Cranioplasty by means of molded polymethylmethacrylate prosthetic reconstruction after radical excision of neoplasms of the skull in two dogs

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- Dogs with osteoma or multilobulated tumor of bone have a good prognosis after complete resection of the mass.
- Complete excision of large skull tumors may involve resection of the calvarium below the horizon of the brain or removal of the dorsal orbital rims.
- Large resections predispose the brain and eyes to potential trauma; protection of these tissues can be provided via reconstruction of the calvarium with preformed molded polymethylmethacrylate prosthetic implants.

A 2-year-old 10-kg (22-lb) spayed female English Cocker Spaniel was evaluated at the **University of Wisconsin Veterinary Medical Teaching Hospital (UW-VMTH)** for surgical removal of a mass of the dorsal aspect of the skull of 8 months' duration. Results of a biopsy performed previously had indicated that the mass was an osteoma; however, a **multilobulated tumor of bone (MLTB)** could not be ruled out after examination of the tissue sample obtained at that time.

On physical examination, the dog was bright, alert, and clinically normal, except for a large mass on the rostrodorsal aspect of the skull (**Fig 1**). Results of serum biochemical analyses were within reference limits, and thoracic radiography revealed no abnormalities. Radiographic examination of the skull revealed a 4.0 × 4.0 × 5.0-cm mass that involved the dorsal portion of the frontal and parietal bones of the cranium. The mass extended dorsally above the cranium and ventrally into the frontal sinuses and cranial vault. Interpretation of radiographic images of this mass was consistent with MLTB.

A **computed tomography (CT)** scan of the skull revealed a well marginated, large, spherical, bony mass that replaced the dorsal portion of the frontal bones and cranium, and the mass depressed the brain and extended rostrally to the rostral margins of the eyes and caudally to the union of the zygomatic and temporal bones. Dorsal to the cranium, the mass extended a distance of approximately 2.5 cm; ventrally, the mass extended a similar distance into the frontal sinuses and intracranial space, causing ventral and lateral displacement of the rostral portion of the cerebral cortices.

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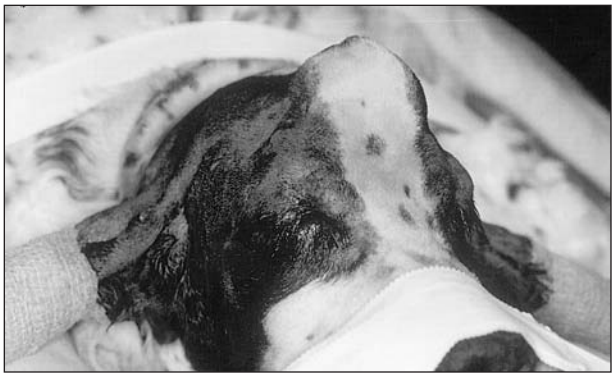

Figure 1—Photograph of a mass (identified as a multilobulated tumor of bone) involving the cranium, frontal sinuses, and cranial vault of an English Cocker Spaniel. The dog was prepared for surgery; its nose (bottom right of image) was taped to the table.

Compared with adjacent brain tissue, the cerebral soft tissue located ventral to the mass was hypoattenuated, which suggested edema.

The dog was anesthetized for surgery, and the skin on the head and neck was clipped and aseptically prepared. Administration of cefazolin (20 mg/kg [9.1 mg/lb] IV, q 6 h) was started at the time of induction of anesthesia and continued postoperatively for 3 days. Skin and soft tissue overlying the dorsal midline of the mass were incised and reflected caudally and laterally to expose the surface of the mass. By means of a high-speed pneumatic drill and burrs, the mass and a 1- to 1.5-cm margin of unaffected cranium was removed en bloc. The resected tissue included the caudal portion of the floor of both frontal sinuses. In the center of the defect, the brain was noticeably depressed; at the edges of the resected calvarium, it protruded approximately 1.5 cm above the bone. The meninges remained intact after removal of the tumor and associated calvarium.

