

Ozonated Liquids in Dental & Medical Practice – A Review

Ozonated Liquids in Dental Practice – A Review

Author: Dr Julian Holmes, Lime Technologies Holdings Ltd, Clinical Director

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In Conclusion: Introduction. Part 10.

In the 1700's a number of people investigated gas behavior in the laboratory. Robert Boyle investigated the relationship between the volume of a dry ideal gas and its pressure. Since there are four variables that can be altered in a gas sample, in order to investigate how one variable will affect another, all other variables must be held constant or fixed. Boyle fixed the amount of gas and its temperature during his investigation. He found that when he manipulated the pressure that the volume responded in the opposite direction. For example, when Boyle increased the pressure on a gas sample the volume would decrease. Mathematically, $PV = \text{constant value}$ if the gas is behaving as an Ideal Gas. A practical math expression of Boyle's findings is as follows: $P_1V_1 = P_2V_2$ where the variables with the 1 subscript mean initial values before the manipulation and the variables with the 2 subscript mean final values after the manipulation.

Modern science has unlocked more of nature's secrets, and we now understand that different chemical molecular structures have unique properties in terms of solubility, and polarity. Pressure is the most important factor when dissolving gases in liquids, according to Richard E. Barrans Jr., PhD, a PG Research Foundation chemist in Darien, Illinois. If the solute is a gas and the solvent is a liquid then changes in pressure will affect solubility; this is the basis of Henry's Law of Gases. In addition, temperature and solvent polarity also play an important role.

If the solute in question is a dissolved gas, increasing the pressure increases the amount of gas in the solution and therefore the concentration of gas. This is Henry's Law: $C = k P$ where C is the concentration, P is the pressure and k is the Henry's law constant for the particular gas/solvent combination - effectively equilibrium constant.

Henry's Law and the Solubility of Gases

Concentration of solutions cited here will all be molar concentrations, because in homogeneous solutions, the active mass is the ratio of amount of substance to unit volume. Molar concentration will be indicated by c , with the solute in parenthesis following the symbol, or by placing the solute molecule or ion symbol in square brackets. Other concentration units, such as molality, are less commonly used in aqueous equilibrium calculations.

According to Prof. Robert Topper, Chair Department of Chemistry, Medical Technology and Physics, Monmouth University West, Long Beach, NJ, Henry's Law describes the bubbles which rise out of solution when you open a pressurised bottle of cola or any other carbonated beverage. If c is taken to be the solubility then one must say that the solubility depends on pressure. On the other hand, if the solute is a crystalline solid then pressure will not make a bit of difference because liquids (and solids) are highly incompressible and the solute is non-volatile, so the concentration depends only on the equilibrium constant's value, which is independent of pressure in all cases.

Gases dissolve in liquids to form solutions. This dissolution is an equilibrium process for which an equilibrium constant can be written. For example, the equilibrium between oxygen gas and dissolved oxygen in water is $O_2(aq) \leftrightarrow O_2(g)$. The equilibrium constant for this equilibrium is K

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$= p(\text{O}_2)/c(\text{O}_2)$. The form of the equilibrium constant shows that the concentration of a solute gas in a solution is directly proportional to the partial pressure of that gas above the solution. This statement, known as Henry's law, was first proposed in 1800 by J.W. Henry as an empirical law well before the development of our modern ideas of chemical equilibrium.

Stating the pressure-concentration ratio as an equation and use of the usual modern symbol for the Henry's law constant on a concentration basis, K'_c , gives the following form of Henry's law:

$$p = K'_c c$$

In this form p is the partial pressure of the gas, c is its molar concentration, and K'_c is the Henry's law constant on the molar concentration scale. Henry's law is found to be an accurate description of the behavior of gases dissolving in liquids when concentrations and partial pressures are reasonably low. As concentrations and partial pressures increase, deviations from Henry's law become noticeable. This behavior is very similar to the behavior of gases, which are found to deviate from the ideal gas law as pressures increase and temperatures decrease. For this reason, solutions which are found to obey Henry's law are sometimes called ideal dilute solutions.

Values of the Henry's law constants for many gases in many different solvents have been measured and these constants can be downloaded from the www or found in chemical tables. The solubility of a gas in a liquid depends on temperature, the partial pressure of the gas over the liquid, the nature of the solvent and the nature of the gas. The most common solvent is water.

Gas solubility is always limited by the equilibrium between the gas and a saturated solution of the gas. The dissolved gas will always follow Henry's law.

The concentration of dissolved gas depends on the partial pressure of the gas. The partial pressure controls the number of gas molecule collisions with the surface of the solution. If the partial pressure is doubled the number of collisions with the surface will double. The increased number of collisions produces more dissolved gas or higher gas concentration.

The illustration shows that if the pressure is doubled then the concentration of dissolved gas will double.

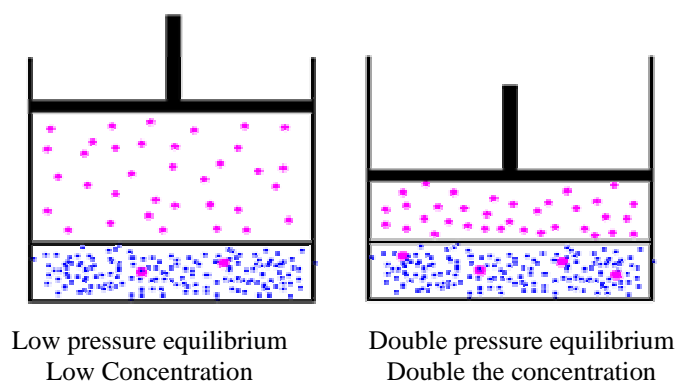
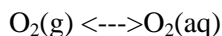


Fig 10.01 Henry's Law of Gases simplified

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The dissolving process for gases is an equilibrium. The solubility of a gas depends directly on the gas pressure. The number of molecules leaving the gas phase to enter the solution equals the number of gas molecules leaving the solution. If the temperature stays constant increasing the pressure will increase the amount of dissolved gas.



Gas Solubility \propto Gas Partial Pressure

$$P_{\text{gas}} = kC \text{ at constant } T$$

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The Henry's law constant "k" is different for every gas, temperature and solvent. The units on "k" depend on the units used for concentration and pressure.

