The Lexan Calvarium: An Improved Method for Direct Observation of the Brain

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The evolution, since 1811, of cranial windows for direct observation of the brain has been well documented by Shelden et al. These authors introduced the Lucite calvarium, a permanent cranial window covering extensive areas of both cerebral hemispheres while retaining the ability to maintain normal intracranial hydrodynamics. Visual observations through this extensive window offered a means for detecting phenomena associated with a wide variety of physiological and pathological conditions. Combined with high-speed cinematography, the technique is invaluable in determining morphologic intracranial changes resulting from exposure to high and low barometric pressure, alterations in inspired gases, head injury, and whiplash trauma. Motion, texture, and color of the brain and vascular changes over its surface under these conditions are clearly visible. Both acute and chronic observations are made feasible and offer a unique opportunity for correlation with other physiological recordings. In spite of these advantages the technique did not gain acceptance, probably because of the technical complexity involved in the fabrication of a Lucite calvarium.

In the course of our investigations in experimental brain trauma in Rhesus monkeys, we developed certain improvements over past methods for processing a transparent calvarium. Materials and methods are now available which were non-existent when the original method was described 23 years ago, and our method enables a new type of transparent brain window, the Lexan calvarium, to be easily fashioned within a few hours.

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*Editor's Note: Strictly correct usage would be "calvaria" (not calvarium) from the feminine singular Latin noun of identical spelling meaning "a skull." However, common usage and euphony dictate preference for "calvarium."

The Old Method

The previous method leading to a successful preparation of a transparent calvarium was divided into four steps, requiring a few days between a two-stage operation. The four steps were as follows:

1. The first stage of operation
2. The Lucite processing technique
3. The second stage of operation
4. Postoperative care.

After the first stage of operation (exposure of the dura over the area to be covered and the taking of an impression of the bony defect with hydrocolloid), the scalp was closed and a helmet secured in place. This served to protect the brain against injury during the ensuing 5 days required to prepare the animal for his second operation and to process the Lucite prosthesis. In making the Lucite calvarium, established dental prosthetic techniques were used. After the impression was obtained, a gypsum working model was made. The model was built up with wax to simulate the Lucite calvarium; a two-piece mold was cast; the wax was removed by boiling in water; and the Lucite polymer was compression-molded therein. To achieve a final high luster, the Lucite required grinding away of adherent pieces of separating tinfoil, and polishing with revolving stones, wet pumice, and whiting. At this stage considerable care was needed so as not to generate excessive frictional heat in the plastic, which could result in permanent embedding of the polishing grit. The second stage of the operation was performed after an interval of 5 days. The wound was reopened and prepared for the application of the Lucite prosthesis. The plastic was cold-sterilized because its low heat distortion point precluded autoclaving. The dura mater was removed and the calvarium attached to the skull by means of self-tapping screws.
The skin fold was sutured in place and sterile gauze dressings applied.

Postoperative care consisted of periodic changing of gauze dressings during the first 2 weeks, and drainage of "subdural" space.

The New Method

Many of the disadvantages of the old method of processing a transparent calvarium have been overcome by recently available methods and materials. Within the past 5 years, a new material, Lexan* polycarbonate, has become available. This material approximates the same degree of optical clarity in thin sections as the Lucite† previously described and is readily available in a wide range of sheet thicknesses. It is extremely tough and shatter-proof. Dangers of cracking and crazing due to high humidity are less than with the Lucite. This material has a heat distortion point above 120°C, making it suitable for sterilization by autoclaving. We therefore developed a procedure utilizing polycarbonate plastic and thermoforming method to shorten and simplify the processing of a transparent calvarium. This resulted in a method having only two stages:

1. The operation and prosthesis fabrication
2. Postoperative care.

Operation and Prosthesis Fabrication. The operation consisted of surgical preparation of the monkey and an extensive calvarium resulting in wide exposure of the undisturbed dura mater. We did not leave a strip of bone over the sagittal sinus. An impression was then taken of the bony defect using a silicone-rubber casting compound. This compound had been steam-sterilized and prepared by adding stannous octoate as the cross-linking catalyst to RTV-11, a dimethyl siloxane polymer. Stannous octoate is relatively innocuous when dispersed in the silicone rubber. Pieces of vulcanized silicone rubber have been successfully implanted in many parts of the human body with little or no tissue reaction. By varying the amounts of stannous octoate used, a

* Lexan = trademark, General Electric Company.
† Lucite = trademark, E. I. DuPont de Nemours Co., Inc.

| Catalyst concentrations for low viscosity room temperature vulcanizing silicone* |
|---------------------------------|-----------------|---------------|---------------|
| Stannous Octoate† Pts per hundred weight | Working Time‡ (min) | Setting Time (min) |
| ml | drops |  |  |
| 0.75 | 15.0 | 2 | 10 |
| 0.62 | 12.5 | 4 | 14 |
| 0.50 | 10.0 | 6 | 20 |
| 0.38 | 7.5 | 11 | 35 |
| 0.25 | 5.0 | 20 | 60 |
| 0.13 | 2.5 | 120 | 240 |

* RTV-11 (dimethyl siloxane) T.M. General Electric Co.
† Nuocure 28, T.M. Nuodex Products, Elizabeth, N.J.
‡ Based on ability to flow through an 18 gauge needle driven by a 5 cc syringe.

range of working times are available. Table 1 indicates the concentrations of stannous octoate required for various working and setting times of the impression-taking silicone rubber compound.

Once the impression material was set, a rigid matrix of quicksetting plaster of paris was mounded over the silicone impression material. This matrix was necessary to insure stability and accuracy of contour with the highly flexible silicone. Both steps in taking this impression did not require more than a 20-minute lapse of time before easy removal from the dura and skull margins could be assured and the subsequent processing of the calvarium began.