After resection of the tumor, sterile aluminum foil was molded as a dome over the brain and bony edges of the excision site to create a mold of the calvarial defect.[1] This mold was lightly coated with sterile aqueous gelatin lubricant[a] to act as a releasing agent, and **polymethylmethacrylate (PMMA**[b]; with no other additives) was poured onto the interior surface of the mold and allowed to harden. On removal of the foil, a PMMA positive-cast of the bone defect and interior dome of the calvarium had been created (**Fig 2**). This cast was covered with an adhesive plastic drape[c] and sterile aqueous gelatin lubricant. The lubricated surface was covered with a 0.5 to 1.0-cm thick layer of PMMA and allowed to harden. After release from the cast mold of the calvarium, this second molding of PMMA replicat-

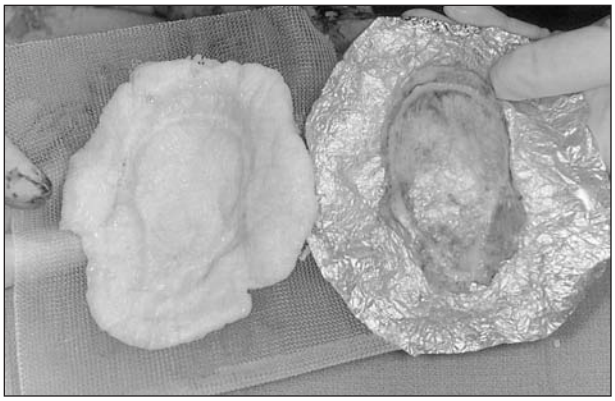

Figure 2—Photograph of a polymethylmethacrylate mold (left) that was made by use of an imprint in sterile aluminum foil (right) of the calvarial defect after resection of the mass in the dog in Figure 1.

ed the interior of the calvarial dome without compression of the brain or other vital structures. The edges of this molded prosthetic conformed to those of the bony resection site. Thus, after careful trimming with a pneumatic drill and burr, the prosthetic mold would fit into the defect in a lock-and-key manner. A simple means of securing the prosthesis would have been to place suture material or wire into holes drilled through it and into the cranium near the edges of the resection. However, during trimming, a crack occurred that partially spanned the prosthesis. To repair the mold, a nonabsorbable knitted polypropylene mesh[d] was adhered with a thin layer of PMMA to its surface. The mesh was subsequently trimmed to create a free margin. By means of simple interrupted sutures (2-0 polypropylene suture), the periosteum at the edge of the excision site and the mesh were sutured together to secure the prosthetic mold in place. A fat graft was obtained from the dorsal region of the neck via the original skin incision and placed in the frontal sinus prior to routine closure of the temporalis muscle, overlying fascia, subcutaneous tissue, and skin. Via histologic examination, the tumor was identified as an osteoma that extended to the margin of the tissue sample. However, the spatial relationship of the tumor to the outer edge of the resection margins could not be accurately evaluated, since burring of the bone to accomplish the excision had destroyed the outer 0.5 to 0.75 cm of excised bone.

The dog recovered from anesthesia without complications and was placed in the critical care unit to be monitored for neurologic deficits and seizure activity. After surgery, the dog developed slight lagophthalmos of the right eye, which persisted at follow-up examinations. The dog also developed subcutaneous emphysema of the dorsal region of the neck; after aspiration, this resolved without further intervention. Three days after surgery, the dog was discharged. During the next 14 days, treatments included enrofloxacin (15 mg/kg [6.8 mg/lb] PO, q 24 h), amoxicillin trihydrate-clavulanate potassium (23 mg/kg [10.5 mg/lb], PO, q 12 h), and topical administration of methylcellulose artificial tears (0.25-inch strip, left eye, q 12 h). At re-evaluation 14 days after surgery, the dog had no signs of infection or other complications, and incision sites had healed

