Deep Hypothermic Circulatory Arrest: I. Effects of Cooling on Electroencephalogram and Evoked Potentials

Mark M. Stecker, MD, PhD, Albert T. Cheung, MD, Alberto Pochettino, MD, Glenn P. Kent, BS, Terry Patterson, PhD, Stuart J. Weiss, MD, PhD, and Joseph E. Bavaria, MD

Departments of Neurology and Anesthesia, and Division of Cardiothoracic Surgery, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania

Background. Deep hypothermia is an important cerebral protectant and is critical in procedures requiring circulatory arrest. The purpose of this study was to determine the factors that influence the neurophysiologic changes during cooling before circulatory arrest, in particular the occurrence of electrocerebral silence.

Methods. In 109 patients undergoing hypothermic circulatory arrest with neurophysiologic monitoring, five electrophysiologic events were selected for detailed study.

Results. The mean nasopharyngeal temperature when periodic complexes appeared in the electroencephalogram after cooling was 29.6°C ± 3°C, electroencephalogram burst-suppression appeared at 24.4°C ± 4°C, and electrocerebral silence appeared at 17.8°C ± 4°C. The N20-P22 complex of the somatosensory evoked response disappeared at 21.4°C ± 4°C, and the somatosensory evoked response N13 wave disappeared at 17.3°C ± 4°C. The temperatures of these various events were not significantly affected by any patient-specific or surgical variables, although the time to cool to electrocerebral silence was prolonged by high hemoglobin concentrations, low arterial partial pressure of carbon dioxide, and by slow cooling rates. Only 60% of patients demonstrated electrocerebral silence by either a nasopharyngeal temperature of 18°C or a cooling time of 30 minutes.

Conclusions. With the high degree of interpatient variability in these neurophysiologic measures, the only absolute predictors of electrocerebral silence were nasopharyngeal temperature below 12.5°C and cooling longer than 50 minutes.


The most important cerebral protective measure used during procedures requiring circulatory arrest is deep hypothermia [1]. Therefore, the selection of an optimal temperature for circulatory arrest is critical. A circulatory arrest temperature that is too high [2] may predispose to cerebral ischemia. A circulatory arrest temperature that is too low prolongs the periods of cooling and rewarming and hence the time on cardiopulmonary bypass (CPB) and its associated risks [3]. In addition, extremely low temperatures may produce brain injury [4–7] as a result of the formation of intracellular ice crystals or denaturation of proteins [8]. At the present time, there is no agreement on the best temperature for the safe conduct of circulatory arrest [9–18] as indicated by the different protocols summarized in Table 1. Some authors use strict criteria based on nasopharyngeal and central temperature measurements. These measurements do not necessarily provide a reliable indicator of brain temperature [19], especially in the presence of cerebrovascular disease. For this reason, other investigators have used a physiologic measure such as electrocerebral silence (ECS) on electroencephalogram (EEG) to determine the best temperature for circulatory arrest.

A detailed understanding of the temperature-related changes in EEG and evoked potential (EP) studies during cooling for deep hypothermia is important for two reasons. First, it can provide additional information on the relationship between the different criteria used to determine the best temperature for circulatory arrest. Second, it is important for interpreting the data provided by intraoperative neurophysiologic monitoring used to detect cerebral ischemia. With the initiation of CPB and the onset of ventricular fibrillation during cooling, there are changes in aortic flow patterns that, in the setting of a dissection, could result in perfusion of only the false lumen or cause a flap to occlude one of the great vessels, with subsequent cerebral ischemia. It is therefore important to understand the normal neurophysiologic changes associated with cooling on CPB to differentiate these changes from those caused by cerebral ischemia.

The first purpose of this article is to describe the time course of EEG and EP changes during cooling before circulatory arrest. The second purpose is to determine whether specific patient and surgical factors influence the time course of neurophysiologic events during cooling on CPB.
Table 1. Published Criteria for Determining the Temperature for Circulatory Arrest

