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Clinical Article

Clinical evaluation of a new intracranial pressure monitoring device

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Summary

Background. Continuous monitoring of intracranial pressure (ICP) still plays a key role in the management of patients at risk from intracranial hypertension. Numerous ICP-measuring devices are available. The aim of the present study was to investigate the clinical characteristics and the magnetic resonance imaging (MRI) compatibility of the recently developed Neurovent-P® (REHAU AG+CO, REHAU, Germany) ICP monitoring device.

Method. In a prospective two-center study, a total of 98 patients with severe head injury, subarachnoid haemorrhage, intracerebral haemorrhage, and non-traumatic brain edema underwent intraparenchymal monitoring of ICP using the Neurovent-P®. A control group comprising 50 patients underwent implantation of the Camino®-OLM-110-4B ICP monitor. The zero drift of the probes was determined before and after the ICP recording period. Technical and medical complications were documented. The MRI compatibility of the Neurovent-P® ICP probe was investigated by evaluating artifacts caused by the probe, probe function and temperature changes during MRI, and probe movement caused by the magnetic field.

Findings. The mean zero drift was 0.2 ± 0.41 mmHg (maximum 3 mmHg) for the Neurovent-P® ICP probes and 0.4 ± 0.57 mmHg (maximum 12 mmHg) for the Camino®-OLM-110-4B ICP probes. No significant correlation was identified between the extent of zero drift following the removal of the probes and the length of monitoring. Intraparenchymal haemorrhage spatially related to the probe occurred in 1 out of 50 (2%) patients with a Camino®-OLM-110-4B probe and in 1 out of 98 (1%) with a Neurovent-P®. Damage of the probe due to kinking or overextension of the cable or glass fiber occurred in 4 of the 50 (8%) Camino®-OLM-110-4B ICP probes and in 5 of the 98 (5%) Neurovent-P® probes.

On T2-weighted MR images, the Neurovent-P® ICP probe induced only small artifacts with very good discrimination of the surrounding tissue. On T1-weighted MR images, there was a good imaging quality but artifact-related local disturbances in signal occurred. There was no temperature change in the Neurovent-P® probe and in the surrounding brain tissue during MR imaging.

Interpretation. The Neurovent-P® ICP measuring system is a safe and reliable tool for ICP monitoring. Handling of the Neurovent-P® system is safe when performed properly.

Introduction

An optimal device for continuous monitoring of intracranial pressure (ICP) should have a high accuracy and long-term stability combined with minimal zero drift. In addition, the probes used should be robust, easy to implant and to calibrate. Recordings should be possible with a bedside monitor without calibration problems. The latter property is especially relevant for patient transport. Magnetic resonance imaging (MRI) studies should be possible with the ICP probe in place without risk to the patient or damage to the device.

The present study investigated the recently developed Neurovent-P® device (Fig. 1) for the measurement of ICP in terms of its suitability for clinical use, zero-calibration stability, and medical and technical complications. The MRI compatibility of the device was studied in a series of experiments to examine artifacts caused by the probe, probe function and temperature changes during acquisition of different MR sequences, and probe movement caused by the magnetic field.

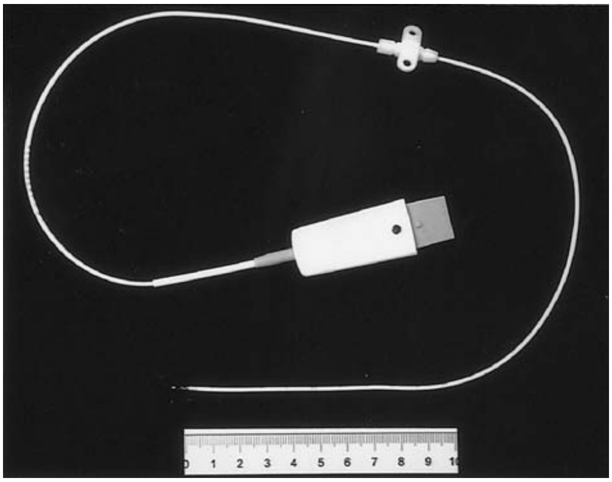

Fig. 1. Neurovent-P® probe for intraparenchymal monitoring of intracranial pressure. Pressure measurement is based on a piezoelectric transducer coated by a silicone membrane

Patients and methods

The present prospective study included a total of 148 patients with head injury, intracranial haemorrhage, or non-traumatic brain edema treated at two neurosurgical centers (Table 1). Patients in whom an increase in ICP was suspected were implanted with a pressure probe. In 50 consecutive patients, the Camino®-OLM-110-4B ICP probe (Camino Neurocare, San Diego, CA, USA) was used. These patients served as a control group. In November 2000, the use of the Neurovent-P® ICP measuring system (REHAU AG+CO, Rehau, Germany) was started. Ninety-eight consecutive patients were monitored with this ICP probe.