The value for "k" is the same for the same temperature, gas and solvent. This means the concentration to pressure ratio is the same when pressures change. The following equation can be used to relate pressure and concentration changes.

$$\frac{C_1}{P_1} = \frac{C_2}{P_2}$$

Example 1:

The concentration of dissolved oxygen is 0.44g / 100 mL solution. The partial pressure of oxygen is 150 mm Hg. What is the predicted concentration if the partial pressure for oxygen is 56 mm Hg?

Solution:

$$\frac{C_1}{P_1} = \frac{C_2}{P_2}$$

$$P_1 = 150 \text{ mm Hg}$$

$$C_1 = 0.44 \text{ g O}_2 / 100 \text{ mL solution}$$

$$P_2 = 56 \text{ mm Hg}$$

$$C_2 = ?$$

$$\frac{0.44 \text{ g O}_2}{150 \text{ mm Hg}} = \frac{C_2}{56 \text{ mm Hg}}$$

$$C_2 = (56 \text{ mm Hg}) \left(\frac{0.44 \text{ g O}_2 / 100 \text{ mL solution}}{150 \text{ mm Hg}} \right) \quad C_2 = 0.15 \text{ g O}_2 / 100 \text{ mL solution}$$

(Referenced from R. Sander (1999) Compilation of Henry's Law Constants for Inorganic and Organic Species of Potential Importance in Environmental Chemistry (Version 3) <http://www.mpch-mainz.mpg.de/~sander/res/henry.html>)

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The inverse of the Henry's law constant, multiplied by the partial pressure of the gas above the solution, is the molar solubility of the gas. Thus oxygen at one atmosphere would have a molar solubility of $(1/756.7)\text{mol/litre}$ or 1.32 mmol/litre .

Example 2.

The amount of oxygen dissolved in air-saturated water under normal atmospheric conditions at 25°C can be calculated as follows.

Normal atmospheric conditions are 20.948 mole per cent oxygen, which makes the partial pressure of oxygen 0.20948 atm or 20.67 kPa .

Using Henry's law, the concentration of oxygen is $0.20948\text{ atm}/(756.7\text{ atm}/(\text{mol/litre}))$ which is $2.768 \times 10^{-4}\text{ mol/litre}$ or 0.2768 mmol/litre .

The value of the Henry's law constant is found to be temperature dependent. The value generally increases with increasing temperature. As a consequence, the solubility of gases generally decreases with increasing temperature. One example of this can be seen when water is heated on a stove. The gas bubbles which appear on the sides of the pan well below the boiling point of water are bubbles of air, which is evolved when water which was air-saturated at lower temperatures is heated and the amount of air which it can contain (the molar solubility of air) decreases. Addition of boiled or distilled water to a fish tank will cause the fish to die of suffocation unless the water has been allowed to re-aerate before addition.

The decrease in solubility of gases with increasing temperature is an example of the operation of Le Chatelier's principle. The heat or enthalpy change of the dissolution reaction of most gases is negative, which is to say the reaction is exothermic. As a consequence, increasing the temperature leads to gas evolution.

(Reproduced from James A. Plambeck (Jim.Plambeck@ualberta.ca). 1996, <http://www.psigate.ac.uk/newsite/reference/plambeck/chem2/p01182.htm>)

Dentistry in the 'Real World'.

General Dental Practitioner's around the world are super efficient at 'drilling and filling', or 'amputation therapies'. The term 'amputation therapies' was coined by Professor Edward Lynch and Dr Julian Holmes in their series of presentations on 'Ozone – The Modern Management Of Caries'.

Taken across the world, this is a massive number of patients entering 'the repeat restorative cycle' This term was coined by Edward Lynch, Julian Holmes & others in 'Ozone – The Revolution In Dentistry, Quintessence 2004. The repeat restoration cycle is cavity preparation by substrate removal, restorative repair with filling materials. This most common form of treatment results in more extensive and costly treatment options in the future, and potentially leads to dentition loss.

Dental surveys of oral health in the United Kingdom have revealed a reduction in the incidence and prevalence of dental caries in certain age groups (*Nunn et al 2000*). This is a positive finding, but there remain large areas of the United Kingdom where dental diseases are out of control and continue to pose a major public health problem.

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Parts of Wales and Ireland for example are known to have some of the worst dental health in Europe. Dental fear and phobia are closely associated where dental disease frequently occurs. Ignorance and lack of dental health, diets rich in refined carbohydrates, sugar loaded soft drinks and consumption of great amounts of sticky treats are the norm in those areas: this is often linked to the poorer socio-economical groups and communities. The perception that health is expensive does not seem to dissuade these population groups from having a higher spend on tobacco and fast foods, despite the well publicised health risks. Even schools in these areas ignore the health hazards of disease by allowing vending machines to be placed on their premises. The growing body of evidence to suggest the carbonation products in sodas could be associated with gastrointestinal problems will hopefully start to limit its expansion into a population group that is naïve and prone to commercial marketing.

General dental practitioners working within these areas come into contact with patients of all ages with staggering levels of dental disease. Acute dento-alveolar abscesses, acute necrotising ulcerative gingivitis, pulpitis and broken down teeth, as well as fear and phobia towards dental treatment are common.

There are two models that help to explain the observed development of decay in dental tissues:

1. The first is the old model of caries: this describes caries as the loss of dental tissues as a process proceeding from the tooth's outer surface to the centre, creating a crater in the hard tissues. If left untreated, these lesions proceed towards the blood supply system, and would lead to an infection in the bone. These lesions are easily detected visually or mechanically using a probe and radiography.
2. In second model, caries starts at the enamel dentin junction (EDJ), as the consequence of bacterial penetration and colonisation via fissures, pores and fractures in the enamel surface of the tooth, which appears untouched. Demineralisation and proteolysis proceed into dentine following the dentinal tubular structure. The lesion spreads into an "anchor" or "fishing hook" shape when seen on histological sections.

If left untreated, caries triggers enamel destruction and infection of the tooth pulp tissue. Caries is now recognised as an infection. This new discovery opens the door to different techniques to control it, especially as we now see caries as a cyclical process fuelled by a specific localised ecological niche of acid producing microorganisms when they are fed fermentable carbohydrates.

