Intracranial pressure monitoring with the Neurodur-P epidural sensor: a prospective study in patients with adult hydrocephalus or idiopathic intracranial hypertension

MARIA A. POCO, M.D., PH.D., FRANCISCO MARTÍNEZ-RICARTE, M.D., JUAN SAHUQUILLO, M.D., PH.D., ROBERTO LAstra, M.D., RAMÓN TORNE, M.D., AND MARIA S. ARMENGOL, R.N.

Department of Neurosurgery, Vall d’Hebron University Hospital, Institut de Recerca Vall d’Hebron, Universitat Autònoma de Barcelona, Spain

Object. Continuous intracranial pressure (ICP) monitoring using an epidural sensor is a common technique used in selected neurosurgical patients. The aim of this study was to assess the safety and accuracy of the Neurodur-P epidural sensor in the clinical setting.

Methods. The zero drift, as well as the medical and technical complications, of using the Neurodur-P sensor placed in the epidural space was evaluated in 106 patients with hydrocephalus of varying causes or with suspected intracranial hypertension.

Results. The median duration of ICP monitoring was 8 days (interquartile range [IQR] 6–12 days). In 78 (73.6%) of the 106 patients the pressure reading was recorded at sensor removal. No zero drift was observed in 28 sensors. The median drift was 0 mm Hg with an IQR of −1 to 1 mm Hg. No significant differences were found between patients monitored for ≤5 days and those monitored for >5 days (t = 5.35, p = 0.100). No correlation was found between zero drift and monitoring time (r = 0.153, p = 0.181). Of the 83 patients with a follow-up computed tomography scan, 3 showed a <1 ml collection of blood at the catheter tip. No clinical infections could be attributed to the devices. Only 1 sensor malfunctioned.

Conclusions. Continuous ICP monitoring using the Neurodur-P sensor is safe, reliable, and easy to perform. At present, using this device is the authors’ standard method for the long-term monitoring of patients with alterations in complex cerebrospinal fluid dynamics or with implanted shunts. (DOI: 10.3171/JNS/2008/108/5/0934)

KEY WORDS • epidural pressure • intracranial pressure • intracranial pressure monitoring • Neurodur-P

Continuous ICP monitoring is a common technique used in selected neurosurgical patients. In neurocritical care patients, the instruments of choice for continuous ICP monitoring are intraventricular and intraparenchymal ICP sensors. Intracranial pressure measurements obtained in the epidural space systematically overestimate the true ICP value, and consequently this method should never be used to make decisions about treatment in neurocritical care patients undergoing ICP monitoring. A less invasive method such as epidural pressure monitoring, however, is very useful in patients that may require ICP monitoring for long periods, such as some patients with suspected NPH or shunt dysfunction, those who require monitoring of ventriculostomy patency, and others in whom making a diagnosis may be difficult. In these patients a relatively un invasive method is required, because ICP monitoring may be required for >5 days or a shunt may have been implanted. Although epidural sensors may overestimate absolute ICP values, in these patients the most important information is provided by analysis of the frequency and amplitude of slow ICP waves.

In a previous study we demonstrated that epidural ICP recording is a completely valid monitoring method because the recordings obtained using this technique showed the same shape as those obtained from the subarachnoid lumbar space. Additionally, in patients with a high risk of hemorrhagic complications (because of acute liver failure, Reye syndrome, and others), some authors have proposed that epidural pressure monitoring devices should be the method of choice. Keeping the dural covering intact not only reduces the rate of hemorrhagic complications, but also minimizes the risk of infection.

In the last few years, one of the most popular epidural devices has been the LADD system (LADD Research Industries, Inc.). This system was recently discontinued and alternative systems such as those of Spiegelberg and, more
Epidural ICP monitoring with the Neurodur-P sensor

recently, Raumedic AG devices have been specifically designed for continuous ICP monitoring in the epidural space. Because of the low accuracy of pneumatic devices for monitoring pressure in the epidural compartment, at our institution we selected Raumedic devices, which include a microchip precision sensor located at the catheter tip. Raumedic devices include sensors that use the same technical principles and have been adapted for use in the brain parenchyma, in the ventricular system (Neurovent-P sensor), or in the epidural–subdural space (Neurodur-P sensor). Whereas Neurovent-P sensors have been tested in the laboratory\textsuperscript{12,28} and in a clinical trial,\textsuperscript{22} there is no clinical information available on the Neurodur-P sensor.