All ICP probes were inserted through a frontal burr hole and placed in the white matter of the frontal lobe of the affected side or of the right frontal lobe in patients with generalized brain damage. The affected side was chosen in patients with focal lesions because many animal studies as well as clinical trials have demonstrated interhemispheric differences in ICP. These studies found a higher pressure on the side of the lesion as compared to the unaffected side [13, 15, 21]. Possible ICP lowering therapy thus justifies measurement of the higher pressure on the affected side. All Camino®-OLM-110-4B ICP probes were implanted using the bolt kits supplied with the probes. The Neurovent-P® probes were implanted through the bolt kit or tunneled subcutaneously.

Medical complications

Medical complications were documented. They included intracranial haemorrhages related to the probe, disturbances in wound healing, and infections. The frequency of these complications was analyzed in relation to the probe type used.

Technical complications

Technical complications included measuring errors, probe dislocation, unplugging, and probe damaging due to cable rupture or pronounced kinking of the sensor. We analyzed whether these complications occurred during nursing manoeuvres, during transport of the patient, or for other reasons. The frequency of these complications was analyzed in relation to the type of probe used. A measuring error without mechanical damage was defined either as repeated increases or decreases in pressure within seconds occurring out of synchrony with the pulse or as the complete loss of pulsatility of the curve. These two observations were assumed to be measuring errors when accompanied by preservation of the systolic and diastolic flow component synchronous with the pulse in transcranial Doppler ultrasound and when the probe was found to be mechanically intact (as verified after explantation).

Zero stability

Deviations from zero were determined before probe implantation and following explantation at the end of the recording period to calculate mean zero drift. Measurement was done in dark conditions with the probe tip immersed below the surface of physiological saline solution heated to a temperature of 37 °C. The zero deviation was analyzed in relation to the duration of ICP monitoring and the type of probe used.

MRI compatibility

Patients with a Camino®-OLM-110-4B probe cannot undergo MR imaging because it contains components with ferromagnetic properties.

The MRI compatibility of the Neurovent-P® was investigated experimentally on two different clinical scanners operating at two magnetic field strengths (Magnetom Open, 0.2 Tesla, and Magnetom Vision, 1.5 Tesla, Siemens AG, Erlangen, Germany).

Table 1. *Age and diagnosis of 148 patients at risk from intracranial hypertension who underwent ICP monitoring with one of two different intracranial pressure probes*

	Total	Camino®-OLM-110-4B	Neurovent P®
Number	148 (110 m; 38 f)	50 (37 m; 13 f)	98 (73 m; 25 f)
Age [years]	43.5	49	40.8
Age range [years]	6–87	11–87	6–84
Acute subdural haematoma	27	13	14
Brain edema and contusions	79	25	54
Intracerebral haemorrhage	15	6	9
Subarachnoid haemorrhage	11	3	8
Non-traumatic brain edema	9	1	8
Epidural haematoma	6	1	5
Chronic subdural haematoma	1	1	0

Temperature changes. Potential temperature changes of the ICP probes induced by MRI were evaluated by temperature measurements in a pig brain specimen immediately before, during, and after acquisition of different MRI sequences in the scanner room. The scanner room was air-conditioned to a temperature of 26.7 °C to avoid cooling of the probe. In a fresh pig brain specimen in physiological NaCl solution, an ICP probe was placed at a depth of 2 cm below the brain surface. Temperatures in the brain were measured by 2 microthermistors (REHAU AG+CO, Rehau, Germany), one adjacent to the tip of the pressure probe, the other at a distance of 5 cm from the tip. The MRI examination time of the pig brain added up to a total of approximately 45 minutes, corresponding to the duration of a routine clinical MRI study. The following sequences were used:

Magnetom Open (0.2 Tesla): T2-weighted gradient-echo sequence (FLASH 2D; relaxation time (TR) 500 msec, echo time (TE) 60 msec, flip angle (FA) 40°) in transverse, coronal, and sagittal/oblique slice orientation; T2-weighted turbo spin-echo sequence (TR 5866 msec, TE 134 msec, turbo factor (TF) 15) in coronal orientation; gradient-echo sequence (TR 10.6 msec, TE 5 msec, FA 70°) in oblique orientation.

