Technology, Ultrasonics and Dentistry

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Abstract: **Initially used to drill cavities in teeth, ultrasonic instrumentation may now be employed for descaling tooth surfaces, root canal preparation and in apical surgery. The probe tips used to perform these procedures are available in a variety of designs to enable easier access to different areas of the mouth. This article reviews the technology behind some of the present dental ultrasonic instruments and suggests ways in which that technology could be advanced.**

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Clinical Relevance: **As well as being less manually fatiguing, the clinical benefits of techniques that utilize ultrasound include acoustic streaming and, in the case of scaler tips, cavitation. Clinical procedures have been adapted to take advantage of these associated phenomena.**

Ultrasound is a useful and widely used technology in dentistry. First used to drill cavities in teeth (via the use of an abrasive slurry),[1] it is now mostly employed as a scaling instrument to remove plaque and calculus from tooth surfaces. The basic method of ultrasound generation has changed little over the last 50 years. However, although the technology cannot be termed new, it is reliable and ultrasonic scaling units are present in almost every dental practice in the UK.

The main advances that have occurred within dental ultrasonics are in relation to the insert design, primarily the type and shape of the probe. These probes can now be used for a variety of tasks including scaling of teeth, endodontics and apical surgery. The purpose of this article is to review the technology involved with the present range of dental ultrasonic instruments and to look at future developments.

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ULTRASONIC AND SONIC SCALERS

Ultrasonic scalers were first introduced into the field of periodontics in the 1950s and are accepted as an alternative to the use of hand instruments in the removal of plaque, calculus and stains from teeth. The generators, which drive the scaler tips, operate using magnetostriction or piezoelectricity and produce ultrasound in the lower kilohertz range (usually 20–30 kHz).

Sonic scalers, also used for tooth debridement, were introduced in the 1970s. These instruments differ from their ultrasonic counterparts as they are powered by the compressed air from a dental unit and usually operate at much lower frequencies (typically in the range 3–6 kHz).

Sonic and ultrasonic scaler tips are available in a variety of designs to enable easy access to different areas of the mouth (Figure 1).

Both sonic and ultrasonic instruments remove deposits from tooth surfaces using the mechanical chipping action of the scaler tip. As water flows over the surface of the tip, cooling the point where tip and tooth contact, streaming patterns close to the tip surface may be observed (Figure 2). This is known as *acoustic microstreaming* and, although the flow velocities are low, very large hydrodynamic sheer stresses are created.[2,3] These streaming patterns assist in the removal of deposits from the site of cleaning.

An advantage of the ultrasonic scaler over the sonic is the production of *cavitation*, again occurring within the cooling water supply. Cavitation may generally be categorized as stable or transient (unstable) bubble activity within a liquid. It is the energy generated in the destructive, transient, cavitation that results in large shockwaves, which may disrupt plaque and calculus during ultrasonic scaling.[2] The water flowing over the tip therefore not only cools but also brings about additional cleaning effects.

The oscillation patterns of sonic and ultrasonic scalers differ, with ultrasonic scalers exhibiting a predominantly linear motion and that observed with sonic scalers being more elliptical.[4]

