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Ultrasonic Debridement of Root Canals: Acoustic Cavitation and Its Relevance

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The phenomenon of cavitation was investigated in an Enac-Osada ultrasonic unit using a #15 Cavi-Endo file 25-mm long. The observed cavitation was incorporated in a subsequent study which investigated the effects of cavitation on debridement. One group of 10 teeth was subjected to the cavitating file while a second group served as a control. Scanning electron microscopic observations revealed that there was no difference in cleanliness between the two groups of teeth studied. Cavitation might have resulted in the formation of pits in some of the canals and should not be regarded as an important mechanism in debridement.

The recent introduction of ultrasonic root canal instruments into the endodontic armamentarium has attracted considerable interest and controversy. Several studies have highlighted the ability of the instrument to produce cleaner canals compared with conventional hand instrumentation (1, 2), while others have stressed the inherent difficulties in ensuring total debridement of root canals (3, 4). One attractive feature of this instrument lies in its flow-through irrigation system which is an undoubted advantage over hand instruments. The predominant mode of action responsible for its acclaimed superior debridement ability as well as disruption of bacteria has been linked to the phenomenon of cavitation (5, 6). A recent study (7) has discounted the role of cavitation in one ultrasonic unit (Cavi-Endo; Caulk, Dentsply, York, PA). In view of the emphasis placed on the role of cavitation in debridement by the proponents of the technique, this study was undertaken to throw further light onto this phenomenon by examining its role in ultrasonic debridement using a different ultrasonic unit (Enac-Osada, Tokyo, Japan).

The investigation was a three-part study. The first part involved measuring the range of displacement amplitude generated by files driven in the Enac unit in order to determine the most effective amplitude range, type, and size of file that could generate cavitation. The second part involved detection of cavitation using the selected file driven in the Enac unit. The final part of the investigation assessed the effectiveness of the observed cavitation on debridement of root canals.

MATERIALS AND METHODS

Displacement Amplitude Measurements

A preliminary study that was performed revealed that a total of 10 hand K files (Zipperer, Munchen, West Germany) fractured when driven in the Enac unit. It was decided therefore to use Cavi-Endo files with the Enac unit. The experimental arrangement for the measurement of the displacement amplitude has been described previously (8). The tip of the file was viewed under a traveling microscope at a magnification of ×100 and illuminated from the side such that a pinpoint source of light was observed at the very tip. When the file was set into oscillation, this light was visible as a thin transverse line, half of which gave the value of the transverse displacement amplitude. Cavi-Endo K files of sizes 15 and 20, each 29-mm long, and size 25 (25-mm long) were investigated at power settings ranging from 1.0 to 3.5. It was decided to investigate up to power 3.5, although the maximum power setting recommended for endodontic purposes indicated on the unit was 3.0. For each file investigated, five readings were obtained and the mean derived. Preliminary results showed that a #15 file, 29-mm long, displayed the highest range of values. This size was further examined at a different length; 4 mm of the coronal end of the file was removed leaving a file 25-mm long, a length used commonly in clinical practice. Three files at this length were examined for their displacement amplitude as described previously.

Detection of Cavitation

When the file was vibrated in a liquid medium, the acoustic energy was carried through the liquid by the back and forth motion of the molecules along the direction of propagation. This produced alternate compressions and rarefactions in pressure.

At a certain threshold displacement amplitude of the file and at a critical value of the negative acoustic pressure amplitude, dependent on the liquid's local conditions of temperature, viscosity, dissolved gas content, and microscopic particulate content, the tensile strength of the liquid was exceeded and a vapor cavity was formed. The subsequent positive pressure phase of the acoustic field then forced this vapor-filled cavity to implode, thereby converting the potential energy gained in growth into a concentrated region of kinetic energy as the cavity collapsed. This phenomenon was very

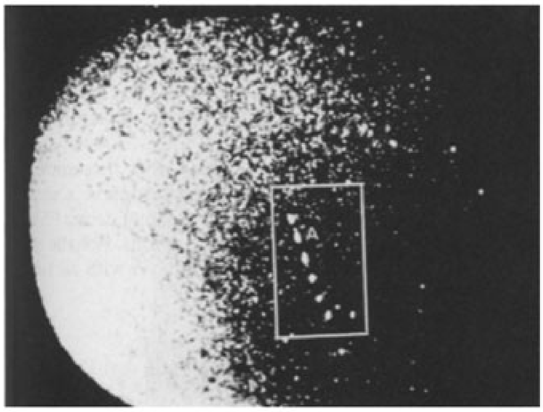

FIG 1. Apical half of the file viewed under the image intensifier lens (*A*, apical end). The file was illuminated with a low level external source of light and shows several spots where light was strongly reflected from its surface.

