Profound Hypothermia in Neurosurgery: Open-Chest Versus Closed-Chest Techniques

John D. Michenfelder, M.D., Howard R. Terry, Jr., M.D., Edward F. Daw, M.D., Collin S. MacCarty, M.D., Alfred Uihlein, M.D.

SINCE March 1960, profound hypothermia and total circulatory arrest have been utilized at the Mayo Clinic in selected cases for the surgical repair of intracranial aneurysms. Up to December 1961, 18 operations had been done with the use of Drew's open-chest technique for hypothermia.[1-5] Between December 1961 and August 1962, 18 additional procedures were done with a closed-chest technique.[6,7]

In view of the existence of comparable series (18 cases each), this seemed an appropriate time to compare the open- and closed-chest techniques in an attempt to determine which, if either, is the better method for obtaining the desired goal of deep hypothermia and total circulatory arrest.

Anesthetic Management

The anesthetic problems presented by both techniques are similar, and although differences do exist, they are minor. Premedication as a routine procedure has been avoided in both groups for fear of prolonging into the postoperative period any depression resulting from the delayed excretion of drugs during deep hypothermia. For similar reasons, induction of anesthesia has been limited in both groups to short-acting, rapidly dissipated agents; in six cases this has been accomplished with methohexital (Brevital) 100 mg., and in the remaining 30 cases induction was accomplished with halothane (Fluothane) or cyclopropane. Succinylcholine (60 mg.) was used in each instance to facilitate intubation.

Accepted for publication December 3, 1962. Drs. Michenfelder, Terry, and Daw are in the Section of Anesthesiology, and Drs. MacCarty and Uihlein are in the Section of Neurologic Surgery, Mayo Clinic and Mayo Foundation, Rochester, Minnesota. This paper was presented at the Annual Meeting of the American Society of Anesthesiologists, Inc., New York, New York, October 26, 1962.

Maintenance of anesthesia in both groups was accomplished with halothane, 0.5 to 1.0 per cent; nitrous oxide, 3 liters minute; and oxygen, 2 liters minute. All of the patients' lungs were intentionally hyperventilated with use of a Bird Mark IV anesthesia assistor-controller and Mark VIII respirator with positive-negative pressure phasing at a rate of 16 to 20 per minute. This differed somewhat in the open-chest group in that manual hyperventilation was utilized while the heart was being cannulated and during the perfusion.

In both groups a Therm-O-Rite blanket was placed beneath the patient, although it served somewhat different purposes: in the open-chest group, primarily to minimize the downward temperature drift following rewarming; in the closed-chest group, primarily for cooling the patients to 30° to 32° C. before perfusion and secondarily to minimize temperature drift after rewarming. This variation in procedure reflects the significantly longer cooling times that prevail with the closed-chest technique.

Monitory differed somewhat in the two groups. A blood pressure cuff, an esophageal stethoscope, and thermistors placed in the esophagus and nasopharynx were considered adequate for the open-chest group since visual monitoring of the heart was possible and was of sufficient accuracy for clinical appraisal of the cardiac status. In the closed-chest group, visual monitoring was replaced by the procedure of taking central venous pressure from a catheter threaded into the superior vena cava via an antecubital vein and arterial pressure from a needle placed in the radial artery by way of a cutdown; the electrocardiogram was monitored continuously on an oscilloscope. In none of the cases did complications result from the monitoring procedure.

