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REVIEW ARTICLE

Application and development of ultrasonics in dentistry

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Since the 1950s, dentistry's ultrasonic instruments have developed rapidly. Because of better visualization, operative convenience, and precise cutting ability, ultrasonic instruments are widely and efficiently applied in the dental field. This article describes the development and improvement of ultrasonic instruments in several dental fields. Although some issues still need clarification, the results of previous studies indicate that ultrasonic instruments have a high potential to become convenient and efficient dental tools and deserve further development.

Introduction

Ultrasonic instruments use ultrasound energy with a wave frequency that is generally 20 kHz above human hearing. Basically, ultrasonic vibration is created by two methods: magnetic and piezoelectric methods.[1] The magnetic method transfers electric magnetic energy to mechanical energy through changes in the magnetic field. However, the piezoelectric method applies the switch of the electric charge to cause the dimension deformation of piezoceramic disks, thus producing a vibration.

Compared with the magnetic method, the advantages of the piezoelectric method include higher efficiency of energy transfer and greater vibration from a linear motion. The high efficiency of energy transfer reduces energy consumption and the rise of temperature during the transferring process. In addition, the linear back and forth vibration can produce a more precise vibration mode, compared to the figure-eight motion mode created by the magnetic method.

At present, ultrasonic frequency applied in dentistry is approximately 25–40 kHz.[2] The vibration mode and amplitude of ultrasonic instruments depends on the

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morphology, structure design, frequency, and power supply of the devices.[3] Because of physical properties, like node and anti-node vibration characteristics, ultrasonic instruments need an appropriate morphology and structure design, with matched frequencies, to create an ideal vibration for clinical application.[4]

The ultrasonic instrument was first introduced to the dental field as a method of cavity preparation with an abrasion slurry.[5] Although it has lower cutting efficiency when compared to conventional high- or low-speed air turbine devices, ultrasonic instruments have many advantages in dental application, including improved visualization, a conservative approach, selective and accurate cutting performance, and an acoustic streaming reaction.[2,6] Depending on clinical requirements, there are various ultrasonic instruments with different devices in the market. Furthermore, they are broadly applied across dental fields, including operative and prosthodontic dentistry, periodontology, endodontics, orthodontics, oral and maxillofacial surgery, and oral diagnosis.[7]

Ultrasonic instruments in operative and prosthodontic dentistry

The first application of ultrasonic instruments in the dental field was for tooth preparation in the 1950s. Ultrasonic instruments were combined with abrasion slurry, to facilitate tooth structure preparation.[5] Development of ultrasonic tooth preparation stopped because of lower efficiency compared to the high- or low-speed air turbine instruments. However, improving the manufacturing process with diamond coating, chemical vapor deposition techniques,[8] and new tip designs, effectively raises the cutting efficiency of ultrasonic instruments on the tooth structure.[9] Although the cutting efficiency of ultrasonic instruments is still not comparable to high- or low-speed air turbine instruments, even after appropriate improvements,[10] ultrasonic instruments' advantages include conservative cavity preparation, a less painful caries removal procedure, and minimal noise generation. All of these improvements are presented by clinical case reports.[11] Moreover, not damaging the soft tissue is the characteristic feature of ultrasonic instruments when applied to operative or prosthetic dentistry during cavity preparation. Previous studies indicated that increases in intrapulpal temperature after ultrasonic preparation are similar to, or higher than high-speed air turbine preparation, but the increase remains below the critical value of 5.5°C.[12] In an *in vivo* study by our research group, the temperature change during ultrasonic preparation was also lower than the critical value under a sufficient irrigation. It indicated that in this condition, the ultrasonic preparation with a sufficient irrigation can provide safety to the surrounding tissue during the procedure. Although a scanning electron microscopy (SEM) investigation revealed that tooth surfaces after ultrasonic instrumentation are rougher than those after high-speed air turbine instrumentation,[13] there is no significant difference in the marginal seal of resin restoration between the two preparations.[14]