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Criterion for Circulatory Arrest</th>
<th>Retrograde Cerebral Perfusion</th>
<th>Patients</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newberger et al [9]</td>
<td>1993</td>
<td>Rectal temp 18°C</td>
<td>No</td>
<td>Children</td>
<td>18% neurologic deficits</td>
</tr>
<tr>
<td>Coselli et al [12]</td>
<td>1989</td>
<td>Rectal temp 2°C below temp at which EEG becomes isoelectric for 3 min</td>
<td>No</td>
<td>Adults</td>
<td>9% neurologic deficits</td>
</tr>
<tr>
<td>Lin et al [13]</td>
<td>1996</td>
<td>Rectal temp 21°–25°C</td>
<td>Yes</td>
<td>Adults</td>
<td>0% neurologic deficits</td>
</tr>
<tr>
<td>Ganzel et al [14]</td>
<td>1997</td>
<td>Electrocerebral silence on EEG</td>
<td>Yes</td>
<td>Adults</td>
<td>10% neurologic complications</td>
</tr>
<tr>
<td>Kouchoukos et al [15]</td>
<td>1995</td>
<td>Nasopharyngeal temp 12°–14°C and rectal or bladder temp 15°–19°C</td>
<td>No</td>
<td>Adults</td>
<td>4.3% stroke</td>
</tr>
<tr>
<td>Kitamura et al [16]</td>
<td>1995</td>
<td>Temp 18°–20°C (site unspecified)</td>
<td>Yes (some)</td>
<td>Adults</td>
<td>4% (all groups combined)</td>
</tr>
<tr>
<td>Thorion et al [17]</td>
<td>1982</td>
<td>Nasopharyngeal temp 16°–20°C (minimum 20 minutes of cooling, gradient between NP and blood temperature is kept &lt; 8°C)</td>
<td>No</td>
<td>Children</td>
<td>6.9% (seizures, psychosis, slow to wake)</td>
</tr>
</tbody>
</table>

EEG = electroencephalogram; Temp = temperature.

Material and Methods

Patient Population

Data from 109 consecutive patients undergoing thoracic aortic surgical procedures requiring circulatory arrest at the Hospital of the University of Pennsylvania from January 1995 to December 1998 with EEG or EP monitoring were prospectively entered into a database in accordance with a protocol approved by the Institutional Review Board.

Patient age, sex, and body surface area (BSA) were recorded. When carotid ultrasonography was performed preoperatively, the degree of stenosis in the most affected carotid artery was recorded. The following surgical variables were also examined: whether the arterial cannulation site was aortic or femoral, the hemoglobin concentration at the time of circulatory arrest, the arterial carbon dioxide tension during cooling using alpha-stat management, the maximum isoflurane concentration during cooling, and the mean CPB flow rate during cooling. Although the rate of cooling was not constant, the mean rate of cooling was estimated as follows. The time required to cool from 3°C below the nasopharyngeal temperature at the onset of CPB to a temperature 3°C above the temperature at circulatory arrest is computed. The cooling rate is the ratio of the change in temperature over this range to the time required for cooling between these two temperature points.

Surgical Procedure and Anesthesia

All patients were anesthetized with fentanyl, midazolam, isoflurane, and pancuronium. Cardiopulmonary bypass was instituted using standard bicaval venous cannulation and arterial cannulation of either the left femoral artery, ascending aorta, or aortic arch. The left ventricle was vented through the right superior pulmonary vein. Patients were cooled on CPB (model 11160 heater/cooler unit, Sarns Inc, Ann Arbor, MI) according to a standardized protocol for a minimum of 30 minutes. Cooling on CPB was initiated with a heat exchanger setting of 1 (minimum cooling) until the blood temperature reached 27°C. After ventricular fibrillation, the heat exchanger setting was increased to 4 (maximum cooling) until circulatory arrest. The water bath temperature of the heat exchanger was permitted to decrease to less than 12°C. Antegrade cerebral perfusion was not interrupted until the EEG became isoelectric (< 2 \muV for 3 minutes) and the N20-P22 component of the somatosensory evoked response had disappeared (amplitude, < 0.05 \muV) bilaterally. At that time, the patient was partially exsanguinated, the superior vena cava was snared between the right atrium and the azygous vein, and retrograde cerebral perfusion was administered. Retrograde cerebral perfusion with oxygenated blood was adjusted to maintain a right internal jugular venous pressure of 25 mm Hg with the patient in an approximately 10-degree Trendelenberg position. Retrograde cerebral perfusion was interrupted for variable periods of time during deep hypothermia as required by various surgical maneuvers. The temperature of the retrograde perfusate was maintained at 12°C. After completion of aortic arch anastomoses, air was removed from the aorta and graft by allowing it to fill by retrograde cerebral perfusion. After arch deairing, a cross-clamp was placed across the ascending aortic graft, and standard CPB with antegrade cerebral perfusion (antegrade graft perfusion) was reinstituted for the final repair and rewarming.

