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# Craniectomies for dogs with skull multilobular osteochondrosarcoma using the Misonix bone scalpel: cadaveric evaluation and retrospective case series

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**Highlights**

- The Misonix Bone scalpel can be used to perform craniectomy in dogs.
- Dural tears and suspected bone necrosis were observed during craniectomies for MLO without evident clinical impact.
- The Misonix bone scalpel can be used with a neuronavigation system.
- The risk for recurrence is high despite attempts to perform disease free margins in craniectomies for skull MLO.

**Title page**

Craniectomies for dogs with skull multilobular osteochondrosarcoma using the Misonix bone scalpel: cadaveric evaluation and retrospective case series.

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**Abstract**

**Objectives:** To evaluate the Misonix bone scalpel (MBS) for craniotomies in dogs and describe clinical findings and surgical experience in three dogs with large multilobular osteochondrosarcoma (MLO) of the skull.

**Study design:** Cadaver evaluation and retrospective case series.

**Animals:** One canine cadaver; three client-owned dogs.

**Methods:** Craniotomies of different sizes and at different locations were performed with MBS. Dural tear and bone discoloration were recorded. Clinical, imaging, and surgical findings of dogs diagnosed with MLO and where MBS was used for craniectomies were retrospectively included.

**Results:** Cadaveric evaluation identified MBS as an efficient tool for rapid craniectomies (> 5minutes) albeit dural tears and some small foci of bone discoloration were observed. Craniectomies could be performed without complications in three dogs with MLO without dural tear or bone discoloration. .Excision was in complete in all cases. The short-term outcome was good, and the long-term outcome was fair to good.

**Conclusion:** Piezoelectric bone surgery with the Misonix bone scalpel is an alternative technology to perform craniectomies in dogs. It was not associated with complications in 3 dogs diagnosed and surgically treated for MLO. Dural tears and suspected bone necrosis can occur. Great care should be taken when using CT to establish disease free surgical osteotomy.

Keywords: piezoelectric-bone scalpel- osteochondrosarcoma-dog

Abbreviations:; MLO: multilobular osteochondrosarcoma; MBS: Misonix Bone scalpel; CBCT: cone beam computed tomography

**Introduction**

Multilobular osteochondrosarcomas (MLO) are slow growing, locally invasive uncommon tumors of bone reported to affect the skull of dogs [1,2,3]. Metastasis to the lungs are most common and the metastatic rate is 56% following treatment with a median time to metastasis of 426-542 days [2]. Complete surgical excision can lead to excellent short and long-term outcomes and has been reported in association with multimodal therapy (surgery, +/- systemic chemotherapy, and radiation therapy)[1,2,4,5]. Benefits of adjuvant therapies such as radiation or chemotherapy for residual tumor following surgical treatment of MLO is unknown. Although surgical and reconstructions techniques have been described [4-12], the infiltrative nature of MLO, especially those originating in the calvarium, or orbit can represent a technical challenge. Conventional craniectomy techniques for MLO removal include a combination of powered instruments (pneumatic drill, oscillating saws) and manual bone-cutting (rongeurs) with potential complications including cosmetic and functional changes but also cerebral edema, hemorrhage or cardiopulmonary dysfunction depending on tumor location [13]. These complications arise from a combination of the instruments being used and the expansive nature of the MLO. Powered instruments and forceps can indeed lead to thermal and physical injury to the surrounding tissues. Based on their locations on the skull, MLO can displace brain parenchyma, nerves, blood vessels, or the eye.

The Misonix Bone Scalpel (MBS) offers ultrasonic cutting of bone by amplifying an electrical signal and converting it into a high back-and-forth motion of a blunt blade or round diamond shaver at the extremely high frequency of 22,500 times per second. This allows for transection of hard and crystalline structures while mostly sparing soft tissues like neural structures (brain, spinal cord, nerves) and blood vessels [14]. Because soft tissues have greater elastic properties than bone, they can therefore withstand high amounts of impact energy and vibrate in harmony with the scalpel. The technology helps in the creation of a well-controlled environment for bone removal while minimizing the risk of damage to surrounding soft tissues and critical structures, [15,17]. Primary advantages include decreased intraoperative hemorrhage, iatrogenic tissue damage, intraosseous hyperthermia, and bone necrosis. Surgeon visualization is improved, possibly enabling more extensive tumor excision or better surgical margins [14,18]. For these reasons, we believed the technology would be attractive for use in craniectomies of dogs with skull MLO where proximity to neural and vascular structures as well as intraoperative hemorrhage (from the tumor or adjacents blood vessels) can dramatically impact intraoperative complications and outcome.

This report first describes the technical evaluation of MBS for craniotomies in a canine cadaver then reports on the clinical findings, surgical experience, and outcome of three dogs that underwent craniectomy for MLO.