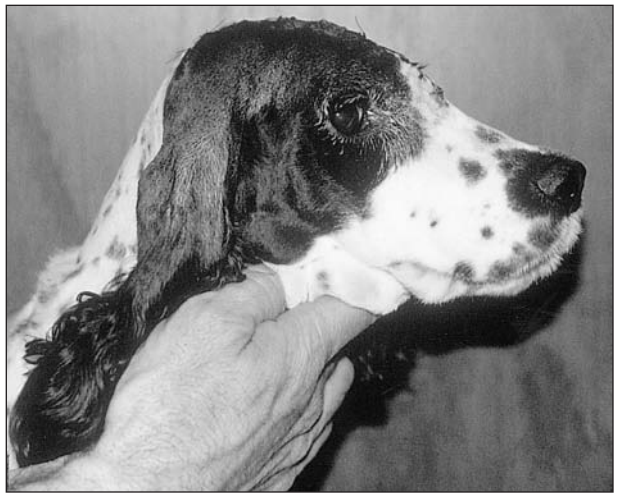

Figure 3—Photograph of the head of the dog in Figure 1 obtained 14 days after resection of the cranial mass and placement of a polymethylmethacrylate implant. Notice the successful wound healing and cosmesis.

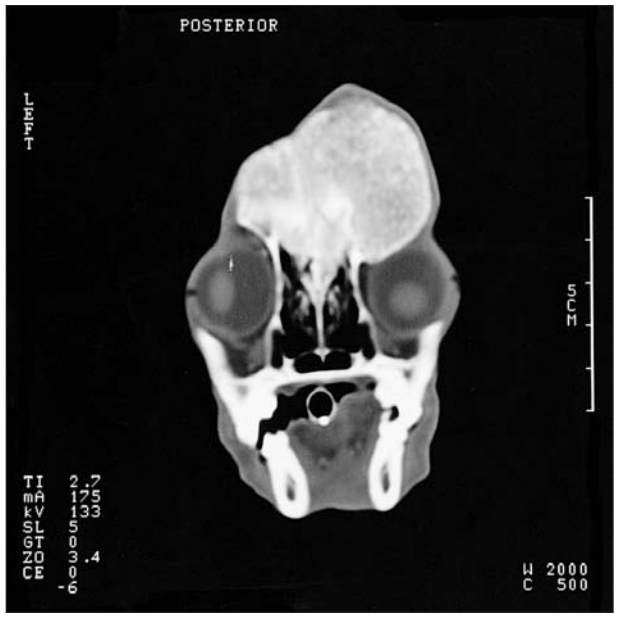

Figure 4—Transverse computed tomographic image of a well-circumscribed bony mass (identified as a multilobulated tumor of bone) along the margin of the calvarium and partially extending within the rostral calvarium in a dog. The mass protrudes well above the calvarial horizon.

with excellent cosmesis (**Fig 3**). Three years after surgery, the dog had 1 seizure; a CT scan of the skull obtained showed no regrowth of the tumor. At that time, there was no infection or other complication associated with the PMMA prosthesis. Seizure activity did not recur in the subsequent 2 years up to the time of this report.

A 1.5-year-old 7.0-kg (15.4-lb) spayed female Terrier mix was evaluated at the UW-VMTH because of a mass on the dorsal aspect of the skull of 4 to 5 months' duration. At another institution, the mass had been identified as a multilobulated osteochondrosarcoma, but surgical excision of the mass was not undertaken because of its extensive nature. On physical

examination, the dog was alert and clinically normal, except for a 4.0 × 5.0 × 5.0-cm nonpainful mass above the eyes.

Results of serum biochemical analyses were within reference limits, and thoracic radiography revealed no abnormalities. A CT scan of the skull (**Fig 4**) revealed a large, well-circumscribed bony mass extending along the margin of the calvarium and partially into the rostral calvarium, which was consistent with the diagnosis of MLTB. The mass invaded both orbital rims, both frontal sinuses, and approximately a third of the length of the nasal cavity bilaterally.