The early lesions described above are difficult to diagnose:

1. Visually, as no or little evidence appears on the outer enamel surface except for pits and fissure stains.
2. Mechanically, as no macroscopic alteration in the enamel structure is present.
3. Radiographically (*Christensen 1996, Lussi 1993*) as a limited amount of minerals are lost, and radiographic evidence occurs only in later stages where the area of demineralisation may be 2-4 mm into the dentine beyond the EDJ.

Whatever the pathogenesis of this new caries model is, new diagnostic techniques need to be found to detect and evaluate these lesions. Visual magnification, with the aid of dyes, laser induced fluorescence, and chemical reactions to bacterial metabolites are the main tools that can be used clinically. These diagnostic methods differ from the classical visual, tactile and radiographic procedures because they do not look for the loss of tissue. Instead, the modern

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diagnostic tools aim to trace the metabolic processes involved. Specificity and sensitivity of such methods allow a very early detection in metabolic changes (*Anusavice 2000, Attrill 2001, Lussi 1993, Lussi et al 2001, Paterson et al 1991, Pinelli 2002*). It is now possible to detect the first stages of demineralisation with diagnostic tools such as the DIAGNOdent (KaVo GmbH, Germany)

Any further process, which involves irreversible tissue destruction, can only be described in terms of impairment, disability and handicap. Any later diagnosis is the naturalistic observation of the absence of self-regenerative resources, and possibly a failure on the clinician's part to correctly diagnose with modern diagnostic tools. At this stage, the only possible intervention is amputation of infected and necrotic tissues, and prosthetic replacement when possible and where available to reintegrate loss of function and ensure protection.

One of the benefits of early diagnosis is the rising of a new dental science, called minimally invasive dentistry, although Dr Julian Holmes and Professor Edward Lynch now feel that the new standard of care for the 21st Century should be termed "micro-invasive dentistry" (*Holmes & Lynch, in 'Ozone – The Modern Management Of Caries, a jointly produced lecture series*). This new science and art still performs amputations, but due to early detection, they are very, very small cavities. Procedures are quick, no or little pain is caused and no local anaesthesia required in the majority of cases. Fillings are very small and consequently longer lasting (*Christensen 1999*).

The ideal treatment has two objectives: arresting any microbial metabolism and boosting the natural host defence in a short period of time and with long lasting effects. Therefore, dental caries can be redefined as a reversible metabolic process.

Research has shown that fluoride only partially fulfils these requirements, and so do other disinfectants and antibiotics. Fluoride's effects take a long period of time to establish protection, and these effects may be more significant in the old caries model rather than the new model of caries. New data suggests that fluoride merely delays the onset of caries. An example of this would be when the subject moves out of the family and home-care environment. In this case oral hygiene may become worse, and the dental-juvenile-adult (DJA - a term coined by Dr Julian Holmes to describe the young adult who leaves home, falls outside 'maternal protection', and perceives that dental care is unaffordable) experiences dental decay as a result of factors that allow demineralisation and infection, start to predominate.

Up to the present, it the wide belief was that dental caries is an infective process and the only real 'treatment' option was the cutting away, or 'amputation', of all diseased tissue and its replacement with some form of restorative material. This is the teaching that most dental students still receive at dental schools around the world today, and is practiced by the vast majority of dentists around the world.

This invasive process involves needles, injections and drills. It is a highly stressful treatment for everyone concerned. This amputation approach has not changed for over 100 years. There is evidence from Egyptian times that dental care was more holistic and less invasive then, than is the norm some 3000 years later. What has improved in recent years is the general dental practitioner's understanding of the carious disease process. The prevention movement established in the 1970's attempted to educate people that the real treatment of the disease is centred on changing the diet and in improving plaque control combined with the use of fluoride containing products. It is known that people are highly resistant to accepting messages of good health education and effecting change through these messages. Some general dental practitioners do not put enough

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effort into presenting convincing dental health education to their patients, neither is the average dental practitioner well trained to do so. Sitting in a dental surgery, surrounded by the tools of drilling and filling, some patients fail to understand what the hard working dentist tells them! They may feel intimidated, uncomfortable and sceptical because they may not be well informed. The well educated and qualified dental practitioner is for the most part a highly skilled and adept practitioner of tissue amputation, and generally does not make a good educator.

The best option to avoid such stress and discomfort is for the practitioner to adopt a minimal invasive dentistry philosophy. Minimally invasive dentistry has advantages for the patient and general dental practitioner. Many techniques however still involve the physical removal of tissue before the final restoration is put into place. The ideal treatment solution is the simple removal of the cause of the disease with no associated loss of sound tissue and no associated physical discomfort for the patient. This is now available with recent advances in the field of ozone treatment (*Baysan et al 2000, Baysan 2002, Baysan & Lynch 2004, Baysan et al 2004, Baysan et al 2001, Baysan & Lynch 2001, Holmes 2003, Lynch 2003, Abu-Naba'a, 2003, Abu-Salem 2004, Domingo & Holmes 2004, Holmes 2004*). For the first time, the general dental practitioner can break the vicious circle of restorative dentistry, as it would appear that it is no longer necessary to place the initial restoration that will require eventual replacement and subsequent re-treatment. By breaking this cyclic destruction, the patient enters into a treatment pattern that is less frightening, simpler, quicker and more efficient. For the general dental practitioner, this treatment technique is simple. It provides greater efficacy for the dental practice, it is profitable (*Domingo et al 2004*), and the practice team will not have to cope with a waiting room full of anxious patients any longer.

Another advantage of the ozone treatment is that patients accept it willingly. In the past, continual advances in both materials science and treatment methods have brought outstanding benefits for our patients in terms of simplicity of the treatment. Successful dentine bonding systems have obviated the need for the design of the “Black” retentive cavity in most cases and hence dramatically reduced the use of the air turbine to design what may be termed as classical ‘amputation cavities’. Modern bonding systems have allowed the general dental practitioner to concentrate almost exclusively on the removal of carious tissue while retaining as much sound hard tissue as possible. This was the first step towards the minimally invasive approach now advocated. However this carious tissue has still to be removed whether by use of the handpiece, air abrasion, or with hand instruments (ART) when used in conjunction with caries removing liquids and gels (e.g. Carisolv).