## Materials and Methods

*Cadaver evaluation*

The Misonix Bone Scalpel (MBS) was used in an approximatively 15 kg male castrated French bulldog cadaver for the purpose of craniotomies. Following dissection of the temporal muscles, small (four +/- 0.5cm x 0.5cm), medium (+/- 1.5cmx1.5cm) and large (+/- 3cm x 2cm) craniectomies were performed using MBS coupled to a neuronavigation system (Medtronic O-Arm system, Stealth S7 Navigation system, Medtronic AG, Münchenbuchsee, Switzerland). Following the attachment of a reference array onto the occipital protuberance, Cone Beam Computer Tomography (CBCT) of the skull was acquired using the O-Arm (Figure 1). Then, navigated instruments were registered including the bone scalpel attached to a reference tracker. This allowed the navigation system to know precisely where the tip of the bone scalpel blade was in relation to the skull (supplementary video S1) and could be visualized in real-time on the stealth station screen. This set up was used to allow the coupling of the surgeon's tactile feedback of the MBS with visual feedback of the neuronavigation system and would especially be tested for the use in extensive craniotomy close to other important anatomical structures (frontal sinus, dorsal sagittal sinus). Visual inspection of the integrity of the dura mater below the craniotomy cuts was performed by one of the authors. The MBS was used with settings at maximum level (power: 10, irrigation: 10). The 20 mm Blade Blunt (MXB-20, Misonix) was used.  The Ø4.4 Diamond Shaver (MXB-S3, Misonix) was not used as itis not recommended for use in cortical bone removal and its width too large for a narrow osteotomy. The navigation system was only available for the purpose of the cadaveric evaluation.

*Clinical cases*

Medical records (January 2017– May 2019) of dogs presented with MLO at the authors' institutions were reviewed. Case inclusion required craniectomy with Misonix bone scalpel (MBS) of MLO confirmed by histopathology. All surgeries were performed with the head elevated above the heart and ensuring no compression of the jugular veins.

**Case 1:** A 10-year-old female spayed Golden Retriever presented for a unilateral mass on the head. Physical and neurological examinations were unremarkable. Complete blood test (CBC, biochemistry) and urinalysis were normal. Contrast-enhanced computed tomography (CT) of the skull identified a large, bilobed occipital mass (6.7x5.4cm and 3.3x4.3cm) with a combination of regions of thickening or cortical disruption compressing the underlying structures, including the venous sinus system (dorsal sagittal sinus, left transverse sinus), most compatible with MLO (Figure 2A, D). Fine needle aspirates cytology was suggestive of MLO. Thoracic radiographs were normal. Treatment consisted of surgery and radiation therapy.

**1.1 surgical technique:**

CT was reviewed to establish the regions of the calvarium connected to the mass, its impact on the important adjacent (vascular and neural) structures and select margins free of tumor (1cm gross margins). Following dissection of the temporal muscles and muscles of the neck (Semispinalis capitis, obliquus capitis cranialis, obliquus capitis caudalis, rectus capitis dorsalis major, semispinalis capitis), the skull and mass were exposed. The 20 mm Blade Blunt was initially used to cut off the large protruding portions of the tumors in a piecemeal fashion. A combination of pneumatic drill and rongeur was then used to remove the outer cortex of the skull along a line representing expected clean margins. The Ø4.4 diamond Shaver was then used to finish the osteotomy by removing cancellous bone and inner cortex with the intent to avoid iatrogenic trauma to the underlying cerebellum parenchyma and blood vessels (Supplementary Video S2). No cranioplasty was performed. Routine muscle closure was done, and a Jackson-Pratt closed suction drain was placed, subcutaneous and skin closure was made in a routine fashion. Figure 3 A, D shows pre-and postoperative CT. A Grade 2 MLO (with incomplete margins) was confirmed by histopathology.

**1.2 perioperative care:**

Analgesia was with opioids (Fentanyl 2-5 µg/kg/h IV) and non-steroidal anti-inflammatory drugs (Carprofen 2.2 mg/kg, orally, every 12 hours). Mild generalized tetra ataxia was present on the day after surgery. The dog was normal and discharged two days later with Fentanyl transdermal patch (3 µg/kg/h for 5 days), Carprofen (2.2 mg/kg, orally, every 12 hours, for 5 days), Methocarbamol (20-25 mg/kg, orally, every 8 hours, for 7 days), Amoxicillin-clavulanate (14mg/kg, orally, every 12 hours, for 10 days).

**Case 2:** An 8-year-old female spayed Labrador cross was presented for a left temporo-occipital region mass. Physical and neurological examination identified a grade 2/6 left systolic heart murmur. Complete blood (CBC, biochemistry), coagulation panel (PT, PTT), blood typing were performed and within normal ranges. Echocardiography identified myxomatous mitral valve degeneration stage B1. Contrast-enhanced CT of the head, neck, and thorax confirmed a large, heterogeneous, predominantly mineral, granular, lobulated minimally contrast-enhancing mass (5.2 (l) x 4.6 (h) x 5.0 (w) cm), centered over the left temporal fossa of the parietal bone, characterized by a combination of thickening or cortical disruption areas, and extending into the tentorium cerebelli, to the level of the temporomandibular joint and to the mid-body of C1. The left occipital lobe and adjacent venous sinus system (dorsal sagittal sinus and left transverse sinus) were compressed by the mass effect, as demonstrated by the loss of normal contrast enhancement of the regional vasculature (Figure 2B, E). MRI of the brain showed similar findings. There was no evidence of pulmonary metastasis. Craniectomy and prosthesis was the treatment recommended.