The aims of this study were to assess the factors leading to zero drift and to analyze the medical and technical complications of using the Neurodur-P sensor placed in the epidural space in patients with adult hydrocephalus of different causes or with suspected benign intracranial hypertension. To avoid problems associated with the initial learning curve, this study was begun 1 year after the introduction of this device at our center. We also discuss the characteristics, advantages, and disadvantages of this new monitoring system.

**Clinical Materials and Methods**

**Patient Population**

Between May 2005 and December 2006, prospective data were collected on 125 consecutive patients with hydrocephalus of varying causes or with suspected intracranial hypertension by a team with 1 year of experience of using this type of sensor. An epidural Neurodur-P sensor was used in all patients. In 19 patients (15.2\%) the dura mater was accidentally opened during sensor implantation and consequently the sensor was inserted in the subdural space. These 19 patients were excluded from the analysis. Data presented in this study are from the 106 patients in whom the sensor was implanted in the epidural space. Written informed consent was obtained from all patients or from the next of kin of patients whose cognitive impairment precluded them from understanding or signing the informed consent document.

**General Description of the Neurodur-P Probe**

The Neurodur-P probe is a silicon catheter that contains a small pressure transducer included in a titanium case located at the catheter tip. The measuring element of the Neurodur-P probe consists of a semiconductor pressure sensor with a flexible elastic silicon membrane, into which resistors have been diffused. A full Wheatstone bridge is integrated into the chip, ensuring the required measuring accuracy and independence from variations in input voltage and environmental temperature.\textsuperscript{24} The atmospheric ambient pressure acts on the upper side of the membrane through the reference pressure duct on the inside of the catheter (Fig. 1). Intracranial pressure is measured on the lower side of the sensor. Any difference between the pressure measured and the reference pressure will cause the membrane to be deformed. By means of the piezo-resistive effect, the mechanical membrane tension is converted into a change in electrical resistance proportional to the pressure (data provided by the manufacturer). The Neurodur-P pressure sensor is connected to an ICP cable, which is connected to a zero-point module (NPS-2) specific to the monitor used. This NPS-2 is used to readjust the zero point when the monitor is changed or when monitoring is temporarily interrupted.

All of the ICP sensors were connected to a Dräger monitor (Dräger Medical Systems, Inc.). To increase the definition of slow waves in ICP recordings, an advanced fifth-order hardware filter based on a Bessel low-pass filter was placed between the ICP monitor and the analog pen recorder. This device filters electrical noise and high-frequency signals, optimizing the detection and definition of slow waves without distorting the basic components of conventional ICP recordings. Intracranial pressure recordings with and without the filter were analyzed at our center (unpublished results).

**Methodology for Sensor Implantation and ICP Monitoring**

In all patients, after induction of local anesthesia, the intracranial ICP sensor was implanted parasagittally through a bur hole in the precoronal region of the left hemisphere.\textsuperscript{30,31} A 3-cm incision was made in the scalp 11 cm from the nasion and 3 cm from the midline. A 14-mm bur hole was made, followed by careful blunt dissection of the epidural space ~ 25 mm in a forward direction from the bur hole in the anterior 180° arc. The dissection of the epidural space was completed in the posterior 180° arc by ~ 10–15 mm and the sensor was introduced into the epidural space. Because the dura is sometimes firmly adhered to the inner table of the skull, especially in the elderly, it can be unintentionally opened during dissection. When this occurred, the sensor was inserted into the subdural space, applying the sensitive side of the sensor directly over the brain. The remaining steps were performed in the same manner as those for implantation in the epidural space. Care was taken to ensure that the sensitive side of the sensor was in the epidural position (the black marks on the upper part of the catheter were visible). In all patients the correct position of the sensor was checked before wound closure. The catheters were not tunneled in this series.

Intracranial pressure monitoring, including overnight recording, was performed for at least 24 hours in all patients except 1.\textsuperscript{30} During continuous ICP monitoring, to make the procedure more comfortable for the patient, we routinely alternate periods of 17–24 hours when the patient is connected to the ICP monitor while remaining flat in bed with periods of 24 hours without monitoring, in which the patient can sit up or walk around.\textsuperscript{30}

**Zero Drift and Sensor Malfunction**

For each device, the following data were recorded: operating surgeon, daily mean ICP value (obtained from the nurses’ end-hour register), duration of ICP monitoring, and zero drift at sensor removal. After sensor removal, potential zero drift was always determined by reading the pressure value under conditions of zero pressure (immersion in liquid and without direct light). To detect possible correlations between the severity of intracranial hypertension and zero drift, mean ICP was divided into 2 groups: ≤ 20 mm Hg and > 20 mm Hg. To analyze the influence of the dura-
tion of ICP monitoring on zero drift, we compared sensor readings at removal in 2 groups of patients: 1) those patients who underwent ICP monitoring for ≤ 5 days, and 2) those who underwent ICP monitoring for > 5 days. Any sensor malfunction was registered.