Ozone treatment of dental caries removes the requirement for physical removal of infected tissue as remineralisation, not amputation, of carious dentine is promoted. The benefits to patients are therefore obvious. Most patients are scared and nervousness arises from their understanding that the hand piece may be an unpleasant and traumatic experience. Combined with the requirement for local anaesthesia, the fear has led to the universally accepted misconception that the visit to the dentist is unpleasant. By using ozone treatment, general dental practitioners are now capable of alleviating those concerns of both the patient and their cares, and improving the public's perception of dental treatments (*Domingo et al 2003, Freeman, Holmes and Lynch in 'Ozone – The Revolution in Dentistry': p287-294*).

Nonetheless, there are still situations where treatment will follow more classical lines. General dental practitioners offer treatment of a wide variety without the need for local anaesthesia or drilling, and they are now able to treat many lesions in a short period of time. This procedure is entirely painless and atraumatic. Experience has shown that patients are delighted after treatment and are particularly motivated towards oral hygiene and dietary control when they realise that by

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improving and concentrating on these areas they can avoid the local anaesthesia/drill approach. Patient acceptance is therefore virtually universal.

The integration of the ozone treatment has altered the general practitioner's approach to the treatment of his or her patients in numerous ways and many thousands of dentists in Europe have already treated tens of millions of their patients' teeth using ozone. General dental practitioners have completely reassessed their diagnostic detection criteria of dental caries and treatment of the carious lesion. The dental probe is no longer of any use for fissure caries diagnosis. Consequently, examination should now be aided by the use of a digital intra oral camera combined with selective use of the DIAGNOdent. Some dental practitioners have suggested that air abrasion should also be used as part of this diagnostic stage, as unless the organic plug is removed, it is impossible to visualise or diagnose what is occurring in the deeper part of the fissure pattern (*Holmes 1994*).

This has several advantages to the examination appointment: It is simple and without trauma for patients. It also involves the patient in their examination in what is called 'Co-Diagnosis' (*Holmes 1994*). Dental surgeons see a dramatically increased awareness of oral health care for this reason. This in return helps explain the problems that may arise, and allows the patient to co-operate in the diagnosis and their treatment planning. From the clinicians point of view the advantages of intra oral imaging cannot be stressed enough. Images of the dentition can be magnified many times to assist in diagnosing. The enlarged direct vision of the region being examined on the monitor is an essential adjunct to the direct vision intra orally (*Holmes 1995*).

This imaging combined with the use of the DIAGNOdent in areas where caries may be suspected results in an extremely thorough and meticulous examination and provides general dental practitioners with a quantitative assessment of any disease process present. Explaining to the patient what is required for treatment is very simple. Images can be shown on a TV screen and the DIAGNOdent reading explained. This serves to additionally enhance the patients' confidence and education in oral hygiene and a healthy diet. Finally, these images can be stored with cross reference to the patients' notes for later use if necessary.

Following this examination, records are made of any positive DIAGNOdent readings and the particular teeth these are related to. This concept of 'Caries Mapping' can then be used as part of a wider 'risk assessment', and to establish potential treatment needs. Treatment options can be explained to the patient and ozone treatment recommended where indicated. Images can be saved via the intra oral camera of the teeth to be treated, annotations made on the images about the lesion, appearance, etc and ozone is applied. There is rarely any requirement to make further appointments for the patient apart from the ozone review visits.

Hence the provision of ozone treatment is extremely time efficient, something which is valuable to clinician and patient alike. The patient's visit to the surgery is completely painless and atraumatic and they leave well informed and educated on both the reasons for treatment and what is required for a successful outcome. In addition to these factors, GDP's can look at the effects of the employment of ozone treatment on the dental profession as dentists. GDP's naturally subject themselves to a degree of stress as GDP's all desire to provide patients with pain free treatment as efficiently as possible.

Using ozone treatment as the primary approach to the treatment of most dental caries removes most potential stressors. There is no local anaesthesia to give, usually no use of the drill or packing of restorative material. The time spent on providing the actual treatment is also minimal in the extreme. GDP's can therefore provide the most modern and most natural treatment available to their patients without fear that they may cause any physical or mental trauma – all the

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potential sources of stress for the surgeon in restorative treatment of the carious lesion are removed and yet GDP's are providing the very best in dental care.

Over the previous pages the concept of alternative strategies for the treatment of infection have been introduced. The 'drill and fill method' has shown to belong to the 20th Century. Ozone treatment provides a modern pharmaceutical method to treat and eliminate infections of both hard and soft tissues. It has an important part to play in the at-home phase of patient care. The concept of 'Gums of Steel' as propounded by Dr Chris Kammer in Madison, WI USA will have a profound impact into at-home health care in the 21st Century.

Ozone therapy provides a treatment with benefits for dental patients of all ages. It is applicable to a wide range of conditions of the intra-oral hard and soft tissues. The treatment of carious lesions is effective and much more acceptable for the patient than the "drill and fill" method. This makes it especially attractive to younger patients, who are often scared of the "drilling". For the elderly people with medical problems, that can complicate conventional dental treatment, the ozone treatment is also easier and more efficient. The treatment is simple, completely safe and often eliminates the need to introduce potentially toxic restorative materials.

Patients are happy after the uncomplicated ozone treatment and their enthusiasm could create a 'buzz' in the local community. The more patients know about the ozone treatment, the more benefits it will bring to the community. Anything that can help slow down dental decay, treat caries and eliminate the fear of dentists is welcome nowadays. The ozone users' experiences have shown that the ozone concept enhances the general dentist's ability to talk to patients who rapidly understand the new method. It seems to stimulate their interest. The therapy has also proven to be a financial asset within the dental practice.

The precision of treatment consists of the high oxidative action on substrates and microorganisms. The treatment is supported by the very rapid kinetics of ozone oxidative reactions, and by the long lasting effects of remineralisation.

Hundreds of clinical and laboratory studies on non invasive ozone treatment in oral and dental pathologies are either completed or are underway, filling the gap between the naturalistic observations and the comprehension of these complex mechanisms and pathways. The dental community is increasingly sharing the awareness that ozone indicates new preventive and therapeutic possibilities, which have never been achieved before and allows a new vision, which complies with needs and demands of the public for non-invasive and effective preventive dental care.