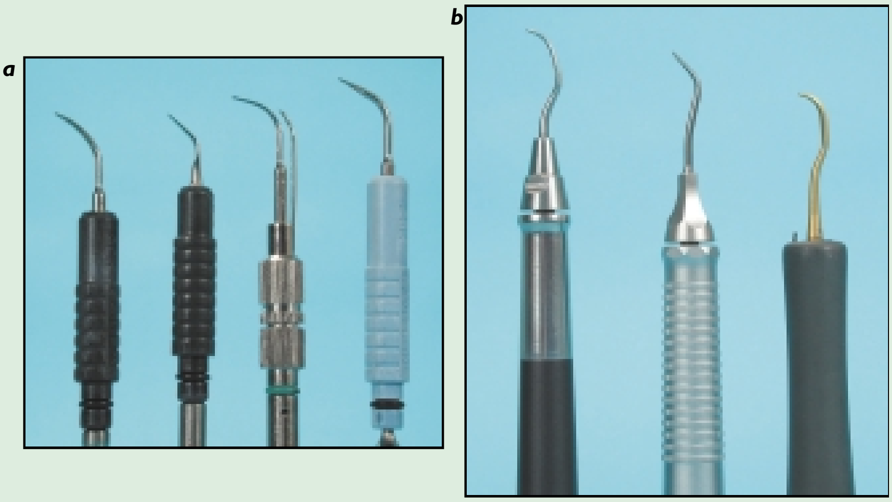

Figure 1. (a) *Selection of (Dentsply, York, PA, USA) ultrasonic scaling tips (with operation frequency): (L–R) TFI-10 (30 kHz), TFI-3 (30 kHz), Slimline SLI-10S with external water (30 kHz) and FSI-10 (25 kHz).* ***(b)*** *Selection of sonic scaling instruments: (L–R) Titan with universal tip (Star Dental, Lancaster, PA, USA), SONICflex with perio tip (KaVo, Lake Zurich, IL, USA) and Relacs 7000 with universal tip (Micro Mega, Geneva, Switzerland).*

Despite these differences, the clinical response following treatment is very similar.[5] Both types are less time consuming and less manually fatiguing to use than conventional hand instruments.

The main advance in ultrasonic scaling instrument technology has been the introduction of slimmer probe tips, which are designed to improve access to the tooth and root surfaces during scaling procedures. These tips usually include an internal borehole that allows the water to reach the working tip, and it is this that limits the minimum tip size which may be used clinically without breakage occurring.

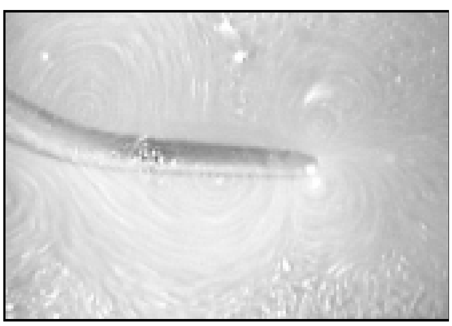

Figure 2. *Acoustic streaming patterns, observed in water around an ultrasonic scaling tip, caused by the high frequency oscillations. (Adapted from Khambay and Walmsley.[2])*

Clinical Use

Ultrasonic scalers are used for the removal of deposits on tooth surfaces, such as calculus and plaque. The working tip needs to be held so that its longitudinal motion goes across rather than directly at the tooth surface (Figure 3). Although high generator power settings will potentially remove gross calculus more effectively than lower power settings, there is an increased risk of damage to the tooth surface and so low or medium generator power settings should be used. The continual movement of the tip also ensures minimal damage to the tooth surface.

ULTRASOUND IN ENDODONTICS

The use of ultrasound in the field of endodontics was first suggested in 1957,[6] with the adaptation of an ultrasonic scaler that could be used for apicectomies and root canal therapy. However, it was not until 1976 that the first ultrasonic device, specifically designed for instrumentation of the root canal, was introduced.[7] The preparation and cleaning of the root canal using ultrasound is termed *endosonics* and may offer advantages over the use of conventional hand instruments:[6]

- easier pre-flaring;
- better flared and smoother canals;
- conservative of tooth tissue;
- acoustic streaming within irrigant;
- greater debridement;
- constant/intermittent irrigation;
- increased bactericidal action;
- less need for canal medication;
- reduced extrusion material through apex;
- reduced postoperative pain;
- increased patient comfort;
- faster;
- reduced operator fatigue.

Research has shown that little cavitational activity occurs within the associated irrigant during usage of ultrasonic files.[8] However, a biophysical effect that does occur is the generation of acoustic microstreaming around the oscillating file, producing large hydrodynamic sheer stresses. To maximize the efficiency of the endodontic technique, the irrigant used is usually one that can act as both a lubricant and as a disinfectant. One of the most common irrigants for the endosonic system is a 2–3% solution of sodium hypochlorite.