Conversely, ultrasonic instruments could also be a support tool to enhance treatment quality and facilitate the procedure process. In a previous study, ultrasonic instruments were used to seat composite inlays and then compared with seating the composite inlays with finger pressure; the results showed that the ultrasonic technique is better than the finger pressure method for high-viscosity cement.[15] Walmsley and Lumley also demonstrated that using an ultrasonic loading technique for the composite luting agent, results in a substantially shorter loading time and lower loads.[16] When comparing the fracture strength of resin composite laminates with either the conventional or ultrasonic cementation technique, even if the fracture strength of composite laminates is not affected by the two methods, the ultrasonic technique group has more favorable failure types.[17] Other findings on the application of ultrasonic instruments in operative and prosthetic dentistry procedures, like the marginal insert of ceramics, composite inlay insertion, and packable composites used as posts, also showed that an ultrasonic technique can benefit the procedure process and has favorable results compared to the conventional technique.[18] Considering the promotion of minimally invasive treatment, ultrasonic preparation could be an alternative approach for tooth preparation procedures. Based on clinical experience, ultrasonic instruments are helpful when removing caries close to the pulp, or proximal caries hardly approached by traditional high-speed instruments.

Ultrasonics in periodontology

Ultrasonic instruments have been used in periodontal treatments since the 1960s,[19] and many aspects of ultrasonic instruments compared to hand instruments used in periodontal treatments, have been widely discussed. There is no significant difference in the effectiveness of hand or ultrasonic instrumentation in removing subgingival plaque.[20] Oosterwaal et al demonstrated that subgingival debridement by either a hand or an ultrasonic instrument was equally effective in reducing probing pocket depths, bleeding scores, and microscopic bacterial counts.[21] In other studies, ultrasonic instruments also demonstrated comparable results in clinical and microbiological aspects when compared with other treatment methods,[22] although ultrasonic instruments produce a rougher root surface and remove less tooth substance compared to hand instrumentation.[23] Conversely, after the commencement of an improved tip design[24] and coating techniques,[25] the efficiency of ultrasonic instruments increased for specific treatments. Sugaya et al demonstrated that the ultrasonic furcation tip, a tip specifically designed for furcation debridement, can significantly improve the treatment of degree II furcation involvement of mandibular molars.[26] Oda and Ishikawa also presented an *in vitro* study with a newly designed tip for furcation debridement, which could create a smoother root surface compared with the conventional ultrasonic tip, or the Gracey curette.[24] The diamond-coating technique can also raise the ability of root surface removal by an ultrasonic instrument, although the residual root surface roughness still increases. This minor side effect should be considered when applying an ultrasonic instrument during periodontal root planing procedures.[25] The design of the tip shape and the surface treatment are two important issues for ultrasonic instruments in periodontal therapy. Based on our recent research, the finite element analysis (FEA) performed before the tip fabrication, could simulate the vibration mode to increase the efficiency and flexibility of the tip, in order to create a better vision for facilitating the clinical operations. Furthermore, the newly developed coating technology, chemical vapor deposition, is another advance in enhancing the cutting efficiency.[8]

In 1999, an ultrasonic instrument system named "Vector" was introduced. The Vector system has a linear oscillate principle that provides a vibration parallel to the root surface and differs from the conventional ultrasonic system. Previous studies have indicated that the Vector system can reduce pain and discomfort during treatment and improve patient compliance, but it may not be suited for removing large masses of supragingival calculus.[27] The Vector system also provides comparable results when treating moderate-to-severe chronic periodontitis, compared to manual instruments or conventional ultrasonic instruments.[28] The Vector system reports advantages like less removal of cementum and a smoother root surface after instrumentation, compared with conventional ultrasonic instruments.[29] These characteristics make the Vector system suitable for periodontal maintenance treatment.

