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Gas Bubbles in Polymethylmethacrylate Cranioplasty Simulating Abscesses: CT Appearance

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Polymethylmethacrylate (PMMA) cranioplasty procedures were performed on 20 patients over a 2-year period. Nine of these patients had a total of 17 CT examinations, performed when clinically indicated. On 16 of the 17 CT scans, the appearance of the cranioplasty plate was characteristic of plates with gas bubbles. The appearance of these bubbles was stable over an extended period of time, ruling out clinical reasons for this appearance. The original interpretations of the CT scans were variable, inconclusive, or even erroneous. An understanding of the application of PMMA plates and their characteristics is necessary to accurately interpret the CT appearance of the PMMA cranioplasty plate.

Polymethylmethacrylate (PMMA) is one of the most common prosthetic materials used for plastic repair of craniotomy defects. Most cranioplasty procedures using PMMA to correct a cranial defect after trauma or craniotomy are performed some time after the initial insult in order to avoid potential complications of attendant edema or infection. The morbidity associated with the implantation of the prosthesis in this stabilized population is thereby greatly reduced. Because there is usually little clinical indication for performing CT on these patients, the appearance of the cranioplasty may not be attributed to the inherent characteristics of the plate, but may be misinterpreted to represent infection.

We have reviewed the clinical data and radiographic interpretations of patients on whom CT of the brain was performed after PMMA cranioplasty. An understanding of some of the physical and chemical properties of methylmethacrylate (MMA), the polymerization process, and the cranioplasty technique is necessary to obtain an accurate interpretation of the CT scan through the level of the PMMA prosthesis.

Materials and Methods

PMMA cranioplasty procedures were performed on 20 patients at our institution in the past 2 years. Reasons for the original craniotomy and/or craniectomy varied in these patients and included excision of tumors, elevation of fractures, and evacuation of hematomas. The clinical data and radiographic interpretations of CT scans taken after cranioplasty were reviewed.

A self-curing MMA product (Cranioplastic, L. D. Caulk Co., Milford, DE) was used for all patients. The liquid component is added to the solid component and mixed rapidly to ensure homogeneity of material. In a few minutes the consistency of the mixture becomes doughlike and the material is easily handled. After the incision and retraction of the skin, subcutaneous tissues, and galea, excision of the cicatrix around the defect is performed, exposing healthy bone circumferentially. The semiplastic MMA is then troweled directly onto the fibrous tissue overlying the dura mater and shaped to the form of the skull. Copious irrigation is used to remove the excess heat from polymerization. Holes are then drilled into the plate and adjacent skull, and the PMMA is sutured to prevent future slippage. The galea, subcutaneous tissues, and skin are then replaced and sutured. An alternative technique uses an underlying stainless steel mesh that is cut to conform to the defect. The mesh is sutured into position and the

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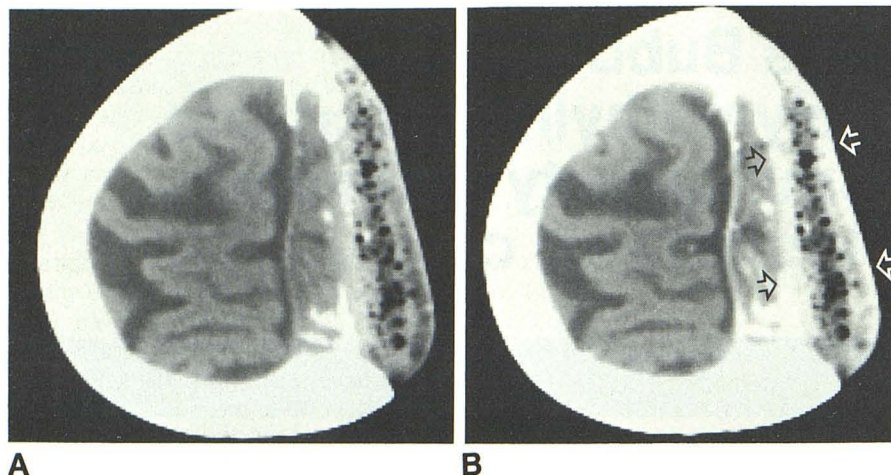


Fig. 1.—A, Precontrast scan showing inhomogeneity and gas bubbles within the polymethylmethacrylate plate. B, IV-contrast enhancement. Borders of the plate are defined by skull, enhancing meninges (black arrows), and enhancing scalp (white arrows).

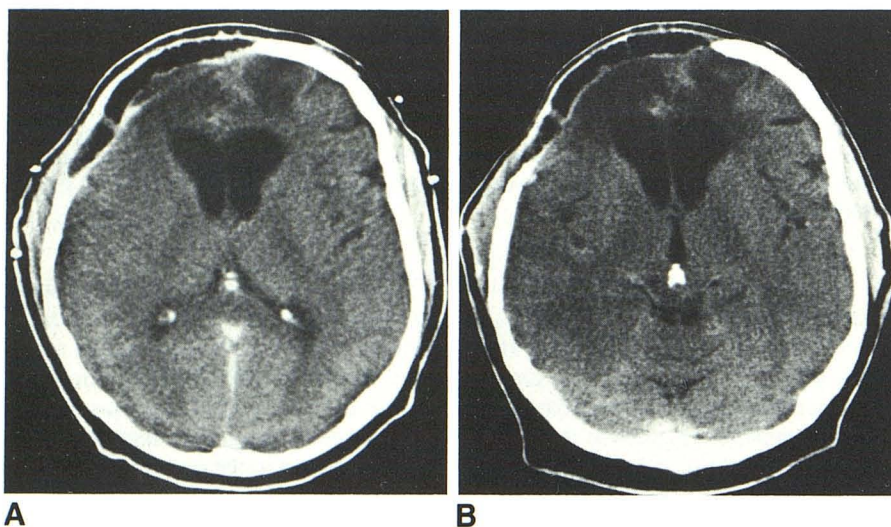


Fig. 2.—Different patient from Figure 1. A, Post-contrast scan 10 days after cranioplasty. B, Post-contrast scan 1 yr after cranioplasty.