Magnetom Vision (1.5 Tesla): T2-weighted turbo spin-echo sequence (TR 5300 msec, TE 128 msec, TF 23); T2-weighted gradient-echo sequence (FLASH 2D; TR 344 msec, TE 52 msec, FA 15°) in coronal and sagittal slice orientation; T2-weighted gradient-echo sequence (FLASH 2D; TR 224 msec, TE 15 msec, FA 15°) in coronal orientation; T2-weighted gradient-echo sequence (FLASH 2D; TR 429 msec, TE 52 msec, FA 40°) in transverse orientation; echo planar imaging (EPI) sequence (TR 4295 msec, TE 110 msec) in transverse orientation.

Image artifacts. The ICP probe was placed in the parenchyma of a fresh pig brain specimen at a depth of 2 cm. The acquired MR images were evaluated for the reliability of discriminating cerebrospinal fluid (CSF), cortex, and subcortical white matter on T2- and T1-weighted images as well as fast low angle shot (FLASH) and gradient-echo sequences. The maximum diameter of the artifacts was measured using standard software. Maximum artifact generation by the ICP probe was investigated by acquiring MR images with a gradient-echo sequence in three orthogonal planes. This sequence is highly susceptible to artifacts. The MRI sequences were acquired with the following parameters:

Magnetom Open (0.2 Tesla): T2-weighted gradient-echo sequence (FLASH 2D; TR 500 msec, TE 60 msec, FA 40°) in axial and coronal orientation; T2-weighted turbo spin-echo sequence (TR 5866 msec, TE 134 msec, TF 15) in coronal orientation; T2-weighted turbo spin-echo sequence (TR 4000 msec, TE 134 msec, TF 15) in axial orientation, gradient-echo sequence (TR 10.6 msec, TE 5 msec, FA 70°); T1-weighted spin-echo sequence (TR 308 msec, TE 15 msec, FA 90°).

Magnetom Vision (1.5 Tesla): T1-weighted spin-echo sequence (TR 420 msec, TE 12 msec); T2-weighted turbo spin-echo sequence (TR 5300 msec, TE 128 msec, TF 23); T2-weighted gradient-echo sequence (FLASH 2D; TR 344 msec, TE 52 msec, FA 15°) in sagittal slice orientation; T2-weighted gradient-echo sequence (FLASH 2D; TR 224 msec, TE 15 msec, FA 15°) in coronal slice orientation; T2-weighted gradient-echo sequence (FLASH 2D; TR 429 msec, TE 52 msec, FA 40°) in transverse slice orientation.

Probe function during MRI. The ICP probe was placed in a container of physiological saline solution in such a way that a constant pressure of 2.4 mmHg was recorded. The probe was connected to a patient monitor (Dash 3000, Marquette, Germany) via the zero simulator NPS-2 (REHAU AG+CO, Rehau, Germany). Changes in the measuring signal were determined during acquisition of different MRI sequences. Pressure data were sampled at a rate of 10/sec and stored digitally by a datalogger (REHAU AG+CO, Rehau, Germany). The data were processed using a spreadsheet program (Microsoft Excel 97, Microsoft Corporation, USA). The following MRI sequences were acquired:

Magnetom Vision (1.5 Tesla): T2-weighted turbo spin-echo sequence (TR 5300 msec, TE 128 msec, TF 12), T1-weighted spin-echo sequence (TR 3800 msec, TE 96 msec, TF 7); T2*-weighted turbo spin-echo sequence (TR 5300 msec, TE 128 msec, TF 12); T2-weighted gradient-echo sequence (TR 288 msec, TE 18 msec, FA 20°) in coronal and sagittal orientation; EPI sequence (TR 1.7 msec, TE 64 msec, FA 90°).

Probe movement. Probes and peripheral components of the Neurovent-P® intracranial pressure monitoring system were tested for translational motion and torque in the magnetic field. These tests were performed at the entrance of the magnetic coil.

Results

Medical complications

One patient (2%) developed epidural bleeding after placement of a Camino®-OLM-110-4B ICP probe. This complication was due to epidural malpositioning of the probe resulting from inaccurate puncture of the dura. An intraparenchymal haemorrhage spatially related to the probe occurred in 1 of 50 (2%) patients after placement of a Camino®-OLM-110-4B ICP probe and in 1 of 98 (1%) with a Neurovent-P® probe. Both patients had a severe head injury and thrombocytopenia. One patient from each group developed a superficial wound infection which responded to local treatment.

Technical complications

Dislocation without damage to the probe was seen in 7 of 50 (14%) patients having received a Camino-OLM-110-4B ICP probe, in 5 instances (10%) during positioning in the ICU and in 2 patients (4%) during transport. In the Neurovent-P® group 2 of 98 (2%) probes were dislocated, 1 (1%) during positioning and 1 (1%) during transport. Damage of the probe due to kinking or overextension of the cable or glass fiber occurred in 3 of 50 (6%) Camino®-OLM-110-4B ICP probes during positioning and in 1 case (2%) during transport and in 5 of 98 (5%) Neurovent-P® probes (4 during positioning, 1 during transport).