Ultrasonics in endodontics

Since the 1980s, after the ultrasonic and synergistic system for root canal instrumentation and disinfection was introduced by Martin and Cunningham,[30] the use of ultrasonic instruments for endodontic procedures increased in three areas: dentin preparation, chemical irrigation, and procedure enhancement. Because of the physical properties and stiffness of stainless steel files, ultrasonic instrumentations caused undesirable results, like deviation or elbow formation in root canal preparation.[31] Compared to hand instruments, ultrasonic instruments are less effective for increasing the canal space, removing debris, and canal wall planning under histological evaluation.[32] Furthermore, the root canal shaping demonstrates incontinuous taper after obturation.[33] Although some reports still show a lower incidence of zip or elbow formation and a similar shaping quality compared to hand instruments,[34] the ultrasonic root canal-shaping technique is not recommended in modern endodontics, especially after Ni-Ti rotary instruments were developed.[35,36]

However, ultrasonic instruments can provide better results for root canal irrigation, like chemical disinfection, debris cleaning, and smear layer removal.[6] Ultrasonic instrument vibration can stimulate two mechanisms in a root canal filled with irrigation solution; these are the cavitation effect and the acoustic streaming reaction, which in turn have cleaning and disinfection effects.[37] Although the action of cavitation may be limited in a narrow space, like a root canal system,[37] the acoustic streaming reaction from the passive ultrasonic irrigation technique can still provide a better performance in canal cleaning and disinfection compared to the conventional syringe irrigation technique.[38] Moreover, these results indicate that during endodontic treatment, the passive ultrasonic irrigation technique is a reliable method. With a suitable instrument design, better visualization, precise preparation properties, and high-frequency vibration, ultrasonic instruments can facilitate endodontic retreatment procedures including gutta percha, silver point, post, separated instrument removal,[39] and finding a missing canal.[40] Compared to techniques using a traditional hand instrument and solvent, the ultrasonic gutta percha removal technique produces heat from high-frequency vibration, which in turn softens the gutta percha and facilitates its removal. Previous studies revealed that the ultrasonic gutta percha removal technique is faster and has similar removal effects compared to the traditional hand instrument and solvent technique.[41] Additionally, the design of the ultrasonic instruments provides better visualization compared to high- or low-speed air turbine instruments, and this advantage can increase the success rate and safety in separated instrument removal, or missing canal searching, especially when combined with the use of a microscope.[40] Ultrasonic vibration-generated heat may diffuse through dentin and cause necrosis of the periodontal ligament or bone tissues.[42] Ultrasonic instruments require proper irrigation for cooling during the entire procedure.[43]

Ultrasonic instruments are also used in other procedures during endodontic treatment. For example, Baumgardner and Krell demonstrated that the ultrasonic condensation of the gutta percha mass is more homogeneous and shows fewer voids compared to condensation without ultrasonic activation.[44] Yeung et al studied hand condensation with indirect ultrasonic activation, for mineral trioxide aggregate (MTA) condensation, which resulted in a significantly heavier and denser MTA filling in both curved and straight canals than MTA condensation by hand only.[45] Some authors used ultrasonic instruments for placement of pastes, like calcium hydroxide [46] and sealers in the root canal, which showed a better result in the ultrasonic instrument-activated groups.[47]

Ultrasonic instruments in orthodontics

Ultrasonic instruments were applied in orthodontic treatment in 1990, when Bishara and Trulove used an ultrasonic technique for orthodontic bracket debonding.[48] They found that the incidence of bracket fracture during debonding with the ultrasonic technique was significantly decreased to 0%, compared to the failure rate of 10—35% for conventional debonding methods. Moreover, the combination-bond failures decrease noticeably in the ultrasonic technique group.[49] Even though the debonding times are significantly greater, the ultrasonic group has less surface roughness. After completing orthodontic treatment, a smoother enamel surface can facilitate the finishing preparation. By contrast, in 1995 Boyer designed an ultrasonic chisel for ceramic bracket debonding. This ultrasonic chisel markedly reduces the debonding force required to debond the brackets. However, because of the time-consuming nature of the treatment and complaints of uncomfortable feelings by the patients, this experimental device is not recommended for orthodontic usage.