efficient in energy concentration and extremely high temperatures and pressures could be generated. It should be noted that in the authors' definition of cavitation described here, they refer only to "transient cavitation" as the phenomenon of interest. A related effect, called "stable cavitation" was associated with gas bubble production and oscillation and was not an efficient energy concentration mechanism. When transient cavitation occurred, the cavity collapses were so violent that visible light emission could be observed.

This light emission could be detected by a sensitive image intensification technique which allowed observations of the spatial and temporal distributions of the light (9).

The file which was shown in the first part of the study to generate maximum displacement amplitude (#15 file, 25-mm long, see "Results") was used in the experiment to detect cavitation. The experimental arrangement was similar to that which has been described in an earlier study (7).

The file under investigation was immersed in a container measuring 100 mm × 50 mm × 100 mm containing tap water. The lens of the image intensifier viewed a circular area of approximately 100 mm^2 at the apical half of the file, the tip of the file positioned at the 11 o'clock position of the lens (Fig. 1). The power setting was slowly increased from 1.0 to 3.5. Light emissions from the irradiated liquid were focused by a lens system onto the input photocathode of an EMI Type 9912 image intensifier tube. The input photons released photoelectrons from the input photocathode, which were then multiplied in number and energy as they traversed the tube and were subsequently recorded as discrete spots on the output phosphor of the tube. The phosphor was viewed by a video camera, recorded on magnetic tape, and displayed simultaneously on a television monitor. A polaroid camera was used to record features of interest observed on the monitor.

Investigation of the Role of Cavitation in Ultrasonic Debridement of Root Canals

To investigate the effects of cavitation on debridement, it was necessary to simulate the conditions at which cavitation was detected. The file should vibrate in the root canal at a

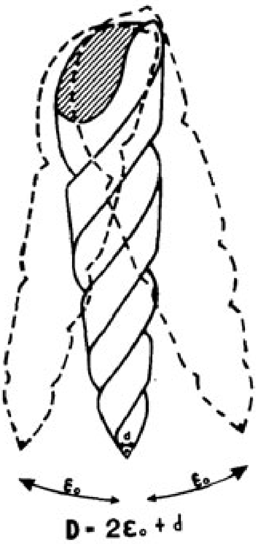

FIG 2. Diagrammatic representation to show the minimal width to which the canal should be enlarged in order to ensure cavitation (ϵ_0, displacement amplitude of the file; *d*, diameter of the tip of the file; *D*, diameter of the root canal).

displacement amplitude for cavitation inception. This corresponded to a value of 135 μm (see "Results"). To provide ample space for the cavitating file to vibrate freely without any restriction from the canal walls, it was necessary to ensure that the width of the root canal was equal to or more than the sum of the diameter of the tip of the cavitating file (#15) and twice the displacement amplitude (Fig. 2). This minimal width could be achieved by enlarging the canal to a #40 file. Twenty freshly extracted maxillary canines with straight roots and large canals, stored in saline, were used in this part of the study. Access was achieved through the crown of each tooth. The canal was ultrasonically filed with a copious flow of 2.5% NaOCl using files of sizes 15, 20, 25, 2 min for each instrument driven in the Cavi-Endo unit. The latter was used as the Enac unit under investigation, had no provision for sodium hypochlorite. The coronal aspect of the canal was then filed with a #35 diamond file until the width of the canal allowed at least a #40 file to be negotiated to the full length of the canal. Upon completion of instrumentation, the teeth were randomly divided into two groups, each of 10 teeth.

To ensure that the file would vibrate freely without contacting the walls of the root canal, the crowns were removed from the roots. For the first group of 10 teeth (cavitation group), the file which was found to generate cavitation (see "Results") was positioned until the tip reached the middle third of the canal. This was done as it was impossible to ensure a completely free contact from the canal walls while oscillating if the file was placed to the full working length. The power setting on the Enac unit was turned on at 3.5 and the file was allowed to vibrate with free flow of 2.5% NaOCl for 5 min. The latter was delivered to the coronal aspect of the tooth via a plastic tube tied to the ultrasonic handpiece and connected to the Cavi-Endo reservoir.

