Reduction of Bone Dust with Ultrasonic Bone Aspiration: Implications for Retrosigmoid Vestibular Schwannoma Removal

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Abstract

Objective. Postoperative headache is not uncommon after retrosigmoid vestibular schwannoma removal. Bone dust dispersed into the subarachnoid space during drilling may be responsible. If dispersion could be reduced, headache incidence might be decreased. An ultrasonic bone aspirator (UBA) containing an integrated suction at the tip may more effectively suction bone dust created during bone removal. The objective is to determine whether a UBA results in less bone dust dispersion than a standard otologic drill.

Study Design. Cadaveric temporal bone quantitative model.

Setting. Laboratory.

Subjects and Methods. Temporal bone blocks were placed in a watertight enclosure. Under irrigation, bone was removed by use of either a drill or a UBA. The settings of the UBA were varied. The irrigant containing bone dust was microfiltered, and bone dust was weighed. Differences were compared across groups (n = 2-9 per group). Ablation times were also recorded (n = 3 per group).

Results. Only 3% (SD = 1.6%, n = 7) of the drilled bone mass was re-collected as bone dust with the UBA under optimized settings (power = 15%, suction = 100%, irrigation = 15 mL/min) compared with 81% (SD = 10%, n = 4) with the drill and external suction (P < .001). Increasing UBA power and reducing suction led to significantly more bone dust dispersal than with optimized settings. Varying irrigation did not have a significant effect. Bone ablation time was 1.4 times longer with the UBA at 50% power compared with the drill at maximum power.

Conclusions. The UBA resulted in approximately 25 times less bone dust dispersion than the otologic drill at optimized settings.

Keywords

ultrasonic bone aspirator, Sonopet, bone dust, headache, retrosigmoid, vestibular schwannoma, acoustic neuroma

Introduction

Postoperative headache may be a frustrating complication following the removal of vestibular schwannoma (VS). The reported incidence is between 17% and 80%1-3. The retrosigmoid approach has a significantly higher incidence of headache (17%) compared with the translabyrinthine (0%) and middle cranial fossa approaches (8%).1 Several theories may explain the pathogenesis, including dural adhesions to suboccipital musculature and injury to the occipital nerves.3 Dispersion of bone dust within the subarachnoid space causing irritation or chemical meningitis is a leading theory.2 This dispersion occurs during drilling of the posterior petrous temporal bone to open the internal auditory canal (IAC) while the subarachnoid space is exposed. The risk of bone dust dispersion into the subarachnoid space during VS surgery is unique to the retrosigmoid approach, as drilling during the translabyrinthine and middle cranial fossa approaches is typically performed before the dura is opened.

Currently, several measures are taken to reduce bone dust dispersion during drilling. A suction tube is typically held in the nondrilling hand approximately 0.5 to 2 cm from the drilling site. Water is irrigated into the field, mixing

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with the bone dust, and the solution is then suctioned from the field. Packing may also be placed over posterior fossa structures and cerebrospinal fluid cisterns to capture the bone dust. However, these methods may be incompletely effective.

Ultrasonic bone removal devices (UBRDs) have recently emerged as a new tool for skull base surgery. One such device is an ultrasonic bone aspirator (UBA) that combines bone removal, irrigation, and suction into a single handpiece. Like a standard drill, the UBA allows different tips for specific applications, for example, sawing versus curetting. With certain tips, the suction port is 1 mm away from the site of bone fragmentation. This close and fixed proximity may allow for highly effective suctioning of bone dust. The device also allows suction, power, and irrigation settings to be adjusted individually. Adjusting these parameters may allow optimization to minimize bone dust dispersion.

UBRDs have been implemented for a variety of otologic and neurotologic procedures, including removal of the round window overhang, mastoidectomy, stapedotomy, facial recess, and excision of glomus tympanicum. In a cadaveric study, the UBA was used for middle cranial fossa facial nerve decompression, with no injury to the cochlea or facial nerve.

None of these studies have investigated applications that specifically take advantage of the unique proximity between the UBA’s integrated suction and aspiration ports. Here, we present evidence in a human cadaveric model that the UBA causes significantly less bone dust dispersion compared with an otologic drill. These findings may have implications for the reduction of postoperative headache following retrosigmoid excision of VS and may pave the way for an appropriate clinical trial.

Methods

Ultrasonic Bone Aspirator

The UBA (Sonopet; Stryker, Kalamazoo, Michigan) (Figure 1) has suction and irrigation mechanisms built into its body and tip. Therefore, bone fragmentation, suction, and irrigation are accomplished with a single instrument. The aspiration feature is unique and not present in other UBRDs (eg, Piezosurgery; Carasco, Italy). The UBA allows adjustment of 3 variables (power, suction, and irrigation) independently. The tips are interchangeable; both bone removal and soft tissue removal tips are available in a variety of shapes and sizes.

