19%)	3 (7%)	5 (12%)

<u>Source of information</u>
1= Radio/TV
2= Newspaper
3= Friends
4= Local dentist (GDP)
5= Dental Hospital Consultant
6= Operator

<u>Preferred technique</u>
1= Drilling with injection
2= Drilling without injection
3= Laser
4= Treatment under general anaesthesia
5= No preference

<u>Referral Reason</u>
1= Dental anxiety
2= Specialist Hospital
3= High caries rate
4= Dental Hospital patient
5= More convenient
6= Medical reasons

Table 6.10: The number of positive and negative responses to Ethyl Chloride by both laser and drill treated teeth in five occasions before and after the treatment with related findings of the clinical examination.

			Number of responses (throughout the study period)				
			before treatment	after treatment	1 month later	6 month later	12 month later
Ethyl Chlorid	laser	Pos	68 (84%)	64 (79%)	70 (86%)	61 (76%)	61 (81%)
		Neg	13 (16%)	17 (21%)	11 (14%)	19 (24%)	14 (19%)
	drill	Pos	73 (90%)	66 (81%)	63 (78%)	65 (83%)	63 (83%)
		Neg	8 (10%)	15 (19%)	18 (22%)	13 (17%)	13 (17%)
Cinical Condition	laser	N	81(100%)	81 (100%)	81(100%)	77 (96%)	72 (97%)
		A	0	0	0	3 (4%)	2 (3%)
	drill	N	81(100%)	81 (100%)	81(100%)	77 (99%)	75 (99%)
		A	0	0	0	1 (1%)	1 (1%)

Pos=Positive,
Neg= Negative
N=Normal,
A=Abnormal

6.9 Result - Pulp assessment:

6.9.1 Electric pulp test:

Table 6.11 demonstrates the distribution of the number of pulpal responses to EPT in both the laser-irradiated teeth and those treated with the drill in five different observation stages. Nine out of the forty treated patients (19 %) refused to be assessed by EPT in the first visit, which was to be expected given their anxiety problem. The data in table 6.11 only represents those who were assessed. A wide range of pulpal responses to the Electric Pulp Tester was recorded. Repeated measurement of a random selection of the cases showed similar values. Individual responses to EPT with time are shown in figures 6.10 to 6.13 for laser-treated teeth, and in figures 6.14 to 6.17, for teeth treated by the drill. Summarised data using a cut-off point of EPT values of 60 are shown in figures 6.18 and 6.19. It was noticed that the number of teeth responded below 60 were decreased following the caries removal procedure both using the laser irradiation and the conventional drilling. The pulpal responses to EPT was found to be highly significant ($p= 0.001$) between the groups of teeth treated by laser and drill when they were tested using a Chi-squared test (Table 6.12). However pulp responses were shown to have returned to values below 60 within the first month of treatment, in both groups of teeth. There was no significant difference ($p= 0.1$) between the two groups of laser- and drill-treated teeth in their recovery rate after 6 and 12 months, post operatively. The result of a Chi-square test on the response rate of the pulp before, immediately after treatment and one month later showed a significant difference in both laser ($p= 0.04$) and drill treated teeth ($p= 0.04$) (Table 6.12). The sequences of the pulp

Table 6.11: Number of positive and negative responses to EPT by both laser and drill treated teeth in five occasions before and after the treatment.

		Electric Pulp Testing				
	Test time	1 - 20	21 - 40	41 - 60	61 - 80	>80 (none)
Laser	Before treatment	0	20	22	14	20
	After treatment	3	9	15	10	39
	After 1 Month	2	14	15	19	27
	After 6 Month	1	13	19	16	28
	After 12 Month	1	10	18	22	21
Drill	Before treatment	5	12	21	15	16
	After treatment	3	10	10	16	30
	After 1 Month	1	14	16	17	29
	After 6 Month	4	11	14	22	24
	After 12 Month	2	11	18	14	26

Table 6.12: Results of Chi-square test on the pulp response to EPT before, immediately after and 1 month after caries being removed, using laser/drill.

Examination	Test time	Treatment	x^2	df	p
Electric Pulp Test	before/after/1m Tr.	Laser	6.565	2	0.04
		Drill	6.660	2	0.04
		Laser/Drill	33.134	5	0.001
	Overall times	Laser	6.852	4	0.2
		Drill	26.796	4	0.001

X^2 = Chi-square,
df = degree of freedom,

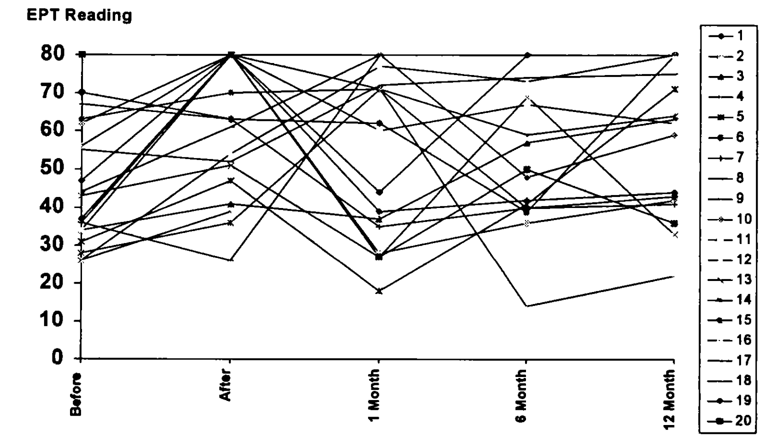


Figure 6.10: Demonstration of the response level of individual teeth to EPT following laser treatment in five tested occasions (teeth 1-20).

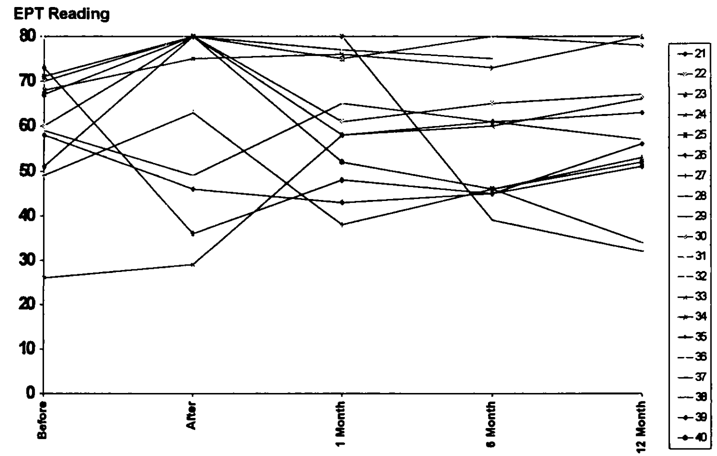


Figure 6.11: Demonstration of the response level of individual teeth to EPT following Laser treatment in five tested occasions (Teeth 21-40).

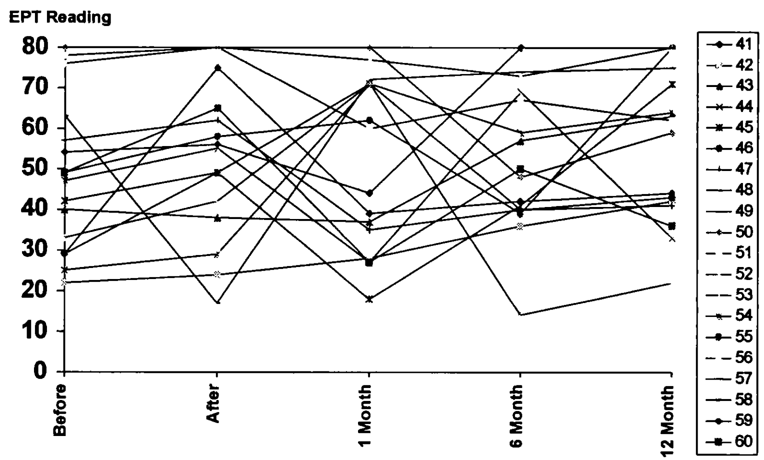


Figure 6.12: Demonstration of the response level of individual teeth to EPT following laser treatment in five tested occasions (teeth 41-60).