Measuring errors without mechanical damage were documented in 4 of 50 (8%) Camino®-OLM-110-4B ICP probes. Two Neurovent-P® probes yielded wrong measurements but these were found to be due to overextension of the cable when the probes were checked.

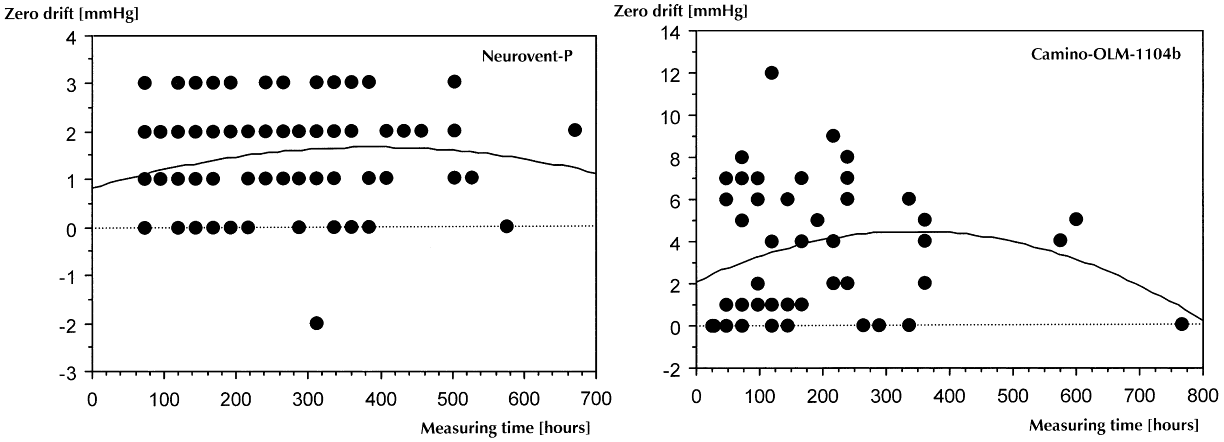

Fig. 2. Zero stability of the Neurovent-P® (left) and Camino®-OLM-110-4B probes (right). There is no statistically significant correlation between the duration of ICP monitoring and zero shift

Zero stability

The mean duration of ICP monitoring per probe was 224.3 ± 137.1 hours (range 24–768 hours) with 190.7 ± 152.58 hours (range 24–768 hours) for the Camino®-OLM-110-4B ICP probes and 241.2 ± 125.31 hours (range 72–672 hours) for the Neurovent-P® ICP probes.

The mean zero drift prior to probe implantation was 0.2 ± 0.41 mmHg for the Neurovent-P® ICP probes and 0.4 ± 0.57 mmHg for the Camino®-OLM-110-4B ICP probes. After the end of ICP monitoring and removal of the probes, mean zero drift was 1.7 ± 1.36 mmHg (Neurovent-P® ICP probes) and 3.5 ± 3.1 mmHg (Camino®-OLM-110-4B ICP probes) ($p < 0.01$; Mann-Whitney test). The Neurovent-P® ICP probes showed a maximum drift of 3 mmHg and the Camino®-OLM-110-4B ICP probes of 12 mmHg ($p < 0.01$; Mann-Whitney test). No significant correlation could be identified between the extent of zero drift after probe removal and the duration of ICP monitoring for either probe type (Spearman rank correlation test) (Fig. 2).

MRI compatibility

Temperature changes. The thermocouple tests demonstrated no temperature change near the ICP probe and in the surrounding brain tissue during MR imaging (Table 2).

Image artifacts. On T2-weighted MR images, the Neurovent-P® ICP probe induced only small artifacts with a maximal diameter of 8 mm. There was a very good surrounding tissue discrimination. On T1-weighted MR images, the artifacts had a greater diameter as compared to the T2-weighted images. However, there was a good imaging quality but artifact-related local disturbances occurred. On gradient-echo sequences at a magnetic field strength of 1.5 Tesla, MR images had no diagnostic imaging quality. On these sequences, the maximal artifact diameter was 20 mm with reasonable to insufficient surrounding tissue discrimination. (Table 3, Figs. 3–6).