The second group of 10 teeth (no cavitation) received the same treatment but the file was vibrated at a lower power setting of 1.0 at which no light emission was observed. After completion of these procedures, the teeth were split into halves with a mallet and a chisel, coded, dried for 24 h, and sputter coated with gold for viewing under a scanning electron microscope. Observations of the canal surfaces were made at the coronal, middle, and apical thirds of the canal at various magnifications. Evaluation of debridement was carried out by the first author through blind scoring separately, the smear layer and the superficial debris remaining on the canal surfaces at the coronal, middle, and apical thirds at magnification ×800. Prior to scoring, photographs of the representative areas of canals at ×800 were taken to represent the gradations of the scoring system. This magnification was chosen because it showed the detail required while maintaining as large a field as possible. Four photomicrographs of the superficial debris at ×800 (Fig. 3) and four of the smear layer at ×800 (Fig. 4) were used as reference standards during the subsequent scoring.

A scale of 0 to 3 was used to rank order the amount of superficial debris and smear layer. For the debris, a score of 0 represented no superficial debris, 1 minimal debris, 2 moderate debris, and 3 represented heavy amounts. For the smear layer, a score of 0 represented no smear layer with all tubules

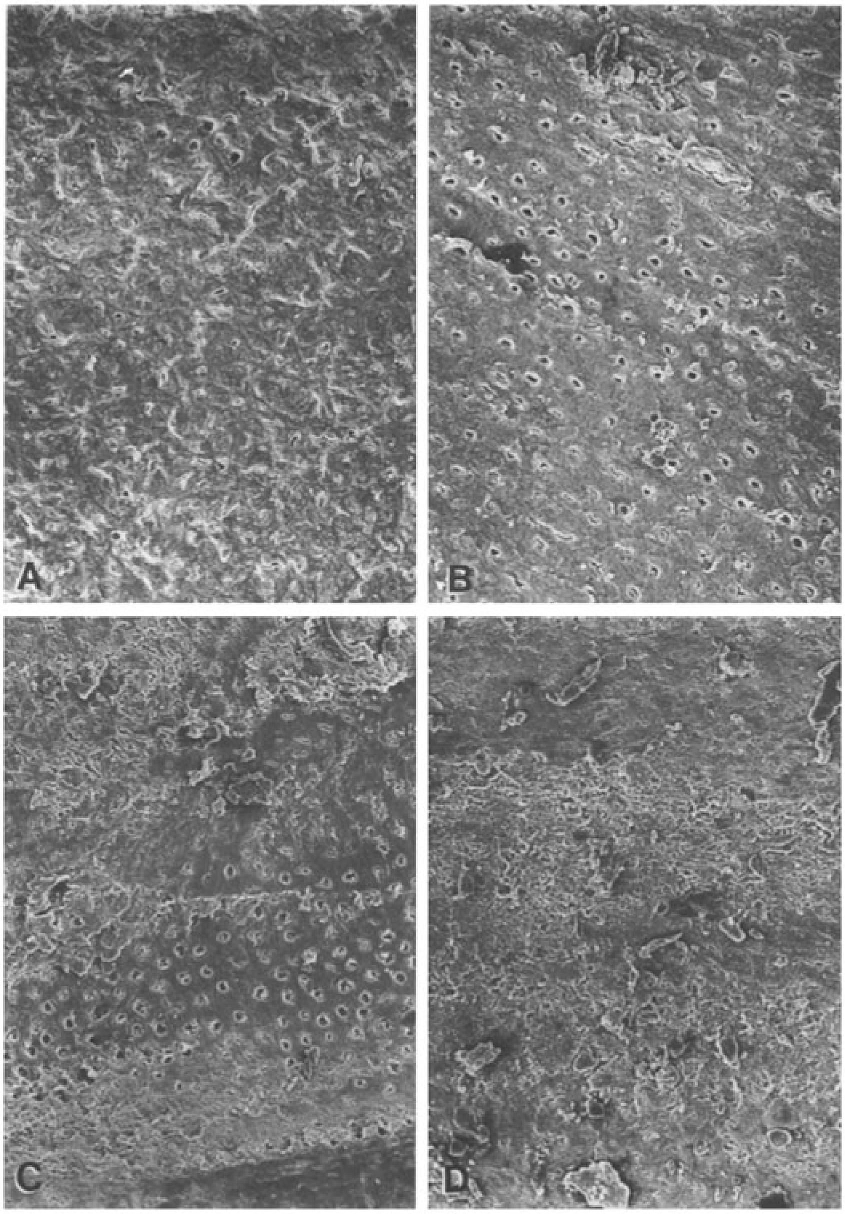

FIG 3. Reference photomicrographs showing the various gradations of debris used to score the specimens (original magnification ×800). *A*, Score of 0. *B*, Score of 1. *C*, Score of 2. *D*, Score of 3.

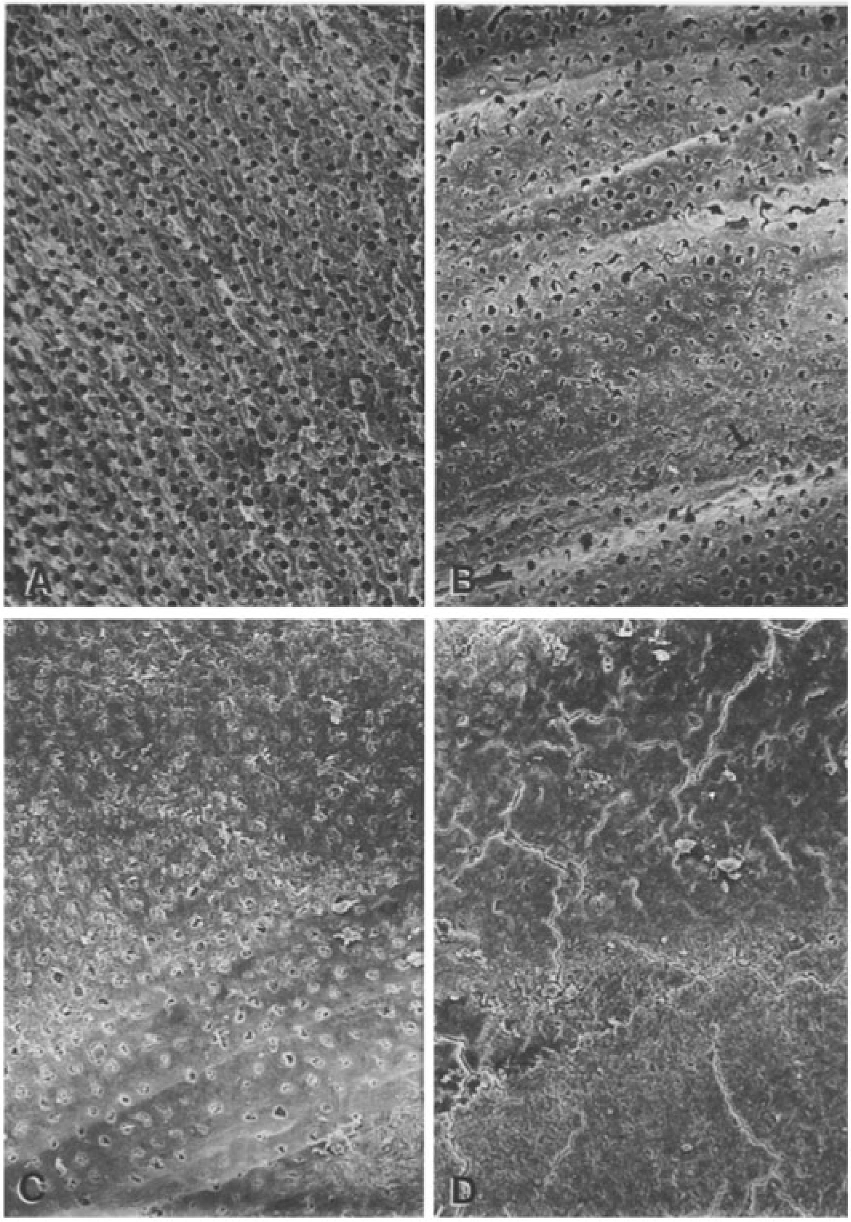

FIG. 4 Reference photomicrographs showing the various gradations of smear layer used to score the specimens (original magnification ×800). *A*, Score of 0. *B*, Score of 1. *C*, Score of 2. *D*, Score of 3.

opened, 1 little smear layer with more than 50% of the tubules opened, 2 moderate smear with less than 50% of the tubules opened, while 3 represented heavy smear with outlines of tubules obliterated.