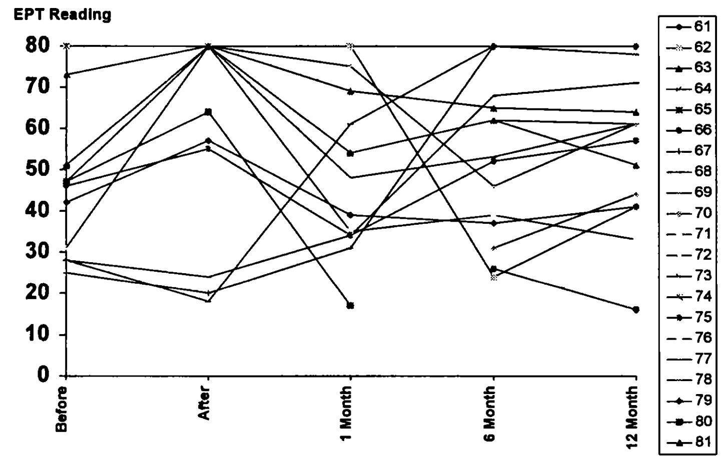


Figure 6.13: Demonstration of the response level of individual teeth to EPT following laser treatment in five tested occasions (teeth 61-81).

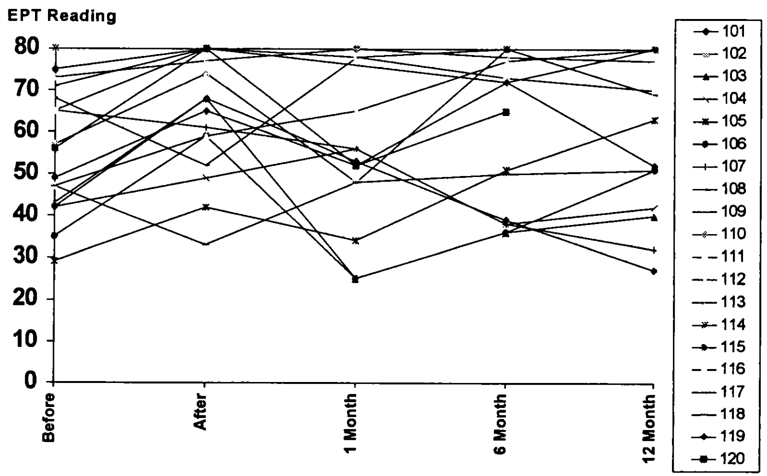


Figure 6.14: Demonstration of the response level of individual teeth to EPT following Drill treatment in five tested occasions (Teeth 101-120).

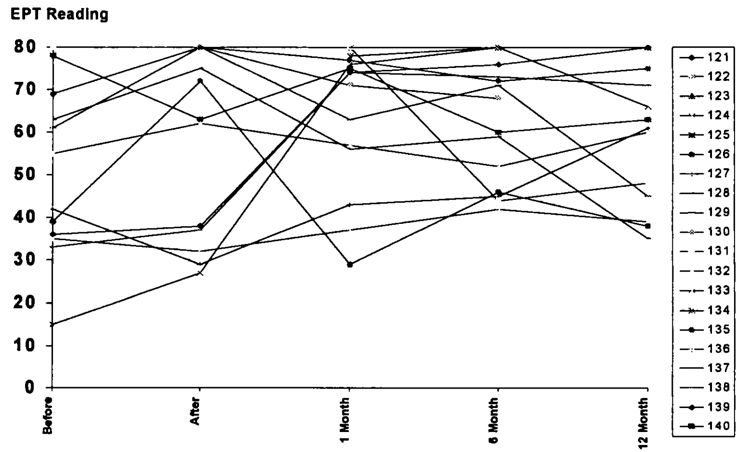


Figure 6.15: Demonstration of the response level of individual teeth to EPT following Drill treatment in five tested occasions (Teeth 121-140).

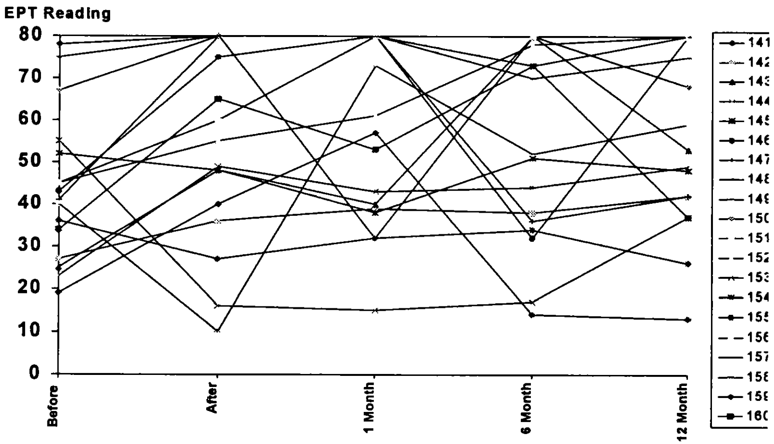


Figure 6.16: Demonstration of the response level of individual teeth to EPT following Drill treatment in five tested occasions (teeth 141-160).

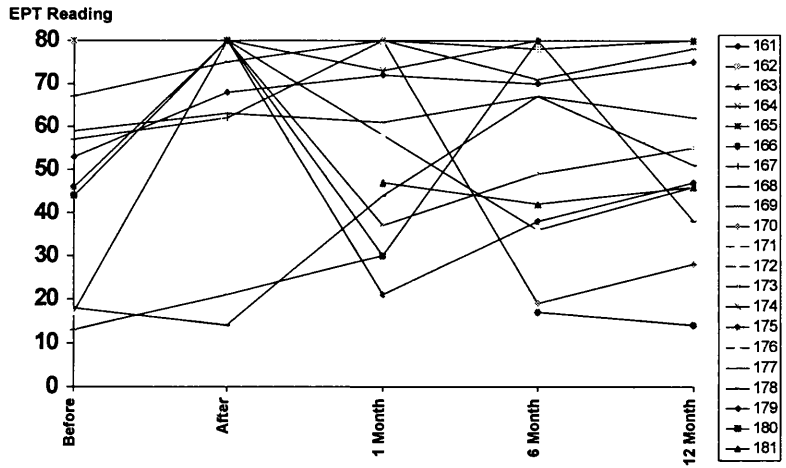


Figure 6.17: Demonstration of the response level of individual teeth to EPT following Drill treatment in five tested occasions (teeth 161-181).

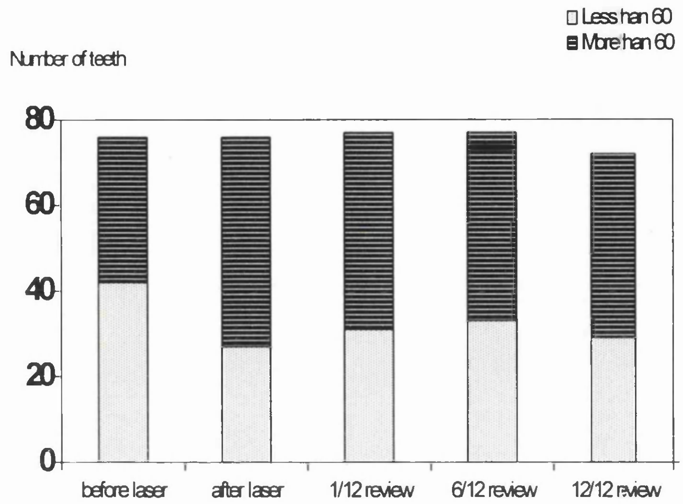


Figure 6.18: Histogram shows the distribution of responses to EPT for teeth treated by laser, in five different measurements.