Probe function during MRI. All MRI sequences investigated affected the measured pressure values to varying extents during acquisition. In general, the probe intermittently underestimated the actual pressure with the highest values measured during acquisition roughly corresponding to the initially measured pressure. In the intervals between image acquisition, a return to the originally measured pressure occurred

Table 2. *Temperature changes of the Neurovent-P® ICP probe occurring during MR imaging. The ICP probe was placed in a fresh pig brain specimen contained in physiological saline solution. Temperatures were measured by two microthermistors in the pig brain, one placed adjacent to the probe tip, the other at a distance of 5 cm. The room was air-conditioned to 26.7°C to avoid cooling effects. Values are arithmetic means of two measurements*

Temperature [°C]	Magnetom open		Magnetom vision	
	ICP probe	Tissue	ICP probe	Tissue
Start	24.34	24.67	21.88	22.15
8 min	24.38	24.57	21.65	22.03
16 min	24.24	24.54	21.65	22.12

Table 3. *Image artifacts caused by the Neurovent-P® ICP probe occurring during MR imaging. The ICP probe was placed in a fresh pig brain specimen contained in physiological saline solution*

Device	Sequence	Maximum artifact size (probe tip)	Surrounding tissue discrimination
Magnetom Open (0.2 Tesla)	T1-weighted spin-echo	10 mm	good
	T2-weighted turbo spin-echo, axial	3 mm	good
	T2-weighted turbo spin-echo, axial	4 mm	good
	T2-weighted gradient-echo, axial, coronal and sagittal	8 mm	good
	Gradient-echo	3 mm	good
Magnetom Vision (1.5 Tesla)	T1-weighted spin-echo	15 mm	good
	T2-weighted turbo spin-echo, axial	6 mm	good
	Gradient-echo, axial	12 mm	reasonable
	Gradient-echo, coronal	15 mm	sufficient
	Gradient-echo, sagittal	20 mm	insufficient

TR Relaxation time, *TE* echo time, *TF* turbo factor, *FA* flip angle.

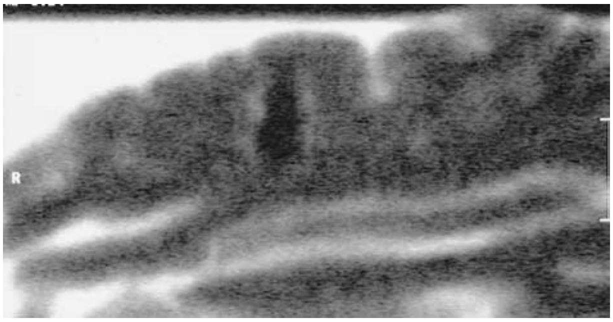

Fig. 3. MRI artifacts caused by the Neurovent-P® ICP probe implanted in a fresh pig brain specimen imaged at 0.2 Tesla using a T2-weighted turbo spin-echo sequence

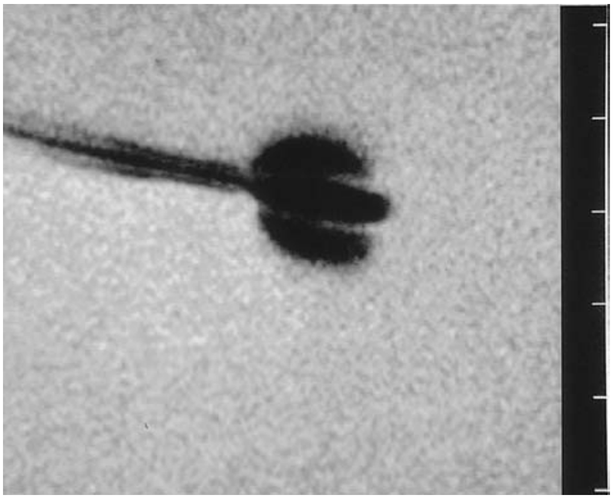

Fig. 4. MRI artifacts caused by the Neurovent-P® ICP probe in water imaged at 1.5 Tesla using a T2*-weighted gradient-echo sequence

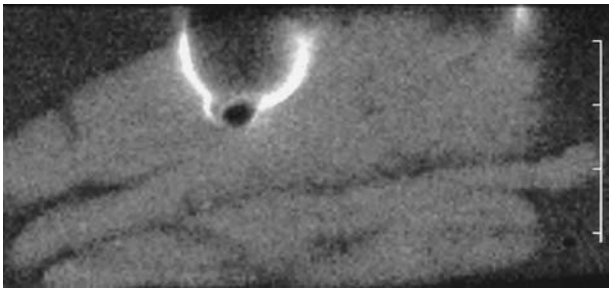

Fig. 5. MRI artifacts caused by the Neurovent-P® ICP probe implanted in a fresh pig brain specimen imaged at 1.5 Tesla using a T1-weighted spin-echo sequence