For each group, the sum of the scores for a particular region of the root canal was calculated and divided by 10 to give the mean score. To calculate the overall score, the sum of the mean scores of the coronal, middle, and apical thirds were divided by three. In order to see if there were any differences between the degree of debridement in the two techniques, the overall scores were statistically evaluated using the Mann-Whitney *U* test.

RESULTS

Displacement Amplitude Measurements

The results of the displacement amplitude values of the files investigated are shown in Fig. 5. It is evident that increasing the power setting tended to increase the displacement

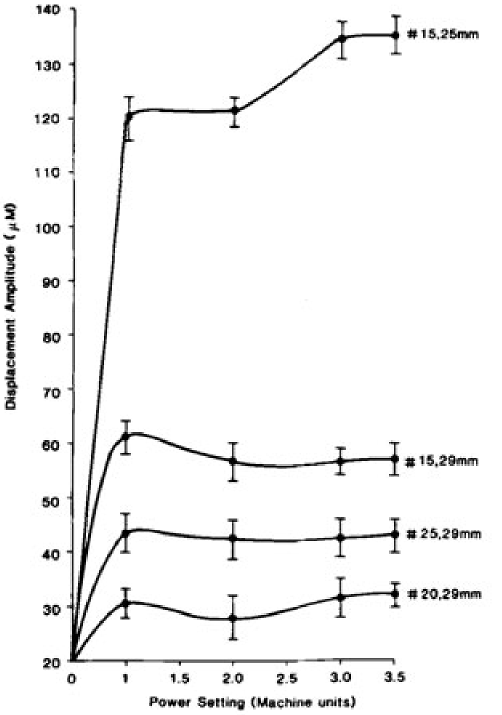

FIG 5. Transverse displacement amplitude values as a function of power setting with different file sizes driven in the Enac unit (*error bars* ± SD, *n* = 15).

amplitude. In general, the smaller files, #15, at both lengths, exhibited higher displacement amplitude than the other files. Shortening the #15 file to 25 mm appeared to double the displacement amplitude for each power setting investigated. The highest value attained was 135 μm and this corresponded to the highest power setting investigated.

Detection of Cavitation

Light emissions occurred at power setting 3.5 and this corresponded to a displacement amplitude value of 135 μm. No emission occurred at lower power. Figure 6 shows the photograph taken from the television monitor displaying the phenomenon of light emission. Each small white spot recorded on the photograph represents a single light photon. It was noted that the spots were grouped at the apical tip of the file occupying an area of approximately 0.7 mm^2. This light emission indicated that a violent form of cavitation had occurred in the region of the high concentration of spots.

Scanning Electron Microscopic Observations

No difference was apparent in the distribution and the amount of surface debris in the two groups of specimens (Fig. 7, p = 0.9397). In general terms, the canals were clean (Figs. 8 and 9), although debris could be observed to be distributed randomly throughout the length of the canals, particularly when viewed at high magnifications. Both groups exhibited a

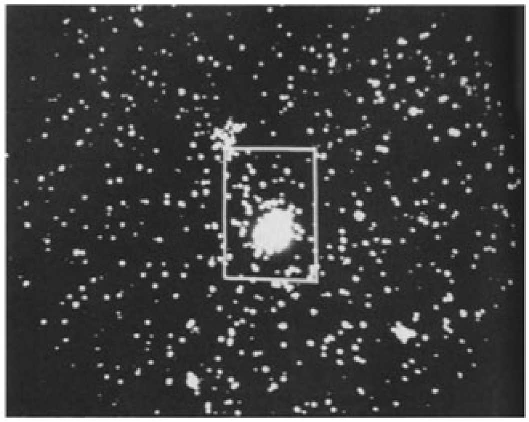

FIG 6. Light emissions observed from the oscillating file. The individual spots are single photon events; the concentration of spots near the center (*boxed*) show regions of the file where cavitation was occurring. Almost all of the cavitation was associated with the apical end of the file. The single photon events that were randomly distributed are most likely due to electronic and thermal "noise."