**2.1 surgical technique:**

Based on CT data, a one-centimeter gross margin was delineated around the mass by removing the outer cortical bone with a pneumatic drill. The MBS (Bone scalpel, Misonix) Ø4.4 Diamond Shaver was then used to go through the cancellous bone and inner cortex. (Supplementary Video S3). The entire delineation of the margin could be performed safely, without any damage to the brain, cerebellum, or neighboring blood vessels. The mass was also adherent to dura and infiltrated the tentorium cerebelli. Micro-chalazion scoop forceps and a freer elevator were used to remove them later. Two sections of small dural tears were closed with 6-0 polypropylene. Hemostasis was achieved using a combination of bipolar cautery and bone wax. Cranioplasty was with Cefazolin impregnated PMMA prosthesis (1Gram Cefazolin/40Gram PMMA) customized to the defect as previously described[4]. Additionally, nonabsorbable knitted polypropylene mesh was included in the prosthesis to allow reattachment of the cervical musculature, fascia, and tendinous raphe where the nuchal crest had been replaced (Figure 4A). This was a preventative measure to avoid post-surgical complications of head ventroflexion, (experienced in a previous MLO case by one of the authors, different from case1). The temporalis muscles were apposed over the prosthetic implant with 3-0 polyglactin 910 in a simple continuous pattern. The subcutaneous tissues and skin were closed in a routine fashion. Figures 3 B, E show pre and post CT. MLO was confirmed by histopathology with incomplete excision..

**2.2 perioperative care:**

In the immediate recovery period, the dog's mental status was abnormal (stuporous). Brain edema was suspected and treated with mannitol (1g/kg, IV) and glucocorticoids (Dexamethasone SP 0.15 mg/kg, IV, once daily). Analgesia was with continuous rate infusion (CRI) of Fentanyl (2-5 µg/kg/h, IV) and Ketamine (2-10 µg/kg/min, IV). Cefazolin was continued (25mg/kg, IV, every 6 hours). Trazadone (2-5 mg/kg, orally, every 8 hours PRN), acepromazine (0.02mg/kg, IV, q8 PRN) and maintenance IV fluids were administered to prevent overactivity. The following day, mentation was improved, yet abnormal (depressed), generalized cerebellar ataxia, and proprioceptive deficits were present in all four legs. By day 4 post-operatively, the neurologic examination had normalized. The patient was discharged the following day with a Fentanyl transdermal patch (3 µg/kg/h for 5 days), Gabapentin (10mg/kg, orally, every 8 hours, for 14 days), Dexamethasone (0.15 mg/kg, PO, once daily for 4 days; then 0.075 mg/kg, orally, once daily for 7 days; then discontinue) and Cephalexin (22-25mg/kg, orally, every 12 hours, for 7 days).

**Case 3:** A 1-year-old female spayed Shih Tzu-cross presented with a large mass on the right side of the face associated with exophthalmos, decreased retropulsion OD, exotropia

OD, ocular hypertension (intraocular pressure 25mmHg OD and 14mmHg OS). The physical and neurological examinations were normal. CBC, serum biochemistry, abdominal ultrasound, and thoracic radiographs were normal. CT identified a 2.9 x 1.5 cm mineral mass in the right ventral calvarium (parietal and frontal region), displacing the right globe ventrally and rostrally (Figure 2C, F). A diagnosis of MLO was suspected based on imaging and cytology.

**3.1 surgical technique:**

A three-dimensional printed model of the patient's skull, tumor, and eye was printed for surgical planning and to demonstrate the surgery principle to the owners. The zygomatic arch was cut using the 20 mm Blade Blunt of the MBS and reflected ventrally. Margins of normal appearing fascia or muscle were removed at the same time as the soft tissue structures in contact with the mass. The conus of the eye and eyeball was gently retracted ventrally. The protruding portion of the mass was initially removed in sections using the 20 mm blade blunt until its base was reached. The skull was then cut circumferentially around the base of the mass (Figure 4B), several millimeters (about 10mm) away from the abnormal bone until the affected skull could be lifted off and removed (Supplementary Video S4). The dura appeared intact. Gelfoam (Pfizer New York, NY) was placed over the exposed dura. Hemostasis was achieved with bipolar cautery and ligation of smaller vessels with 7-0 polyglactin 910. The zygomatic arch was reconstructed using cerclage wire passed through 8 holes drilled in the zygomatic arch bones. The temporalis muscles were apposed with 3-0 polyglactin 910 in a simple continuous pattern. The platysma muscle and skin were closed in a routine fashion. Because of exophthalmos, a right eye temporary tarsorrhaphy was performed. Figures 3

C, F show pre-and postoperative CT. A grade 1 MLO was confirmed by histopathology with incomplete excision.