All experiments were conducted with the Long Spetzler Micro Claw tip (0.25 × 2-mm ablation surface). The built-in suction port is 1 mm from the closest edge of the bone ablation surface.

Otologic Drill and Suction Irrigator

An electric drill (Core Saber; Stryker) was used. All experiments were conducted by use of a 3-mm diamond bur at 60,000 RPM.

For a portion of the experiment, a 5 × 7F suction irrigator was used (5F irrigation port, 7F suction port). The rate of irrigation was 35 mL/min. The rate of suction was 600 mL/min.

Bone Ablation

A watertight plastic container with a removable lid was used for the bone dust collection experiments. Two 1.5-cm holes in the enclosure served as ports for placement of the drill, UBA, bone forceps, or an external suction irrigator.

Bone ablation was conducted by technicians under the direct supervision of a neurotology fellow experienced with the retrosigmoid approach. The ablation technique (ie, pressure applied by the instrument tip, stroke amplitude) was designed to closely mimic what would be performed in the operating room. Technicians were given a practice trial period until their technique and bone dissemination percentages were consistent before data collection was begun.

Bone Ablation with External Suction Tube. Either the UBA (with its built-in suction feature) or the drill was used along with an external suction irrigator. Blocks of temporal bone (2 × 3 cm) were harvested from the squamosa of cadaveric temporal bone. Bone blocks were then mounted in a House-Urban-style bone holder. The bone and holder were placed in the watertight plastic enclosure. The drill or UBA was inserted through 1 enclosure port. A 5 × 7F suction irrigator was inserted through the second enclosure port. The suction irrigator tip was kept approximately 0.5 to 1 cm from the drill bur or UBA tip during bone ablation. A 1 × 1 × 0.5-cm region within the block was then ablated. Dispersed bone dust was collected within the irrigant (n = 4 per group).

Bone Ablation without External Suction Tube. To measure the amount of bone dust dispersed due to the intrinsic use of the
instruments alone, no external suction devices (ie, no separate suction tube) were used. This simplified experimental design also allowed easier assessment of different UBA settings.

Blocks of temporal bone (1 × 1 cm) were grasped with forceps and inserted through 1 port of the watertight container. Either the UBA or drill was inserted through the second port. Next, a 0.5 × 0.5 × 1-cm region within the block was ablated. During ablation with either device, the bone was in contact with water. When the drill was used, the container was partly filled with water, and the block was periodically submerged. When the UBA was used, the built-in irrigation feature was engaged.

To investigate the effect of the UBA settings (power, suction, and irrigation) on bone dust dispersion, 5 separate experiments were performed during which 1 setting was varied and the other 2 were kept constant.

Experiment 1 (changing power): Suction was kept at 50%, irrigation kept at 15 mL/min, and power set at 5% (n = 3), 15% (n = 2), 50% (n = 9), or 100% (n = 3).

Experiment 2 (changing suction): Power was kept at 50%, irrigation kept at 15 mL/min, and suction set at 5% (n = 3), 25% (n = 3), 50% (n = 9), or 100% (n = 3).

Experiments 3 and 4 (changing irrigation): In experiment 3, power and suction were constant at 50%, while irrigation was set at 15 (n = 3), 25 (n = 3), or 40 (n = 3) mL/min. In experiment 4, power and suction were constant at 100%, while irrigation was set at 15 (n = 4), 25 (n = 3), or 40 (n = 2) mL/min.

Experiment 5 used optimal settings for the minimization of bone dust dispersion (power = 15%, suction = 100%, irrigation = 15 mL/min) (n = 7).

Measurement of Bone Dust Dispersion

During all bone ablation experiments, water and bone dust were collected within the container. Dispersed bone dust was defined as any bone dust that was collected within the irrigation (ie, not suctioned) at the end of bone removal.

Once bone ablation was completed, the bone–irrigation mixture was run through a 500-mL bottle top filter (Fisher Scientific, Waltham, Massachusetts) with 11-μm pore filter paper (Whatman #1, Sigma-Aldrich, St Louis, Missouri). After the filters containing moist bone dust were air dried, the dispersed bone dust was weighed on a microscale. The temporal bone blocks were also weighed, when dry, before and after bone ablation. The percentage of bone dust dispersed during bone ablation was then calculated as follows:

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\text{Weight of bone block ablated} = \text{Weight of bone block before ablation} - \text{Weight of bone block after ablation}
\]

\[
\% \text{ of bone dust dispersed} = \frac{\text{Weight of dispersed bone dust}}{\text{Weight of bone block ablated}}
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Measuring Bone Ablation Time

Temporal bone squamosa (1 cm³) was ablated by use of either the UBA (n = 3) or a standard otologic drill (n = 3) under timing. The UBA settings were power = 50%, suction = 50%, and irrigation = 15 mL/min.