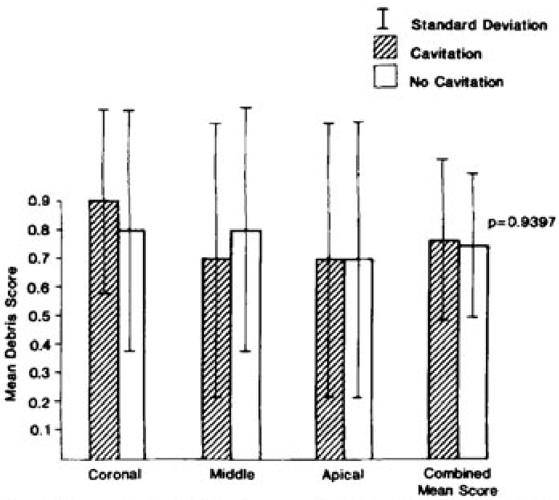

FIG 7. Comparison of debris score for two different treatments measured for each third of 10 roots. *Bars* represent the mean debris score.

typical smear layer appearance, particularly in the coronal third of the canal. At the middle and apical ends in both groups, there was less evidence of smearing, although the dentinal tubule openings were occluded. No statistically significant difference was observed in the smear layer scores between the two groups of specimens (Fig. 10, p = 0.5708).

In the cavitation group of specimens, observations relating to areas in close vicinity to the apical end of the file deserve comment. Four of the specimens exhibited irregularly distributed small pits confined to the lower middle region of the canal (Fig. 11). The latter corresponded to the position of the apical end of the file when it vibrated freely in the canal. These pits differed in size from each other but measured 40 μm in diameter. A typical feature of these pits was the virtual

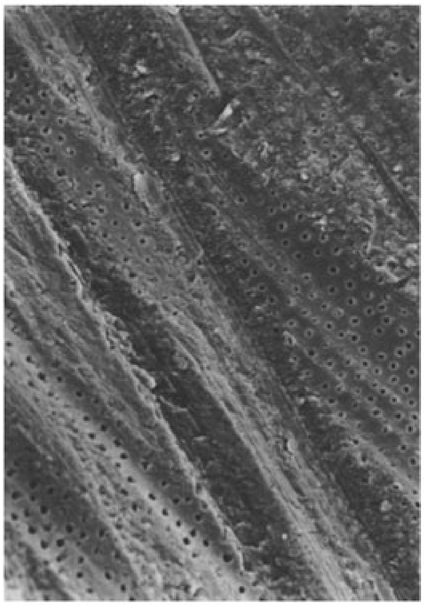

FIG 8. A typical example of the middle third of a root canal subjected to a file vibrating at displacement amplitude for cavitation inception (power 3.5), scored as 1.0 for both debris and smear layer (original magnification ×500).

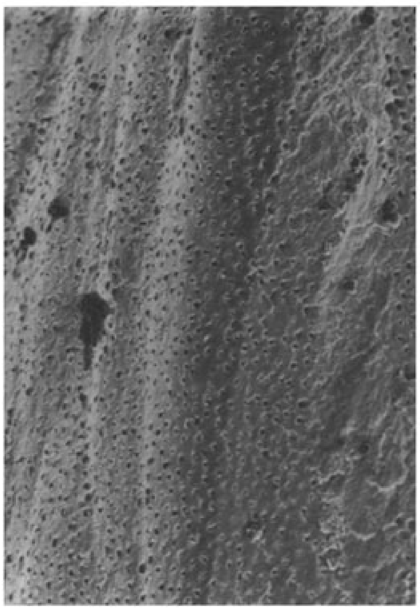

FIG 9. A typical example of the middle third of a root canal subjected to file vibrating at power 1.0 (no cavitation), scored as 1.0 for both debris and smear layer (original magnification ×500).

absence of smear layer at the base of the pits, with the openings of the tubules clearly evident (Fig. 11*C*). No more than 10 pits were present in any one canal. The distribution of debris or smear layer around the vicinity of these pits did not vary