**Medical Complications**

In each patient, coagulation parameters were determined before the sensor was implanted. Abnormal coagulation was defined as a platelet count < 100,000, prothrombin time > 14 seconds, or partial thromboplastin time > 50 seconds. All patients showed normal coagulation before the ICP sensor was implanted. When possible, a follow-up CT scan was performed in the first few days after sensor implantation. The CT scans detected the presence of any blood collections caused by sensor implantation and, if present, the blood collection volume was calculated.

After sensor removal, a swab from the part of the sensor inserted into the cranium was sent for microbiological analysis. In patients requiring CSF dynamics studies or ventriculostomy, additional microbiological analysis of CSF was performed. Prophylactic antibiotics were not administered in any of the patients studied. Routine precautions against infection were taken during sensor insertion and daily care. If CSF leaked after the device was removed, a suture was applied.

**Statistical Analysis**

All descriptive statistics were analyzed and summarized using the SigmaStat software package (version 3.5, Systat Software). The assumption that data were normally distributed was tested using the Kolmogorov-Smirnov test. In normally distributed data, the mean ± standard deviation was used to summarize the variables. In skewed samples, the median and the IQR were used. To determine whether a linear relationship existed between quantitative variables, the Pearson rank correlation coefficient was used with normally distributed variables and the Spearman rank correlation coefficient was used with nonnormally distributed variables. Differences in zero drift and in the number of positive cultures according to the duration of ICP monitoring in independent samples were analyzed using the non-parametric Mann-Whitney rank sum test. To compare the medians among groups, the Friedman test was used. Dif-

---

**Fig. 1.** Photographs and illustration of the Neurodur-P sensor. **Upper:** Photographs of the Neurovent-P sensor adapted for use in the ventricular system (A) and in the brain parenchyma (B), and the Neurodur-P sensor (C). **Lower:** Drawing of the main elements of the distal Neurodur-P sensor inserted in the epidural space: 1) reference pressure duct; 2) chip with membrane; 3) catheter connection; 4) catheter; 5) titanium case; and 6) connecting wires (information provided by the manufacturer).
Epidural ICP monitoring with the Neurodur-P sensor

ferences were considered statistically significant when the probability value was < 0.05.

Results

A total of 106 Neurodur-P epidural sensors were implanted in 96 patients with hydrocephalus of varying causes and in 10 patients with suspected benign intracranial hypertension (Table 1) by 4 members of the neurosurgery department (1 staff neurosurgeon and 3 neurosurgical residents). There were 46 women (43.4%) and 60 men (56.6%) in the study, with a median age of 63 years (IQR 40–74 years, minimum age 15 years, maximum age 86 years). The median duration of ICP monitoring was 8 days (IQR 6–12 days, minimum 1 day, maximum 31 days). The shortest ICP monitoring period was < 12 hours, occurring in a patient with dementia who tore out the sensor.

Zero Drift

In 78 (73.6%) of the 106 patients, the pressure reading was recorded at sensor removal. Twenty-eight sensors showed no zero drift (a reading of 0 mm Hg at sensor removal). In 20 sensors a negative reading was obtained, whereas 30 readings were positive. When calibrated at atmospheric pressure, the median drift was 0 mm Hg with an IQR of −1 to 1 mm Hg (Fig. 2). Readings ranged from −13 to 6 mm Hg, but extreme outliers were only found in 1 sensor (−13 mm Hg). No significant differences were found between patients monitored for ≤ 5 days and those monitored for > 5 days (t = 535, p = 0.100). No correlation was found between zero drift and monitoring time (r = 0.153, p = 0.181; Fig. 3).

In 60 (76.9%) of the 78 patients in whom zero drift was recorded, mean ICP was ≤ 20 mm Hg, whereas in 18 patients (23.1%) mean ICP was > 20 mm Hg. The Mann–Whitney rank sum test showed no statistically significant differences in zero drift between these 2 groups of patients (t = 137.0, p = 0.109, t = 5.0, p = 0.352; Fig. 4).