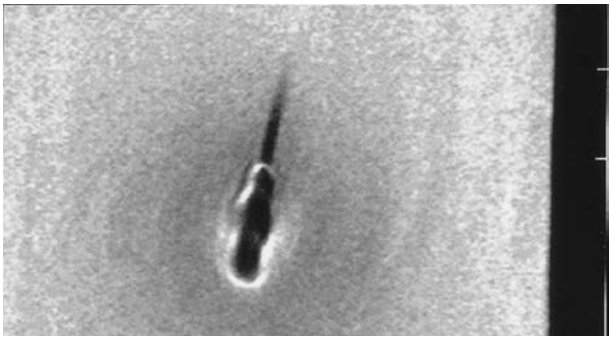

Fig. 6. MRI artifacts caused by the Neurovent-P® ICP probe in water imaged at 1.5 Tesla using a T2-weighted turbo spin-echo sequence

without delay. The following values were measured during the different MRI sequences: Pre: 2.4 ± 0.11 mmHg (1.6–3.2 mmHg); T2-weighted turbo spin-echo sequence: −12.7 ± 6.45 mmHg (−23.1–2.4); Interval 1: 2.3 ± 0.07 mmHg (2.2–2.4 mmHg); T1-weighted

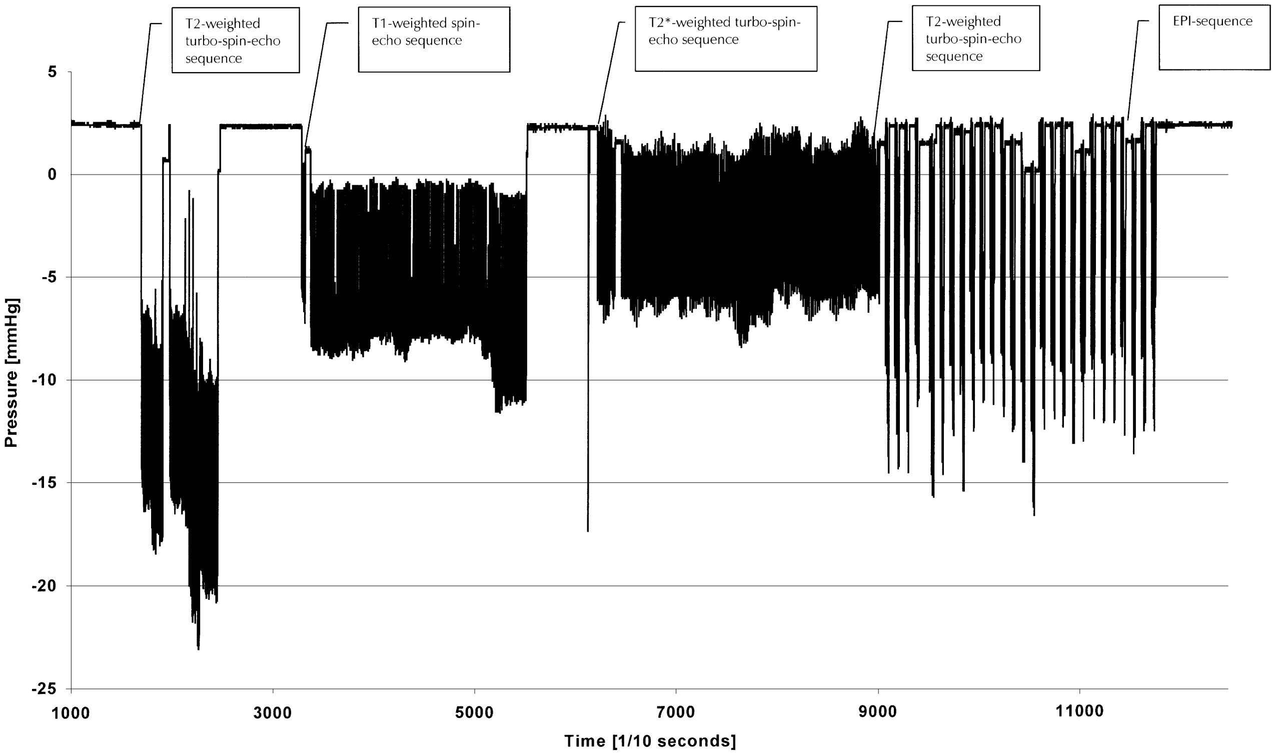

Fig. 7. Effect of MRI on the measuring accuracy of the Neurovent-P® ICP probe during acquisition of different sequences. MRI was performed at a magnetic field strength of 1.5 Tesla (Magnetom Vision, Siemens AG, Erlangen, Germany). All sequences used affected the measuring accuracy of the probe but the measured values returned to the original level without delay after the end of data acquisition

spin-echo sequence: −6.6 ± 2.58 mmHg (−11.6–1.3 mmHg); Interval 2: 2.2 ± 0.75 mmHg (−17.4–2.4 mmHg); T2-weighted turbo spin-echo sequence −4.0 ± 3.09 mmHg (−14.6–2.7 mmHg); Interval 3: 2.2 ± 0.05 mmHg (2.2–2.4 mmHg); T2-weighted gradient-echo sequence: −3.6 ± 5.6 mmHg (−14.4–2.6 mmHg); Interval 4: 2.2 ± 0.07 mmHg (2.1–2.4 mmHg); EPI sequence: −0.3 ± 3.9 mmHg (−16.7–2.8 mmHg); Post: 2.2 ± 0.08 mmHg (2.1–2.4 mmHg) (Fig. 7).