Ultrasonic instruments are also used to facilitate the setting of glass ionomer cement during bracket bonding procedures. In an *in vitro* study of a setting reaction, glass ionomer cement showed a significantly shorter setting time and higher bond strength to the enamel surface after a 60 second application of the ultrasonic instruments during the setting procedure.[50] Using SEM, Coldebella et al demonstrated that ultrasonic excitation resulted in significantly reduced inner porosity of the glass ionomer cement during setting.[51]

Ultrasonics in dental surgery

Ultrasonic instruments have many advantages in surgical application, like a micrometric cut, which can produce a precise and secure action that limits tissue damage, a selective cut between soft and hard tissue by using frequency control, and better surgical site visualization through instrument design. With the application of ultrasonic instruments, dental surgery is improved in many aspects, like success rate, and a decrease in surgical risks. [52] In our recent clinical study, ultrasonic instruments applied on the lower impacted third molar extraction, promoted wound healing and new bone formation.[53]

Retrograde preparation with ultrasonic instruments after the surgical apicoectomy procedure is demonstrated to have a more controlled apical preparation and a more successful outcome.[52] Application with ultrasonic root-end resection takes longer and results in rougher cutting surfaces, compared with the high- and low-speed air turbine carbide.[54] However, an SEM examination indicated that root-end cavity preparation by ultrasonic instruments results in cleaner and deeper root-end cavities, which can aid retention of root-end filling materials and efficiently remove infected dentin, compared with results from conventional high-speed air turbine instruments preparation.[29] Furthermore, ultrasonic instruments accurately and safely perform osteotomy for alveolar bone crest augmentation, maxillary sinus lifting, and removal of dental implants. Schlee et al indicated that implantology surgical procedures, like bone harvesting, crestal bone splitting, and sinus floor elevation, can be performed with greater ease and safety through the application of ultrasonic instruments.[55] The application of ultrasonic instruments is relatively important to dental surgery. Due to the precise and easy-handling characteristics, ultrasonic instruments provide a minimally invasive surgery technique, which could not only minimize the accidental damage to adjacent soft tissue structures, but also accelerate the bone ablation.

Ultrasonics in dental diagnosis

Reflection of high-frequency ultrasound on a tissue interface can detect abnormal masses or lesions in the human body and present real-time information to operators. These data cannot be acquired with other radiation diagnosis methods, like cone-bean computed tomography (CT).[56] Because ultrasound examination still has two difficult aspects, i.e., insufficient accuracy and experience sensitivity for dental diagnosis, it is generally not recommended for diagnosing all oral and maxillofacial pathology.[57] The diagnosis situation can be improved through the advancement of technology, including a suitable detection probe design and better analysis software. In 2000, Cotti et al described echography, a real-time ultrasound imaging technique for periapical lesion detection,[58] and all their study cases obtained an echographic image. This study proves that ultrasound real-time imaging is a promising diagnostic technique. To compare the efficiency of differential diagnosis of periapical lesions among ultrasound, digital and conventional plain film-based images, Gundappa et al investigated 15 patients with periapical lesions associated with anterior maxillary or mandibular teeth which required endodontic surgery.[59] They showed that ultrasound images can be used to assess the size, content, and vascular supply, and provide a provisional diagnosis that can differentiate between cysts and granulomas. A radiation image can diagnose the existence of a lesion more accurately than ultrasound. However, the radiation image could not tell the pathological nature of the lesion, e.g., whether it was a cyst or granuloma tissue, whereas an ultrasound image can provide accurate information about the pathological nature of the lesion.