The dog was anesthetized for surgery, and the skin on the head and neck was clipped and aseptically prepared. Administration of cefazolin (20 mg/kg, IV, q 6 h) was started at the time of induction of anesthesia and continued postoperatively for 3 days. A 14-cm skin incision was made over the dorsal aspect of the mass; skin and underlying soft tissue were reflected laterally and caudally to expose the tumor. The mass, with a 1- to 1.5-cm margin of cranium, was removed en bloc by use of a high-speed pneumatic drill and burrs. Resected tissue included the rostral calvarium, the dorsal orbital rims and a portion of the medial orbital walls, the frontal sinuses, and approximately a third of the nasal bone. A PMMA prosthesis that included dorsal orbital rims was fashioned as described and placed over the defect after the bony portions had been removed. The prosthetic mold was secured by placement of simple interrupted sutures (2-0 polypropylene suture) into predrilled holes in the calvarium and nasal bones.

The dog recovered from anesthesia without complication and was placed in the critical care unit for observation. Histologic examination of the mass confirmed the diagnosis of MLTB. While in the critical care unit, the dog regurgitated and was administered a constant rate IV infusion of metoclopramide (0.2 mg/kg [0.1 mg/lb]), ranitidine (4.0 mg/kg [1.8 mg/lb], SC, q 12 h), and chlorpromazine (0.3 mg/kg [0.1 mg/lb], IM, q 8 h) for the first 24 hours after surgery. Thoracic radiography was performed 3 days after the episode of regurgitation and revealed no evidence of aspiration pneumonia.

Four days after surgery, there was a slight amount of bloody drainage from the medial canthus of the right eye. Nevertheless, the dog was otherwise doing well and was discharged after application of a fentanyl transdermal patch (25 µg/h for 3 days). The dog's treatments included amoxicillin-clavulanic acid (22 mg/kg [10 mg/lb], PO, q 12 h) and metoclopramide (0.5 mg/kg [0.2 mg/lb], PO, q 8 h) for 7 days, famotidine (0.5 mg/kg, PO, q 24 h) for 8 days, and topical administration of methylcellulose artificial tears (0.25-inch strip, right eye, q 8 h) for 14 days.

One month after surgery, a fistulous tract had developed over the PMMA mold in the region dorsal to the right eye. Crusted ulcerative lesions near the midline of the face were evident, but these were not draining at that time. Edema and redness were visible around the right eye, and there was drainage of purulent material from a second small fistula in the area of the medial canthus of the right eye. The medial edge of the PMMA mold was visible through the fistula at the medial canthus of the eye. Skull radiographs obtained during anesthesia revealed no evidence of tumor recurrence or osteomyelitis. Injection of radiographic contrast material into the fistula at the right medial canthus resulted in drainage of the contrast material into the frontal sinus cavity and proximal nasal cavity. Contrast material did not pool in any soft tissue cavities, indicating free drainage of material around the implant into the nasal cavity. The dog was prepared for surgery, during which the edge of the PMMA mold was trimmed back to lessen pressure on the overlying canthal tissue, and the wound was débrided and closed with 5-0 polyglactin 910 suture in a simple interrupted pattern. The ulcerative lesions on the mid-frontal area of the head were excised, and the skin was closed with 4-0 polypropylene suture in a simple interrupted pattern. Samples of the purulent material from the draining wound were obtained for bacteriologic culture, including identification of *Pseudomonas* spp and antimicrobial susceptibility testing.

The dog recovered well from anesthesia and surgery. Two days later, the dog was discharged and received treatment with ciprofloxacin (20 mg/kg, PO, q 24 h) pending results of antimicrobial susceptibility testing. This treatment was discontinued after 5 days, and amikacin was then administered (15 mg/kg, SQ, q 24 h) for 7 days, because antimicrobial susceptibility testing indicated resistance of the microbial population to ciprofloxacin and its susceptibility to aminoglycosides and third-generation cephalosporins. Approximately 3 months after the original surgery, the dog was admitted to the VMTH with infection and skin necrosis associated with the PMMA implant. On physical examination, approximately 0.75- and 1.0-cm-long areas of necrosis were evident over the implant along the medial canthus of the right eye and left orbit, respectively; a small area of purulent drainage from the right frontal sinus and the right eye was also noted.

