The detection of dental decay has conventionally been dependent upon direct visual assessment of the dried tooth surface under good illumination, tactile assessment of open dental caries using a probe to help clean debris within fissures, clinical experience and the use of dental radiography. Studies have shown considerable variation between clinicians in the detection of dental caries. Recent additions to assist the accurate detection of dental caries include the DIAGNOdent (KaVo GmbH, Germany), caries detector dyes and digital radiography.

Pre-1980s, a sharp-tipped explorer, of various design, was used to ‘probe’ all accessible tooth surfaces for detection of any defects. It was thought correct to apply pressure on the explorer to detect any ‘sticky’ areas. The degree of ‘stickiness’ of an area was subjective and in general a sticky pit or fissure indicated a carious area that required conventional treatment. This comprised mechanical removal of the sticky area until crisp, hard tissue remained, and the restoration of the subsequent defect by some form of filling material.

In the 1980s the dental profession acquired a better understanding of the caries process. It became known that an early carious lesion is in a constant state of balance between the loss of dental mineral as a result of the acids produced by plaque micro-organisms, and the re-precipitation of mineral from oral saliva. With this knowledge came the realisation that aggressive use of sharp probes into early lesions would actually disrupt the dental tissue and create a physical cavity, causing more harm than good. Advice followed that an explorer should be used as gently as possible, merely acting as a tactile sensor for the detection of roughness, rather than being pressed into suspicious areas to see if the instrument would ‘stick’.

What changes have been made in detecting dental caries in recent times?

Front surface reflecting mirrors have provided a less distorted and sharper image of the dental tissues. There have been advances in conventional dental x-ray films providing good images with a reduction of x-ray exposure times. Clinicians have been investing in the use of magnification loupes that are a welcome advance as they can magnify the field of view by 2.5 to 4.0 times, facilitating a superior view compared with the naked eye. Intra-oral imaging systems, such as the intra-oral camera have also been introduced. Such dental cameras have become easy to use and relatively inexpensive. They are capable of producing excellent colour images of tooth surfaces. Such images can be magnified and printed as hard copies. This technology allows fine visual examination of tooth surfaces and is also a great educational tool as the patient can be included in the assessment of the area under investigation.

Digital technology has allowed advances in camera technology and digital radiography has allowed virtually instant x-ray images to be examined on the computer screen. Digital radiography has also brought a substantial reduction of x-ray dosage. Digital technology allows for computer enhancement of images that can help reveal lesions clearly.

The profession has also seen the use of various caries detector dyes and some oral diagnostic tests to detect carious potential in the oral cavity.

In spite of these advances, accurate detection of carious lesions remains subjective and studies have demon-
strated accuracy in the diagnosis of carious lesions is an ongoing problem. Failure to accurately detect early carious lesions may often result in the individual concerned requiring extensive restorative help at a later stage when the lesion has progressed to a point where gross cavitation of the tooth occurs, or symptoms of pain arise. At this point the restorative treatment has become technically demanding, time consuming, potentially uncomfortable for the patient and has considerable financial implications for all concerned. Implications for the patient, if they are paying for their dental care, or for the nation, under a state-funded system.

Are there any advances to help the clinician be more objective in the detection of caries?

The introduction of a system capable of detecting early carious lesions with a high predictability and a new technology capable of the eradication of the carious process at an early stage, together with the therapeutic use of agents to encourage remineralisation of the lesion would be welcomed.

In the specialist dental research centres, the Electrical Caries Monitor (ECM), by Lode Diagnostics, Holland, is used to measure the depth of carious lesions. However, the ECM has considerable disadvantages for use in general dental practice. It is expensive and the repeat measurements required for reliable results are very time consuming. In its present form, the ECM does not appear ideally suited to a busy general practice setting, but it is a useful research tool.

The ‘DIAGNOdent’ instrument (KaVo, Germany), has been available to the profession for the past few years. This instrument is relatively inexpensive and is fairly straightforward to use in a busy general practice setting. Details about the DIAGNOdent are discussed in the Chapter from Prof Lussi, but a summary of use for general practice is presented here.