As with ultrasonic scalers, endodontic ultrasound may be derived from magnetostriction and piezoelectricity. The instrument designed by Martin in 1976 exploited the phenomenon of magnetostriction to drive the endodontic file at ultrasonic frequencies. Both piezoelectric and magnetostrictive instruments work at low ultrasonic frequencies (usually 20–42 kHz) and show comparable patterns of file oscillation. Another class of device has been developed, which uses the passage of compressed air through the instrument handpiece to produce tip oscillations at sonic frequencies (i.e. below 20 kHz).

Sonic and ultrasonic devices are similar in design in that they consist of a removable endosonic file, clamped at an angle of between 60° and 90° to the long axis of the driver (Figure 4). In normal operation, a series of nodes and

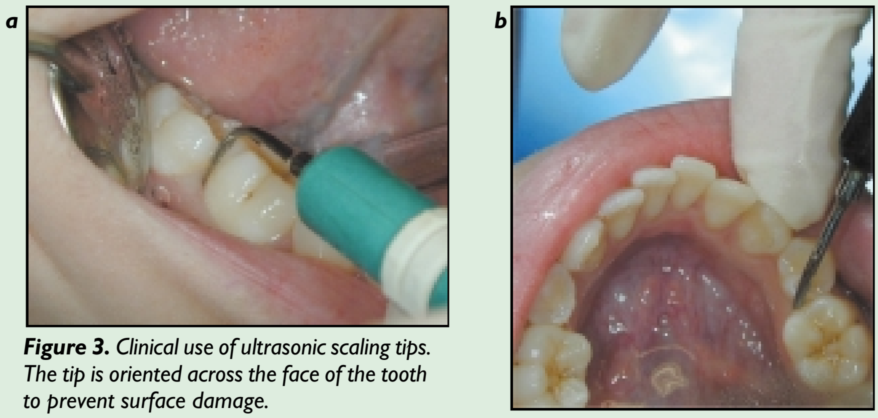

Figure 3. *Clinical use of ultrasonic scaling tips. The tip is oriented across the face of the tooth to prevent surface damage.*

anti-nodes are set up along the whole length of the file, with the greatest shear stresses (produced by acoustic microstreaming) being generated around the anti-nodes (points of maximum displacement amplitude). Many clinical techniques have been adapted to maximize the cleansing effect of acoustic microstreaming, the efficiency of which is dependent upon the amount of file constraint occurring.

Clinical Use

Endosonic equipment is designed for the preparation of the root canal and a series of files are made for this purpose. Acoustic streaming caused by the oscillating file plays an important role in the cleaning process: these instruments are effective irrigators of root canals[9] due to the effects of acoustic streaming and clinical techniques are directed to maximizing its occurrence (Figure 5). However, the oscillation of the endosonic file could be stalled if it is introduced into narrow root canals, limiting the effectiveness of the system. Therefore the root canal should be opened up with instruments such as Gates Glidden burs, creating space for the oscillation of the file and hence for the acoustic streaming to take effect. The file should be kept moving at all times.

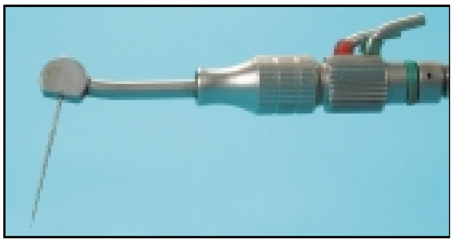

Figure 4. *A typical magnetostrictive endosonic handpiece (25 kHz) and file (Dentsply).*

ULTRASONIC RETROGRADE CAVITY PREPARATION

The first application of ultrasound in apical surgery was described by Richman, who used an ultrasonic chisel to cut bone and resect tooth tissue.[10] The use of ultrasonic instruments for the preparation of root end cavities during endodontic surgery is becoming more widespread. Ultrasonic tips enable easier access by cutting at 90° to the root surface and provide cleaner surfaces than those created by burs.[11] A variety of tip designs are available, varying in complexity from simple curves to multi-angled bends (Figure 6). Research has shown that these tips operate most efficiently at medium to high power settings;[10] however, they are prone to breakage, with the incidence of breakage increasing with angulation of the tip.[11]