The periapical lesion is a common pathological problem.[60,61] Combining ultrasound with a power Doppler and CT can overcome difficulties in histological diagnosis[62] and the differentiation between periapical cysts and granuloma tissue, which is one of the evaluation factors for the necessity of treatment.[63] Aggarwal et al demonstrated that diagnoses obtained by a CT scan and ultrasound power Doppler flowmetry are both consistent with the histopathological findings of a surgical biopsy specimen.[64] Ultrasound can also be used to judge the location of the lesion to other anatomy structures. Garcia et al used ultrasound techniques to compare the proximity of a periapical lesion to the maxillary sinus before a surgical procedure.[65] Marti et al applied the ultrasound method to evaluate the proximity of the apical lesion to the mandibular canal.[66] Visualization of the lingual nerve with the ultrasound device has also been demonstrated by Olsen et al.[67]

Ultrasonic devices are able to offer information about the area around the lesion before surgery, in addition to detecting the distance to anatomy landmarks during the operation, by combining the ultrasound probe and the surgical osteotome.[68] The ultrasonic technique can be used to evaluate the transmission velocity of the ultrasound, to assess the bone quality and to differentiate bone types, e.g., among cortical, cancellous, and mixed bones. Compared to histomorphometry, cone-beam CT, and computerized microtomography, ultrasound measurement is similar to other methods for discriminating between bone types. Tsiolis et al demonstrated that ultrasound imaging has a better and more repeatable result for pig jaw periodontal bone-level measurements than traditional transgingival detection.[69]

When a trauma occurs, diagnosing whether a fracture has occurred is crucial,[70,71] and ultrasonography can be used to investigate potential fracture lines of the injured bone through a real-time examination. Compared to a CT scan and submentovertex films, ultrasonography can assess zygomatic fractures with a sensitivity of 88.2% and a specificity of 100%.[72] In orbital trauma cases, ultrasonography can have a sensitivity of 77%, a specificity of 89%, and an accuracy of 97%, for infraorbital rim fractures, and a

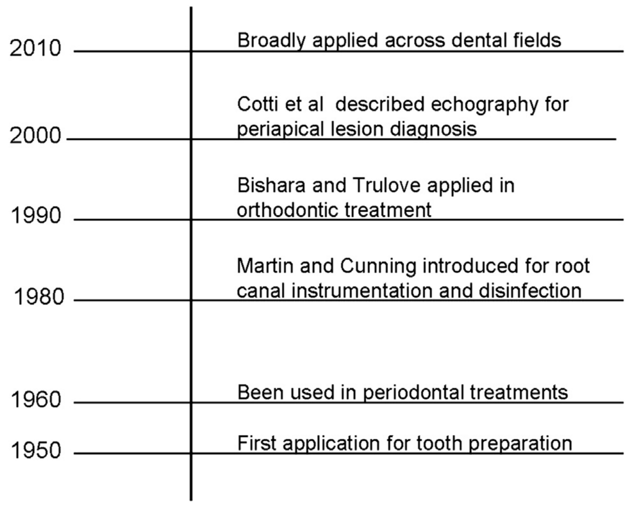

Figure 1 The development of ultrasonics in dentistry.

specificity of 57% and an accuracy of 96% for orbital floor fractures.[73] These results indicate that ultrasonic diagnosis accurately visualizes bone fractures and offers real-time information without radiation exposure.

Ultrasound is a noninvasive, economical, and painless diagnostic tool for tissue imaging, and it can be used to examine many oral lesions or structures for reasons including surgical evaluation and differential diagnosis, examination of the possibility of mobility by bone level and thickness measurement,[74] and even fracture line detection.

Conclusion

Because of better visualization, operative convenience, and precise cutting ability, the application of ultrasonic instruments has increased greatly.[2,7,52] Following improvements and better designs, ultrasonic instruments can have wide and efficient usage in dental fields (Fig. 1). Although some issues must still be considered, like high-frequency noises,[75] interference with pacemakers,[76] and a low cutting efficiency compared with conventional high- or low-speed air turbine instruments, the results of previous studies indicate that ultrasonic instruments have an extremely high potential to become convenient and efficient tools for various dental treatments, and deserve future development.

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