Statistical Analysis and Regulatory Approval

Statistical analysis was performed in SPSS 19.0 (IBM, Armonk, New York) and Microsoft Excel 2011 (Microsoft, Redmond, Washington). Means between groups were compared via an independent-samples t test. Linear regression analysis was used to assess trends. Significance was defined as P < .05. Mean values are presented ± standard deviation.

Approval from the institutional review board and the institutional animal care and use committee was not necessary because all experiments were performed on cadavers.

Results

Bone Dust Dispersion

Use of the drill without an external suction tube resulted in almost the entirety of the original bone weight being left within the container as bone dust (94% ± 12% bone dust dispersion; ie, 94% of the bone dust generated was collected from the container, n = 8). This demonstrates that our enclosure was proficient in containing generated bone dust. Adding an external suction tube did not result in a significant change in bone dust dispersion (81% ± 10% dispersion; P = .07, n = 4).

In comparison, the UBA under optimized settings (power = 15%, suction = 100%, irrigation = 15 mL/min; n = 7) resulted in 3.2% ± 1.6% bone dust dispersion. This represents a 25-fold reduction in bone dust between the drill with external suction compared with the UBA without external suction (P < .001). We predict that had an external suction been added to the UBA under optimized settings, this magnitude would have been even greater.

We additionally looked at the effect of external suction with the UBA at a more powerful setting. With the UBA alone at power = 50%, suction = 50%, and irrigation = 15 mL/min, there was 45% ± 10% bone dust dispersion (n = 9). Adding an external suction resulted in only 13% ± 6% dispersion (n = 4). Thus, even at this relatively high power UBA setting, there was a 6-fold reduction in bone dust from the drill when an external suction was used in both cases (P < .001) (Figure 2).

We then assessed the effect of the UBA power, suction, and irrigation settings on bone dust dispersion. For the purposes of these optimization studies, no external suction device was used.

First, power was varied while suction was held constant at 50% and irrigation at 15 mL/min. The percentage of bone dust dispersion diminished from 51% ± 5% (n = 3) to 7% ± 2% (n = 3) as power was decreased from 100 to 5 (r² = 0.94) (Figure 3).

Second, suction was varied while power was held constant at 50% and irrigation was held at 15 mL/min. The
The percentage of bone dust dispersion rose from 31% ± 3% (n = 3) to 82% ± 7% (n = 3) as suction was decreased from 100 to 5% (r^2 = 0.99) (Figure 3).

Third, 2 experiments were performed to compare irrigation. In one experiment, power and suction were held at 50%, while irrigation was varied. Bone dust dispersion ranged from 45% ± 10% to 32% ± 7.0% as irrigation increased from 15 to 40 mL/min (r^2 = 0.43). In the other experiment, power and suction were held at 100%, while irrigation varied. Bone dust dispersion ranged from 17% ± 7% to 22% ± 2% as irrigation increased from 15 to 40 mL/min (r^2 = 0.32) (Figure 4).

**Bone Ablation Time**

The time to ablate a 1-cm³ block of bone was 11 minutes 18 seconds ± 48 seconds with the UBA on half power (power = 50%, suction = 50%, irrigation = 15 mL/min; 2 × 1.25-mm Micro Claw attachment; n = 3). This compared with 7 minutes 44 seconds ± 26 seconds with an otologic drill on full power (60,000 RPM, 3-mm diamond bur; n = 3) (Figure 5). The difference was significant (P < .01).

**Discussion**

In our cadaveric study comparing the UBA and an otologic drill, there was an approximately 25-fold reduction in the amount of bone dust dispersed with the UBA under optimized settings. Even under nonoptimized settings of relatively high power and suboptimal suction, there was a 6-fold reduction in bone dust dispersion with the UBA compared with the drill. Because one of the leading etiologic theories for post–retrosigmoid approach headache is bone dust dispersion into the subarachnoid space, using the UBA during IAC bone removal may represent a significant advantage for headache reduction.

With the increasing use of ultrasonic bone removal devices for cranial procedures, studies should focus on specific indications that warrant the use of these new devices. To our knowledge, using the UBA for IAC bone removal during the retrosigmoid approach for VS removal has not yet been studied.

The reason for the UBA’s superiority in preventing bone dust dispersion is its integrated suction port located only 1 mm from the bone ablation site. In contrast, the distance between the external suction tube and the bur of an otologic drill is far larger and more variable. Based on analysis of our technique in the operating room, we estimate this to be...
instruments other than suction. For example, specially designed retractors could be used, leading to safer surgery when working near vital critical structures. In addition, the UBA may allow easier bone removal under endoscopic visualization. This supports our hypothesis that external suction tubes have a relatively minor effect at minimizing bone dust dispersion.