**3.2 perioperative care:**

A postoperative CT scan was performed with no obvious evidence of abnormal tissue at the surgery site margins. Analgesia was with CRI of Fentanyl (2-5 μg/kg/h, IV), Ketamine (2-10 μg/kg/min, IV). Dexmedetomidine CRI (1-3 μg/kg/min, IV) was also given. Meloxicam (0.1mg/kg, orally, once daily) and cefazolin (25mg/kg, IV, every 6 hours) were given for 3 days. Menace response OD and the palpebral reflex on the right side were absent upon recovery suggesting damage to the palpebral branch of the right facial nerve. Significant right-sided facial swelling was observed the day after surgery; it gradually improved over the following 3 days, and the dog was discharged into the owner's care. Discharge medications included a Fentanyl transdermal patch (3 μg/kg/h for 5 days), Meloxicam (0.1mg/kg, orally, once daily for 14 days), Tramadol (3-5 mg/kg, orally every 8 hours starting after Fentanyl patch removal for 10 days), and Genteal Severe Dry Eye (¼" strip OD every 6 hours for 14 days).

**Results**

*Cadaver evaluation*

The four small craniotomies could be performed under 2 minutes each. Each time the blade was held perpendicular to the bone surface, pushed downwards then retracted then pushed deeper as recommended. This back-and-forth motion allowed for the irrigation to lubricate the blade and likely cool down the bone. Tactile feedback was mostly used to establish that the inner cortex had been cut through. Focal bone discolorations (brown/black) were observed along the cut and were likely related to excessive friction and likely represented thermal injury. The dura was perforated focally in every craniotomy. The middle size craniotomy was performed under 3 minutes. Here, the craniotomy was made by first applying forces downward to perforate both cortices then retracted out partially, so that the outer cortex stayed in contact with the lateral part of the cutting edge of the blade then moved laterally and downward again. This allowed for a rapid craniotomy with a 1mm osteotomy line. Several dural tears were also observed as well as some small foci of bone discoloration. The large size craniotomy was performed using the navigation system with the aim to come as close as possible to the frontal sinuses without perforating them and evaluate how it would perform close to the area of the dorsal sagittal sinus. MBS coupled with the navigation was a great combination which allowed a precise cut on the edge of the frontal sinus, without perforation. This extensive craniotomy was performed under 5 minutes, dural tears and blackened bone surface also occurred. Dural tears evaluation for all craniotomies are represented in figure 1. No pathology was performed of the discolored bone.

*Clinical evaluation*

**Case 1 outcome:**

There were no dural tear or bone discoloration observed. The irrigation system of the MBS allowed for a constant flush of the surgical site. Ventroflexion of the head was observed two weeks after surgery and never normalized thereafter. Radiation therapy was planned at the same time, started a week later with a protocol of 20 daily 2.5 Gy fractions, and completed by week 7 after surgery. Radiation-induced dermatitis was observed at week 4 after surgery, which was treated with prednisone therapy (0.75 mg/ kg, orally, once daily), and VRTOG (Veterinary Radiation Therapy Oncology Group) grade 1 toxicity to the ears was suspected at week 5, for which the dog received a successful therapy of tramadol (3-5 mg/kg, orally, every 8 hours) and Gabapentin (15 mg/kg, orally, every 8 hours). Recurrence of mass effect at the surgery site and pulmonary metastasis developed around 6 months after surgery, and euthanasia was performed 14 months after surgery.

**Case 2 outcome:**

The diamond shaver was initially tested to perform the osteotomy but was found to be ineffective to go through the outer skull cortex (too slow). The combination of using the pneumatic drill to draw the osteotomy line through the outer cortex followed by the diamond shaver to remove the cortical bone and safely remove the inner cortex offered both rapidity and safety. The constant irrigation of the surgical site was provided through the MBS handpiece. Two dural tears occurred but were not related to the use of the MBS and occurred when the dura was detached from the adherent mass. No discoloration of bone was observed. Two weeks post-operatively, clinical and neurological evaluation was unremarkable. Follow-up CT was performed 3 weeks later with static implants and no evidence of early clear disease regrowth. About 3 months after surgery, the dog developed generalized tonic-clonic seizures and was started on antiepileptic drugs (AED) by the referring veterinarian (levetiracetam (25mg/kg, orally, every 8 hours) and phenobarbital (4 mg/kg, IV, every 6 hours for 4 doses, then 3 mg/kg, orally, twice daily)). At the time of consultation, abnormal mentation (dullness), reduced menace OS, ataxia on all four limbs, and left hemiparesis were identified on neurological evaluation with a lesion affecting the right prosencephalon suspected. The differential diagnosis included inflammatory, vascular, post-surgical trauma etiologies. CBC and biochemistry only identified changes compatible with phenobarbital therapy. CT and MRI of the head identified meningeal enhancement and dystrophic mineralizations of the muscles surrounding the surgical site with mild enhancement consistent with tumor infiltration or dystrophic mineralizations secondary to chronic inflammation (i.e. postoperative changes). Cerebrospinal fluid tap showed changes most consistent with peripheral blood contamination. Meningitis was suspected based on the imaging finding. Prednisone (0.5 mg/kg, orally, twice daily for 5 days; then once daily for 5 days; then every 48 hours for 3 days) therapy was initiated, and AED continued. The dog was euthanized one week later because of further seizures and owners 'concerns over the dog's quality of life. Histopathology confirmed the suspicion of meningitis (lymphoplasmacytic infiltration) and identified recurrence of MLO within the occipital bone and regional dura.