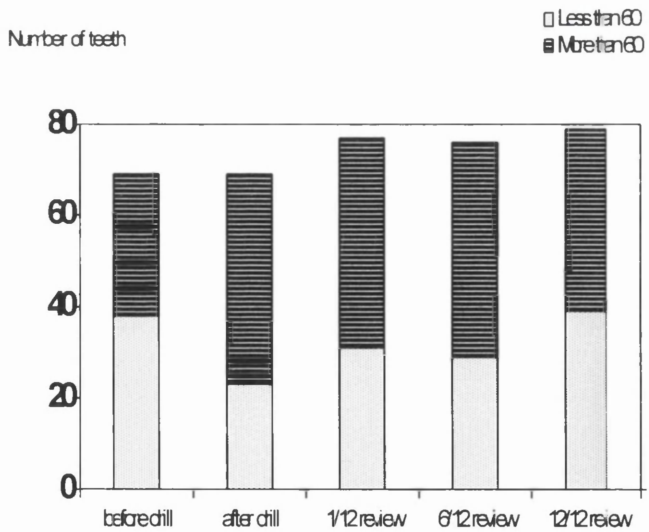


Figure 6.19: Histogram shows the distribution of respomses to EPT for teeth treated by drill, in five different measurements.

responses in individual teeth can be seen in figures 6.10 to 6.17. The distribution of teeth in each category of pulpal responses to EPT are demonstrated in table 6.11, for all five examination points. The pulp response of both groups, did not show a dramatic change thereafter.

6.9.2 Thermal test:

Table 6.11 details the response rates of the pulp to ethyl chloride, as the thermal stimuli, with their related percentages. The results recorded from the thermal test of the laser-treated teeth showed an 84% positive response before treatment declining to 79% immediately after irradiation and rising to 86%, one month later. Statistical analysis (X^2 test) on the pulpal response rate before and after laser and drill treatment showed no significant differences in any of the comparisons. The probability values for laser treated teeth was p= 0.2 while this value was p= 0.1 for drill treated teeth and p= 0.2 when both groups were compared before and after the treatment (Table 6.13).

6.9.3 Clinical Examination:

Apart from those necrosed cases, mentioned above, clinical and radiographic evaluation of the teeth did not show any particular pathology or complication associated with either of the techniques. The results of the clinical evaluation of the surrounding soft tissue of the treated teeth are presented in table 6.10. Only two of the cases from the laser-treated teeth and one following drill cavity preparation resulted in pulp necrosis within the first six month following treatment. It was not clear to whether the necrosis was caused by the

Table 6.13: Results of Chi-square test on the pulp response to ethyl chloride before and after caries removal using laser/drill, in addition to the results of the clinical examination.

Examination	Test time	Treatment	x^2	df	p
Ethyl Chloride	before/after/1m Tr.	Laser	1.643	2	0.2
		Drill	4.636	2	0.1
		Laser/Drill	6.279	5	0.2
	Overall times	Laser	3.804	4	0.2
		Drill	4.640	4	0.2
Clinical Examination	6/12 v 12/12 .	Laser	0.194	1	0.2
		Drill	0.000	1	0.2
		Laser/Drill	1.489	3	0.2
	Overall times	Laser	8.218	4	0.1
		Drill	3.173	4	0.2

X^2 = Chi-square,
df = degree of freedom,
v= versus

preparation process, i.e. laser radiation, or to the carious activity close to the pulp. Of the 38 patients seen at the 18 month review, again no further pulpal complication had been noted.

Clinical evaluation of treated teeth showed only a 6 % failure rate in teeth treated by the laser and 3 % in drill-treated teeth after 6 to 12 months (Table 6.10). Chi-square test was also carried out for the clinical findings, results of which represented no significant difference (p=0.2) between the response rates before and after treatment using laser or drill (Table 6.13).

6.9.4 Radiographic Examination:

Radiographic evaluation of the treated cases after six months showed only 4 laser treated cases (5%) with radiolucencies at either the furcation or periapical areas, while this figure was 5 (6%) in the drill group, results of which are presented in table 6.14.

From all the diagnostic information available, only 3 teeth (2 laser-treated and 1 drill-treated teeth) were diagnosed as having pulpal necrosis within the first six months following treatment. This diagnosis was confirmed after extraction of the teeth by further histological examination. No other teeth developed pulpal necrosis during the 6 to 18 months follow up period.

Table 6.14: Findings of the radiographic assessment of the pulp reaction after 6-18 months.

Treated group	Radiographic review				
	Normal	Abnormal	(X^2)	p	df
Laser	74 (95%)	4 (5%)	0.132	0.2	1
Drill	72 (94%)	5 (6.5%)			

X^2= Chi-square, df= degree of freedom

Table 6.15: The number of cases required the use of high speed for access opening, cases which hand excavator was used and the number of cases received indirect pulp capping.

Test group		High speed used	Hand excavation	Base	CR success
Laser	yes	20 (25%)	48 (59%)	79 (98%)	65 (80%)
	No	61 (75%)	33 (41%)	2 (2.5%)	16 (20%)
Drill	yes	19 (23%)	37 (46%)	80 (99%)	72 (89%)
	No	62 (77%)	44 (54%)	1 (1%)	9 (11%)

CR= Caries removal
Base= Setting calcium hydroxide

6.10 Results - Preparatory criteria:

6.10.1 Laser caries removal efficacy:

Clinical assessment of laser-treated cavities, using conventional, visual and tactile criteria, revealed that caries had been removed efficiently. In patients with poor co-operation, caries removal was performed, with both methods, in association with the use of a hand excavator or, in two separate visits. Recorded data shows that in 40% of the cases a hand excavator was used for gross caries removal during the laser caries removal compare to 54% of those treated by drill (Table 6.15).

6.10.2 Assessment of prepared dentine surface using SEM:

Scanning electron microscopic observation of the replica of the specimens revealed that laser irradiated surfaces produced a completely different appearance compared to that of the drill or untreated carious lesion. A solid feature of a bulbous appearance was observed at the dentine surface as a result of the high surface temperature in laser-treated teeth, while cutting marks and lines indicated the use of the drill in control teeth (Figures 6.20 and 6.21). No smear layer was observed at the laser-prepared surfaces, while a superficial layer of debris was present on dentine surfaces prepared by the drill.

6.10.3 Differences of the length of treatment period between laser and conventional drilling:

Table 6.16 demonstrates the mean time taken for completion of caries removal procedure using either of the techniques based on the clinically judged size of