All patients underwent a brief neurologic examination preoperatively and a standard neurologic examination postoperatively. Patients with suspected neurologic injury underwent brain imaging by computer-assisted tomography when stable. Patients with abnormal neurologic examinations postoperatively were followed up with serial clinical examinations until neurologically stable.

Electroencephalogram and Evoked Potential Recording

Somatosensory evoked responses were monitored as described by Stecker and associates [20] with some modifications. The somatosensory stimulus consisted of 0.5-ms pulses of 25-mA intensity at the beginning of each
case. From the initiation of cooling before circulatory arrest until the recovery of the evoked responses after antegrade cerebral perfusion, the stimulus current was increased to levels as high as 100 mA to ensure adequate stimulation at low temperatures [21]. The P22 cortical response, the N20 thalamic response, and the N13 response that arises from the cervicomedullary junction were identified [20]. Although the N20-P22 complex was present in all 106 patients undergoing EP monitoring, only 67 recordings in neurologically normal patients (patients without preoperative strokes, intraoperative strokes or postoperative confusion) were available for analysis. The N13 waveform was more difficult to reliably identify than the N20-P22 complex, and thus reliable serial recording of N13 throughout the process of cooling and rewarming was possible in only 34 neurologically normal patients.

Two discrete events were noted in the EP waveforms during cooling. The first event was the disappearance of the N20-P22 complex, and the second event was the disappearance of the N13 potential. The time elapsed from initiation of cooling to the disappearance of the N20-P22 complex was designated $T^{D}_{N20}$ and $NT^{D}_{N20}$ and CT$^{D}_{N20}$ were the nasopharyngeal and central (rectal or bladder) temperatures, respectively, at this time. In all cases, the N20-P22 complex disappeared before circulatory arrest. The N13 potential was observed to disappear in only 19 of 34 patients in whom well-formed N13 responses were recorded [22]. In the remaining 15 patients, the N13 potential was detectable at the time of circulatory arrest. The time at which N13 disappeared during cooling and the nasopharyngeal and rectal temperatures at that time were labeled $T^{D}_{N13}$, $NT^{D}_{N13}$, and CT$^{D}_{N13}$, respectively. Only data from patients in which the N13 did vanish before circulatory arrest were analyzed.

All EEG data reported in this article were recorded using a 16-channel Electroencephalograph using gold cup electrodes placed on the scalp with collodion. In some emergent cases in this series, EEG monitoring was limited to two channels. Electroencephalogram data from these cases were not analyzed because of limitations in interpretation of such tracings. The advantage of the 16-channel recordings is that they allow the electroencephalographer to easily identify artifacts, especially those caused by the electrocardiogram and the roller pump, and hence they provide a much more accurate estimate of when the various EEG landmarks occur.

Three specific electroencephalographic events were identified during cooling. The first event was the appearance of either unilateral or bilateral periodic complexes (Fig 1) in the EEG. The elapsed time between the initiation of cooling and the appearance of periodic discharges, $T_{PED}$ occurs at a nasopharyngeal temperature designated $NT_{PED}$ and a central temperature, $CT_{PED}$. With further cooling, burst suppression appeared after a time interval, $T_{BS}$ at a nasopharyngeal temperature of $NT_{BS}$ and central temperature, $CT_{BS}$. The final event during cooling was the occurrence of ECS, which was defined as the absence of electrocerebral activity of more than 2 $\mu$V for at least 3 minutes on the 16-channel EEG. The time from the onset of cooling to ECS was called $T_{ECS}$. The nasopharyngeal and central temperatures at the onset of ECS were called $NT_{ECS}$ and $CT_{ECS}$ respectively.

Statistics

Analysis of variance (Statistica, Statsoft, Tulsa, OK) was used to test for differences between the measured variables in three groups of patients: neurologically normal patients, patients with preoperative strokes, and patients with postoperative neurologic impairment.

A Spearman rank correlation analysis was used to determine which factors affected the EEG and EP events during cooling. Because of the use of multiple comparisons in the univariable analyses, statistical significance was taken as $p$ less than 0.005, although a relationship was considered a significant trend when $p$ was less than 0.02. Factors with a $p$ value less than 0.2 in this analysis were selected for entry into a stepwise multiple linear regression analysis to determine whether any of the associations seen in the univariable analysis remained significant in the multivariable analysis. The $F$ value to enter the regression was chosen as 2.0.