**Case 3 outcome:**

No dural tear or bone discoloration were observed. Two weeks postoperative, the surgical site was well healed and the tarsorrhaphy was intact. Upon neurological and ophthalmological examination, a clinical diagnosis of right-sided facial nerve paralysis with secondary keratitis and corneal ulceration (ulcerative keratitis) was made. Tarsorrhaphy was maintained and Neo/poly/bac (1/4" strip OD 4-6x daily) and Genteal Severe Dry Eye (drops 2-3 drops OD 4-6x daily) were dispensed. Two weeks later, the corneal ulceration had resolved, and the facial nerve paralysis with secondary keratitis was static. The tarsorrhaphy was removed and the dog was prescribed Genteal Severe Dry Eye (drops 2-3 drops OD 4-6x daily) for life. Reexamination was performed 2 years 4 months later for clinical signs suggestive of local recurrence (mass effect observed in the area of the previous surgery). The dog was euthanized 3 years 8 days after surgery.

**Discussion**

We report on the technical experience of using the piezoelectric Misonix Bone Scalpel to perform craniectomies in dogs. We identified that in a cadaveric model, craniotomies were subjectively easily and rapidly performed when compared to previous experience with a pneumatic drill. However focal dural tears and bone discoloration were often observed when using the Blade blunt and MBS. Three dogs underwent craniectomies for skull multilobular osteochondrosarcoma removal using the MBS without evident clinical complications related to its use nor dural tears or bone discoloration.

The safety of using the Misonix bone scalpel for craniotomies in dogs has not previously been evaluated. Piezoelectric devices have been evaluated in dogs for dentistry implants osteotomies[27], veterinary oromaxillofacial surgeries[14], and neurosurgeries[28,29] including four craniotomies[28]. Not all piezoelectric devices utilize the technology in the same manner. For example, the MBS has a back-and-forth micromotion (longitudinal vibration) at a frequency of 22.5khz, representing 22,500 strokes per second, whereas the Sonopet (Stryker NeuroSpine ENT, Kalamazoo, MI, USA), used in some of the aforementioned studies, uses longitudinal and torsional vibration at a frequency of 25Khz or 34Khz depending on the handpiece being used. Care should therefore be taken when drawing conclusion from these studies as results might be instrument specific. There were no clinical complications related to the use of the bone scalpel in the three reported clinical patients with MLO craniectomy. Although dural tears were observed in dog 2, they were unrelated to the use of MBS. Dural tears were observed in the cadaver when the blunt blade was used. Although, the lack of epidural space in the canine skull may represent a predisposing factor for dural tears during craniotomies, similar risks are reported in human with elderly skull, meningiomas or hyperostosis frontalis where adhesion of the dura to the bone is observed[22]. Dural tears can lead to intraoperative complications, sometimes life threatening, when in the proximity of large vessels such as venous sinuses which are contained within a duplication of the dura mater. The identification of dural tears in the cadaver should be interpreted with caution as the histological integrity of the meninges had not been evaluated following the freeze/thaw cycle. The absence of dural tears in the clinical cases is suspected to be related to the use of the diamond shaver for case 1 and 2. Dural thickening secondary to the adjacent skull tumor might also be a plausible explanation however no histopathology was performed. Dural tear can be a complication of craniotomies when using the blunt blade of the MBS.

Focal bone discoloration was observed on multiple occasions where osteotomies had been performed in the cadaver. This discoloration was suspected to be a thermal injury secondary to the friction of the blade against the bone although no histopathology of these sample had been performed. In spinal surgery, heat generation during high-speed burring is a well-known phenomenon with concerns for osteonecrosis (above 50°C) and neural thermal injury (above 45°C)[23]. For the latter, histological nerve root injury were demonstrated in a rabbit model where the use of chilled saline irrigation had a more prominent effect than room temperature saline in reducing the incidence of the thermal injury during extended drilling[24]. Although this represents a good reason to search for pneumatic drill alternatives, this phenomenon can also occur with piezoelectric instruments. It was found that when performing laminectomies with the MBS, the inner cortex temperature did not reach the osteonecrosis threshold however the tip reached temperature above neural thermal injuries. The bone model used in this study were made of low-density polyurethane foam however and findings should therefore carefully be translated to dog bone[25]. The MBS user manual warns the user that the tip and irrigant temperatures may indeed exceed the tissue necrosis point if insufficient irrigation flow rates are used. For hard tissue removal, setting the irrigation flow rate to a setting no less than the comparable vibration setting is recommended. For example, if the vibration setting is set at 7, a minimum flow setting of 70% should be used at the console. Additional external irrigation, e.g. by administering sterile saline with a syringe over the distal tip portion, may be necessary for removal of very dense, hard osseous structures. Tissue necrosis may result if the tip is not moved relative to tissue, and we believe this is what was observed in the cadaver. The absence of osseous bleeding during the osteotomy could also have had a role to play. A continuous, lateral sweeping motion is therefore recommended to minimize contact duration with the ultrasonic tip and minimize heat build-up. When lateral motion is not possible, withdrawing and re-inserting the tip frequently is advised. No bone discoloration was observed when using the diamond shaver.