The DIAGNOdent’s handpiece ‘shines’ a laser beam at the tooth surface and into the fissure or suspect area. The instrument measures the fluorescence of the structures in the path of the beam. It is essential that the area under investigation is as clean and dry as possible. Research has shown that the most effective method of cleansing the surface, in particular the occlusal fissures is by air polishing (Clifford, 2003; Clifford, 2004). This is a powerful jet of water, air and sodium bicarbonate in combination. There are several varieties of dental air polishing units available. The unit chosen by the ozone research teams in the UK is the ‘PROPHYflex’ (KaVo, Germany). This unit was shown to be effective in removing all surface debris, biofilm and stains.

After simple calibration, the DIAGNOdent scans the surface under investigation. The unit emits an audible tone throughout the measurement. The display screen on the unit provides a reading of a value from 09 to 99. The higher pitch of the audible tone indicates a larger area of decay. This is also displayed as a higher number on the display screen. It is also highly useful in terms of patient response. The patient can easily understand the higher the readout figure, the worse the lesion is. Equally the increasing pitch of the audible tone captures their attention!

The DIAGNOdent does have some shortcomings. The readout figure has a maximum value of 99. A lesion reading 99 could be significantly worse than 99 and on this arbitrary scale, it could well represent a read out of 150 or 200, or higher. A further problem is that re-mineralised enamel can be of a darker colour and that would produce a false reading on the unit. Care would also be required if part of the fissure had a tooth coloured restoration, that had the property of fluorescence, which could also give a false reading.

The DIAGNOdent readings would need to be carefully recorded on a record card, or on a computer and ideally the area examined mapped out. Sequential readings over time are essential for the monitoring of the progress of the lesion. The use of an intra-oral camera is a considerable help in mapping out the lesions. Clinical photographs of the areas in question can be taken and notes of the readings can be added to the photograph.

Understanding the niche environment and dental caries

Dental caries is the result of microbial infection of a susceptible tooth and the subsequent interaction with fermentable carbohydrates, which commence the demineralisation by producing organic acids causing loss of mineral and the resultant softening of the tissue. The micro-organisms can have a sheltered environment within the dental tissue and with ample substrate (fre-
quent consumption of fermentable carbohydrates) washing through the lesion the micro-organisms progress with demineralisation and the invasion of the tooth tissue. Since the 19th Century, the best practice in treating decay was physical amputation of softened tissue from the tooth. Conventional treatment of the removal of this diseased tissue is by various physical means, usually, a drill. Over many years dental students were taught engineering principles in cavity design, as clearly exemplified by the work of G.V. Black. The amputated tissue would then be replaced with some form of restorative material, i.e. the filling.

As we move into the 21st Century, the dental profession offers essentially the same form of treatment of dental decay as was practised in the 19th Century: drill and fill or amputation treatment. There have been significant improvement in equipment and technology over the years, but the fundamentals remain the same. Sadly, even with the highest technical and surgical skill, the drill and fill approach involves weakening of the tooth structure, compromising the vitality of the dental pulp. The procedure is also stressful for the patient involving a local anaesthetic, the drilling of the tooth and so on. This form of treatment also has significant cost implications in terms of the dental hardware involved i.e. the equipment, materials, dental staff wages, coupled with the implications of the value of the time involved for the patient to undertake the procedure.

Since the 1960s the 'prevention' movement has seen some success. The use of agents such as fluoride in various forms, to toughen the enamel to help resist the acids produced by oral micro-organisms and the effect of fluoride to help re-mineralise an early carious lesion has been well established. Dietary advice to reduce the frequency of consumption of fermentable carbohydrates and better oral hygiene measures have all played their part. The use of "pit and fissure sealants" offered a logical defence of the tooth in terms of artificially eliminating these anatomical 'weak spots', depriving oral micro-organisms from colonising these areas and thereby establishing potential carious sites. The fissure sealing modality is not a predictable event, although a marked reduction in the frequency of consumption of fermentable carbohydrates, coupled with excellent oral hygiene frequently delivering fluoride can tip the balance in favour of repair of the lesion.