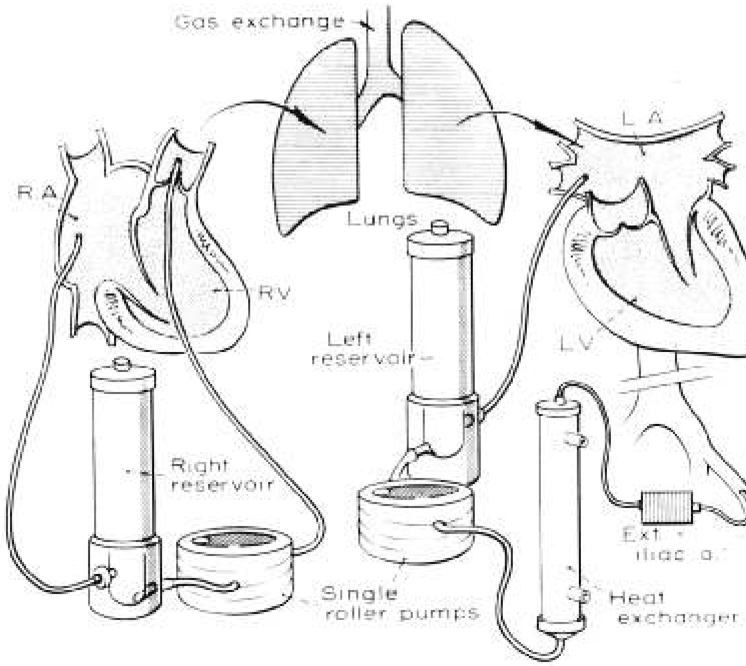

FIG. 1. Circuitry of open-chest perfusion.

Perfusion Technique

In both series the conduct of the perfusion was the responsibility of the anesthesiologist; in the closed-chest method this was accomplished with the help of a technician. Since the two techniques differ in every way, except in that they both permit lowering of body temperature to 15° C., they will be described separately.

Open Chest (Drew). Basically, this method bypasses both the right and left sides of the heart, and it utilizes the patients's lungs as the oxygenator (fig. 1). The volume required for priming the apparatus and for transfusing during perfusion is 3,500 ml.; this permits flow rates of 2.0 to 2.5 liters per minute per square meter of body surface area. The perfusate was freshly drawn, heparinized blood. Four cannulas are used with this technique—one through an incision in each atrium, one placed in the pulmonary outflow tract through an incision in the right ventricle, and one in the external iliac artery; this requires a median sternotomy incision and total heparinization (90 mg./m.²).

Initially, only the left heart is bypassed, and cooling is instituted by maintaining the blood that leaves the heat exchanger at a temperature that is 12° C. cooler than the patient's esophageal temperature. As soon as the heart beat becomes ineffective (28° to 30° C.), right-heart bypass is instituted, and cooling progresses with constant flow rates of 2.0 to 2.5 liters/minute/m.² until body temperature is lowered to about 15° C. At this point, either low flows of 0.6 to 1.0 liters/minute/m.² or circulatory arrest may be established for the duration required by the neurosurgeon; during this time blood is taken from the patient (about 1,000 to 1,500 ml.) to improve exposure and reduce static bleeding. Rewarming is accomplished in reverse order of the cooling process, with maintenance again of a gradient of 12° C. between the temperature of the blood leaving the heat exchanger and the temperature of the esophagus. When patient's temperature reaches 30° to 32° C., the heart is defibrillated internally and then taken off right bypass. When the temperature reaches 37° to 38° C., left-heart bypass is discontinued, the cannulas are removed, and the effect of the heparin is reversed with administration of hexadimethrine (Polybrene) (135 mg./m.²).

Closed Chest. This technique involves peripheral cannulation with bypass through a pump-oxygenator and, depending on the patient's temperature, functions as either a partial or a total bypass system (fig. 2). The pump-oxygenator is a small Mayo-Gibbon type[5] which incorporates a Brown-Emmons heat exchanger. The volume required for priming and transfusing during the perfusion is 3,000 ml. The perfusate consists of 1,500 ml. of citrated bank blood to which is added 45 mg. of heparin and 1,500 mg. of calcium chloride, and 1,500 ml. of 5 per cent dextrose in water to which is added 240 ml. of serum albumin. The flow rates during the perfusion have ranged from 1.3 to 1.7 liters/minute/m.[2] Three cannulas are used with this technique, one in each common femoral vein and one in a common femoral artery. One venous cannula is passed to the level of the diaphragm if possible.

The patients are cooled to 30° to 32° C. prior to perfusion. Following heparinization, the cannulas are inserted and perfusion is instituted with flows gradually increased to about 1.4 liters/minute/m.[2] Cooling is accomplished by maintaining a gradient of 12° C. between the temperature of the blood leaving the heat exchanger and the temperature of the esophagus. Initially, this is a partial bypass system with the heart contributing to the total-body perfusion; the part played by the heart is essential to the safety of the technique, since a flow rate of 1.4 liters/minute/m.[2] would of itself be inadequate at temperatures above 28° C. At temperatures below 28° C. the heart becomes ineffective and usually fibrillates, at which point total-body perfusion is being provided by the pump-oxygenator. During cooling, 7 per cent carbon dioxide is metered into both the lungs and the oxygenator in order to provide cerebral vasodilatation and thereby hasten cooling of the brain. Ventilation of the lungs is discontinued as soon as the heart beat becomes ineffective. When the nasopharyngeal temperature reaches 15° C., low flows of 0.6 to 1.0 liters/minute/m.[2] or circulatory arrest may be established as with the open-chest technique, and during this time blood is taken from the patient (1,000 to 1,500 ml.) to improve exposure and reduce static bleeding. Rewarming is accomplished with the same flow rates (1.3 to 1.7 liters/minute/m.[2]) and