The technology has been previously evaluated in an ovine model which included clinical, neurophysiological and histopathological evaluations following L3-L5 laminectomies[17]. The procedure was compared between 2 groups, one using a high-speed drill versus another using a bone scalpel. Clinical and neurophysiological findings were not different between each group, suggesting no evidence of thermal injury. One sheep in the bone scalpel group demonstrated focal nerve disruption with mild axonal loss. The mean operative time of the bone scalpel group was significantly shorter. Bone necrosis was present in segments of the initial osteotomies but was reduced through adjustment of power, irrigations levels, and surgeon experience (new tactile feedback learning curve). Surgery location (L3-L5) was selected because in sheep, the spinal cord is present at that location. The thin and friable dura mater in sheep was also an attractive characteristic of the ovine model for the authors. A notable reduction in osseous bleeding with local hemostatic effect was also reported. These findings were for laminectomies, and it is likely that similar conclusions are true for skull and brain. We have experienced similar benefits in the clinical cases. The reduction in osseous bleeding has also previously been reported in human clinical cases[26-29] and we have found it particularly useful for MLO surgeries, which are lengthy and bleeding operations. To the author's knowledge, there are no reports of adverse events directly related to the use of piezoelectric technology for craniectomy in humans[14,30-34].

Subjective surgeons experience with the MBS found the technology particularly useful to perform craniectomies for MLO. Recommendations based on our limited experience are here given to benefits other surgeon doing surgery in these complex tumors. First, it is paramount to learn the tactile feedback of the MBS by trialing the instrument on cadavers or other bone models. Second, the MBS with the blade was very effective to rapidly amputate the protruding portions of the MLO and reach the skull surface. The osseous bleeding reduction with the MBS was a great advantage of the device. Third, the MBS blunt blade allows for a precise and narrow (1mm) osteotomy. Adequate irrigation settings and lateral sweeping motion (or back-forth insertion of the tip) are less likely to lead to thermal injuries. Being aware of the variation in skull thickness along the osteotomy line will likely decrease the risk of dural tears. Fourth, to minimize the risk of iatrogenic venous sinus injury, it is recommended to use MRI or CT contrast studies to predict their patency and to use the round diamond burr to remove the above cancellous and inner cortex. The diamond shaver was not found to be efficient to remove the outer cortex likely due to the 0,4 mm surface of contact and the back-and-forth motion. Fifth, using cold saline throughout the craniotomy is also likely to decrease intraoperative bleeding. Sixth, vessel trauma occurs easily during skull resection, and the source of hemorrhage may not be readily visible or assessable until complete tumor removal is accomplished. Therefore, in some instances, the tumor and affected calvarium may need to be removed in segments to facilitate access. Seventh, the positioning of the animal with the head elevated relative to the remainder of the body can help reduce venous hypertension and/or hypostatic congestion at the surgical field, in turn helping to reduce overall blood loss[5,8]. Eight, rapid, complete obliteration of the dorsal sagittal sinus can lead to catastrophic consequences, and if the latter is expected to be necessary, a technique for occlusion of the dorsal sagittal sinus has been reported for dogs with MLO[9]. Ninth, reconstructions techniques are important when large skull defects result from surgery. Craniectomy with cranioplasty in dogs has been described[4,5,8,10,11]. Tenth, decreased cervical range of motion and low head carriage has previously been reported following craniotomy surgery[4]. This may be related to disruption of muscle and soft tissue attachments to the back of the skull as in dog 1. Careful dissection of the muscle off the skull and planning of its reconstruction is recommended. Finally, the MBS can be successfully coupled to a neuronavigation system. Benefits included the real-time identification of the underlying bone thickness and observation of anatomical landmarks to preserve or avoid.

The main limitation of this case series is the low number of clinical patients, and the findings of this report cannot therefore be extended to any dog size or breed. Despite the original intent to achieve complete excision, none of the clinical cases achieved complete excision. A craniotomy line with a 10mm disease-free margin around the mass was intended in all clinical cases but lead to incomplete tumor excision and prompts for a more precise evaluation and delineation of tumor margins to prevent recurrence. Careful evaluation on CT for abnormal bone characteristics with subsequent clean margin delineation should guide the surgeon and should be performed on a recent imaging dataset of the tumor. The use of 3D printed surgical guides could assist in achieving such objective. If complete margins cannot be achieved because of anatomical constraints, recurrence is highly likely. Further research is needed to establish how to best delineate disease free osteotomies in dogs with skull MLO. We performed piecemeal sections of the MLO to achieve volume reduction when its size interfered with access to the skull. Whether this technique can lead to seeding of tumor material is possible. Whether the mineralizations observed in the soft tissue of case 2 were metastasis and whether they were related to this technique cannot be confirmed as histopathology was not done.