The alteration of the ecological niche environment of the tooth or lesion, namely dramatically reducing the micro-organisms, and therefore the associated metabolites such as the organic acids, allows the healing of the lesion with a far greater predictability and success. Improved biofilm control with toothpastes, sprays and mouthwashes also enhance the re-mineralisation process, especially combined with Ozone treatment. As mentioned previously, the use of fissure sealants have not resulted in the preventive success they originally promised. It was thought that the sealant would have the effect of cutting off the food supply to the micro-organisms established in the depths of the fissure and so the progress of any carious activity would cease. This is not always the case. We now know that it is possible for leakage to occur around the margin of the sealant, which can be impossible to detect clinically. With such ingress of fermentable carbohydrate substrate the 'trapped' micro-organisms are able to con-
continue the carious process unchecked. Visual and tactile examination of such teeth may reveal nothing significant. At this stage even good quality bitewing radiographs may fail to reveal any early demineralisation of occlusal carious dentine. Radiographic dentinal caries and its progression in occlusal surfaces was assessed in Dutch 17-year-olds in a 6-year longitudinal study (Poorterman et al., 2003). In this study, the status of 705 occlusal surfaces of first and second molars of 90 17-year-olds was analysed longitudinally in a 6-year follow-up, using a combination of clinical and radiographic information. Between the age of 17 and 23 years, about one third of sound occlusal surfaces developed a new dentinal radiolucency, and over 70% of existing radiolucencies showed progression, both irrespective of the presence of a sealant. In both examination years, almost 20% of the restored surfaces showed signs of a dentinal radiolucency. It was concluded that at the age of 17 occlusal surfaces are still highly susceptible to new dentine caries and further progression of dentinal radiolucencies already present.

The clinical and radiographic judgement of occlusal caries in adolescents has also been examined (Poorterman et al., 2000). In this study, the clinical and radiographic material of two groups of 17- and 20-year-old adolescents, born either in 1970 or in 1976, was compared to study changes in the prevalence of occlusal dentine caries and to determine the additional value of the bitewing radiographs. The first and second molars of 478 participants were included. After clinical and radiographic examination, around 33% of the occlusal surfaces of the 17-year-olds and around 25% of the 20-year-olds exhibited dentine caries. The clinical prevalence of occlusal caries in first and second molars was highly underestimated when compared with the radiographs. In the 1976 group, more sealants were recorded during the clinical examination. On the bitewing radiographs, radiolucencies were found underneath one-half of the sealants of the 17-year-olds and underneath one quarter of the sealants present in the 20-year-olds.

Weerheijm et al. quantified the bacterial counts in carious dentine under restorations after 2-year in vivo (Weerheijm et al., 1999). Little was known about the long-term effects of fluoride-releasing materials on carious dentine in vivo. The aim was to investigate the 2-year influence of a resin-modified glass ionomer cement and amalgam on the bacteriological counts of carious dentine that remained under class I restorations in a split-mouth design. The enamel of the carious molars was removed, and the carious dentine was sampled under aseptic conditions just beneath the dentinoenamel junction. The molars were alternately restored with resin-modified glass ionomer cement or amalgam without further removal of carious dentine. The samples were processed for microbiological determination of total viable counts, mutans streptococci, and lactobacilli. The molar pairs of 25 patients were re-evaluated after 2 years using the same clinical techniques and were permanently restored after complete caries removal. Both materials showed a substantial decrease in numbers of total viable counts and lactobacilli of the carious dentine after the 2-year period. Compared to amalgam, the decrease in the numbers of lactobacilli was significantly more pronounced for resin-modified glass ionomer cement. Micro-organisms were detected in 39 out of the 50 molars after the 2-year period (6 resin-modified glass ionomer cement and 5 amalgam were the exceptions). Based on this study using no method to kill the micro-organisms prior to restoration, the authors suggest that complete removal of carious dentine is still the best conservative treatment, irrespective of the restorative material used.