Clinical Use

The ultrasonic tips are multi-angled and smaller in size than rotary instruments, allowing better access to the resected root end and minimizing the loss of bone/root length. Another benefit of ultrasonic instrumentation is better alignment of root-end cavities, to the long axis of the root, than those prepared with burs. The apex of the tooth is removed during the surgical procedure (Figure 7a) and the tip introduced into the root, allowing preparation of the retrograde cavity (Figure 7b). Use of ultrasonic retrograde tips should be accompanied by irrigation, for removing debris and reduction of heat at the tip/tooth interface. Good technique is required when employing this equipment and care must be taken to avoid contact of the heated tip with bone or soft tissues.

The instruments available have fine tips, which are liable to break if worked in air at high settings or if too great a contact force is used. Minimal pressure during clinical use and switching the device on with the probe contacting the tooth surface helps to avoid tip breakage.

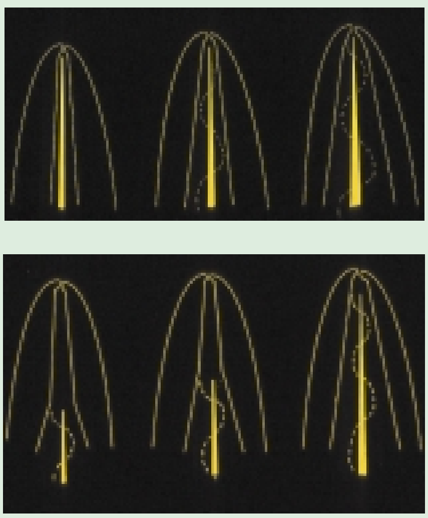

Figure 5. *Different techniques employed with endosonic instruments to maximize the effect of file oscillation and acoustic streaming.* ***(a)*** *The file introduced into the narrow canal will not oscillate fully until the canal is opened up.* ***(b)*** *The canal is opened up with Gates Glidden burs, which then allows the file to oscillate fully.*

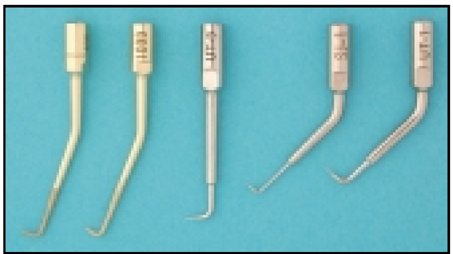

Figure 6. Examples of ultrasonic retrograde tips for use in apical surgery: (L–R) KiS-1, KiS-2 (Spartan, Fenton, MO, USA), UT-5, SJ-1 and UT-1 (EIE/Analytic, Glendora, CA, USA).

TECHNOLOGICAL ADVANCES IN DENTAL ULTRASONICS

The motion of probes driven at sonic and ultrasonic frequencies is difficult to visualize owing to the high frequency vibrations and it is thus difficult to determine whether they are working correctly. The technique of scanning laser vibrometry (a non-invasive technique for measuring the vibration velocity of oscillating objects) has made it possible to study the vibration patterns of sonic and ultrasonic dental equipment.[12] In this technique laser light, scattered from the vibrating target object, is Doppler frequency shifted, the magnitude of the shift being proportional to the velocity of the target. From this, the associated computer software can calculate the vibration frequency and displacement amplitude of the oscillating target.

Measured (or calculated) data may be displayed as either a three-dimensional mesh (Figure 8) or a colour map (Figure 9). The mesh facility provides a computer-generated animation of the target vibration, showing all nodes and anti-nodes, at reduced speed. This allows the user to observe the tip motion easily and therefore to assess the currently available ultrasonic/sonic systems.