The dog was anesthetized for surgery during which the rostral two thirds of the implant was removed so that only the caudal third of the prosthetic material remained covering the brain. Nasal and frontal sinuses were flushed, and infected and devitalized tissue was débrided. Samples of the débrided tissue were submitted for anaerobic and aerobic bacteriologic culture and antimicrobial susceptibility testing. The medial eyelid wounds were closed in 2 layers with simple continuous suture patterns of 4-0 monofilament polyglyconate suture in the deep subcutaneous tissues and 3-0 polyglactin 910 suture in the superficial subcutaneous tissues. Using 4-0 polyamide suture, skin of the medial eyelid wounds was closed with a simple interrupted suture pattern, and skin near the eye was closed with a figure of eight suture pattern. The midline incision of the head was closed in 3 layers; deep subcutaneous tissues were closed with 4-0 polyglactin 910 suture in a simple continuous suture pattern, superficial subcutaneous tissues with 3-0 polyglactin 910 suture in a simple continuous suture pattern, and skin with 4-0 monofilament polyamide suture applied as simple interrupted sutures and vertical mattress sutures in areas of tension. After results of bacteriologic culture and antimicrobial susceptibility testing became available, the dog was administered amoxi-

cillin-clavulanic acid (13 mg/kg [5.9 mg/lb], PO, q 12 h) for 14 days.

Seven months after the original surgery, the dog was returned to the UW-VMTH because of chronic infection of the implant with *Pseudomonas* and *Staphylococcus* spp. Two fistulous tracts associated with the head were evident; 1 tract was located above the left eye, and 1 was in the mid-frontal area. The dog was unable to blink its right eye fully because of severe scarring of the upper eyelid. Both eyes appeared to be somewhat buphthalmic, but there was no corneal ulceration. Anesthesia was induced, and the implant was removed; the tissues covering the brain had thickened considerably with granulation and fibrous tissue deposition that appeared to provide some degree of protection to the brain. A 0.25-inch Penrose drain was placed in the surgical site, and the skin margins around the draining tract were débrided and the wound closed routinely. Four days later, the dog was discharged and administered ciprofloxacin (20 mg/kg, PO, q 24 h) for 14 days and topical application of methylcellulose artificial tears (0.25-in strip, q 12 h) in both eyes. In a telephone interview 31 months after implant removal, the owner reported that the dog was doing well and had a normal activity level. On 3 occasions, the owner had observed accidental blunt trauma to the dog's head, and although the dog's reaction indicated that these events were painful and caused some transient disorientation, the owner had observed no long-term adverse effects at that time. However, it appeared that the dog had become protective of its head, based on observed tentative behaviors when contact of the head with any object might occur, and also avoided being petted on the head; this behavior had not been observed prior to the trauma and during the period when the implant was in place.

The biological behavior of MLTBs and osteomas make en bloc excision the treatment of choice. The prognosis for dogs with these tumors can be excellent if the mass is removed completely, as confirmed by histologic examination; however, the location of these tumors can make achievement of this goal quite challenging.[1-3] Some resections may require extensive excision of the frontal and parietal bones, extending into the calvarium and also into the sinuses and nasal cavity. Excisions of the frontal bone may also require removal of the orbital rims to obtain clean surgical margins. Such an extensive excision may result in exposure of the brain and dorsal aspect of the eyes to subsequent trauma; surgeons must decide whether the exposure of vital organs is sufficient to warrant reconstruction of the bony structures. Making this decision requires consideration of the estimated risk of injury to these exposed tissues versus the difficulty of prosthetic reconstruction and its associated risk of complications. This evaluation may be weighted more heavily in favor of prosthetic reconstruction in young, active animals that may be more prone to incidental trauma because of their active behavior patterns and potentially long life span after surgery, such as the 2 dogs of this report.