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**Figure legends**

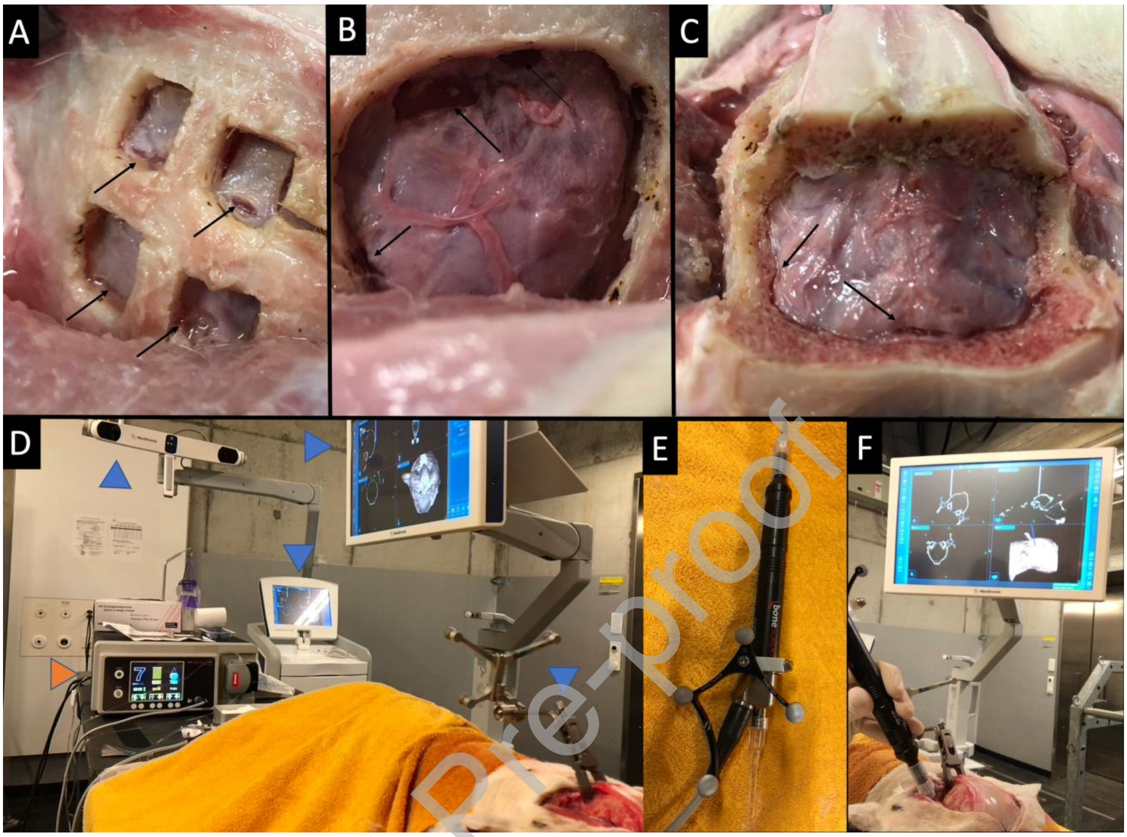

Figure 1: Cadaveric evaluation. Misonix Bone scalpel and neuronavigation system are shown. Dural tears and bone discoloration occurring during the different types of craniotomies.


Figure 2. Clinical and imaging presentation of the 3 dogs. A and D: dog1, B and E: dog 2, C and F: dog 3.