Results

Demographics

A total of 109 patients underwent circulatory arrest with deep hypothermia and were monitored with either EEG, EP, or both. Sixty-one were men and 48 were women. The mean age of the patients was 64.9 years. A total of 18 (16.5%) patients had preoperative strokes, 9 (7.3%) had intraoperative strokes, and 27 (25%) had postoperative confusion. Table 2 contains a detailed breakdown of the various patient-related and surgical factors in the neurologically normal patients, the patients with preoperative strokes, and the patients who suffered either intraoperative stroke or postoperative confusion. The only statistical trend was a tendency for longer circulatory arrest time in the patients with intraoperative strokes or postoperative confusion ($p = 0.006$). This relationship will be further explored in the accompanying article [25].

Electroencephalogram During Cooling

A total of 47 patients who were neurologically normal both preoperatively and postoperatively underwent high-quality 16-channel EEG monitoring. In these patients, a predictable series of events occurred on the EEG [11, 12] (Fig 1D–G; Table 3). In 29 patients (60%), periodic complexes appeared on the background of continuous EEG activity between 2 and 15 minutes (mean, 7.9 minutes) after the start of cooling at nasopharyngeal temperatures ranging from 21.5°C to 34.2°C (mean, 29.6°C ± 3°C). These periodic complexes could be either unilateral or bilateral and were often asynchronous. This phase was followed by a reduction in the amplitude of the background electrical activity and the appearance of burst suppression. Burst suppression appeared in all patients between 2 and 28 minutes (mean, 12.7 ± 6 minutes) after the start of cooling, with nasopharyngeal temperatures ranging from 15.7°C to 33.0°C (mean, 24.4°C ± 4°C). This was followed by ECS, which occurred between 12 and 50 minutes (mean, 27.5 ± 10 minutes) after the start of
cooling, with nasopharyngeal temperatures ranging from 12.5°C to 27.2°C (mean, 17.8°C ± 4°C). The distributions of times to cool to various EEG events are displayed in Figures 1A–C. Figure 2 illustrates the cumulative proportion of patients achieving ECS as a function of time of cooling and nasopharyngeal temperature.

Prolonged time to cool to any EEG milestone predicted a prolonged time to cool to the other milestones (Spearman rank correlation test: T_{PED} versus T_{BS}, r = 0.62, p = 0.0004; T_{PED} versus T_{TECS}, r = 0.36, p = 0.056; T_{BS} versus T_{TECS}, r = 0.45, p = 0.002), although the correlation values are only moderate. Similarly, a lower temperature for one event was associated with lower temperatures for the other events (NT_{PED} versus NT_{BS}, r = 0.75, p < 0.00001; NT_{PED} versus NT_{TECS}, r = 0.31, p = 0.11; NT_{BS} versus NT_{TECS}, r = 0.48, p < 0.001).

Univariable analysis of the correlation between the patient-specific and surgical variables and the various EEG events in the group of neurologically normal patients was performed. No significant effect of age, carotid stenosis, cannulation site, isoflurane concentration, or the arterial carbon dioxide tension on the time or tempera-
ture of any of the EEG landmarks was demonstrated. Although there was a weak relationship between the time required to cool to burst suppression (T<sub>BS</sub>) and the BSA (r = 0.39; p = 0.008), flow rate (r = 0.38, p = 0.01), hemoglobin concentration (r = 0.33; p = 0.03), and cooling rate (r = -0.32; p = 0.04), only the effect of BSA persisted in the multivariable analysis, with longer cooling times in patients with larger BSA (p = 0.02; slope, 9.9°C/m<sup>2</sup>). Only the cooling rate correlated with T<sub>ECS</sub> in the univariate analysis (r = -0.46; p = 0.002). In the multivariable analysis, the time to cool to ECS (T<sub>ECS</sub>) was prolonged by increased hemoglobin concentration (p = 0.02; slope, 2.5 min · dL · mg<sup>-1</sup>), decreased nasopharyngeal cooling rate (p = 0.008; slope, -14.4 sec·°C<sup>1</sup>), and decreased arterial carbon dioxide tension during cooling (p = 0.008; slope, -0.56 min/mm Hg). There are no significant effects of any explanatory variable on the temperature of any of the EEG events. In fact, even if all explanatory variables are included, only 30% to 50% of the variance in the time of temperature of the EEG events can be explained.

The above analysis is essentially unchanged if, instead of only the neurologically normal patients, all patients with EEG monitoring were included in the analysis.