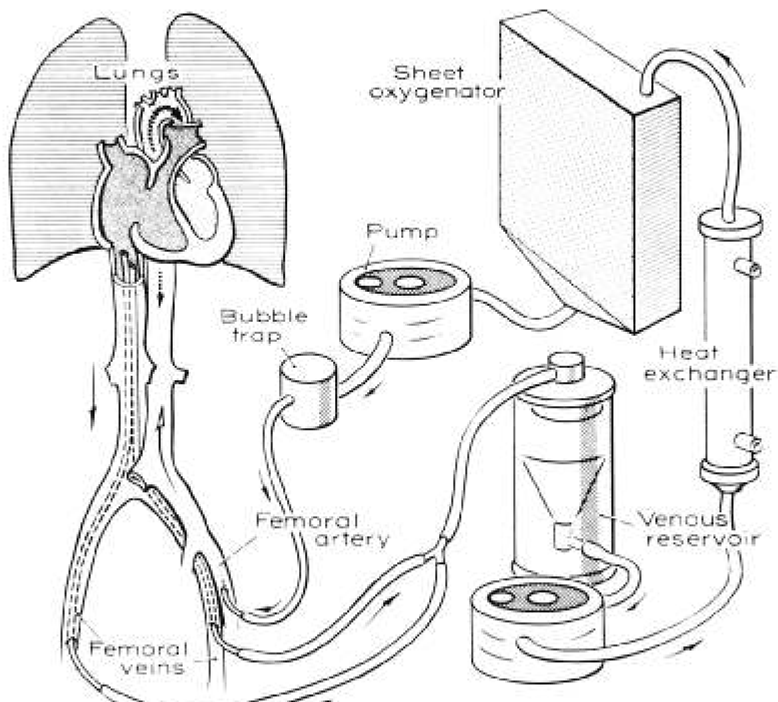

FIG. 2. Circuitry of closed-chest perfusion.

TABLE 1. Comparative Perfusion Data

	Open Chest		Closed Chest	
	Range	Mean	Range	Mean
Flow rates, l./min./m.²	2.0–2.5	2.2	1.3–1.7	1.4
Cooling time, minutes	13–28	18	18–72	41
Warming time, minutes	13–30	21	26–71	43
Low flows (0.6–1.4 l./min./m.²), minutes	0–90	9	0–53	12
Arrest time, minutes	0–44	16	0–39	20

a temperature gradient of 12° C. When esophageal temperature reaches 26° to 28° C., the heart is defibrillated externally according to the technique of Kouwenhoven and his associates[9] with a Morris external defibrillator. Once the heart is defibrillated, the system again becomes a partial bypass system. Rewarming is continued until body temperature reaches 32° to 34° C., at which point the cannulas are removed and hexadimethrine (Polybrene) is administered. Rewarming is then continued with the Therm-O-Rite blankets.

Comment. The outstanding difference in the two techniques is the overall simplification of the closed-chest method, which does away with median sternotomy. The price paid for this simplification has been in terms of flow rates, which are reduced to almost half of those used with the open-chest method. For this reason both the cooling and the rewarming times are approximately double those of the open-chest method (table 1); this is not thought to be a critical factor and is therefore