A further challenge of reconstructive cranioplasty is that lesions located in the rostral aspect of the head may span a portion of the frontal sinus or nasal cavity, both of which contain large numbers of bacteria; in these areas, development of chronic infection around the implant is a potential risk. However, the first dog of this report underwent placement of an implant that spanned both the calvarium and frontal sinus without development of chronic infection. We speculate that secretions were able to freely drain around the implant into the nasal cavity; thus, infection within the surrounding tissues was prevented. In the second dog of this report, necrosis and infection of the soft tissues near the eyes developed at prosthesis-induced pressure points. During reduction of the prosthetic implant at subsequent surgeries, it was determined that it had remained exposed in the nasal cavity and had not become enveloped by granulation or fibrous tissue; thus, sequestration of infected material was not a likely cause of development of draining fistulous tracts. The most plausible explanation for this complication was that the edges of the dorsal orbital rims of the prosthesis caused pressure necrosis of the adjacent tissue, which facilitated bacterial invasion and the production of fistulous tracts in the area of the implant.

Necrosis of skin overlying an implant can develop if the skin is thin or poorly vascularized or is in contact with a sharp edge of the prosthesis that exerts a focal point of pressure. These factors, combined with exposure to an area of high bacterial load (eg, nasal cavity), were probably the cause of implant failure in the second dog of this report in which both orbital rims were replaced. In that dog, replacement of the orbital rims required detachment of the overlying skin from the skull and its subsequent repositioning over the edge of the implant, resulting in focal pressure necrosis and colonization by pathogenic bacteria of the skin and subcutaneous tissues. Prosthetic reconstruction of orbital rims in this type of resection procedure presents a special challenge to distribute pressure evenly throughout the overlying tissues while avoiding distortion of the palpebral fissure or interference with lid function.

Ideally, implant material should have density and expansion coefficient similar to that of bone; have adequate strength and rigidity; be lightweight, inexpensive, easy to obtain, without immunogenic reactivity, and tolerated by tissues; and have ease of contouring and fixation, low thermal conductivity, and radiolucent properties.[4,5] Various materials have been used for cranioplasty in dogs and humans, including bone and synthetic polymer.[4-9] In humans, portions of the iliac crest and ribs have been split to an appropriate configuration with cortical bone on 1 side and cancellous bone on the other for use as autogenous bone grafts.[5,7-9]

In dogs, 1 approach to cranioplasty has involved the use of cortical allografts from another dog skull of similar size.[6] Disadvantages of the use of allografts include the need to ensure destruction of bacterial and fungal microorganisms associated with the grafts and difficulty in maintaining a stock of appropriately sized specimens. Allografting may also be technically challenging, because the method of bone graft conservation and handling prior to implantation will strongly influence the survival and strength of the graft.[5] Other con-

cerns regarding bone grafts are that they are frequently reabsorbed, may become infected, are difficult to contour, and availability may be limited, particularly when the defect is large.[4]

The use of metal for cranioplasty dates back to antiquity; in 1565 AD, Petronious is reported to have performed cranioplasty in a human using a gold plate. Several metals have since been used in such procedures, including platinum, tantalum, cobalt-chromium alloys, aluminum, titanium, and stainless steel. Metal implants are no longer commonly used, because metals are expensive, heavy, and difficult to shape; in addition, they conduct heat and electricity, are radiopaque, and have various degrees of biocompatibility. A notable exception is titanium mesh, which is more radiolucent and has low density and corrosion rate. Titanium mesh allows osteointegration through the openings in the mesh, and it can be used alone or with a PMMA implant. However, it is poorly malleable and very expensive.[5]

At present, PMMA is the polymer most commonly used in prostheses; other polymers include polytetrafluoroethylene, high-density polyethylene, polyester and polyamide mesh, and silicate implants.[5] Polymethylmethacrylate has become widely used, because it is strong and has tensile and flexural strength greater than that of bone.[7] It is also biocompatible, stable in vivo, radiolucent, easy to manipulate, readily available, and inexpensive. There is 1 disadvantage to its use; PMMA has the potential to cause tissue necrosis because of the highly exothermic reaction associated with hardening, but this risk can be avoided by preforming the implant prior to placement in tissues.[5] In another report,[6] use of PMMA as a calvarial implant has been described, but the method of implant construction was different from that described here. In the 2 dogs of this report, surgery was performed to remove a large osteoma or MLTB of the cranium, during which a PMMA prosthetic implant was preformed and fitted to the defect created in the skull. This method is simple and avoids the potential for thermal injury to tissues, particularly the brain, by use of ex vivo casting (to a recommended thickness of 0.5 to 1.0 cm) and molding of the prosthetic implant prior to its placement. The PMMA mold is easy to construct and fit to the skull. The prosthesis prepared for the first dog of this report was fractured as a result of aggressive handling during trimming, which was not attributable to inherent weakness of the implant.