Medical Complications

A follow-up CT scan was performed in 83 (78.3%) of the 106 patients. The remaining 23 patients were discharged without a follow-up CT scan or the CT scan was performed > 10 days after sensor removal. Of the patients with a follow-up CT scan, 3 (3.6%) showed a small but clinically insignificant intracerebral hematoma (estimated volume < 1 ml) next to the Neurodur-P catheter tip, caused by sensor implantation. Figure 5 shows the CT scans of 2 of these patients.

Only 1 of the 106 patients studied had a cutaneous infection of the surgical wound. Swab samples were obtained from 102 (96.2%) of the 106 sensors at removal. Of these swab samples, 12 (11.8%) were positive. The main pathogen in this series was *Staphylococcus epidermidis*, occurring in 7 (58.3%) of 12 samples. In the remaining 5 sensors, cultures were positive for *Staphylococcus aureus*, *Corynebacterium* spp., and *Propionibacterium* spp., and mixed aerobic flora in the remaining 2 samples. Only a few bacterial colonies were found in positive cultures, however, and were probably caused by bacterial colonization of the catheter without any detected infection. Additionally, CSF cultures were obtained in 72 patients (22 from lumbar CSF, 47 from ventricular CSF, and 3 from both lumbar and ventricular CSF). All samples were negative except for 1 ventricular CSF sample, showing only a few *S. epidermidis* colonies. There were no clinical infections found (meningitis, empyema, or brain abscess). Positive cultures were not significantly associated with duration of ICP monitoring.

Technical Data

Of the 106 implanted sensors, technical problems were detected in only 1 sensor. In this case the Neurodur-P sensor failed to work from the outset and had to be changed. Sensor withdrawal was difficult in 7 patients (6.6%), requiring the surgical wound to be opened slightly more than usual. In 6 of these 7 patients, ICP monitoring was > 7 days (mean 15.1 ± 7 days, minimum 4 days, maximum 24 days). Fracture of the distal part of the sensor occurred once during removal. This sensor was implanted in the subdural space and the fragment was lost in the intracranial space with no significant complications.

In 2 sensors, the distal part of the Neurodur-P sensor migrated from the epidural space into the wound. Migration

---

**TABLE 1**

Summary of causes for ICP monitoring in 106 patients*

<table>
<thead>
<tr>
<th>Cause for ICP Monitoring</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>adult chronic hydrocephalus (NPH)</td>
<td>50 (47.2)</td>
</tr>
<tr>
<td>benign intracranial hypertension†</td>
<td>5 (4.7)</td>
</tr>
<tr>
<td>CM-I &amp; intracranial hypertension</td>
<td>4 (3.8)</td>
</tr>
<tr>
<td>CSF fistula‡</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>CM-I &amp; hydrocephalus</td>
<td>11 (10.4)</td>
</tr>
<tr>
<td>sylvius aqueduct stenosis</td>
<td>8 (7.5)</td>
</tr>
<tr>
<td>study of ventriculostomy patency</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>congenital hydrocephalus</td>
<td>4 (3.8)</td>
</tr>
<tr>
<td>study of shunt functioning</td>
<td>12 (11.3)</td>
</tr>
<tr>
<td>other</td>
<td>10 (9.4)</td>
</tr>
</tbody>
</table>

* CM-I = Chiari malformation Type I.
† Pseudotumor cerebri.
‡ Associated with intracranial hypertension.
occurred at the beginning of ICP monitoring in 1 sensor and after several days of monitoring in the second sensor. The migration was confirmed at sensor removal. In these patients, the ICP recording showed small ICP irregularities of low amplitude or a completely flat trace (Figs. 6 and 7).

Mean ICP values on Days 1, 3, and 5 of monitoring were compared in 48 patients. No statistically significant differences were found among these groups using the Friedman test (chi-square = 4.384, df = 2, p = 0.112; Fig. 8).

Discussion

The Neurodur-P probe is a precision pressure catheter with a semiconductor pressure sensor fitted at the catheter tip, which enables the pressure to be measured directly in situ, avoiding the sources of error and problems associated with conventional, hydrostatic fluid-coupled systems. The quality of pressure waveforms obtained with these transducers is higher than that obtained with classic fluid-coupled systems. Absolute ICP values and amplitudes are not subjected to damping or to the presence of air bubbles or blood clots within the catheter. Moreover, because the transducer is in the catheter tip, it does not require leveling to any anatomical point to correct for hydrostatic differences. Although ICP measurement in the epidural space has serious limitations in the treatment of neurocritical care patients because of the well-known, artifactually high pressure readings, the use of this technique may be ideal in the diagnosis of other types of neurological disorders requiring prolonged monitoring, in which the most useful information is provided by the graphical pressure recording.