From a public health point of view, with dental caries being such a problem in large areas of the world and with such a shortage of clinicians in some parts of the UK and Europe, the ozone therapy has a major part to play in the prevention and treatment of dental caries. Dental ozone units and the DIAGNOdent are portable and it is possible to envisage units being used with great effect in dental practices and community clinics, as well as during domiciliary visits to patients' homes. It takes so little time to treat several teeth that it is possible to help many more patients compared to conventional treatment. Dental hygienists and therapists are ideally suited to providing the treatment for all categories of patients. Members of the "Dental Team" could be easily trained to provide treatment to large numbers of Patients in the developing world.

However, the dental profession may need to return to the basic concepts of a preventative approach. The diagnosis of active caries is a *failure* in preventing it. Ozone certainly plays a major role in every preventative-orientated dental practice.

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According to “The Niche Environment Theory”, an “ecological niche” of microorganisms is established within a carious lesion. Microorganisms are far from the ‘simple bugs’ they are often referred to. They have survived for millions of years, whereas humans have a minute time frame of existence in comparison to the period of existence of microorganisms. Dental practitioners should not be surprised to find out that bacteria set up complex interactions with other microorganisms, communicate with neighbouring colonies at times and call for help from others when their host attempts to change their environment. Protein coatings, plaque and debris are known to protect these colonies by acting as a protective coat, reducing the effects of pharmaceutical agents designed to eliminate these microbial colonies.

The concept of dental caries has changed in the last decade. Investigations disclosed the complex mechanism of effects of demineralisation and remineralisation that take place daily in oral hard tissues through interaction with saliva. The dental profession has recently acquired a completely new view of an old pathology. Decay starts as a metabolic imbalance, shifted towards acidity and demineralisation. This process develops in dental plaque. In this kind of environment acidophilic and acidogenic bacteria develop an ‘ecological niche’. Consequently, new methods of diagnosis of caries need to be found (*Pinelli et al 2002, Tam & McComb, Ricketts et al 1997, Schopbach et al 1995, Ekstrand et al 1998, Lynch 1996, Lynch & Beighton 1993, Beighton et al 1993*).

Early in the development of a carious lesion, when enamel and dentine are demineralised and dentine has not been denatured by proteolysis, these dynamics can be easily reversed, and remineralisation can occur if the local environment is altered by reducing causative factors. When the microbial ecological niche is eliminated, remineralisation rapidly occurs as the previously cyclical demineralisation and remineralisation cycles are shifted towards a predominance of remineralisation.

The carious lesion progresses when conditions are suitable for acidogenic bacteria to release acids as metabolic by-products. The acids produced lead to a breakdown of mineralised tooth structure. At times, an equilibrium situation occurs when the rate of mineral gain equals the rate of mineral loss.

Ozone does not only remove the protein protection layer and is bactericidal, through its powerful oxidizing properties, but it also oxidises biomolecules that allow the niche to survive and expand. This severely harms the microbial population in the carious lesion and obliterates the cariogenic microorganisms and the ecological niche. This brings the equilibrium to a level where remineralisation can predominate and occur. No more acid can be produced within the lesion when the acid-producing flora is eliminated.

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For example, the acid pyruvic acid, one of the strongest naturally occurring acids within carious lesions, manufactured by bacteria, and involved in the development of caries, is oxidised by ozone to acetate and carbon dioxide (*Lynch et al 2001, Silwood et al 2002, Silwood et al 2002*). Acetate is much less acidic than pyruvic acid. The decarboxylation reaction leads to mineral uptake due to the more favourable pH conditions in a carious lesion. As soon as ozone therapy takes place, and saliva enters the treated surface, the lesion will become populated with normal mouth commensals. These do not produce the acids associated with the progression of caries and immediately the carious process shifts to a predominance of remineralisation.

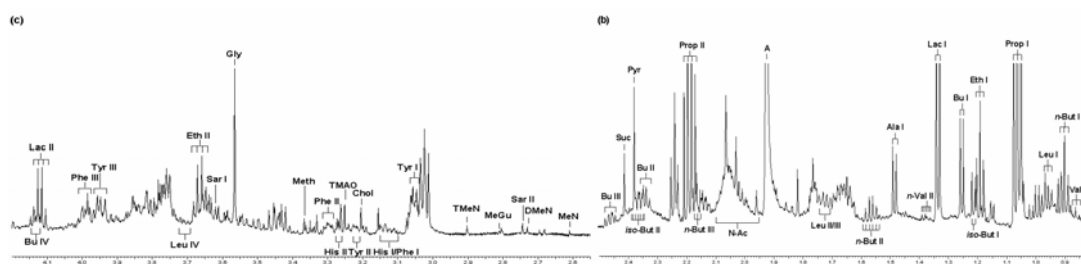


Fig 10.02. 1HMMR analysis of a root caries sample showing the diversity of bio-molecules present

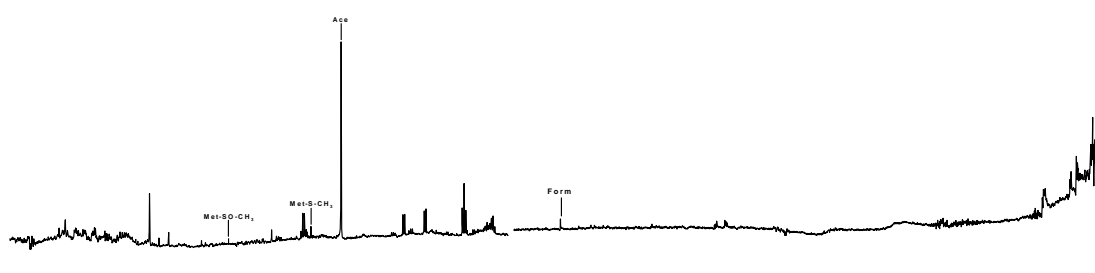


Fig 10.03. The same sample after exposure to ozone. All the bio-molecules have been oxidized to acetate and carbon dioxide

For therapeutic use, ozone is generated by passing oxygen through two high tension electrodes. During generation of ozone some 60 multiple molecular combinations can be found. These last only for nanoseconds breaking down rapidly during collision of the molecules. The quality of the ozone is determined by the purity of the oxygen source. Bottled oxygen provides the purest raw material, followed by oxygen produced from oxygen-concentrators or air feeds from advanced drying systems..

Several vital factors are important for successful ozone treatment in addition to the quality and concentration of ozone used for the treatment. The contact time between the ozone and tissues is important. The longer the ozone is in contact with the tissues to be treated, the more effective the treatment is. As mentioned before, ozone is relatively unstable with a half life of 5 – 30 minutes.