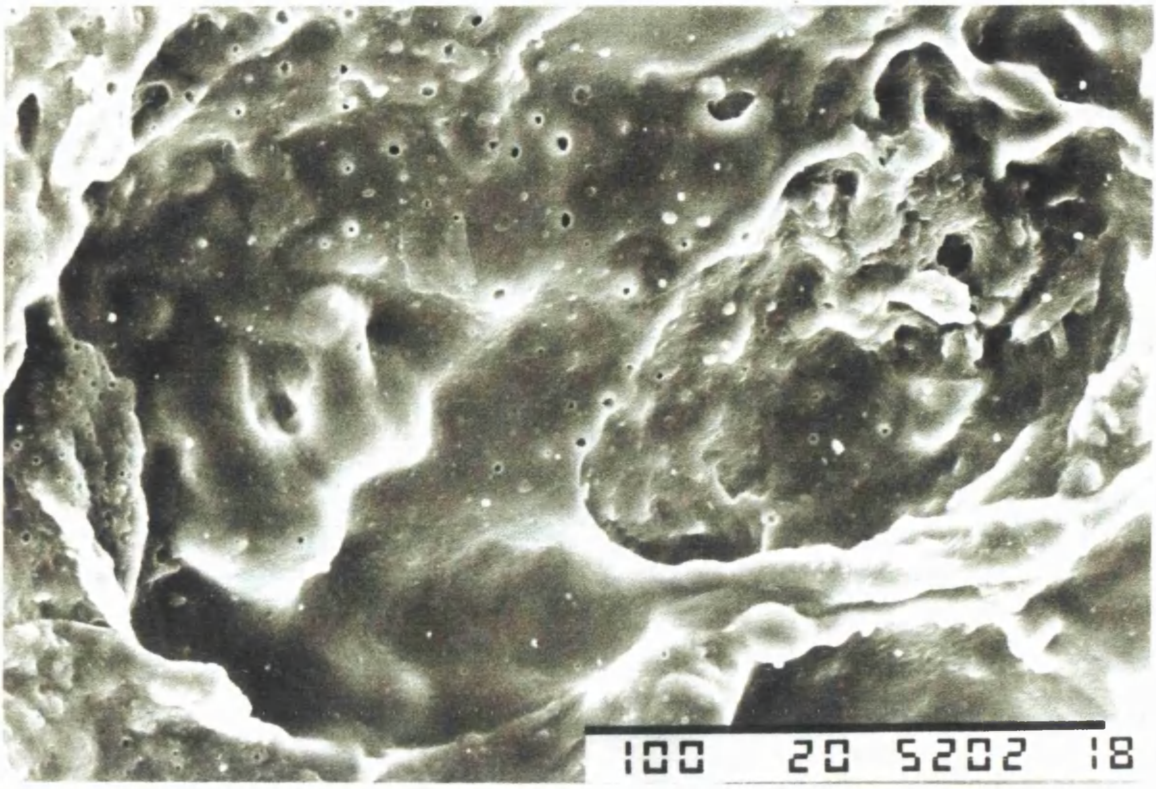


Figure 6.20: Scanning Electron Microscopic view of a laser treated cavity, *in vivo*, a solid feature of bulbous appearance is seen at the dentine surface as the result of high surface temperature (x250).

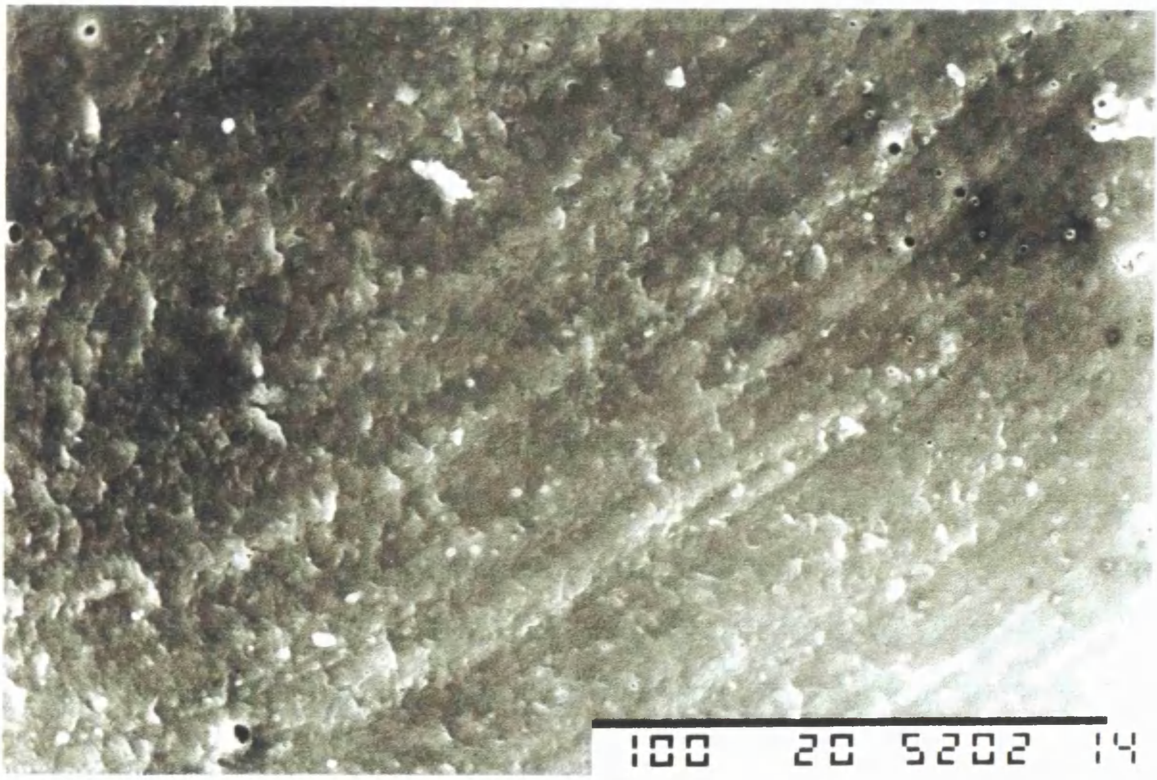


Figure 6.21: Scanning Electron Microscopic view of a conventionally prepared cavity, *in vivo*, note the cutting marks and lines caused by the application of a carbide round bur (x250).

Table 6.16: The length of time taken to achieve caries free cavities using either of the technique in addition to their restoration time.

Treatment technique	Cavity size	No of teeth	Caries Removal Time (sec)	SD for CRT	Restoration Time (sec)	SD for RT
Laser	small	10	51	25	82	16
	medium	44	85	35	104	31
	large	27	92	45	118	31
Drill	small	9	28	20	79	11
	medium	48	57	49	107	30
	large	24	69	55	119	36

CRT= Caries Removal Time,
RT= Restoration Time,
SD= Standard Deviation

the cavities. A mean time of 79 sec (SD= 31) was taken for laser caries removal compared to the mean time of 57 sec (SD= 50) taken for conventional drilling of the cavities. One-way ANOVA showed a significant difference (p= 0.015) between the time taken for removing caries in each cavity size group of teeth when treated by laser. The larger the cavities, the longer the time required for the completion of caries removal. However, for the drill, no significant difference (p= 0.113) was found between the time taken for caries removal in the different size cavities.

To find out the differences between the time required for each of the two caries removal techniques to achieve complete caries removal, Two sample t-tests were carried out between each of the two cavity size groups. The results indicated that there was a significant difference (p= 0.035) between the two groups with the small size cavities treated by laser or drill, with the laser taking longer to complete caries removal. The results of the same test on the other two cavity sizes showed a highly significant difference (p= 0.002) between the time taken for the two groups with medium size cavities and no significant differences (p= 0.11) between the groups with large size cavities.

There was no difference in the time required for the restoration procedure, with a mean time of 106 sec (SD= 30) for restoring laser-treated teeth compare to 108 sec (SD= 31) for drill-treated teeth (Table 6.17). Not surprisingly, highly significant differences were shown between the different size cavities in both

Table 6.17: Findings of the restorations assessment after 6-18 months.

Clinical review of restorations	Leakage			Retention		
	Yes	No	p (X^2)	Yes	No	p (X^2)
Laser treated teeth	11 (14%)	53 (66%)		64 (80%)	16 (20%)	
Drill treated teeth	6 (7.5%)	53 (66%)		59 (73.5%)	21 (26%)	

X^2 = Chi-square

the laser and drill groups (One-way ANOVA, p= 0.007 and p= 0.005, respectively).

6.11 Restoration - Longevity:

The results of the leakage and retention clinical scoring are shown in tables 6.17. There was no significant difference between the level of retention of restorations in the two groups of laser- and drill-treated teeth (Chi-squared test, p= 0.2). The same result was achieved when the two groups were tested by a Chi-square test for the microleakage level after a 6 to 12 months following the restoration placement (p= 0.2). Eleven teeth (13.58%) in the laser group were found to have clinical probe retention as the sign of leakage with 6 teeth (7.41%) in the drill group. However, the number of teeth which had presented with total loss of restoration were 16 (19.75%) in the laser and 21 (25.93%) in the drill treated teeth after 6 to 12 month of restoration placement. There was no further report of any failure of the restoration after the third six month review and restorations of both groups were found satisfactorily retained up to 18 month follow up of this study.