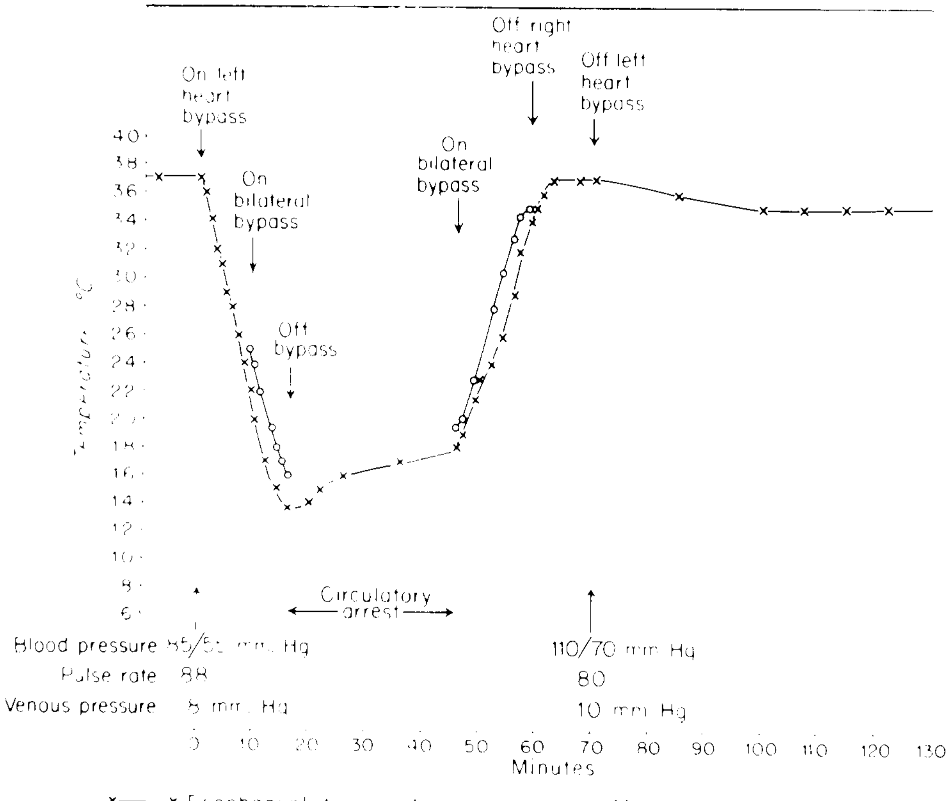

FIG. 3. Temperature graph: open-chest technique (in a case of aneurysm of anterior communicating artery).

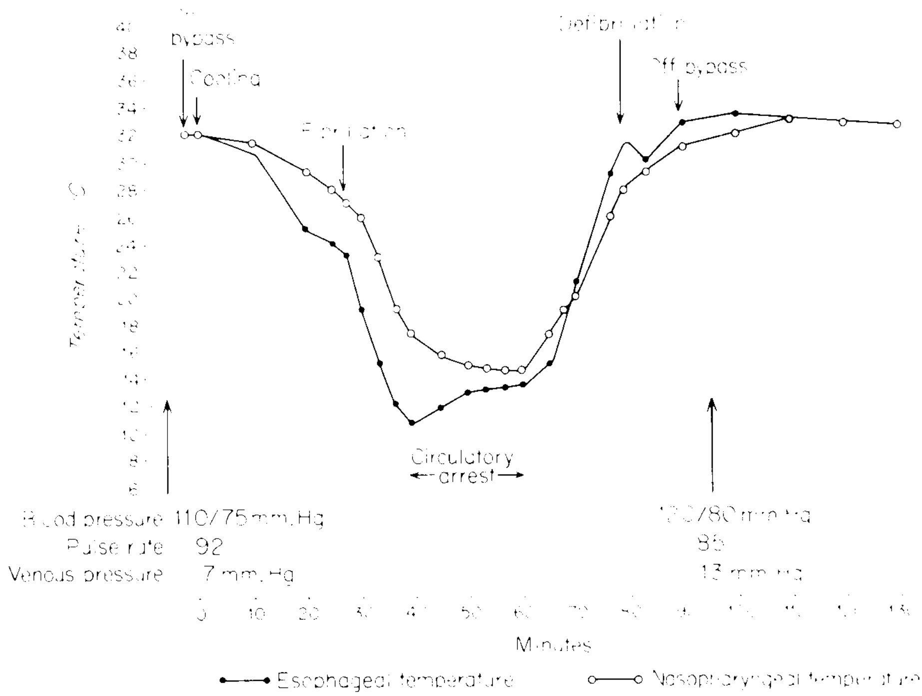

FIG. 4. Temperature graph: closed-chest technique (in a case of aneurysm of posterior communicating artery).