**Evoked Potentials During Cooling**

In the group of 67 patients without preoperative or postoperative strokes (Table 3), the disappearance of the N20-P22 complex (Fig 3) occurred between 4 and 41 minutes after the initiation of cooling (mean, 17.7 minutes) at a nasopharyngeal temperature between 14.5°C and 29.2°C (mean, 21.4°C). This temperature range, al-

### Table 2. Basic Demographic Data

<table>
<thead>
<tr>
<th>Factor</th>
<th>Neurologically Normal Preoperatively and Postoperatively</th>
<th>Preoperative Stroke&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Intraoperative Stroke or Postoperative Confusion&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>N 69 Mean (SD) 62.7 (14)</td>
<td>N 18 Mean (SD) 68.5 (11.4)</td>
<td>N 27 Mean (SD) 69.3 (12)</td>
</tr>
<tr>
<td>Maximum carotid stenosis (%)</td>
<td>N 32 Mean (SD) 19.2 (27.5)</td>
<td>N 6 Mean (SD) 54.8 (38.2)</td>
<td>N 8 Mean (SD) 30.6 (35)</td>
</tr>
<tr>
<td>Cannulation site (0 = aorta, 1 = femoral)</td>
<td>N 48 Mean (SD) 0.38 (0.49)</td>
<td>N 10 Mean (SD) 0.60 (0.52)</td>
<td>N 18 Mean (SD) 0.44 (0.51)</td>
</tr>
<tr>
<td>Body surface area (m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>N 68 Mean (SD) 1.96 (0.24)</td>
<td>N 18 Mean (SD) 1.86 (0.22)</td>
<td>N 27 Mean (SD) 1.9 (0.3)</td>
</tr>
<tr>
<td>Circulatory arrest time (min)</td>
<td>N 69 Mean (SD) 36.6 (11.8)</td>
<td>N 18 Mean (SD) 42.3 (10.1)</td>
<td>N 27 Mean (SD) 51.6 (21.3)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nasopharyngeal temperature at circulatory arrest (°C)</td>
<td>N 69 Mean (SD) 14.5 (1.8)</td>
<td>N 17 Mean (SD) 14.2 (2.1)</td>
<td>N 26 Mean (SD) 14.2 (2.3)</td>
</tr>
<tr>
<td>Central temperature at circulatory arrest (°C)</td>
<td>N 66 Mean (SD) 18.7 (2.6)</td>
<td>N 16 Mean (SD) 18.1 (2.6)</td>
<td>N 25 Mean (SD) 18.7 (2.6)</td>
</tr>
<tr>
<td>Hemoglobin concentration at circulatory arrest (g/dL)</td>
<td>N 67 Mean (SD) 7.8 (1.5)</td>
<td>N 18 Mean (SD) 7.0 (1.7)</td>
<td>N 27 Mean (SD) 7.6 (1.6)</td>
</tr>
<tr>
<td>PaCO&lt;sub&gt;2&lt;/sub&gt; during cooling (mm Hg)</td>
<td>N 68 Mean (SD) 43.0 (6.7)</td>
<td>N 18 Mean (SD) 39.7 (6.6)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>N 27 Mean (SD) 42.0 (8.0)</td>
</tr>
<tr>
<td>Mean bypass flow during cooling (L/min)</td>
<td>N 69 Mean (SD) 4.4 (0.7)</td>
<td>N 18 Mean (SD) 4.0 (0.79)</td>
<td>N 27 Mean (SD) 4.1 (0.66)</td>
</tr>
<tr>
<td>Maximum isoflurane concentration during cooling (%)</td>
<td>N 58 Mean (SD) 0.24 (0.26)</td>
<td>N 17 Mean (SD) 0.19 (0.21)</td>
<td>N 23 Mean (SD) 0.16 (0.21)</td>
</tr>
<tr>
<td>Cooling rate (°C/min) (nasopharyngeal)</td>
<td>N 64 Mean (SD) 0.70 (0.25)</td>
<td>N 18 Mean (SD) 0.61 (0.23)</td>
<td>N 25 Mean (SD) 0.64 (0.27)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Independent of whether or not the patient had an intraoperative stroke or postoperative confusion.  
<sup>b</sup> Independent of whether or not the patient had a preoperative stroke.  
<sup>c</sup> p = 0.006 main effect of intraoperative stroke or postoperative confusion.  
<sup>d</sup> p = 0.013 main effect of preoperative stroke.

PaCO<sub>2</sub> = arterial carbon dioxide tension; SD = standard deviation.