A male mold was made by casting a high strength gypsum cement† into the impression. The gypsum was allowed to harden for 10 minutes after which it was removed and force-dried in a hot air oven; a ½ mm layer of unvulcanized silicone rubber sheet§ was then adapted to the mold over the dural area only. The mold was returned to the oven for ½ hour at a 177°C to vulcanize the rubber film. This rubber film served to seal the gypsum and to provide a smooth surface against which the polycarbonate could be formed. It also served to simulate the normal space between the cranium and the cortex.

† Coecal may be obtained from Coe Laboratories, Inc., Chicago, Illinois.
§ Silastic S-2000 is available from Dow Corning Corporation, Midland, Michigan.
Lexan polycarbonate lends itself readily to thermoforming, a process whereby vacuum and/or pressure is used to make a heated plastic sheet conform to the shape of a solid mold. Pressures up to 14 psi are obtained by evacuating the space between the sheet and the mold. When higher pressures are desired, they are obtained by sealing a chamber to the top side of the sheet and building pressure within by compressed air. Sheets of 1.6 mm polycarbonate were pre-dried at 125°C overnight to remove any absorbed moisture. The model was transferred hot from the drying oven to a standard laboratory vacuum-forming machine and was heated to 204°C prior to thermoforming (Figs. 1 and 2). An overhead pressure-assist chamber fed with compressed gas at 30 psi or greater, was used to increase the molding force. In this manner, accurate detail could be achieved even for the most complicated shapes, thus insuring a perfect fit. Appropriate screw holes and access ports were drilled in the calvarium, and its perimeter trimmed. No polishing was required to bring out the clarity or smoothness of the calvarium. A total of about 3 hours was required for the calvarium to be prepared, sterilized in the autoclave, and be ready for implantation (Fig. 3).

The dura mater was then excised to the edges of the bone defect and of the sagittal sinus. All bleeding points were meticulously cauterized. Small holes for insertion of screws were drilled in the skull at points corresponding to those previously drilled in the Lexan calvarium. Eight No. 2 stainless steel screws were used to obtain the maximum degree of rigidity. Clear autopolymerizing methyl methacrylate* was applied at the periphery to insure a water-tight seal between the bone and the prosthesis. Two access portholes drilled in the vertex of the calvarium were closed by screws and rubber washers.

The cruciate scalp incision made at the outset was then trimmed so that only an edge of scalp overlapped the margins of the calvarium. Antibiotics were flushed under the scalp fold, and sterile gauze dressings were applied. The entire procedure was carried

*Jet is manufactured by Long Dental Manufacturing Company, Chicago, Illinois.
out within a 6-hour period, with only half of that time involved in preparing the calvarium.

Postoperative Care. Dressings were changed periodically during the first 2 weeks, and antibiotics were administered parenterally as well as into the edges of the wound. Drainage of the "subdural" space was required only on a very few occasions to eliminate delayed postoperative clouding beneath the prosthesis. Under aseptic conditions, the screws used to seal the access ports were removed, and xanthochromic fluid was drained followed by a mild flushing with sterile normal saline before replacing the screws. After 2 weeks, the skin edges receded below the margins of the calvarium, curled inward, and adhered to the temporal muscles and pericranium (Fig. 4).

Results

No neurological or behavioral problems followed the attachment of the Lexan polycarbonate calvarium, and the monkeys uniformly gained full consciousness and normal functions by the next morning. This confirmed the earlier observations with the Lucite calvarium. In addition, we have been able to carry out experiments with animals prepared in this way as early as 24 hours after surgery. No leakage of cerebrospinal fluid has resulted during experimental cerebral concussion studies. The polycarbonate has remained unchanged for several months with no evidence of cracking or crazing. Longer use has shown that the prosthesis can withstand repeated concussive impacts. We have eventually repeated and confirmed the observations of Pudenz and Shelden regarding the qualitative nature of brain movement after head impact.

Eight monkeys have been prepared with this technique over the past 2 years. The maximum period of observation has been 9 months for any individual animal. Within about 3 months, or earlier if concussion experiments produce cortical bleeding, the formation of filmy exudates began to obscure the calvarium. At this stage it was possible to remove the calvarium under aseptic precautions and strip the "pseudo-dura" thus formed over the brain, and restore optical clarity without apparent impairment of the animal's neurological status. This type of "calvarium overhaul" was carried out twice in one animal with good results lasting for about 2 to 3 weeks on each occasion. A third operative cleaning of the sub-calvarium space resulted in considerable pial hemorrhages, and the preparation was considered to be no longer useful. Infection of the surrounding tissues as well as bacterial meningitis was seen in two of the animals as an acute postoperative complication. One of these two monkeys succumbed to this infection while the other made a good recovery and was subsequently used in a series of experiments lasting 3 months. Delayed infections were not seen in this small series of animals. The only other postoperative compli-
cation of significance was a slight degree of scratch mark impairment of the Lexan surface due to frequent bumping of the anesthetic calvarial surface against the cage walls. All of these animals were segregated from normal animals and maintained in individual cages.

Further studies using this method for recording the quantitative nature of brain movements as well as the effects of whiplash injury, electroconvulsive shock, alterations in cerebrovascular dynamics, and intracranial pressure changes are underway and will be reported in future articles. The possibility of high-power microscopic observation of cortical structures under tangential illumination is also being investigated. It is hoped that this method will encourage other investigators to consider various potential uses of a transparent calvarium in suitable animals for a variety of physio-pathological problems.

Summary

An improved method for processing a transparent Lexan calvarium for Rhesus monkeys has been realized. Better materials and methods have shortened the procedure from 5 days to a single-stage 6-hour operation. These features mean decreased trauma to the animal and greater impact resistance as well as optical clarity and precise fit.

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References