Contact time is the time when the diatomic molecule which is ozone is in contact with organic or chemical matter in the atmosphere, water or body fluids. When contact happens one oxygen atom breaks away. This is called the singlet O. Singlet O is a very aggressive oxidiser: it oxidises the chemicals or metals into oxides. It will also oxidise all bacteria, moulds and fungi, viruses and

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parasites. Unhealthy cells such as cancer cells are also oxidised. Ozone thus is a non-chemical disinfectant. It is the second most powerful oxidiser in nature, second to Fluorine. In comparison to ozone fluorine is a very toxic gas and has no part to play in medical therapeutics.

The contact time can be defined as the length of time the tissues are exposed to ozone before ozone disintegrates. The longer the contact time, the better the cure rate. Baysan showed that by increasing the contact time from 10 seconds to 20 seconds, the bacterial kill rate changed from ozone being a disinfectant to acquiring sterilising effect (*Baysan, 2002*). The stability of ozone also depends on the alkalinity or acidity of the tissue and body fluid. In an alkaline milieu ozone is more stable and the contact time is increased with better results. Since ozone when disintegrated reverts back to oxygen, it is environmentally friendly.

The singlet oxygen is in a very high energy state and initiates oxidation. Oxidation in turn causes the production of free radicals. When ozone creates all these damaging reactions it seems illogical that it could be a healer. All the healthy cells in the tissues and organs in the body have free radical scavengers and nutrients to prevent oxidation. They are all protected from possible damage by the singlet oxygen and resulting free radicals. Only unhealthy cells which have lost this protective mechanism and organisms which are devoid of antioxidants and scavengers are destroyed. Hence, healthy tissues are not damaged by exposure to ozone.

These natural antioxidants are Vitamins C & E, Beta Carotene, Selenium, Methionine, and Glutathione. Zinc helps activation of antioxidants. Other antioxidants are found in raw tomatoes, grape seed extract, pine bark and red wine. Including these substances in daily diet and taking them as supplements will enhance the antioxidant activity of the tissue.

The cells contain free radicals scavengers such as superoxidase dermatase, catalase, and hydralase. They scavenge the free radicals produced and neutralise them. They inhibit the uncontrolled activity of free radicals and their destruction of tissues by the singlet oxygen. Thus all healthy cells and tissues containing antioxidant and free radicals scavengers are protected from damage. Degenerate cells such as cancer cells, viruses, bacteria and fungi which do not have the protection of the antioxidants and free radical scavengers, will be oxidised by free radicals produced by singlet oxygen. Hence ozone is able to destroy them and sterilise the tissue fluids.

Moreover ozone acts as a catalyst for the cells to increase the concentration of these protective substances. As a bonus, when the singlet oxygen is released the remaining part of the molecule, ozone reverts back to health giving life sustaining oxygen, which circulates in the body nourishing the oxygen starved tissues.

Various other beneficial reactions result with ozone therapy. The electrons in the atoms of the ozone molecules jump from inner orbit, the L level, to K level, the outer orbit, and back. In this quantum jumping of the electrons much electrical and magnetic activity is created and is released. These electromagnetic reactions and electro voltaic reactions result in profuse photon and energy transfer stimulating many beneficial reactions leading to cellular health.

The ability of ozone to sterilise and deodorise by powerful oxidation is used in water purification, in many large cities all over the world. The human body is made up of 57 % of its weight in water. This water is distributed all over the body as blood, lymph, extra cellular and intra cellular fluid. It makes sense that ozone can also sterilise the body fluids helping to get rid of noxious and toxic chemicals and organisms.

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Conclusion.

In conclusion, ozone therapy provides an excellent treatment modality with enormous benefits for dental patients of all ages. It is applicable to a wide range of conditions of the intra-oral hard and soft tissues. The treatment of carious lesions is effective and is exceptionally popular with patients. This makes it especially relevant to the younger patient, who may find conventional treatment unacceptable and for the elderly, who may have medical problems, which may complicate conventional dental treatment. The treatment is simple, completely safe to provide and often renders the need to introduce potentially toxic restorative materials unnecessary. It is not currently available under any socialised health scheme, for example, the NHS in the UK and is only available as a private option.

Patients are delighted and it has created a 'buzz' in each country and area it has been launched. Any innovation that can help halt dental disease and the fear of the dentist has to be welcomed. My personal experience and that of professional colleagues throughout the world have taught me that the ozone concept enhances the dental professions ability to communicate with patients. Patients for too long have had to accept that tissue amputation is the only predictable way to eradicate and control a bacterial infection. Patients, and by this term, I mean members of the general public throughout the world, rapidly warm to the idea that amputation is based on sound Victorian principles. In the 21st Century, these principles no longer are the ideal goal of the dental profession, as research and technology have advanced our understanding of the finer details of our understanding of these biological processes. Ozone therapies have stimulated the public's interest in these novel therapies and the therapy is a financial asset. Yet the basic principles of ozone therapy are old, from the late 19th Century, and for some reason have been allowed to be lost to our profession.

From a dental public health point of view, with dental caries being such a problem in large areas of the world and with such a shortage of clinicians in some parts of the UK and Europe, the ozone therapy has potentially a major part to play in the prevention and treatment of dental caries. The LT-CMU3 machine and the DIAGNOdent are totally portable and it is possible to envisage units being used with great effect in every dental practice and community clinic. It takes such little time to treat several teeth that it may be possible to help many more patients compared with conventional treatment. Being so simple to use, dental hygienists and therapists are ideally suited to providing the treatment for all categories of patient.

From a researcher's point of view, the opportunity to develop a whole-mouth delivery system resolves a number of difficulties with the current single-surface cup system, and introduces a new concept to dentistry. A whole-mouth LT-CMU3 system tray offers routine ozone treatment in a custom tray, which not only delivers ozone to all the tooth surfaces, but to the gingival tissues too. Just because it has been designed to introduce ozone to all the tooth surfaces, does not mean the system has to be confined to a gas-system. Remineralising solutions and other pharmaceutical solutions can be introduced into this tray design. It does not have to be a full-arch tray: it can be designed to enclose selected quadrants, areas or groups of teeth for 'point-of-need' long-term treatment. This type of tray design would be particularly suited to the elderly, medically compromised, long-stay in-patient: for example cancer and chronically ill patients.