Where individuals have experienced exposure to fluoride from an early age the physical properties of their fluoridated enamel maybe greatly enhanced and may resist early obvious clinical cavitation, in spite of being undermined by soft, carious dentine. In the past 25 years we have seen the phenomenon of “occult caries”, or sometimes termed “hidden caries” or a “fluoride bomb”. This is seen clinically where the tooth appears to be totally clinically sound, yet an alarming amount of dentine has been infected. Early carious lesions with infection in dentine are not easy to identify on bitewing radiographs. Sadly, this occult caries progresses and an otherwise sound looking tooth may suddenly collapse revealing a massive cavity; sometimes a radiograph will reveal a seemingly perfect rim of enamel, but a radiolucent lesion beneath which may occupy the entire circum-pulpal dentine.

The introduction of optimum concentrations of fluoride into drinking water and oral health care products such as toothpaste has reduced dental decay over the past few decades. The concern for the profession is the question of whether we will see primary pit and fissure caries becoming a problem later in life. Fluoride in concentrations used in oral hygiene products may be delaying the overall progress of caries rather than arresting the process.
An interesting social change over the past few years is the increasing use of bottled water in the family home. Many health conscious adults feel bottled mineral and spa water offers a healthier option compared with drinking tap water. Some individuals may also prefer to use toothpaste that does not contain fluoride. This may have an impact on their dental caries risk. The preventive use of a novel agent, such as ozone therapy, could offer a great help for such people.

The key to success in helping prevent the spread of pit and fissure primary carious lesions is accurate detection. We have mentioned some of the difficulties faced by clinicians in correct detection. The primary fissure carious lesion accounts for some 70% of all new decay encountered in dental practice. An essential part of the original research into the use of ozone in the treatment of dental caries was to use accurate and reproducible methods to detect and measure the extent and depth of decay.

**How ozone therapy can affect the ecological niche environment**

The ability to treat a carious lesion without the need of amputation of the diseased tissue would be one of the greatest achievements in the history of dentistry. Ozone therapy has the potential to move toward this goal. Remineralised dental tissue is far less likely to decay again. The resistance of further decay may be attributed to many factors including a change in the morphology of the dentine, an altered mineral content in the tooth and changed hardness of the tissue all of which contribute to an increased resistance to new acid attack. Mineral re-precipitation within the dentinal tubules can obliterate the tubular structure, thereby rendering it impenetrable to micro-organisms and their acidic metabolites. Furthermore, the higher fluoride and metal ion content of the newly mineralised tissue offers enhanced resistance to future potential acid attack. The provision of ozone therapy facilitates the remineralisation of lesions. Studies show that caries reversal occurs after ozone treatment. This re-mineralised tissue can then support a restoration, bringing the once diseased tooth back to full function.

In addition to the detection tools described above, a clinician should have at their disposal some form of 'Clinical Index' to assist their assessment of teeth for carious lesions.

It is believed that a number of important changes occur within the carious lesion during ozone treatment. Firstly, any infection by micro-organisms is dramatically reduced. Further, pyruvic acid produced by the micro-organisms is converted to acetate and carbon dioxide. It is also possible that some proteins, which are natural inhibitors to remineralisation, are also reduced and some dentine channels may be opened. These factors allow the bioavailable minerals from the patient's supersaturated saliva, aided by the re-mineralising rinses, sprays and toothpastes, to remineralise the lesion, penetrating the tissue. This morphological change, together with the inability of the ecological niche of acidogenic and aciduric micro-organisms to re-establish easily, creates a favourable environment to encourage re-mineralisation, rather than to be prone to further decay.

There is a logical argument to consider this treatment modality as a potentially highly powerful prophylactic tool in the routine ozone treatment of erupting dentitions in caries risk children. There are compelling arguments to support the cost-effective use of ozone therapy as a prophylactic agent.