Compared with fiberoptic transducers, the main advantage of Neurodur-P sensors is their robustness. According to our results, Neurodur-P sensors are also highly accurate, reliable, and easy to use, with a very low complication rate. Consequently, in our unit this system is currently the standard ICP monitoring method used in complex patients with different types of hydrocephalus or suspected intracranial hypertension. Laboratory studies have confirmed that after 5 days, zero drift in Neurovent-P sensors (a device that uses the same technical principles and has been adapted for use in the brain parenchyma) was very low and that long-term continuous recording of stable and dynamic tests was excellent within a wide range of pressures. Clinical experience using the Neurovent-P sensor has been reported by Stendel and colleagues, providing similar conclusions. A new multicenter clinical trial has recently been completed by the Brain-IT Group to assess the clinical validity of the Neurovent-P sensor.
Epidural ICP monitoring with the Neurdur-P sensor

Zero Drift and Medical Complications

Zero drift of the sensor was very low in the patients studied, and in agreement with previously published laboratory and clinical data obtained with the Neurovent-P sensor. One sensor showed zero drift of \(-13\) mm Hg, but this sensor was implanted during the 1st month of the study and the possibility of poor handling cannot be ruled out. The degree of zero drift was not found to be correlated with time. Consequently, Neurdur-P sensors can be reliably used for \(>5\) days. In our study, neither the surgeon who implanted the sensor nor the presence of intracranial hypertension influenced the zero drift observed. This result is probably because we reported our clinical findings after the learning curve was complete for the management of this type of monitoring.

In 3 patients (3.6%), small, clinically insignificant hemorrhages were detected at the sensor’s tip, which did not affect the patients’ outcomes or management. A possible explanation for this very low hemorrhage rate is that the risk of complications decreases when the dura is not opened to insert the ICP monitoring device. Yet very similar hemorrhagic complications have been demonstrated when using other miniaturized ICP monitoring devices implanted in the subdural or parenchymal compartments. Nevertheless, careful attention, especially in liver disease, should always be paid to ensure normal coagulation parameters and correct implantation technique to prevent hemorrhagic complications. Previous in-depth experience in using a particular ICP monitoring system is also important.

A minimal infection rate is another major benefit of ICP monitoring devices that do not penetrate the dura. Intraventricular ICP monitoring in trauma patients, with a monitor-
The infection time of \( \leq 5–6 \) days is associated with an infection rate of \( 5–10\% \). In intraparenchymatous ICP monitoring, the authors of several studies have reported that no intracranial infections could be attributed to these devices, even though swab samples obtained from sensors at removal were positive in some patient series. In the present patient series, in which Neurodur-P sensors were implanted in the epidural space, 11.8\% of the swab samples obtained were positive for bacterial colonization but not infection. Additionally, all CSF cultures from our patients were negative. These results strongly suggest that obtaining a swab sample at sensor removal is not an optimal method to determine the sensor infection rate.

The role of prophylactic antibiotics in preventing infection associated with ICP monitoring is controversial, and some authors even conclude that the use of prophylactic antibiotics for ICP monitoring in patients with head injuries is unnecessary and potentially detrimental. In our patient series, prophylactic antibiotics were not used in patients with sensor implantation in the epidural space. The results of the present study and those of previous studies using epidural or subdural monitoring for long periods in the same type of patients suggest that this therapeutic maneuver is unnecessary.

**Technical Advantages and Disadvantages of the Sensor**

One of the major advantages of the Neurodur-P sensor is its robustness. In the present study, only 1 sensor malfunctioned and had to be changed the day after implantation. This malfunction was probably due to faulty handling of the sensor during implantation (contact between water and the catheter connector). An additional advantage is that, unlike LADD sensors, Neurodur-P sensors did not artificially increase mean ICP after the 2nd day of monitoring (Fig. 8), making the data more reliable. Accurate data after several days of ICP monitoring allows the functioning of implanted shunts to be studied and provides reliable ICP data during prolonged monitoring in complex patients. This phenomenon could be explained by the small size and the material of the distal part of the Neurodur-P sensor, which possibly produces less fibrosis in the epidural space.