6.12 Discussion:

Since pain and discomfort during caries removal have always been the main reason for a patient's poor co-operation, particularly in children, several research groups have tried to develop alternative pain-free techniques for removing dental caries (Black and Christi, 1955; Sherrer, Mullis and Pashley, 1989; Clarkson, 1992). Amongst those, laser irradiation of the carious tissue has been suggested as a potentially effective means for removing caries without causing pain (Bassie, Chawla and Patel, 1994) which removes the need for local anaesthetic, the main fearful subject. However, despite the FDA approval for soft tissue applications of the Nd:YAG laser for several years (Midda and Renton-Harper, 1991; Miller and Truhe, 1993), its hard tissue application is still awaiting approval. This *in vivo* trial investigated the acceptability of the technique for treating anxious children in addition to its clinical effect on dental structure, including pulp tissue.

6.12.1 Patients' anxiety and laser:

The initial assessment of the patients' anxiety levels were found to be on the high side, based on the results achieved from the operator's assessment. This was further confirmed by analysing the data collected from the patient's self assessment method. This anxiety was found to be even higher prior to the use of the conventional drilling method compared to the laser. The pictorial assessment, however, was not performed for the drill as there was concern as to its repeated use on the same patient, hence this measurement was concentrated on the laser.

The laser technique was found to have a significantly higher level of acceptance with a lower potential for causing anxiety in the patients involved in this study. The analysis of the data indicated a high decrease in patients' anxiety level following the use of the laser for caries removal. This high improvement was also confirmed by the patients, as a high preference was demonstrated for the laser treatment. Pulpal stimulation was reported much less, by patients of this study, during laser application compare to that of the drill. This lower stimulation would directly effect on patient's feeling throughout the treatment period which in turn could provide higher level of patient's co-operation.

The effect of the present pulsed Nd:YAG laser energy has been previously investigated by Whitters *et al.* (1995) result of which has indicated a level of pulpal analgesia being induced following 3 min irradiation using 113 mJ at 15 pps with an increase in the pulpal threshold to electrical stimuli. It is important to note that no local anaesthetic was administered for any of the cases treated by laser or the conventional drilling as to eliminate its effect on patients level of pulp stimulation. In addition, further monitoring the patient's reaction to the treatment method in terms of their anxiety would be interrupted in presence of a local anaesthesia.

There was no effect from the order of treatments on patient's reaction to the second treatment. This was shown by a two sample t-test for treatment effect adjusted and unadjusted for period effect, which showed exactly similar p values ($p = 0.0016$).

Parents reported a significantly high improvement in their child's anxiety level when laser was used for removing carious dentine. Their reply to the questionnaire also indicated that these parents recommend the use of laser for removing dental caries. Overall, the laser treatment in absence of any local anaesthetic was found to be efficient to gain a reasonably high level of patient's co-operation with a considerable reduction of original anxiety of these patients from dental treatment.

6.12.2 History of previous dental treatment and dental anxiety:

It has been established that dental phobic children have often experienced a traumatic dental treatment at younger age (Wright, 1980; Holst *et al.,* 1988). One of the obvious risks involved with the dental fear is the fact that these patients may avoid receiving sufficient dental care both in adults (Berggren, 1984) and children (Bedi *et al.,* 1992). Assessment of the patients' anxiety level revealed that there was a difference between the two groups of patients with and without previous dental experience prior to the drill caries removal but comparing these results with when they were receiving the laser the differences were not significant statistically, using two sample t-test. In addition there was no difference between the two occasions of laser and drill treatment for patients who had a past dental history. However the overall level of anxiety was much higher in patients with history of restoration or extraction.

6.12.3 Assessment of the pulp status:

6.12.3.1 Method of assessment:

Assessment of the pulp was carried out using a series of investigations detailed in section 6.8.2. In children, and particularly for primary teeth, there are limitations and uncertainty on the level of reliability and accuracy of the patient's responses to the pulp test. In the other hand, laser doppler flowmetery, which has been introduced as a more reliable method of pulp assessment (Evans, 1995), was not carried out due to its high sensitivity level and the degree of co-operation required. In conclusion: the repeated measurements associated with the use of combination of the current methods of assessments was considered as sufficient to provide enough information on the pulp status.

6.12.3.2 Laser and the pulp:

Thermal damage of the pulp following laser irradiation of the hard dental tissue is minimised due to the presence of blood circulation and fluid within the pulpo-dentinal complex (Burke *et al.,* 1985; Goodis, Schein and Stauffer, 1988a). However, uncontrolled laser irradiation of the pulp can pass the tolerance limit of the pulp causing irreversible pulpal damage. However, continuous dentine preparation using conventional rotary instruments can also cause severe damages to the pulp, in a dry condition, due to excessive heat production. This can be more dangerous when a local anaesthetic has been administered (Anderson and van Praagh, 1942) which reduces the patients responses and therefore no reflection would be received from patient even in high temperatures.

The laser radiation has been shown to be capable of inducing some degrees of local anaesthesia on the pulp (Bassie, Chawla and Patel, 1994) and therefore care should be taken during the clinical use of the laser by controlling the laser exposure length in addition to the overall number of exposures, to minimise the risks (Taylor, Shklar and Roebor, 1965; Adrian, Bernier and Sprague, 1971). In this respect, a maximum of 30 sec was decided for the application of laser energy on the carious dentine of this experiment. A minimum of 60 sec rest was given to each laser irradiated tooth before any further exposure to reduce the risk of pulp overheating.

Cooling effect of an air water spray in conjunction with the use of an aspirator has been shown earlier to be sufficient to prevent thermal damages of the vital pulp during laser treatment (Miserendino *et al.,* 1993). To facilitate the use of coolant systems, laser manufacturers have modified their products since first they were introduced in dentistry by adding an air/water coolant system which had been shown to be efficient in protecting the tissue and surrounding structures from thermal damage (Miserendino *et al.,* 1994).

As the present laser machine used in these studies was not supplied with any coolant system, it was decided to use a high velocity aspirator associated with the use of an air spray in order to help the cooling process of laser irradiated teeth. Based on the results of the in vitro experiment on pulp temperature rises following laser irradiation, see chapter 4 of this thesis, it was concluded that a short exposure of 30 sec with a 60 sec rest immediately after laser irradiation can significantly effect on reducing the temperature rise of the pulp. However, in the event of patient's complaint laser irradiation was stopped even earlier than the complete 30 sec as to avoid any further pulpal stimulation.

6.12.3.3 Histologic effects of laser:

Earlier histologic assessments showed that the Nd:YAG laser irradiation of the teeth causes reversible changes when the energy and exposure time are controlled (White *et al.,* 1991; MacDonald, Stevenson and Whitters, 1995). White *et al.* (1991) reported that no pulpal disruption had occurred in cases with remaining dentine thickness of even as small as 0.3 mm irradiated by 1 W laser energy for maximum of 20 sec. However, Funato, (1989) reported dilatation of the blood vessels at the lased area of the pulp following the application of the Nd:YAG laser in addition to the loss of tone in vessels. A mild inflammatory response was also reported in the pulp, adjacent to the irradiated area of dentine, with no evidence of similar pattern in the rest of the pulp indicating a focal response of the pulp to laser radiation (Adrian, 1977).

Temporary pulpal disruption has been reported in the form of haemorrhage adjacent to the exposure site following the exposure of teeth to a pulsed Nd:YAG laser radiation (100 mJ at 10 pps for 30 sec) with complete recovery 15 days after irradiation (Bahchall *et al.,* 1993). It may therefore be suggested that the laser treated teeth of this clinical trial would have minimal or no damage as they had a minimum of 1 mm remaining dentine thickness, with exposures of no longer than 30 sec. The RDT was estimated using radiographic views taken prior to the treatment. In addition, a minimum of 60 sec after each exposure was considered as helpful to reduce the temperature of the pulp before any further application.