not a significant disadvantage. The progress of cooling and rewarming with each method is graphically demonstrated in figures 3 and 4. It is of interest to note the increase in rate of cooling seen in the closed-chest method after the heart fibrillates. Apparently the output of the heart resists the retrograde flow of the cold blood to the upper half of the body, and, when fibrillation occurs, the loss of this resistance is reflected by a sharp increase in the cooling rate. This can be confirmed by monitoring rectal temperature, which drops precipitously, often reading 10° to 12° C. lower than the nasopharyngeal temperature prior to fibrillation. Temperature drift during arrest and after rewarming is seen with each method, but it is greater with the open-chest technique. This probably is the result of the more rapid cooling and warming, which results in larger temperature gradients between the various body tissues. This drift has been in the range of 2° to 5° C. in the open-chest group and 1° to 3° C. in the closed-chest group.

The use of a dilute perfusate in the closed-chest method has reduced the amount of blood needed in these cases and has possibly improved the perfusion by decreasing viscosity and reducing the aggregation of red blood cells.[10, 11] It is reasonable to assume that a dilute perfusate could also be used with the open-chest method, but at the time that method was being utilized the advantages of such a system had not been appreciated. Likewise, the need for fresh heparinized blood rather than citrated blood in the open-chest technique is questionable.[12] The use of 7 per cent carbon dioxide for cerebral vasodilatation is based on recent experimental work[13] and would be equally applicable to the open-chest technique. The need for an artificial oxygenator in the closed-chest method might be considered a disadvantage in terms of trauma to red blood cells, but this is minimal and

TABLE 2. Comparative Clinical Data

	Open Chest	Closed Chest
Mortality rate	27.7%	16.6%
Preoperative neurologic "score"* total	15	23
Postoperative neurologic "score"* total	36	30
Arrest plus low flow times, mean in minutes	25	32
Last episode of bleeding, median in days	37.5	25
Age, mean in years	41.6	42.6

* Scoring system described in text

probably of little significance. The dependence on external defibrillation with the closed-chest technique was a matter of some concern initially; however, the results have so far been encouraging. In each group, two of the 18 hearts defibrillated spontaneously; one in each group required multiple shocks before defibrillation was accomplished, and the remaining 30 defibrillated with ease whether the method was internal or external.

The closed-chest technique carries with it several contraindications to its use and has one potential hazard. The contraindications include patent ductus, coarctation of the aorta, and aortic insufficiency. In the presence of such conditions, retrograde aortic flow with this technique would be hazardous or impossible. The potential hazard is that of pulmonary vascular damage. This could develop after fibrillation as a result of persistent bronchial blood flow, some of which is returned to the left atrium; if such blood flow is of sufficient volume, it could result in high left atrial pressures with subsequent increase in pulmonary venous pressure and irreversible damage with pulmonary edema. In the 18 cases in which the closed-chest procedure was used, no such complications occurred; it is none the less a source of some concern and militates against the use of prolonged periods of low flow prior to circulatory arrest. For the same reason early defibrillation during rewarming is considered advisable.

Results

In attempting to evaluate the results in these two groups and thereby draw definite conclusions regarding which is the better method, many difficulties are encountered. These difficulties are compounded by the relatively small number of cases compared. Such important considerations as surgical experience, preoperative condition of the patient, location of the aneurysm, and type of aneurysm all have an important bearing on the outcome; yet, for none of these factors can numbers be applied and direct comparisons made. For this reason, indirect comparisons are necessary, and it is hoped that they will at least indicate which, if either, is the better technique.

Table 2 represents an attempt at making such indirect comparisons. The overall mortality rates favor the closed-chest group, in which there were three deaths as compared with five in the open-chest group. Because of the small series involved, this difference was not statistically significant. One death (open method) occurred in a patient with an arteriovenous anomaly who died from uncontrolled hemorrhage; this is the only nonaneurysmal case in the series and therefore cannot be compared with the other cases. Another death (closed method) occurred in a patient with infarction of the basal ganglia and internal capsule prior to operation; in retrospect this was an inoperable case. A third death (open method) was the result of postoperative pneumonia in a patient who was otherwise doing well. A fourth death (closed method) was the result of a postoperative bleeding ulcer. The remaining four deaths resulted from postoperative cerebral edema, postoperative bleeding, or cerebral infarction—complications which are common to all intracranial procedures. With the exception of the death resulting from pneumonia, which was probably a complication of median sternotomy, none of these was thought to be due to the hypothermic technique itself.