Ozone has been proven to be a superb tooth whitening agent, and fits in very nicely to the current public's demand for 'instant gratification'. It is acknowledged by the vast majority of researchers and commentators on tooth whitening that conventional 10% carbamide gels offer the best long term colour stability, with reduced or often no sensitivity. However, the idea of having to wear a tray through the night or during the day, and the knowledge that the process will take some 10-15

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days on average, is abhorrent to a large proportion of the public who seek the dental profession's help to attain whiter, brighter teeth. In trials in the UK and Spain, the average whitening time with ozone has been found to be 20 minutes: there are no messy gels or chemicals that may cause tissue irritation or burns, and no sensitivity. As an added bonus, it also treats areas of incipient caries.

The full-mouth or partial-mouth delivery tray also would be a huge step forward in offering the general public modern oral health care. The full-mouth delivery system offers the general public the concept of the 'ozone-spa', where patients come into a clinic on a regular basis, say every 3-4 months, are hooked up to a LT-CMU3, and treated for about 10 minutes in a single whole- or partial-mouth treatment session. Any incipient caries is eliminated by the ozone treatment, and the tray could subsequently be flooded with a remineralising fluid so that every tooth surface is washed with the remineralising fluid.

However, the concept of the 'ozone-spa' also may lead to the emergence of a group of patients, especially within the late teenage to 30-year old age group, who will abandon conventional at-home oral hygiene care and control of fermentable carbohydrates. This group of patients are technologically 'aware', well educated and informed. They realise that with the advent of this 'dental-spa' any area of hard tissue infection can be controlled and eliminated by a 'quick fix'. I have called this 'Technology Aware and Abuse Syndrome' (TAAS). Dental practitioners need to be aware of this potential, and stress the continuance of 'at-home' oral care, with conventional use of dentifrices and dental brushes.

This abuse of modern technology has already been seen in medicine. For example, chronic alcoholics in terminal liver failure have had liver transplants, only then to continue their alcohol abuse. Likewise, chronic smokers in heart or lung failure often fail to curb their habit after organ transplant, and go on smoking with their new donor organ. Whilst some may consider the comparison unfair, the outcome is essentially the abuse of modern technology allowing the individual to continue with a habit that has a negative health-related outcome in terms of a variety of costs – either to the socialised health system or health insurer, or to the individual.

Fortunately, the numbers of individuals involved in TAAS tends to be small in number. But where the technology is cheap, easy to apply, access to it is via the practitioner, and the technology is proven, I suspect that dental practitioners will see a growing number of individuals who will abuse this spa treatment.

In the pursuit of looking good, man has always tried to beautify his face. The female of the species tends to be vain, and seems to be striving toward perfection. The cosmetic industry has seized this and through advertisements and media, have contrived to foster a society that seeks cosmetic changes with the perception that it advances the individuals social and economic standing. As this concept has become more pervasive and accepted by the general public, so the demand for cosmetic changes has increased. In tandem with this observation there is an increase in the variety of more invasive cosmetic treatments being offered to fulfil these demands for more radical change in the pursuit of perfection. The alignment and appearance of teeth have been shown to influence the personality, and teeth have received considerable attention. Many people who can afford to, would prefer to have a set of dazzling white teeth as seen on countless magazine covers, television and movie screen. What is often forgotten by this group of people, is that the smiles they try to emulate are false: they do not exist in real life. The images that are often brought to the cosmetic surgeon have been created with computer enhancements and professional make-over teams.

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A variety of tooth whitening options are available today. They include over the counter whitening systems, whitening toothpaste, and the latest high tech option- laser tooth whitening. Research and publications are available to guide the dental practitioner to obtain excellent results (*Goldstein et al 1989, Haywood 1990*) and products are often tested against each other and these results are published to guide the dental professional towards an informed choice about the technique to use, and the materials required (*Darnell and Moore 1990, Nathoo and Chmielewski 1994, Tam 1999*)

As the tooth whitening continues to grow in popularity, research continues into all types of whitening systems. This thesis should be viewed as part of that continuum. In a recent study (*Holmes et al 2003*) specialised bacterial communities have been found to produce extrinsic stains. These chromogenic bacteria are very susceptible to whitening technologies and materials. In conversation with other dental colleagues around the globe as I have lectured, we have reached a similar observation: in the group of patients that come into our dental practices, we have two distinct groups of patients who have had tooth whitening procedures. The first group see effective whitening within 4-5 days, achieve a stable, long-lasting effect, with little sensitivity issues. The second group take from 10 to 30 days, have colours that are difficult to whiten, these patients have sensitivity issues that are either accepted, or respond to one of the many desensitising commercial products, and whose whitening has to be repeated at frequent intervals.

No research has looked at this observation, and one speculation could be that the first group, those patients who see fast results, are those who have these chromogenic bacteria present on the labial surfaces of their upper teeth. The stains these bacteria produce are susceptible to both peroxide and ozone degradation. Whereas the second group who make up the majority of patients do not have these bacteria, or they have them, but there are other factors involved that have yet to be identified, and they have to spend a greater amount of time and effort to reach a level of whitening that at times does not meet their expectations. If there was a simple test to look for the presence or absence of these chromogenic bacterial colonies, this would be a step forward to making patient selection and the whitening system that may perform the best, an easier decision for the dental clinician.

Following tooth whitening, one of the final phases of cosmetic dental treatment may be some sort of bonding, of tooth substance to either porcelain or composite. There are known problems associated with the negative interaction of tooth whitening products and dental material bonding systems. Various studies have highlighted the reduction in bond strengths of composite bonding systems to enamel and dentine after whitening procedures. It is believed the hydroxyl ion released during the break-up of hydrogen peroxide is responsible by interfering with the bonding to the enamel.

A study by Miguel *et al* (*Miguel 2004*) concluded that nightguard (home) whitening with 10% carbamide peroxide for just two hours each day, over a 21-day period, significantly affected resin-dentin bond strengths when dentin was exposed to whitening materials. The clinical significance of this study implies that dentin bonding, such as to exposed root surfaces and cervical areas of the teeth, should not be performed immediately after whitening with 10% carbamide peroxide.