6.12.3.4 Clinical observation:

Previous reports indicated that the Nd:YAG laser irradiation of the vital teeth had no adverse effect after three years follow up (Sectos *et al.,* 1994; White *et al.,* 1993). Follow up of the treated teeth of the present study after 18 to 24 months, revealed that there was no significant difference between the failure rate of the experimental (laser) and control (drill) teeth. These results suggest that the laser energy used within the limits of this study, 1.25 W for maximum of 30 sec, can be considered safe for treatment of carious primary teeth, in agreement to the results reported earlier by white *et al.* (1993) and Sectos *et al.* (1994). The two laser treated cases and one case of drill group with periapical abscess are suggested to be due to the existing pre operative pulpal disease and not the caries removal procedure.

6.12.4 Laser effect on dentine surface:

6.12.4.1 Efficiency of the method of preparation and assessment:

As the SEM assessment of the *in vivo* treated teeth was impossible and extraction of these teeth was unethical, it was therefore decided to use the resin replica of the irradiated surfaces. In comparison, the preparation of the resin replica is much easier than the actual tooth as the dehydration stage would no longer be required, resulting in absence of artificial cracks which could interrupt the interpretation of the surface examination (Radvar *et al.,* 1995). The method used for assessing the *in vivo* prepared dentine surfaces using the resin replica was found to be efficient with producing reasonable details of the prepared surface. The technique is therefore recommended for clinical investigation of the changes at the dentine surfaces.

6.12.4.2 Changes of dentine surface and its effect on restorations:

The melted materials, produced as the result of surface overheating following laser irradiation, covered the opening of the dentinal tubules. This coverage could perhaps help to reduce post operative sensitivity of the restored teeth by protecting the fluid's movement within the tubules, believed to be the cause of dentine pain (Brännström, 1963). In the other hand, no smear layer was found on the prepared dentine surfaces when laser was used compare to the conventionally prepared surfaces as shown in figures 6.20 and 6.21. The absence of smear layer has been advocated as being in favour of the adhesive restorative materials. This has been shown by the results of several studies investigating the effect of removing the smear layer of dentine on the bond strength of different adhesive restorations (Pashley, Michelich and Kehl, 1981; Pashley *et al.,* 1983).

The clinical assessment of the restorations carried out using the modified scoring system as detailed in Section 6.7.7. As to simplify the system, the score 2 and 3 of the system was considered as score 2, and therefore the restorations were either with no fault, retained but showed the gap, or lost. Results based on this assessment method revealed that there was a higher leakage rate of the restorations following laser treatment (13.58%) compare to that of the drill group (7.41%). However, the retention rate was higher in laser group (19.75% in laser treated teeth compare to 25.93% in drill treated teeth). Statistical analysis, however, showed that the differences were not significant. These results indicate that perhaps the laser caries removal can be as efficient as the conventional drilling in preparing a suitable dentine surface for bonding the adhesive restorative materials.

6.12.5 Clinical feasibility of laser treatment:

The pulsed Nd:YAG laser used within the limits of this study was found to be a suitable alternative to conventional drilling in anxious children. This was based on the following characteristics: 1. simple and easy clinical application, 2. effective for removing carious tissue 3. safe for sound underlying dentine and the pulp, 4. reasonably quick, and finally 5. safe clinical use. The technique was highly accepted and preferred to the conventional drill by these young fearful patients. Overall two year follow up of these patients suggested that the laser caries removal had no adverse effect on the pulp and surrounding tissues. The restorations were also found to have a similar survival rate to the conventionally treated teeth. It is therefore concluded that the anxious patients may benefit from the laser to remove caries in primary teeth. The patients co-operation was improved with the use of laser therefore these patients were keen to come back for further treatments which is a great achievement in this area. It seems that the laser caries removal technique even as an intermediate treatment, by treating carious primary teeth, can be employed to gain patient's confidence and therefore providing treatment of permanent teeth with a more relaxed situation, in later visits. As far as the caries removal time is concerned, laser technique was found to be as short as the conventional method particularly when the co-operation is poor.

Further histological examination of the pulp condition is necessary before any definite statement can be made on the condition of the pulp of these laser irradiated teeth.

6.13 Conclusion:

1. The pulsed Nd:YAG Laser, within the conditions tested in this study, can be considered an efficient tool to remove dental caries.
2. The laser caries removal causes less anxiety in young patients.
3. Laser takes slightly longer time than the drill (mean time for medium size cavities: laser= 85 sec, drill=57 sec).
4. Laser effect on the pulp was found to be comparable to that of the conventional drilling the primary teeth, within the conditions of this study.
5. Restorations of laser treated teeth are comparable to the drill prepared cavities.

CHAPTER VII

GENERAL DISCUSSION AND CONCLUSION

CHAPTER 7: GENERAL DISCUSSION AND CONCLUSION:

7.1 Introduction:

The need for an alternative technique for caries removal to the conventional system has become highlighted in recent years. Caries prevalence continues to be a problem due to wide continuation of a high carbohydrate intake. Untreated carious teeth lead to pain, which causes more difficulty in the treatment period particularly on the level of patient's co-operation. Some patients, including children, do not seek treatment perhaps due to anxiety and fear. The studies documented in this thesis, were carried out to assess the potential of an Nd:YAG laser (ADL) to remove carious dentine, as well as its acceptability for treating young, dental phobic patients. The four experiments are discussed here.

7.2 Laser effects on the irradiated dentine surface:

The effect of laser radiation on dentine of both primary and permanent teeth was examined using light microscopic assessment of ground and demineralised sections prepared from the same specimen. Microradiographic examinations were also performed. The findings of these investigations indicated that laser energy of 1.25 W was efficient at removing of dentine caries without damage to the underlying sound dentine. Altered collagen was observed close to the prepared surfaces in some demineralised sections. There was concern that this may have been the result of laser-induced overheating of the tissue. However, examination of laser-irradiated non-carious dentine revealed that such changes could not occur with the range of laser energies used here. It was concluded, therefore, that such mild alterations were due to caries rather than the laser.

Scanning Electron Microscopic examination of laser-irradiated surfaces revealed resolidified globules of melted material covering the dentine surface, presumably the result of the high surface temperature produced by the laser. This covering layer of dentine is thought to be advantageous as it may prevent invasion of the dentinal tubules by micro-organisms or even the penetration of micromolecules of restorative material (Pashley *et al.,* 1992). High surface temperature, in itself, may also have a bactericidal effect, as reported earlier (Whitters *et al.,* 1994; Hooks *et al.,* 1980; Bassie *et al.,* 1994), therefore, reducing the potential risk of recurrent caries.

7.3 Pulpal temperature changes following laser cavity preparation:

When the tissue is irradiated, the surface temperature will rise as a result of absorption of the laser beam, which in turn will generate heat, which will then travel through the bulk of the target tissue. In the case of teeth, the heat produced at the surface may cause an increase in pulpal temperature which could be potentially damaging to the pulp (Zach and Cohen, 1965). It is, therefore, important to ensure that a safe range of power is used during laser application. *In vitro* measurement of the pulp temperature showed relatively high rises in temperature in the pulpal cavity following laser irradiation of carious dentine.

The effect of the laser on the pulp is due to a previous rise in temperature produced at the surface of this tissue. To estimate the magnitude of these effects clinically, several methods have been employed, including measurement of temperature at the tooth surface (Hibst and Keller, 1990) or even measuring the temperature at the pulpodentinal junction using an animal model (Goodis and Rosenberg, 1991). Direct measurement of temperature changes was carried out at the pulpodentinal junction *in vitro*, the results of which demonstrated a mean peak temperature rise of 15 ± 7 °C following laser irradiation of a carious lesion for a maximum of 30 sec bursts (2 mm RDT). The resting time following each irradiation was important, as this permitted time for the irradiated tooth to cool. The resting time was also important, particularly when frequent laser applications were required, since heat accumulation occurred following each exposure and resulted in a rise of the baseline temperature.