In an attempt to evaluate morbidity as well as mortality, a neurologic scoring system was devised in order to compare both the preoperative and the postoperative status of the patients in each series (table 3). This differs somewhat from a previous classification proposed by Botterell and his associates.[14]

This system is based on a 0 to 5 scale wherein the absence of any neurologic deficit warranted a 0 score, minimal deficit (for example, third nerve palsy) was scored as 1, significant deficit without mental alteration (for example, hemiparesis) was scored as 2, mental alteration (confusion, lethargy, and the like) as 3, coma 4, and death 5. With this system the total preoperative score in the open-chest group was 15, and in the closed-chest group, 23. Postoperatively, the total scores were 36 for the open-group as compared with 30 for the closed group. This suggests that the overall preoperative neurologic status of the closed-chest group was worse than that of the open group, yet their overall postoperative status was better. This is, as we indicated, an indirect and artificial comparison, and the postoperative scores are heavily weighted by the deaths.

A third comparison can be based on the length of time required to repair the aneurysm; this involves the assumption that the more time that was required, the more difficult was the procedure. Since the definitive surgical procedure is accomplished during the periods of low flow and circulatory arrest, these times can be compared. For the open-chest group the average time was 25 minutes, and in the closed-chest group it was 32 minutes. Again, this suggests that there were more difficult cases in the closed-chest group, with overall better results.

Finally, one can compare the time that elapsed between the last hemorrhage from the aneurysm and the day of operation. There is general agreement that the longer this period, the less the surgical risk; obviously, there must be a time after which the risk does not alter to any significant degree. It has been suggested in other reports[14, 15] that 14 days is the critical time, after which the risk remains about the same. In the open-chest group the median time which elapsed was $37\frac{1}{2}$ days, and in only one patient was the time less than 14 days. In the closed-chest group the median time was 25 days, and in six patients the time elapsed was less than 14 days. This again indicates a bigger risk factor in the closed-chest group.

Comment

From the clinical results it is reasonable to conclude that the closed-chest method is at least as good as and perhaps better than the open-chest method.

TABLE 3. Preoperative and Postoperative Neurologic Status

Neurologic Status	Score	Open Chest: Preoperative, Patients	Open Chest: Postoperative, Patients	Closed Chest: Preoperative, Patients	Closed Chest: Postoperative, Patients
No deficit	0	8	5	8	7
Minimal deficit	1	6	6	4	4
Significant deficit	2	3	1	0	1
Mental alteration	3	1	1	5	3
Coma	4	0	0	1	0
Death	5		5		3

Scoring system described in text.

In comparing the two techniques without consideration of clinical results, the closed-chest method must be considered the preferred technique. This is so primarily because it does away with the need for opening the chest and thereby greatly simplifies the entire procedure. This is reflected in the amount of blood required by each method; the average amount in the open group was 10,000 ml. as compared with 3,900 ml. in the closed group. Because of this simplification and because less blood need be made available, operation can be scheduled at a much earlier date, thus reducing the potential hazard of fatal bleeding while the patient awaits operation; such was the outcome in two patients during the time the open-chest technique was in use. It is hoped that, in the near future, operation by the closed-chest technique can be carried out within 24 hours after the diagnosis is made.

One further advantage offered by the closed-chest method is its overall adaptability. This method could easily be utilized in both abdominal and thoracic operations if the indications for hypothermia and prolonged total circulatory arrest should arise in these regions.

Summary and Conclusion

Profound hypothermia and total circulatory arrest have been applied by two different techniques to 36 patients of which all but one had intracranial aneurysms. Eighteen of these patients were managed with Drew's open-chest technique and 18 with a closed-chest method. The overall simplification permitted by the closed-chest technique, which

does away with the need for median sternotomy and cannulation of the heart, heavily favors this as the method of choice. The clinical results suggest that the closed-chest method carries with it no more, and possibly less, hazard than does the open-chest technique.

We are indebted to the members of the sections of neurosurgery and cardiovascular surgery, in particular Dr. John W. Kirklin, for their cooperation in the collection of the material presented in this paper.