### Table 3. Summary of Times and Temperatures for Events During Cooling<sup>a</sup>

<table>
<thead>
<tr>
<th>Description</th>
<th>Time of Events After Cooling Bypass</th>
<th>Temperature of Events During Cooling (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic complexes appear</td>
<td>T&lt;sub&gt;PED&lt;/sub&gt;</td>
<td>Factor Mean (SD) 29.6 (3)</td>
</tr>
<tr>
<td>Burst suppression appears</td>
<td>T&lt;sub&gt;BS&lt;/sub&gt;</td>
<td>N 24.4 (4)</td>
</tr>
<tr>
<td>Onset of electrocerebral silence</td>
<td>T&lt;sub&gt;ECS&lt;/sub&gt;</td>
<td>N 17.8 (4)</td>
</tr>
<tr>
<td>Disappearance of N20-P22</td>
<td>D&lt;sup&gt;0&lt;/sup&gt;N&lt;sub&gt;20&lt;/sub&gt;</td>
<td>N 21.4 (4)</td>
</tr>
<tr>
<td>Disappearance of N13</td>
<td>D&lt;sup&gt;0&lt;/sup&gt;N&lt;sub&gt;13&lt;/sub&gt;</td>
<td>N 17.3 (4)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Includes only patients without preoperative or intraoperative strokes or postoperative confusion.

Max = maximum; Min = minimum; SD = standard deviation. For abbreviations of factors, see Material and Methods.
though large, was similar to that reported previously by other authors [26].

Univariate analysis demonstrated significant correlations only between $T^{D_{N20}}$ and BSA ($r = 0.36; p = 0.003$), and this was confirmed by multivariable analysis demonstrating a significant prolongation in $T^{D_{N20}}$ in patients with larger BSA ($p = 0.004$; slope, 12.4°C/m²). There was a strong correlation between $T^{D_{N20}}$ and $T_{ECS}$ ($r = 0.49; p < 0.0004$), although the correlation coefficient is only moderate.

Fig 2. (A) The cumulative probability of electrocerebral silence on electroencephalogram (EEG) as a function of cooling time. (B) The cumulative probability that electrocerebral silence (ECS) is not achieved for temperatures above that indicated.

Fig 3. The distribution of nasopharyngeal temperatures at which various evoked potential landmarks occur: (A) disappearance of N20-P22, and (B) disappearance of N13. Examples of typical evoked potential patterns during cooling are also shown: (C) precooling, (D) disappearance of N20-P22 and prolongation of the latency of N13, and (E) disappearance of N13. Each evoked potential trace represents the following two channels (C4’-C3’ and cervical7-Fpz).
Only weak effects of any surgical or patient-specific variables were seen on the times to cool to disappearance of N13 or the temperature at the disappearance of N13.

**Comment**

Although the clinical data from patients undergoing aortic arch reconstruction with hypothermic circulatory arrest and retrograde cerebral perfusion was complex and analysis involved a large number of patient-specific and surgery-specific factors, a number of important conclusions can be generated from this data.

The first conclusion is that the cortical and thalamic evoked responses disappeared at temperatures much higher than the temperature at which ECS occurred on the EEG. The major implication of this finding is that disappearance of the N20-P22 complex and the time to ECS, the value of the correlation was only moderate, indicating that pre-existing T_ECS. The increased time to cool to ECS in the setting of higher hemoglobin concentrations can be explained by increased blood viscosity causing reduced cerebral blood flow [24]. The increased time to cool with hypocarbia was also expected as this causes cerebral vasoconstriction, reduced cerebral blood flow, and thus a decreased cerebral cooling rate. The prolonged time to cool in patients with larger BSA could also be explained by a decreased rate of achieving thermal equilibrium in larger patients despite attempts to index CPB flow rates to body habitus.

Finally, this study cannot be used to determine the best temperature for circulatory arrest. We cannot predict whether an end point of ECS provides any better clinical outcome than cooling to a fixed temperature, but we have shown that these two end points are different. We have also demonstrated that the effect of ECS can be guaranteed only by cooling more than 50 minutes or cooling to a nasopharyngeal temperature of 12.5°C. None of the patient-specific or surgical factors examined allowed better predictions regarding the temperature of ECS.

**References**

11. Mizrahi EM, Patel VM, Crawford ES, Coselli JS, Hess KR. Hypothermic-induced electrocerebral silence, prolonged circulatory arrest, and cerebral protection during cardiovas-