Since all the laser parameters were fixed, temperature rises between samples could not be due to the laser energy or duration of exposure. Only the remaining dentine thickness could have had a potential influence on the value of the recorded temperature of the PDJ in individual teeth.

Temperature rises of 16.8 ± 1.5 °C were recorded following laser irradiation of primary teeth, while in permanent teeth these temperatures were 11.9 ± 1.8 °C. It was expected, however, that such temperature rises would not be as high in vital teeth, as pulpal blood circulation would effectively reduce the rise in temperature within the pulp chamber. It seems, therefore, that controlled laser irradiation may be used safely for the treatment of carious lesions. By comparison, little temperature change was associated with the use of rotary instruments, probably because of the use of an air coolant.

It was of particular interest that rises in pulp temperature were recorded following the use of PBL, with little difference being evident whether caries was present or not (3.7 ± 1.7 °C in presence of caries and 4.6 ± 1.6 °C after caries removal). In an earlier study, it was advised that routine application of a curing light should be used with caution, due to heat production at the pulpal level when used for polymerising restorative materials (Strang *et al.* 1988). However, the findings of this thesis on the recorded temperature rises of the pulp following a 60 sec application of the PBL were not above the pulp threshold suggested by Zach and Cohen (1965). In addition, as stated previously, it is likely that the temperature rise would be lower in a vital tooth due to the presence of the systemic circulation.

7.4 Restorations following laser cavity preparation:

Evaluation of restored cavities prepared by either the laser or the drill revealed that the laser prepared surfaces were as suitable as conventionally prepared surfaces for adhesion of Dyract® restorative material, and perhaps in some cases even better than the control group. This was demonstrated by a higher degree of microleakage around the restorations of the conventionally prepared cavities in primary teeth.

There is a wide range of temperature around the mouth, especially whilst consuming a daily meal (Michailesco *et al.,* 1995) and, therefore, any *in vitro* test should be carried out under a similar range of temperatures. Thermocycling of the restored teeth prior to the application of dye is commonly used for *in vitro* evaluation of the margins of restorations. This technique was employed for the assessment of restored teeth *in vitro* in this study to simulate oral conditions and, therefore, assess the changes of the restoration margins following a series thermal shocks.

The effect of temperature changes on the gap size at the margins of restorations were not significant in either experimental or control groups, in both light and electron microscopic examinations. The number of gaps present at the margins of restorations was higher in conventionally treated teeth compared to the laser-treated group. The changes of the size of these gaps were not significantly different between before and after thermocycling which support the work of Chan and Glen-Jones (1994) as thermocycling being ineffective on the restoration behaviour as such.

7.5 Clinical applicability of the laser radiation for removing dentine caries:

The findings from the clinical trial confirmed that the pulpal effects from the selected laser energies were minimal, as only two cases within the experimental group showed pulpal necrosis. There was one case, however, showing necrosis from the control group, perhaps indicating preoperative pulpal involvement. Laser caries removal also appeared to be efficient in reducing the pre-operative anxiety of patients, as well as being effective at removing dentine caries. The long term pulpal status following laser caries removal was found to be uneventful in this study, which was followed up for the full length of this study (two years).

Patients' attitudes towards dental treatment was improved significantly following the laser treatment. It appeared that since the laser technique did not involve any physical contact, and works only by means of evaporation of the carious tissue, the procedure seemed more tolerable. Sensations of vibration and noise associated with the use of rotary instruments, and particularly pain (when used without local anaesthesia) associated with the mechanical cutting, would be avoided when the laser is used. Some, patients did express some concern over the heat and smoke produced by the laser.

Pulpal status was monitored before and after the application of laser radiation on teeth using conventional electric and thermal pulp tests. The reliability of these two currently used pulpal assessment techniques have recently been confirmed on primary teeth when patients of 7 to 10 years old were tested (Asfour, Miller and Smith, 1996). However, general concerns has been raised regarding the reliability of these tests (Bender *et al.,* 1989; Robinson, 1987), and also changes of the level of pulp sensibility to EPT during the different stages of root formation (Brandt, Kortegaard, and Poulsen, 1988), clinical examination of the surrounding tissues, along with periapical radiography of the treated teeth were performed as complementary tests. The pulsed Nd:YAG laser using the parameters which were found to be safe, showed no destructive effect on the irradiated tissues when used for caries removal in primary teeth. The side effects of the laser on the pulp and surrounding tissues can be minimised if at least 60 sec rest is given between exposures. The long-term assessment of the restorations of laser-treated teeth showed comparable success to the conventionally prepared teeth. It was possible to prepare the dentine surface without the production of a smear layer which should, therefore, provide a higher bond strength (Pashley *et al.,* 1992).

7.6 Conclusion:

1. The pulsed Nd:YAG laser, used in this study, with the power of 1.25 W was found to be effective in removing dental caries.
2. The remaining dentine thickness was found to be an important determinant on the amount of heat reaching the pulp with lower temperatures in higher RDT.
3. It is suggested to use the high velocity aspirator and an air spray during the laser caries removal procedure, as it helps to prevent pulpal overheating,
4. The clinical application of this laser wavelength was found to cause no pathologic pulpal changes when used for maximum exposure time of 30 sec bursts. This was clarified by a series of examination of the treated teeth within two years follow up.
5. Patient's lowered anxiety level towards laser treatment suggest that the laser can be an acceptable alternative to drill for treatment of anxious children.

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APPENDICES

APPENDIX A:

Local rules suggested for a safe laser application in clinical dental practice:

Safety requirements during the laser operation controlled by the direct supervision of the laser safety officer of the Glasgow Dental Hospital and School NHS Trust:

a- Laser protective glasses were worn by all personnel in the operating room.

b- All access windows to the outside of the operating room were sealed with thick paper pads, which were carefully checked.

c- A notice of "Laser in operation - Do not enter" was placed at the entrance to the operating room.

d- The operating room was checked preoperatively in order to ensure that there were no combustible materials (explosive anaesthetic gas) present at the time of laser operation.

APPENDIX B:

Patient's anxiety scoring using the modified Venham's pictorial form.

Score	(Before treatment)	(After treatment)
1 =	Highly anxious	Highly improved
2 =	Moderately anxious	Highly improved
3 =	Slightly anxious	Moderately improved
4 =	Anxious (Uncertain)	Highly improved
5 =	Anxious (Uncertain)	Slightly anxious
6 =	Anxious (Uncertain)	Moderately anxious
7 =	Anxious (Uncertain)	Highly anxious
8 =	Anxious (Uncertain)	Highly anxious

APPENDIX C:

Questionnaire by which parent's views on laser caries removal system was evaluated. No: ....

Dear parent :

Could you please answer these questions, related to your child's treatment at the Dental Hospital. Your help in answering the questionnaire is highly appreciated:

1. How much do you know about the lasers:
None ☐ Little ☐ Enough ☐ A lot ☐

2. How much did you know about lasers in dentistry before it was offered to your child
None ☐ Little ☐ Enough ☐ A lot ☐

3. How much information did you receive at the dental hospital before the treatment.
None ☐ Little ☐ Enough ☐ A lot ☐

4. Did you search any more for information about laser treatment after your child had been treated: Yes ☐ No ☐

5. Where was the first place you heard about lasers in dentistry?
Radio/TV ☐ Newspapers ☐ Friends ☐ Local Dentist ☐
Dental hospital Consultant ☐ Surgeon who treated your child ☐
None of the above ☐ (please specify) ....