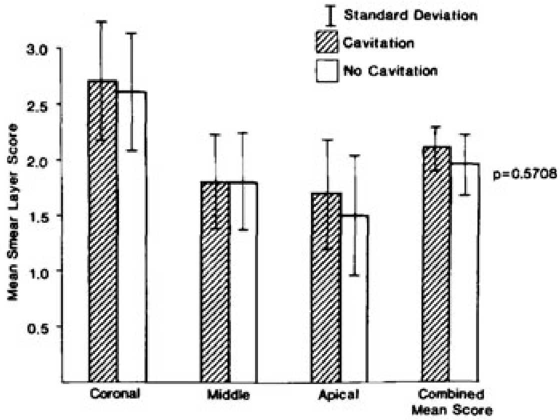

FIG 10. Comparison of smear layer scores for two different treatments measured for each third of 10 roots. *Bars* represent the mean smear layer score.

greatly from those canals in the control group. None of the specimens in the control group exhibited any of these pits.

DISCUSSION

The investigation has shown that it is possible to achieve transient cavitation from an ultrasonic file provided optimum conditions are satisfied and a certain threshold displacement amplitude is achieved. Although this partly confirms some of the claims made by the manufacturers, it dispels the popular view that cavitation can occur during actual clinical procedures using the technique presently recommended for instrumentation. The reasons for this are 2-fold. First, the threshold power setting at which this phenomenon would occur was found to be beyond the range that is normally used for endodontic purposes; the maximum power setting for endodontic purposes indicated on the unit was 3.0, while light emission was observed at a higher setting (3.5). Second and more important, for cavitation to occur in the root canal, the file must vibrate at a displacement amplitude of at least 135 μm. This would be impossible to achieve in the clinical situation using the recommended technique of instrumentation as the filing motion would dampen considerably the oscillatory motion of the file and its displacement amplitude.

The conditions ideal for the formation of cavitation had to be simulated to ensure that cavitation occurred. It meant that the root canals had to be enlarged to the size of a #40 file, which is approximately the minimum size that would permit clearance and free vibration of the #15 file working at the threshold amplitude for cavitation inception. This factor carries a profound clinical implication: cavitation can play little if any part in the cleaning of narrow canals. The result of the study to detect cavitation has clearly demonstrated that there was a spatial relationship between the apical end of the file and the cavitation phenomenon. This would seem advantageous in the clinical context, as it is often the apical end that is the most difficult to clean due to inaccessibility. However, it is evident from our experimental results that cavitation generated in some of the canals only resulted in the random formation of pits that were distributed far apart. Although the