DIRECTION FOR THE FUTURE

Dental ultrasonic devices have changed little since their introduction in the 1950s. In fact, the main advances in this field have been in relation to the probes that are available as attachments to these devices, which enable tooth scaling, root canal preparation and apical surgery.

Ultrasonic scaler tips, such as the slimline inserts, have been designed to be slimmer than previous scaler tips to enable better access to hard to reach areas of the mouth. However, this can cause tip breakage when scalers are operated at high generator power settings (a problem often associated with endosonic K-files and retrograde tips in endosonics). The inclusion of a power inhibition system to prevent use of too high a power setting, no matter what the power control dial on the generator indicates, may be a useful development.

Another problem with ultrasonic equipment is the production of aerosol, caused by too high a power setting with a low water flow rate (aerosol is water, intended for cooling the tip/tooth contact area, being thrown off the tip as a fine mist). An aerosol can cause cross-infection problems by scattering bacteria around the surgery, and can also lead to potential problems with heating at the contact area. A power inhibition system may help to reduce the risk of heating; alternatively, the power and water flow rate controls may be connected internally at the generator. Careful design may lead to an increase in power, resulting in an automatic increase in water and a reduction in aerosol production. Such design features may overcome the problem of heating.

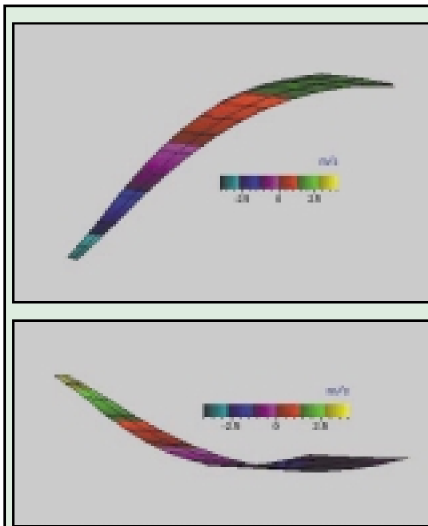

Figure 8. Two stills from a typical computer-generated three-dimensional mesh animation of the (TFI-3) tip oscillation.

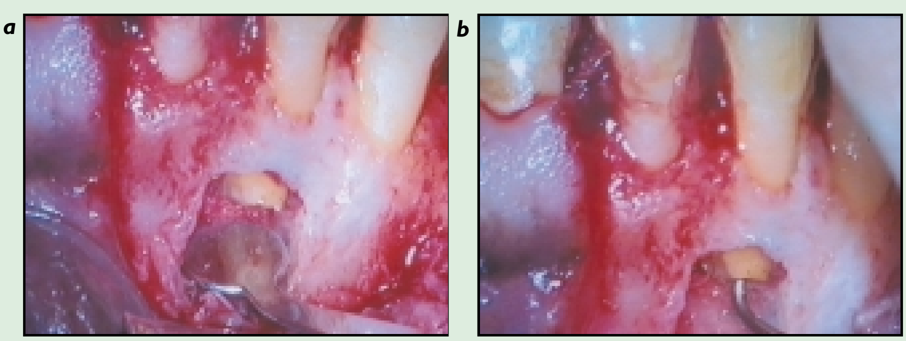

Figure 7. (a) *The apex of the tooth is removed.* ***(b)*** *A multi-angled retrograde tip allows better access to the resected root end than rotary instruments. (Pictures courtesy of Dr P.J. Lumley).*

Research has shown that different scaler tips of the same design often have very different operational characteristics.[13] This may cause difficulties for clinicians and researchers, who expect performance to be consistent between tips of the same style. With better standardization, it may be possible to determine a power/water setting for a particular tip type, to achieve optimum cleaning efficacy.