An in-vitro study showed that where single-step bonding systems are used, there is a significant decrease in enamel bond strength if bonding is performed immediately after tooth whitening (*Miyazaki et al 2004*). For specimens made after 24 hours storage in water, only a small decrease in enamel bond strength was observed and no significant differences were found compared to those of controls (without dental whitening materials). From the results of this study, the

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researchers concluded that the enamel bond strengths of the self-etching primer systems might be affected to a lesser degree after rinsing with water followed by 24 hours storage in water. In a clinical setting, it seems that a delay time of at least 48 hours are required before whitened teeth should be restored with enamel bonding systems.

Cvitko *et al* in 1991 examined the effects of stronger whitening systems are used, such as 35% hydrogen peroxide. Their studies revealed enamel surface changes which result in lower bond strengths of composite resin. Although previous SEM studies (Cvitko *et al* 1991) showed that home whitening with 10 percent carbamide peroxide does not cause surface changes or damage, the results of increased concentration of carbamide peroxide whitening reduces the shear bond strength of composite to etched enamel. Removal of surface enamel, however, restores bond strengths to normal levels. Presumably, this step removes the damaged enamel, allowing fresh undamaged enamel to be bonded.

The van der Vyver study (van der Vyver *et al* 1997) evaluated the effect of an in-office light-activated hydrogen peroxide bleaching agent on the shear bond strength (MPa) of composite resin to etched enamel. Group 1 control specimens were not bleached and served as the control (average MPa 25.1 +/- 3.7): Group 2 consisted of specimens bonded immediately after bleaching (average MPa 14.2 +/- 4.9): Group 3 of specimens bonded 1 week after whitening (average MPa 19.2 +/- 3.2) and Group 4 of specimens bonded 2 weeks after whitening (average MPa 23.1 +/- 3.7). The authors of this study suggested that bonding procedures should be postponed for at least two weeks after any bleaching procedure has been done.

These problems associated with free peroxide-derived hydroxyl radicals would be irrelevant, if ozone is used for tooth whitening. Studies in the UK have shown that although not statistically significant, there is a trend towards an increased enamel bond after ozone treatment. Hussey *et al* (Hussey *et al* 2002) looked at bond strengths of dental materials to enamel and dentine. There was no statistical difference between the controls and treated samples, but a trend towards higher bond strengths. In Campbell *et al*'s paper (Campbell *et al* 2003) the research examined the potential negative effect of ozone on restorative surface hardness. They reported no change in restorative surface hardness. In a clinical setting, this opens the way to treat areas of small secondary caries around pre-existing restorative care, in the knowledge that further damage will not occur, and that the restorative care required is a simple 'repair' rather than wholesale removal and start again. In a further study published as an IADR Abstract, Abu-Naba'a *et al* showed that ozone treatment has no detrimental long-term effect on the retention of bonded materials (Abu-Naba'a *et al* 2004). This group reported 6-month retention data, and a later study (Abu-Naba'a *et al* 2005) reported similar results at 12 months. Research published from a German research group reported their 12-month results (Steier and Steier 2005) and at 15-months (Steier and Lynch 2005), with excellent retention rates and data to support the initial findings of Abu-Naba'a *et al* (Abu-Naba'a *et al* 2004).

The conclusion this author has reached is that where ozone is used as an oxidant, the absence of the hydroxyl group in the whitening procedure will prove to be the key to open the way to treat small areas of secondary caries around margins of pre-existing restorative care where bonding has been used. There will be no risk of reducing the bonding strength during the bonding sequence of restorative care. The clinical significance of this is that at last ozone whitening and treatment can be followed by immediate bonding and final restorative care, and there is no potential to damage existing bond strengths when pre-existing restorations are treated with ozone as part of a preventative management.

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A View of the Future.

As the population of the world changes from undeveloped to developed, the demographic profiles of these countries change from a young to an ageing population. This ageing profile is associated with better nutrition, increased standards of living, and advances in the medical and pharmacological management of degenerative disease. Ageing individuals tend to have gum tissue recession, and the associated exposed root surfaces are more susceptible to caries (*Hellyer et al 1990, Galan & Lynch 1993*).

Some of the pharmaceutical products are sweetened to make them more palatable, increasing the potential for acidogenic bacterial colonisation of tooth surfaces. The micro flora of PRCL's has been shown to contain large numbers of acidogenic and aciduric microorganisms, which correlate with the severity of root caries (*Beighton et al 1993, Lynch & Beighton 1993, Ship et al 1991, Brailsford et al 1998, Lynch & Beighton 1993, Lynch 1996, Lynch & Beighton 1994, Baysan 2002*).



Fig 10.04. Full-Mouth ozone tray on model and in patient's mouth.



Fig 10.05 Partial delivery tray for ozone or pharmaceutical wash



Fig 10.06 Full-Mouth ozone treatment tray on model

Ageing is also associated with a requirement for a plethora of medication to keep us alive as the host body degenerates, and these medications can have a dramatic effect on salivary flow. The benefits of ozone treatment can represent one of the major prevention strategies for these high-risk population groups. The processes involved have been shown to be multi-factorial.

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From a researcher's point of view, the opportunity to develop a whole-mouth delivery system resolves a number of difficulties with the current single-surface cup system, and introduces a new concept to dentistry.

Multi-surface treatment is difficult, and for interproximal caries between adjacent teeth a direct treatment approach is impossible with some systems that require a cup to make a seal around a lesion. These cups are suitable for single-surface lesions, or multi-surface lesions where the cup can be 'wrapped' around the lesion. Where teeth are in close approximation, an alternative cup / delivery tray system needs to be used, or an indirect approach via a tunnel preparation.

A whole-mouth LT-CMU3 system tray offers routine ozone treatment in a custom tray, which not only delivers ozone to all the tooth surfaces, but to the gingival tissues too. Just because this tray has been designed to introduce ozone to all the tooth surfaces, does not mean the system has to be confined to a gas-system. Remineralising solutions and other pharmaceutical solutions can be introduced into this delivery system. It does not have to be a full-arch tray: it can be designed to enclose selected quadrants, areas or groups of teeth for 'point-of-need' long-term treatment. This type of tray design would be particularly suited to the elderly, medically compromised, long-stay in-patient: for example cancer and chronically ill patients. The ramifications of whole-mouth treatment, prevention and the future use of ozone in dental care is set to change the public's view of dentistry and it's perception for ever.

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