The dispersion of bone dust when a drill is used could be reduced by decreasing the proximity between the suction tube and the bur. However, placing the suction within 1 mm of the bur will inevitably result in drilling of the metal suction tip with dispersion of metal fragments into the subarachnoid space. It is reasonable to assume this could be at least as irritating as bone dust (and may also cause metallic artifact signals on postoperative magnetic resonance scanning). Thus, under the ideal operative conditions, it is unlikely that an otologic drill could ever achieve the minimal bone dust dispersion of the UBA.

Because the integrated suction port of the UBA allows such inherently low bone dispersion with a single instrument, this opens the possibility of using the contralateral hand to hold instruments other than suction. For example, specially designed retractors could be used, leading to safer surgery when working near vital critical structures. In addition, the UBA may allow easier bone removal under endoscopic visualization.

To measure how the UBA settings affected bone dust dispersion, we varied power, suction, and irrigation. Increasing the power increased the amount of bone dust left on the field. This is likely due to the increased amplitude of ultrasonic vibration at the tip, dispersing bone material beyond the range of aspiration. As expected, the suction setting showed an inverse correlation: Reducing suction increased bone dust dispersion. Just as with a standard suction tube, care must be taken when high-flow suction is used near soft tissue structures. There have been reported cases of dura and venous plexus injury due to aspiration into the tip of the UBA.9

At the tested power and suction settings, irrigation did not appear to have an effect on bone dust dispersion. It is possible that at more extreme settings (eg, extremely low suction and high power), the irrigation setting may be more relevant.

A concern with any new instrumentation is extra time incurred in the operating room. Bone removal time was 40% longer with the UBA on half-power with a 1 × 2-mm tip compared with an otologic drill at maximum RPM with a 3-mm bur. (Half power was chosen for the UBA because full power subjectively resulted in heat generation.) This suggests that at comparable settings (ie, maximum drill RPM vs 100% UBA power), the 2 instruments would be grossly similar in terms of rapidity of bone removal. In the operating room, however, many other variables will affect the time to remove IAC bone. For example, drilling may be conducted at a slower speed depending on surgeon comfort. Likewise, the power setting of the UBA would likely be reduced to minimize bone dust dispersion. In summary, the UBA at optimized settings will add additional operative time, which must be taken into consideration. Further experiments are needed to assess bone removal times with the UBA at lower power settings.

One limitation of our study was that the individuals removing bone were not blinded to the hypothesis. While the bone ablation technique attempted to closely mimic what would be performed in the operating room, it is possible that subconscious bias may have exaggerated the difference in bone dust dispersion in the drill compared with the UBA groups. However, given the extremely large magnitude of difference (6- to 25-fold), it would be highly unlikely for bias to explain the difference.

A final issue is the possibility of sensorineural hearing loss due to bone-conducted ultrasonic vibrations transmitted to the cochlea. In a recent study, the UBA produced a similar or lesser degree of skull vibration compared with a standard otologic drill.9 A study of 60 patients undergoing middle ear and mastoid surgery with the Piezosurgery UBRD showed no postoperative worsening of bone line pure-tone audiometry.10 In contrast, drilling on the otic capsule with the Piezosurgery device in mice led to basal hair cell loss.11 It should also be noted that ultrasonic aspiration of tumor in close proximity to the cochlear nerve is already widely performed during VS surgery.

In conclusion, use of the UBA resulted in a 25-fold reduction in bone dust dispersion compared with an otologic drill. If the theory that bone dust spread contributes to postretrosigmoid headaches is valid, then use of the UBA may

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**Figure 5.** Elapsed time to drill a 1-cm³ volume of temporal bone with either the ultrasonic bone aspirator (UBA) at half power (power = 50%) or a standard otologic drill at full speed (60,000 RPM) (n = 3 for both groups) (P < .01).
reduce the incidence of headache. Further studies will aim to replicate these data in more realistic operative scenarios and assess for adverse effects of ultrasonic bone removal on sensorineural hearing. We hope that these preliminary studies will pave the way for clinical trials comparing the UBA to the standard otologic drill for retrosigmoid VS removal.

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Disclosures
Competing interests: Ravi N. Samy is on the surgical advisory board and conducts research for Med-El, is on the surgical advisory board for Cochlear Americas, and is a speaker for Stryker, which funded an educational/mission trip unrelated to this project; Justin S. Golub received funding from Stryker for an educational trip unrelated to this project and received book royalties and free books from Plural Publishing for consulting.

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References