6. Which technique for removing decays do you prefer for your child now?
Drilling with injection ☐ Drilling without injection ☐ Laser ☐
Treatment under General Anaesthetic ☐ No preference ☐

7. What do you think about your child's attitudes towards dental treatment after laser visit:
Improved Slightly ☐ Improved a lot ☐
Increased the anxiety ☐ No difference ☐

8. Would you recommend the present technique to the other members of your family or friends. Yes ☐ No ☐ Not quite sure ☐

9. Why was your child referred to the Dental Hospital for treatment (you may tick more than one):
Dental Anxiety ☐ Specialised Hospital ☐ Lots of Decays ☐
Already treated at the Dental Hospital ☐ More Convenient ☐
Medical reason ☐ Other Reasons ☐ Please state ....

10. Did your child complaint or had any complication after being treated by laser
Yes ☐ No ☐ Do not remember ☐ (if yes please specify)..................

*Please return completed questionnaire to the Dental Hospital in envelop enclosed.

With many thanks: Dr. G. Ansari, CDH/ Glasgow Dental Hospital and School, 378 Sauchiehall St., Glasgow G2 3JZ

APPENDIX D:

Demineralised section preparation:

1. Fixation: 24 hours in Buffered formalin.

2. Decalcification: immerse in 20% formic acid in distilled water for 5-7 days, confirmed radiographically, and washed thoroughly in tap water.

3. Dehydration: put in a sequence of: Methanol (70% Alcohol), Absolute alcohol x2, Xylene x2, then followed by mounting in paraffin wax for sectioning.

4. Sectioning: position in microtome for sections of 5μ Thick, and air dried in 60 °C for an hour.

5. Staining: Rehydrated (Xylene, Alcohol, Water) and then stained using the specific stain (H&E or van Gieson).

6. Mounting: sections were mounted on glass slides using HSR mounting medium.

APPENDIX E:

Ethical approval obtained for the clinical laser trial:

GLASGOW DENTAL HOSPITAL
AND SCHOOL

378 SAUCHIEHALL STREET, GLASGOW G2 3JZ
TELEPHONE: 041 332 7020 FAX: 041 353 2180

HAC/MMCC/04

6 May 1994

Dr G Ansari
Dept. of Child Dental Health
Floor 4
Glasgow Dental Hospital

Dear Dr Ansari

Area Dental Ethics Committee

Protocol: "Removal of caries in primary teeth using the dental laser."

I write to inform you that your protocol for a clinical research project has now been approved by the Area Dental Ethics Committee subject to the standard consent form being used. In the information sheet, the phrase "Dental Hospital Staff" should be changed to "our opinion". The name of all investigators should be added to the consent form and a stamped addrssed envelope should be enclosed so that parents can send the teeth to the Hospital. These amendments should be made and the protocol should be sent to the Chairman for approval. The Committee did not give approval for extraction of teeth in this project.

The Committee would be grateful if you would inform them of the results of your project and any ethical problems encountered when the project is complete.

Yours sincerely

H A Critchlow
Chairman
Area Dental Ethics Committee

APPENDIX F:
Parent's consent form

UNIVERSITY OF GLASGOW DENTAL HOSPITAL AND SCHOOL
DEPARTMENT OF CHILD DENTAL CARE
378 Sauchiehall Street, Glasgow G2 3JZ
(041 - 332 7020 Ext 217)

A NEW PROCEDURE FOR THE REMOVAL OF TOOTH DECAY

This letter is to explain a new method to remove decay from teeth. Instead of removing the decay by drilling, this method involves applying a laser light to the tooth to remove the decay. Unlike the drill, this laser light removes only the decaying part of the tooth, and involves no vibrating noises.

Laser light has been developed, approved for this use in the USA. No adverse effects have been observed or reported. Before this treatment can become readily available in the UK, it is necessary to assess its effectiveness and success on a trial basis. We are now ready to offer this treatment to a limited number of children who have suitable decayed teeth. In our opinion, this is a safe and effective way to remove decay from childrens teeth.

If your child has a suitable decayed tooth for this treatment, then a member of staff will explain this procedure. Your child may'be offered an injection to anaesthetise the tooth and the decay will be removed as far as possible with the application of this laser light. A filling would then be inserted in the normal way. Then, when the tooth is shed in due course we would be grateful if you could save it carefully and bring it back or post it to The Department of Child Dental Care at the Dental Hospital. In the event of the tooth needing to be extracted please ask the dentist to save it and send it to the Department of Child Dental Care at the above address. When you return the tooth, please do so in the stamped addressed envelope provided marked "Laser project".

Please contact the Child Dental Health Department if there are any problems following treatment.

If you are agreeable to your child receiving this treatment please indicated this by signing the statement below.

Yours sincerely

Dr J S Reid Dr S Creanor Dr G Ansari

I have understood and read the above and this procedure has been explained to me.

I agree to my child .... receiving this treatment.

Parent/Guardian Name (in block capitals) ....

Address ....

....

Telephone No ....

Signed .... Date ....

APPENDIX G:
Clinical proforma

THE UNIVERSITY OF GLASGOW
DEPARTMENT OF CHILD DENTAL CARE AND ORAL SCIENCES
CLINICAL TRIAL OF CARIES REMOVAL USING DRILL/ND:YAG LASER IN PRIMARY TEETH

Surname : ☐ Initials: ☐ GDH Case Record No: ☐
Date of Birth: ☐ Sex: ☐ Date: ☐
Age at this visit : ☐ Serial Number: ☐ Group (Cont./Exp.): ☐

Number of tooth (FDI)): ☐

Radiograph Taken:
1. Periapical ☐
2. OPT ☐
3. Bite Wing ☐

Radiographic Score of the Surface: ☐
0. Sound
2. Enamel
3. Dentine
4. Dentine and Pulp
5. Restored

Anxiety Scores before treatment: ☐
1. Definitely Negative
2. Slightly Negative
3. Slightly Positive
4. Definitely Positive

Pulp assessment Bef/aft Treatment:
1. Ethyl Chloride ☐ ☐
2. Electric Pulp Test ☐ ☐
3. Clinical Condition (N/A) ☐ ☐

Past Dental experience: ☐
1. Restoration
2. Extraction:
3. None

Cavity Size: ☐
1. Small
2. Medium
3. Large

Time Taken for Caries Removal: ☐
Time Taken for Restoration: ☐

caries Removal technique: ☐
1. Drill
2. Laser

Turbine Used for Access: ☐
1. Yes
2. No

Caries Removed Completely: ☐
1. Yes
2. No

PulpalTreatment: ☐
0. None
1. Indirect Pulp Cap
2. Direct Pulp Cap
3. Pulpotomy
4. Pulpectomy
5. Extraction

Cavity class: ☐

Complain during treatment ☐
1. Yes 2. No

Isolation: ☐
1. Rubber Dam
2. Cotton Roll

Local Anaesthesia: ☐
1. Yes
2. No

Hand Excavator used: ☐
1. Yes 2. No

Restoration (6/12) R/V: ☐
1. perfect
2. leaked
3. lost

Treatment order: ☐
1. Laser first 2. Drill first

Patients attitude Score After Treatment: ☐
1. Definitely Negative
2. Slightly Negative
3. Slightly Positive
4. Definitely Positive

Radiographic View (6/12): ☐
1. Normal
2. Abnormal

Pulpal Response (1/12) after treatment
1. Ethyl Chloride ☐
2. Electric Pulp Test ☐
3. Clinical Condition(N/A) ☐

Pulpal Response(6/12 & 12/12) after treatment:
1. Ethyl Chloride ☐ ☐
2. ElectricPulp Test ☐ ☐
3. Clinical Condition(N/A) ☐ ☐

Date of extraction/exfoliation: ☐
Date tooth Received: ☐

Tooth Removal: ☐
1. Extraction
2. Exfoliation

Pathology report: ☐
1. Normal
2. Abnormal

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