In the first dog of this report, long-term tolerance of the prosthesis was evident, despite its exposure to bacteria of the nasal cavity and sinuses while concurrently in contact with the meninges (dura mater). In retrospect, the 2-week treatment with antimicrobials in the absence of evidence of infection may not have been warranted in either dog of this report. Although exposure of prosthetic implants to bacteria generally has undesirable consequences, we hypothesized that long-term tolerance of the implant in the first dog of this report was possible for several reasons: the intact dura mater may have acted as a barrier to bacterial penetration into the CNS; granulation tissue associated with the prosthesis may have formed a barrier to bacterial invasion of the surrounding soft tissues as well as provided a thicker, more resilient long-term barrier against bacterial invasion of the CNS than the dura mater alone; and free drainage into the nasal cavity directly or via the frontal sinus may have prevented sequestration of infection within tissues. Long-term success of calvarial PMMA implantation has been recorded[6] for another dog and was, therefore, not considered a serendipitous event in the first dog of this report. Complications that developed in the second dog of this report were representative of those anticipated after more extensive resection and reconstruction of the skull. In a situation where the 3-dimensional geometry of the reconstruction may directly compromise the overlying tissue because of pressure or devascularization, invasion of the overlying tissues by bacterial contaminants will be facilitated, and the reconstruction will be prone to chronic infection, tissue necrosis, and development of fistulous tracts. However, it is noteworthy that there was no penetration of bacteria beyond the meningeal barrier into the brain tissue, even in the second dog with recurrent infection of the subcutaneous and epidermal tissue over the prosthetic implant.

In both of the dogs of this report, the PMMA implant was exposed to the microbial flora of the nasal cavity. However, in the first dog, a thin, 1- to 1.5-mm rim of supraorbital bone was preserved, to which the eyelids and overlying skin remained normally attached. Because of this, the pressure placed on the skin was dispersed over a larger surface (as it was normally), and reconstruction was simplified. In contrast, the second dog of this report had both dorsal orbital rims removed, which resulted in destabilization of the skin of the upper lids and allowed focal pressure to develop on a small area of skin at the edge of the prosthetic device. We hypothesize that this resulted in compromise of the skin at that point with subsequent bacterial invasion resulting in necrosis, abscessation, and fistulation. With refinement of the technique, it may be possible to contour the prosthetic to avoid creating focal points of pressure within tissue. Another strategy to minimize these complications may be to incorporate a free edge of synthetic mesh to allow dispersed suturing of the subcutaneous tissues to the mesh. This would allow the distribution of the pressure of the dependent lids over a larger area and allow later ingrowth of connective tissue to anchor these tissues over a broader area than the sutures alone can provide. Regardless, more experience with this procedure would be required to determine whether these complications could be avoided; resection of the dorsal orbital rims, as part of a large cranial resection, may be a limiting factor in the decision whether to implant a prosthetic device during surgery. Although cranioplasty may offer protection from later trauma to the eyes and brain while resulting in improved cosmesis, the placement and construction of PMMA prostheses must be carefully considered to obtain the best long-term results with minimization of complications, such as local sepsis and tissue necrosis.

[a]K-Y lubricating jelly, Johnson & Johnson, Arlington, Va.
[b]Howmedica Inc, Rutherford, NJ.

[c]Incise drape, 3M Corp, St Paul, Minn.
[d]Bard mesh monofilament knitted polypropylene, Davol Inc, Cranston, RI.

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Correction: Evaluation of cat and owner characteristics and their relationships to outdoor access of owned cats

In "Evaluation of cat and owner characteristics and their relationships to outdoor access of owned cats," published June 1, 2003 (2003;222:1541–1545), the number of cats in the Shelter column for 1990–1994 was incorrect. The correct number of cats is 3/9.