Probe movement. At the entrance of the magnetic coil, the plug of the Neurovent-P® probe was moved from its normal position by the magnetic field to a position forming an angle of less than 30° relative to its base. This displacement is induced by a force of about 6 p, which is lower than the weight of the plug of 12.4 p. The plug weight thus exerts less force on probe fixation than the displacement induced by the magnetic field. The probe tip and the zero stimulator did not show any movement when the device was exposed to the magnetic field at the entrance of the magnetic coil.

Discussion

Continuous monitoring of intracranial pressure (ICP) is routinely used in patients at risk due to intracranial hypertension [3]. Different methods for continuously monitoring ICP have been in use for several decades. The most commonly used system is the ventricular catheter connected to an external strain gauge, which has been described as the "gold standard" of ICP monitoring [9]. Due to the disadvantages of this method [18], and with technological development, fiberoptic and piezo-electric ICP measuring devices were introduced into clinical practice. ICP with these newer devices is typically measured in the parenchyma, but ventricular or subdural measurements are also possible [6, 11]. However, medical and technical complications as well as problems with the accuracy, zero drift, and the mechanical robustness of fiberoptic and piezo-electric ICP probes have been identified in laboratory and clinical studies [4, 7, 11, 12, 14, 17, 23].

The Neurovent-P® ICP monitoring system consists of a pressure probe for intraparenchymal use. This probe can be connected to any bedside monitor using a small zero-point simulator specific for the type of patient monitor. Changing the type of bedside monitor during measurement does not cause any problems. The tip of the Neurovent-P® probe has a diameter of about 1.6 mm. The function is based on an electronic chip in the probe tip. The chip is made of silicon and its central portion is flattened, resulting in a thin membrane. This membrane protrudes in proportion to the degree of pressure to which it is exposed. Pressure is measured by determination of the membrane deformity using the piezoresistive effect. The required measuring accuracy and independence from variations in input voltage are ensured by a measuring bridge integrated into the chip. The Neurovent-P® probe has a sensitivity of 5 µV/V/mmHg ± 1%. Linearity and hysteresis errors taken separately are so small in this probe type that they are given as a combined value. The maximum of this combined error is ±0.5% (data provided by the manufacturer: data on file; REHAU AG+Co, Rehau, Germany). The American standard for blood pressure probes allows an individual deviation of ±2% for each of these two parameters.

The complication rate for intraparenchymal devices has been reported to be very low [10, 16, 17]. In the present study only one patient developed intracranial haemorrhage associated with ICP monitoring using the Neurovent-P® probe. This was a thrombocytopenic patient with severe head injury. In the group of patients in whom ICP was monitored with the Camino®-OLM-110-4B probe, 4% of the patients developed intracranial bleeding.

The results of the present study demonstrated a very low infection rate associated with the use of the Neurovent-P® probe. Only one patient developed a superficial wound infection without isolation of pathogens. The infection responded to local treatment. None of the patients developed intracranial infection or meningitis. The infection rate identified here corresponds to the results of other studies investigating intraparenchymal ICP probes [5]. For the other device investigated, the Camino®-OLM-110-4B probe, the rate of superficial wound infections was about 2%. Comparison of these results with the infection rates occurring after ventriculostomy, which are reported to range from 1.6 to 27% [1, 8, 20], suggests that the use of the Neurovent-P® ICP probes is not associated with an increased risk of infection.

The frequency of technical complications associated with the Neurovent-P® probe was relatively low at 7% as opposed to 22% for the Camino®-OLM-110-4B ICP probe. The fairly high complication rate of the Camino®-OLM-110-4B ICP probe is confirmed in a study by Münch *et al.* [11] in which 118 patients underwent ICP monitoring for a mean of 94.1 hours. In this study technical complications occurred in about 23.5% of the cases. A similar rate of technical complications with the Camino®-OLM-110-4B ICP probe was reported by Bavetta *et al.* [2]. In contrast, other studies found much lower rates of technical complications for this probe type [4, 5, 22]. However, in these studies, smaller patient populations were investigated or the duration of ICP monitoring was much shorter. It is important to note here that, in our experience, most complications associated with the use of the Neurovent-P® device occurred in the initial phase after introduction of this new probe. Neither the nurses nor the physicians involved in patient management were aware of the study design in order to avoid bias. After the learning phase, hardly any complications have occurred with the Neurovent-P® device.