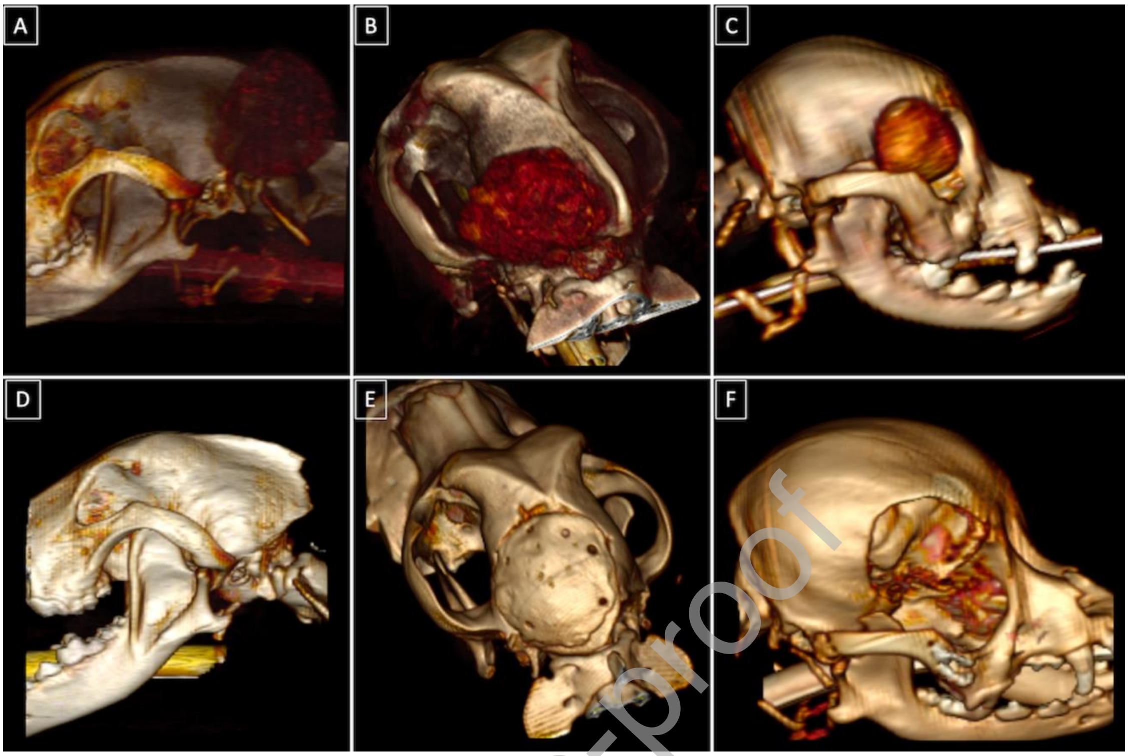


Figure 3. Pre and post-surgical imaging highlighting the craniectomies. Pre and post-surgical imaging highlighting the craniectomies. A and D: dog1, B and E: dog 2, C and F: dog 3.

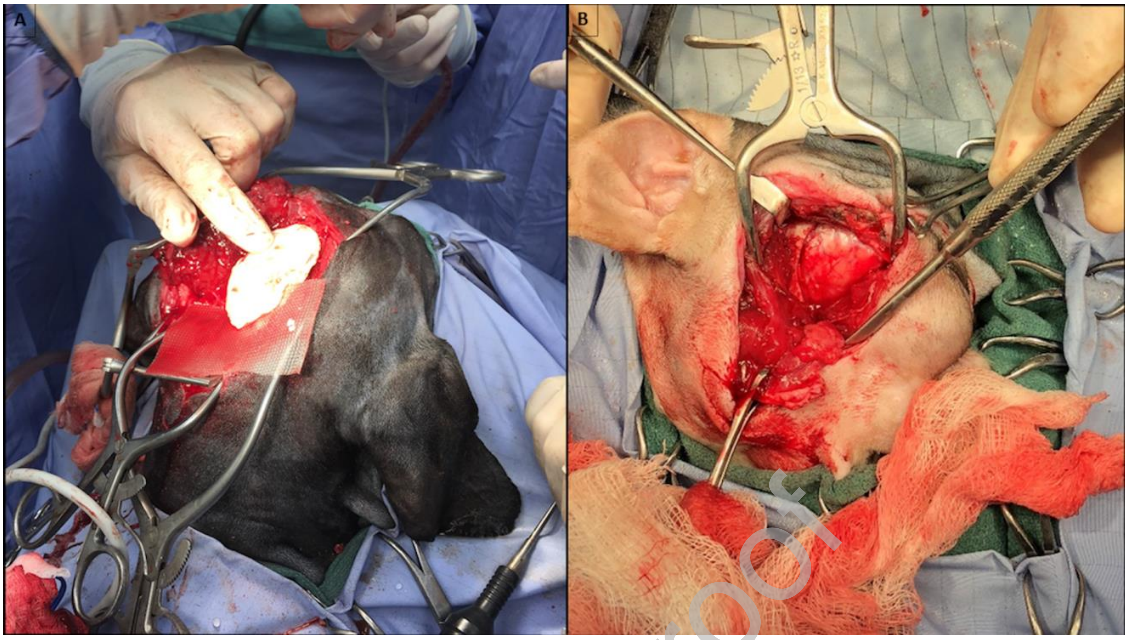


Figure 4. A: The PMMA cranioplasty and polypropylene mesh for muscle reconstruction. B: Craniotomy in case 3 and illustration of the precise cut which can be obtained with the bone scalpel Blade blunt. PMMA: Polymethylmethacrylate

**Video**

The following supplemental material is available for this article online:

Video Clip S1. Cadaveric evaluation of the Misonix Bone Scalpel and neuronavigation

Video Clip S2. Case 1: Removal of the caudal portion of the MLO infiltrating the occiput using the bone scalpel diamond shaver.

Video Clip S3. Case 2: Removal of the MLO using the diamond shaver.

Video Clip S4. Case 3: Craniectomy is being finalized after cutting with the bone scalpel (blade blunt) and the remainder MLO lifted up with cautiously. The protruding portion of the mass was cut with the MLO in a piecemeal fashion (not shown). The brain parenchyma is eventually exposed, intact.

**Author contributions**

Alexander M. Piazza: conceptualization, methodology, original draft; Writing - review & Editing

Jonathan F. McAnulty: conceptualization, methodology, original draft; Writing - review & Editing

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**Disclosure statement**

No personal or professional conflicts of interest to declare