MMA is applied as described above. CT attenuation values were obtained from the solid-appearing portions of the plates, from the gas bubbles within the plates, and from premanufactured PMMA.

Results

CT scans were performed on nine patients postoperatively to evaluate for tumor recurrence, fluid reaccumulation, or cause of change in clinical status. Eight of these patients had plates without wire mesh reinforcement. Sixteen CT examinations were performed on these eight patients, and every study demonstrated a collection of gas bubbles in the region of the cranioplasty plate.

We retrospectively reviewed the original interpretations of these examinations. Seven of these studies were done within a week of the procedure, and the gas was attributed to air introduced at the time of surgery, although gas related to infection was considered. In five studies the collections of gas were just described and no attempt was made to ascribe a cause or significance to the findings. The gas collections were

attributed to abscesses in two others. In the remaining two, the finding had been present for several months and was not addressed in the interpretation. One patient had wire mesh reinforcement in the PMMA plate. The metal caused significant artifacts on the image. No gas bubbles sufficiently large enough to be detected by CT were noted.

Pre- and post-IV-contrast-enhancement studies defined the location of the cranioplasty plate by enhancement of meninges and scalp, while the plate maintained constant attenuation values (Fig. 1). Comparison studies in seven patients, available from the early postoperative period and from intervals ranging from 3 months to more than 1 year, demonstrated stability in the appearance of the cranioplasty plates and the contained gas bubbles (Fig. 2). In addition, none of the patients was felt to have clinical evidence of infection.

Discussion

The appearance of PMMA cranioplasty plates varies from case to case. When a wire mesh was not used, gas bubbles were evident in the plate, usually with a central predominance.

The long-term stability of the appearance of the bubbles makes the probability that this finding is related to abscess very low. None of these patients had clinical evidence of infection.

Bubbles are created by the rapid stirring necessary to mix the components of the plastic homogeneously. The process of polymerization is exothermic. If heat were not dissipated, the temperature of the MMA mass could approach 122°C [1, 2, 3]. Because the boiling point of MMA is 100°C, temperatures approaching or exceeding this value will cause the MMA to exert a significant vapor pressure, or even to boil, which also causes gas bubbles within the plate. In addition, the bubbles expand with the rise in temperature. If adjacent bubbles expand and encroach upon each other, they may coalesce, causing larger pockets of gas. Since the polymerization rate is greatest at the maximum temperature, the solidification of the polymer traps the gas collections in their most expanded state. The expansion of the plate due to the enlarging pores is offset mostly by the shrinkage (about 9%) due to the polymerization and the change in density from that of MMA to PMMA [4].

Too many pores within the plate may compromise the protective integrity of the plate [5, 6, 7]. Because high temperatures lead to an increased number and larger size of the pores, and because high temperatures also have the potential to damage the meninges to which the MMA is applied, copious saline irrigation is used to minimize these consequences. This effectively lowers the exterior surface temperature. Studies have shown, however, that even with saline irrigation, the epidural temperature can rise to 64°C [8]. Damage to the brain is unlikely since the meninges are highly vascularized and effectively remove this heat, so that the subdural temperature has been shown to rise only by 0.55°C [9]. Despite cooling at both surfaces, the internal temperature of the plate remains high because the thermal conductivity of MMA/PMMA is low. Thus, the gas bubbles form predominantly at the plate's center [3, 10].

No gas bubbles were evident in the patient who had the wire mesh inserted. Although only a single case was available, we believe the absence of significantly large bubbles is related directly to the presence of the wire mesh. It is postulated that the mesh functions as a radiator, distributing the heat evenly throughout the plate, and preventing areas of very high temperature, thereby reducing the production, expansion, and coalescence of gas bubbles.

In patients whose plates have pores that are small or sparse, it may be difficult to define the extent of the plate, since the attenuation values may be similar to soft tissue or brain. This is due to diffuse gas pockets within the plates below the resolution of the CT scanner, causing averaging of the attenuation signals of gas and solid [11]. Premanufactured, pressure-cured plates contain no gas bubbles and have higher attenuation values of 90–110 H. By obtaining both pre- and post-IV-contrast scans, the cranioplasty plate is defined

by the enhanced meninges and scalp and the edges of the skull surrounding it (Fig. 1). The plate can be differentiated from an adjacent isodense fluid collection because the surfaces of the plate are more highly attenuating than the interior [12]. The surface cooling by the saline irrigation and meningeal vessels prevents formation of large bubbles at the plate surfaces and results in a slightly higher surface density than there is internally.

Our experience with the appearance of PMMA cranioplasty plates on CT indicates that there are certain characteristic findings that may be inherent to the plates themselves. Gas bubbles are seen within the plates, with larger bubbles located centrally. Thus, the plates have a slightly higher density at their surfaces. The surface density of the plates, where the gas pores are small, is similar to soft tissue or brain. The extent of the plate can be defined on CT by the IV-contrast enhancement of surrounding tissues.

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