All the research findings, and the action of ozone in dramatically disrupting the micro-organism's ecological niche, offer a new hope to future dental health. If newly erupted teeth were ozone treated, coupled with preventive advice, there should be a significant reduction in the need for future costly restorative care. This has important implications in public dental health terms.

Conventional drill and fill dentistry involves the amputation of a considerable volume of diseased tissue. With ozone therapy and re-mineralisation, only minimal quantities of dental tissue need be removed to facilitate a restoration of the tooth. This makes the restorative treatment much simpler, less time consuming and much more cost-effective. For the patient, it is far more comfortable than drilling and filling.

Prevention of disease has always been the most cost-effective modality for any health care system. Modern dentistry has the prevention of dental disease at its heart. We have seen success in the reduced incidence and prevalence of dental decay over the past 30 years, but sadly we still see areas where dental decay poses a significant problem in the community. With an improved strategy of oral health education coupled with prophylactic ozone therapy, there are considerable potential benefits in oral health terms.

In general dental practice, the benefits of the utilisation of ozone therapy as opposed to drill and fill would
Ozone treatment takes a mere 10 to 40 seconds per tooth, and requires a minimum amount of disposable items, such as cotton rolls and so on. Conventional drill and fill treatment can take at least 20 minutes and often a lot longer. It also requires expensive restorative materials.

In England and Wales, the National Health Service figures revealed that for the year 2001/2 some 19.7 million fillings were placed at a cost of £223 million pounds. Conventional fillings weaken the structure of the teeth and the future often brings the need for repeating the restoration as the structure of the tooth/filling break down. The vitality of the dental pulp may also be compromised and endodontic therapy is often required, significantly adding to the cost.

If we postulate that just 45% of these cases could have been successfully treated by ozone then the saving to the National Health Service in England and Wales would have been around £100 million for the single year.

Ozone can now be considered as a realistic alternative management strategy for dental caries and is supported by the published literature. Caries reversal is associated with several factors including the dramatic disruption of microbial infection of the dental tissue and the damage to the ecological niche that supports the acidogenic and aciduric micro-organisms. Shifting the microbial flora in carious lesions to one containing normal oral commensals would predominately allow remineralisation to occur within the lesion.

Patients are astonished by the comfortable nature and the simplicity of the ozone therapy. No local anaesthetic injection, no drills and an appointment time measured in a few minutes. The implications for this new treatment to a general dental practitioner are profound. Ozone therapy has the potential to reduce the cost to a government sponsored dental scheme of restorative treatment. It has unique potential in terms of dental care in developing countries and the poorer regions of the world. For private dental practitioners we have the opportunity to offer patients a totally pain free treatment.

**Conclusion**

Ozone has been successfully utilised by the medical profession, especially in Russia and Cuba, for around 100 years. The purification of public water supplies in over 6000 cities worldwide, including the USA, and the purification of air conditioning units have proven successful over many years. In a nutshell ozone is highly efficient for the elimination of bacteria, fungi and viruses in a variety of situations.

Ozone therapy has the potential to reduce the cost of restorative treatment for both private patients and for government sponsored dental schemes. It offers unique potential for dental health programmes in developing countries and the poorer areas of the world.

Currently, active research is underway into the therapeutic use of ozone in many areas of dentistry, such as endodontics, periodontal therapy and in the treatment of various soft tissue infections. Researchers are examining the beneficial applications of ozone in sterilisation of dental water lines. In fact, in any situation where micro-organisms are producing pathological potential, ozone has the ability to offer a simple and effective solution.

In summing up, the current research is indicating that ozone has proved to be an exciting advance for the dental profession with substantial and far-reaching implications in the delivery of dental care in the 21st Century. Ozone is a powerful anti-microbial agent with the ability to penetrate hard and soft tissues. The benefits of ozone therapy are reduced costs and the potential elimination of dental treatment phobia. Crucially, the profession may now have the ability to treat dental caries without the recourse to the needle and drill.

**References**