The mean zero drift of the Neurovent-P® probes did not exceed 3 mmHg in the present study and the drift determined after probe explantation did not correlate with the duration of ICP monitoring. The extent of the drift determined here suggests that the Neurovent-P® probe allows for sufficiently accurate clinical ICP measurement. This is in contrast to a maximum drift of 12 mmHg determined for the Camino®-OLM-110-4B ICP probes.

The American Federal Drug Administration has defined guidelines for assessing the use of medical equipment in an MR environment. The label "MR-safe" indicates that the use of a device in an MR environment does not involve any additional risk for the patient. The label "MR-compatible" indicates that a device is "MR-safe" and does not affect the diagnostic quality of the imaging procedure significantly or has its operations affected by the MR imaging system [19]. The increasing use of MRI for the diagnostic assessment of critically ill patients has led to the development of a wide range of monitoring and life support devices that are MR-compatible. Particularly patients with raised intracranial pressure might benefit from MRI studies. However, only the Codman-Microtransducer® system was reported to be MR-safe at field strengths of up to 0.5 Tesla, whereas the Camino®-OLM-110-4B catheter was not described as being MR-safe [19].

The results of the present study suggest that MR imaging using different sequences including ones with prolonged acquisition times does not increase the temperature of the Neurovent-P® ICP probe. The probe tip induces relatively small artifacts in T2-weighted and in most T1-weighted images, combined with a good surrounding tissue discrimination. However, on gradient-echo sequences at a magnetic field strength of 1.5 Tesla the artifacts generated by the probe tip were larger and there was only reasonable to insufficient surrounding tissue discrimination.

At a magnetic field strength of 1.5 Tesla, slight movement of the probe plug was observed with the force inducing this movement being lower than the weight of the plug. The probe tip itself showed no movement in the magnetic field. This observation suggests that the weak forces occurring in the MRI scanner will not induce any significant movement of a properly fixed probe, especially of the parts located below the scalp. It must also be noted that the forces acting on the probe are strongest at the entrance of the magnetic coil where the gradient is highest.

The currents induced by the magnetic fields of the MR imager in the metal sensor casing are contained within the highly conductive casing (closed conductor loop). Any risk to the patient by such currents is therefore excluded according to the manufacturer. The same holds true for the connecting wires of the probe and the zero simulator that must be interconnected for adjustment to a bedside monitor. Here, containment is ensured by the conductor loop formed by the low-ohm bridge resistors of the measuring chip.

Since health care expenditure is increasingly becoming an issue, a short cost analysis may be helpful here. It must be noted, however, that such a comparison is difficult since the contracts negotiated with a supplier may vary widely from hospital to hospital and the figures presented here only serve to present rough estimates. The price of a Camino®-OLM-110-4B probe ranges from about EUR 358 to about EUR 375. To this must be added the price of the monitor. According to the manufacturer, the life of the monitor is about 8 years. Maintenance is about EUR 350 per year. In comparison, a Neurovent-P® ICP probe ranges in price from about EUR 330 to 450, depending, among other things, on the number of probes ordered. The Neurovent-P® ICP probe has the advantage that there are no additional costs for the purchase and maintenance of a special monitor as for the Camino®-OLM-110-4B probe. Moreover, one is not left with unusable equipment when switching to a different system at a later time.

In summary, the results of the present study suggest that the Neurovent-P® ICP measuring system seems to be a safe and reliable tool for ICP monitoring. Handling of this system is safe when performed properly.

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Comments

Neurovent P device – a new system for ICP monitoring. As there are many ICP monitoring systems available one could ask if there is a need for a new ICP device. The problems concerning the existing ICP monitoring systems are associated with technical failures, lack of MRI compatibility and high cost of devices. The presented ICP device seems to be technically satisfactory and MRI compatible. Thus in my opinion it is worth to introduce it into clinical practice and evaluate it.

Z. Czernicki

Although there is a fair number of ICP measuring devices commercially available, it appears, as from this manuscript, that there is still a need for further developments in this field. One may question if the improvement in zero drift from 0.4 mmHg (Camino) to 0.2 mmHg (Neurovent) is worth the effort? Nevertheless, in the measurement of physiological parameters, the value should be accurate and not an approximation of the actual value. A maximum zero drift of 12 mmHg for the Camino, as found in this manuscript is, of course, unacceptable.

It appears from this manuscript that the device described has some advantages over the Camino-probe, particularly as far as zero drift is concerned. A major merit of this paper lies in the study of the MRI compatibility of the device, which has been nicely done.

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