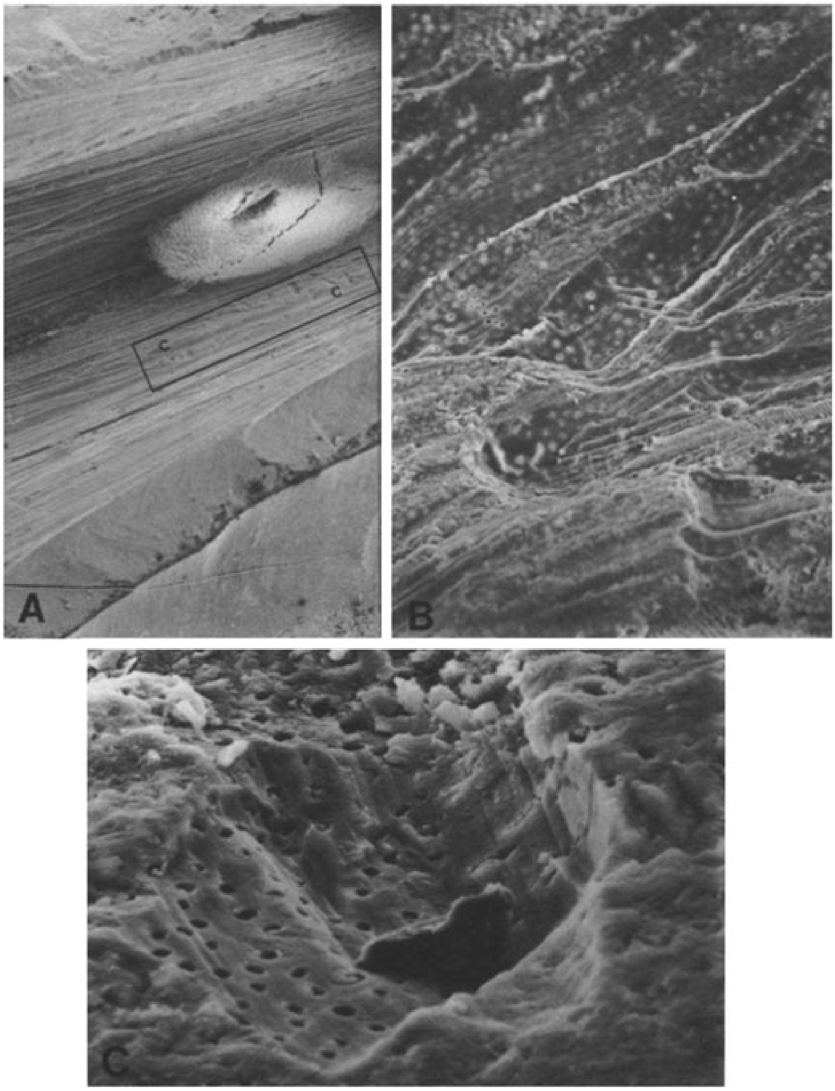

FIG 11. Pitting of canal surfaces (*boxed*) in the middle third region in teeth subjected to the cavitating file. *A*, *C*, cavitation pits (original magnification ×30). *B*, Original magnification ×500. *C*, High-power view of the pit showing exposed dentinal tubules at its base (original magnification ×1,500).

base of each pit revealed patent tubules, cavitation appeared to be ineffective in removing the adjacent smear layer.

These crater-like pits could conceivably have been the result of implosion of cavitation bubbles, owing to their spatial relationship with the middle third of the canal (equivalent position of the tip of the cavitating file), although it would be difficult to prove conclusively. It may be argued that the pits represent mechanical damage from the vibrating file hitting the canal wall. This possibility cannot be discounted, but in view of the random and wide distribution of the pits, this would seem unlikely. Damage created by the tip of a vibrating file would only be confined to a small area as the instrument was clamped. The microerosion of solid surfaces in a cavitating fluid is a well-established phenomenon (10, 11). Several authors (10, 12) have assumed the existence of tiny high-speed inwardly directed water jets inside the collapsing bubbles. Such an asymmetrically collapsing bubble would cause pitting by a "water hammer" action when the water jets impinge upon a surface. When occurring in sufficient magnitude, cavitation can be put to good use as in the ultrasonic cleaning baths widely used in industry (11). In the root canal, this benefit would only be afforded provided that cavitation complexes are present in sufficient numbers and are well distributed throughout the length of the root canal to remove the smear layer significantly and expose patent dentinal tubules. In the present instrument design, the cavitation that would occur is minimal and sited almost exclusively at the apical end of the file where the displacement amplitude is at its maximum.

The failure to detect any difference in cleanliness between the two groups of specimens was not unexpected and further strengthened our view of the lack of importance of cavitation in cleaning. An earlier study by Ahmad et al. (8) had demonstrated that the main mechanism responsible for ultrasonic debridement was acoustic streaming. The latter may coexist with the presence of stable cavitation (9), a form of cavitation not investigated in this study.

Only 4 of the 10 canals exhibited pitting. Assuming that pitting was due to cavitation, this illustrated the difficulty in ensuring the reproducibility of cavitation, even with conditions that attempted to be ideal.

The inherent morphological variations in the shape of the root canals could have imposed constraints on the oscillation of the file. We emphasize that even under apparently optimal conditions which included ensuring a large unobstructured access with adequate enlargement of the canal, cavitation was difficult to reproduce.

CONCLUSION

Evidence has been presented on the generation of transient cavitation by the Enac ultrasonic unit. It has been shown that the inception of cavitation required a threshold amplitude of at least 135 μm generated by a freely vibrating file. This phenomenon could not occur during normal clinical instrumentation using the recommended technique. However, by a slight modification of the technique a vibrating file could be made to generate cavitation in a root canal. Scanning electron microscopic comparisons between teeth subjected to cavitation and noncavitation techniques showed that there was no difference in cleanliness between the two groups. Cavitation might have resulted in the formation of pits on the surface of some canals and should not be regarded as an important mechanism in debridement.

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