It is hoped that close liaison between dental equipment manufacturers, clinicians and researchers who use ultrasonic equipment will advance dental

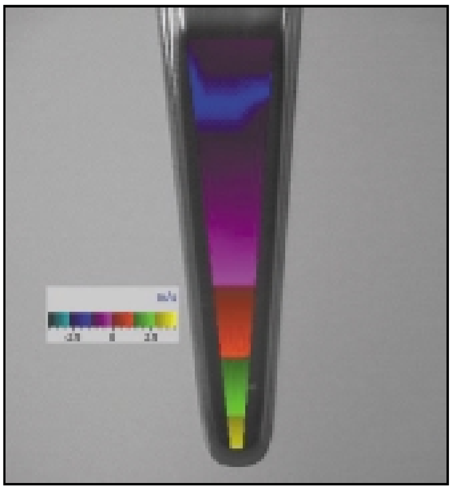

Figure 9. *A colour map representation of the tip vibration. Data is superimposed over a captured video image of the target, here a TFI-3 scaler tip. A colour-graduated scale is used to indicate both the magnitude and the direction of the vibration.*

ultrasonics and lead to the highest standards of safety, reliability and clinical suitability.

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BOOK REVIEW

Seltzer and Bender's Dental Pulp.
Kenneth M. Hargreaves and Harold E. Goodis, eds. Quintessence Publishing Co. Inc., Chicago IL, USA, 2002 (500pp., £70.00 h/b). ISBN 0-86715-415-2

This new book follows in the tradition of the seminal text produced by Seltzer and Bender and is named in their honour. This outstanding text is edited by two leading academics in the field, with contributions from a wide range of endodontists and dental pulp and cell biologists. The 21 chapters cover all aspects of the history, anatomy, physiology and pathology of the dental pulp.

Each chapter is carefully crafted and is easy to read and understand, providing up-to-date information regarding the physiological processes that take place within the pulpo-dentin complex and the pathological changes that may take place. This is done in a very systematic way beginning with a delightful review of the history of pulp biology. There then follow chapters on the development of the pulpo-dentin complex, dentin repair and detailed chapters on the structure of the dental pulp, including the circulation within the pulp and the nerve supply.

Pain is an important aspect of pulpal pathology and two chapters are devoted to pain mechanisms and pharmacological control of dental pain. Inflammation of the dental pulp is discussed in the succeeding two chapters, including the molecular processes that take place in inflamed tissue. A chapter on infection of the pulp, with a detailed description of the microbiology of dental caries, is also included. Although all these chapters provide large amounts of factual information, the layout of the book, the quality of the illustrations and the flow of the text make reading a stimulating experience. In addition, where possible, reference is always made to clinical practice so the science is not dissociated from practical dentistry. The two chapters on vital pulp therapy are interesting as they debate the methods and materials for preserving pulpal health. One of the chapters, written by the late Harold Stanley, discusses in eloquent detail the use of calcium hydroxide, whilst the other explains the use of other materials including mineral trioxide aggregate. Careful sifting of the evidence provided will allow important clinical choices to be made rationally.

Chapter 15 is devoted to the relationship between permanent restorations and the dental pulp. Aspects such as the effect of cavity preparation, microleakage, pin placement and the effects of specific materials are discussed. A useful section on biomechanical considerations of cusp flexure is also included. A detailed synopsis of the effect of thermal and mechanical irritants on the pulp is provided in Chapter 16, including the effects of both lasers and particle abrasion.

Irreversible pulpal damage leads to necrosis and a secondary immune response within the periradicular tissues. These responses are described in detail in Chapter 17 by Professor Philip Stashenko, the world authority on the subject, who reviews the current knowledge. This is followed by a chapter on the relationship between the dental pulp and the periodontal tissues, providing advice on diagnosis and treatment. The final three chapters are excellent reviews of root resorption, differential diagnosis of orofacial pain and the dental pulp in systemic disorders.

Overall, this book is of inestimable value to both the specialist and the general dentist. It gives insight into the biological processes in the dental pulp which fashion our clinical practice. It is very well illustrated, the font is easy to read, and each chapter is very well organized. Some of the terms, including drug names, and pharmacological regimes for treatment, are American but this does not detract. I recommend this text to all general dental practitioners and endodontists.

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