References

1. Drew, C. E.: Profound hypothermia in cardiac surgery, Brit. Med. Bull. **17**: 37, 1961.
2. MacCarty, C. S., Kirklin, J. W., and Uihlein, A.: The application of profound hypothermia to the treatment of cerebrovascular disorders, Res. Publ. Ass. Res. Nerv. Ment. Dis., in press.
3. Terry, H. R., Jr., Daw, E. F., and Michenfelder, J. D.: Hypothermia by extracorporeal circulation for neurosurgery: an anesthetic technic, Anesth. Analg. **41**: 241, 1962.
4. Daw, E. F., Terry, H. R., Jr., Dawson, B. and Uihlein, A.: Repair of an intracranial aneurysm using total body perfusion and profound hypothermia: report of a case, Anesth. Analg. **39**: 518, 1960.
5. Uihlein, A., Terry, H. R., Jr., Payne, W. S., and Kirklin, J. W.: Operations on intracranial aneurysms with induced hypothermia below 15° C. and total circulatory arrest, J. Neurosurg., **19**: 237, 1962.
6. Michenfelder, J. D., Kirklin, J. W., Uihlein, Alfred S., H. J., and MacCarty, C. S.: Clinical experience with a closed-chest method of producing profound hypothermia and total circulatory arrest in neurosurgery, unpublished data.
7. Patterson, R. H., and Ray, B. S.: Profound hypothermia for intracranial surgery: laboratory and clinical experiences with extracorporeal circulation by peripheral cannulation, Ann. Surg. **156**: 377, 1962.
8. Moffitt, E. A., and Theye, R. A.: The Mayo-Gibbon pump-oxygenator. *In* Keown, K. K.: Anesthesia for Surgery of the Heart, Springfield, Ill., Charles C Thomas, Publisher, in press.
9. Kouwenhoven, W. B., Milnor, W. R., Knickerbocker, G. G., and Chesnut, W. R.: Closed chest defibrillation of the heart, Surgery **42**: 550, 1957.
10. Long, D. M., Jr., Sanchez, L., Varco, R. L., and Lillehei, C. W.: The use of low molecular weight dextran and serum albumin as plasma expanders in extracorporeal circulation, Surgery **50**: 12, 1961.
11. Greer, A. E., Carey, J. M., and Zuhdi, N.: Hemodilution principle of hypothermic perfusion: a concept obviating blood priming, J. Thor. Cardiov. Surg. **43**: 640, 1962.
12. Foote, A. V., Trede, Michael, and Maloney, J. V., Jr.: An Experimental and Clinical Study of the Use of Acid-Citrate-Dextrose (ACD) Blood for Extracorporeal Circulation. J. Thor. Cardiov. Surg. **42**: 93, 1961.
13. Payne, W. S., Theye, R. A., and Kirklin, J. W.: Effect of Carbon Dioxide on Rate of Brain Cooling During Induction of Hypothermia by Direct Blood Cooling, J. Surg. Res., in press.
14. Botterell, E. H., Lougheed, W. M., Scott, J. W., and Vandewater, S. L.: Hypothermia, and interruption of carotid, or carotid and vertebral circulation, in the surgical management of intracranial aneurysms, J. Neurosurg. **13**: 1, 1956.
15. Karlsberg, Paul, and Adams, J. E.: Value of hypothermia and arterial occlusion in the treatment of intracranial aneurysms, J. Neurosurg. **19**: 665, 1962.

HYPERTONIC UREA Hypertonic urea in doses of 0.5 to 1.5 g./kg. of body weight given intravenously in 30 minutes to three hours was superior to other drugs for decreasing brain size. In some cases preoperative ventricular tap was omitted when urea was to be given. Intraventricular pressure was reduced after one hour to almost zero; the speed of infusion determining the speed of ventricular pressure fall. Headache resulted from intracranial hypotension in some patients and bleeding may be increased following brain injury. For administration, large veins should be chosen because of danger of thrombosis and perivenous injection must be avoided because of necrosis. Patients must have good renal function, and caution should be observed in patients with liver and heart disease. (*Wenker, H.: Hirndrucksenkung und Minderung des Hirnvolumens durch Intravenose Infusion Hypertoner Harrstofflosungen, Chirurg. 33: 389 (Sept.) 1962.*)