In our opinion, the most important disadvantage of this device is the tendency of the sensor to migrate from the epidural space, probably due to the small size of the tip and the metallic material (titanium) of the distal part of the sensor. Sensor migration attenuates transmission of the pressure signal or can lead to a flat ICP trace, making the final diagnosis impossible or even leading to an incorrect diagnosis. To avoid these problems, careful attention should be paid during sensor implantation to test the sensor’s final position before wound closure. Another possibility is to secure the probe by tunneling the catheter, although this maneuver was not used in the present series.

**Use of Neurodur-P Sensors and Neuroimaging Studies**

Implantation of the Neurodur-P sensor in the epidural or subdural spaces produced no relevant artifacts on CT scans (Fig. 9). On MR images, local artifacts were observed around the sensor (Fig. 9). Heidenreich and associates studied image quality, probe function, and temperature induction when the Neurovent-P sensor was used in the parenchyma of pig brain specimens. Using 1.5- and 0.2-T MR imaging systems, these authors analyzed the results after the acquisition of different MR images and found that, although known for their high-gradient switching rates and artifact induction, transverse T2-weighted turbo spin echo images at 1.5 T showed low signal intensity loss, with
a maximum artifact diameter of 6 mm in relation to a 4-mm probe size. Tissue discrimination next to this artifact was not impaired. Similarly oriented T1-weighted images showed excellent tissue discrimination, despite an artifact with a maximum diameter of 15 mm. Imaging quality was acceptable in the axial plane, satisfactory in the coronal plane, and unsatisfactory in the sagittal plane. Similar results in a patient in the present study are shown in Fig. 9, with the least satisfactory images corresponding to the sagittal plane. No signs of movement or torque were detected by Heidenreich et al. when the tip of the probe was exposed to the magnet bore of the 1.5-T MR imaging system, and no relevant temperature changes (< 0.15°C) were detected in brain parenchyma during data acquisition. The authors conclude that good-to-excellent T1- and T2-weighted images can be obtained in MR imaging studies without the risk of adverse events.

Conclusions

The Neurodur-P sensor is easy to use, safe, and reliable and produces minimal zero drift. The complication rate is low and the sensor can remain implanted for prolonged periods without affecting the reliability of readings. An additional advantage is that this sensor is compatible with neuroimaging techniques and does not produce relevant artifacts.

Disclaimer/Disclosure

The authors of this study do not have any conflicts of interest in the companies that manufacture and distribute Neurodur-P sensors. This study was initiated because of the need of our unit to move from a well-studied technology (LADD ICP sensors) to a new one in the study of patients with alterations of CSF dynamics. None of the participants in the study, including the corresponding author, have received payment for consultancy and/or advisory work, or honoraria for educational or other purposes (including travel or other expenses) from any of the companies mentioned in the paper. None of the participants hold stocks or shares in any of these companies. Juan Sahuquillo, M.D., Ph.D., is a coinvestigator of a European multicenter clinical trial testing the reliability of one of the sensors distributed by Rehau AG for monitoring ICP in traumatic brain injury; this study is being conducted under the aegis of the Brain-IT organization (http://www.brainit.org).

Acknowledgments

We gratefully acknowledge the assistance of Gail Craigie for editorial support and the collaboration of all the nurses of the Department of Neurosurgery, but especially Mercedes Batlle and Pilar Girón. We also thank the technical assistance of Ferran Serena, Ph.D., from CONTER Control de Energía, S.A., Barcelona, Spain, in the design of a hardware filter and signal conditioning device. This hardware was used for acquiring high-definition ICP recordings when using the Neurodur-P sensors with the Dräger equipment.

The study was designed by Dr. Poca. All sensors were implanted by 4 of the authors (M.A.P., F.M.R., R.L., and R.T.). All tests performed in the 125 patients included in the study were made by the same 4 neurosurgeons involved (M.A.P., F.M.R., R.L., and R.T.) with the help of the neurological nurse (M.S.A.) who collaborated specifically in the study. Dr. Poca was responsible for writing the manuscript and Dr. Sahuquillo for critically reviewing it and introducing modifications. All authors reviewed and accepted the final version of the manuscript.


34. Weinstabl C, Richling B, Plainer B, Czech T, Spiss CK: Comparative analysis between epidural (Gaeltec) and subdural (Camino) intracranial pressure probes. *J Clin Monit* 8:116–120, 1992


This study was partially supported by the government of la Generalitat de Catalunya (Grant No. 2005-SGR00411).

Address correspondence to: Maria A. Poca, M.D., Ph.D., Department of Neurosurgery, Vall d’Hebron University Hospital, Passeig Vall d’Hebron 119-129, 08035 Barcelona, Spain. email: 26382app@comb.es.