Camino® intracranial pressure monitor: prospective study of accuracy and complications

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Abstract

***Objectives*—The fibreoptic device is a type of intracranial pressure monitor which seems to offer certain advantages over conventional monitoring systems. This study was undertaken to analyse the accuracy, drift characteristics, and complications of the Camino® fibreoptic device.**

***Methods*—One hundred and eight Camino® intracranial pressure (ICP) devices, in their three modalities, were implanted during 1997. The most frequent indication for monitoring was severe head injury due to road traffic accidents.**

***Results*—Sixty eight probe tips were cultured; 13.2% of the cases had a positive culture without clinical signs of infection, and 2.9% had a positive culture with clinical signs of ventriculitis. The most common isolated pathogen was *Staphylococcus epidermidis*. All patients were under cephalosporin prophylaxis during monitoring. Haemorrhage rate in patients without coagulation disorders was 2.1% and 15.3% in patients with coagulation abnormalities. Drift characteristics were studied in 56 cases; there was no drifting from the values expected according to the manufacturer's specifications in 34 probes. There was no relation between direction of the drift and duration of placement, nor between drift and time.**

***Conclusions*—Although the complication and drift rates were similar to those reported elsewhere, there was no correlation between the direction of the drift and long term monitoring despite the fact that some published papers refer to overestimation of values with time with this type of device.**

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Keywords: intracranial pressure monitoring; fiberoptic device; zero drift; complications

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Contemporary transducers may be classified as solid state and fibreoptic devices. Such devices have an excellent accuracy in their measurements and low zero drift over a long period.[1] This device uses a monitor that senses changes in the amount of light reflected from a pressure sensitive diaphragm located at the tip of a fibreoptic catheter.[2 3] Mean pressure is then displayed digitally on the monitor.[2 3] We could measure intracranial pressure (ICP) when it is not possible to cannulate the ventricular system, and there is no CSF leak as in fluid filled catheters.

Fibreoptic devices need to be calibrated before insertion. It is strongly recommended not to re-zero this device after implantation, even under sterile conditions, which remains their major limitation. The devices do not need to have an hydrostatic zero level, as ventricular catheters do, because the transducer is in the tip and, there is no concern about the level of the transducer.[4] They allow for continuous recording and monitoring of ICP in each brain compartment[2 4 5] and they give accurate pressure readings and allow for the analysis of waveform in the compartment where the tip of the probe is placed.[3–5]

Common complications of ICP monitors are infection, haemorrhage, and drift rate. They have a low infection rate. Colonisation depends on the ICP device and its placement. Bacterial colonisation increases with time, although intracranial infections are uncommon.[6–8] The most frequently isolated pathogens are gram positive, and among them, the *Staphylococcus* group.[8–10] Antibiotic prophylaxis is controversial because it increases the possibility of undiagnosed infections.[11–13]

The incidence of fatal haemorrhage depends on the sensor type. A 5% incidence of fatal haemorrhage in subdural devices, 4% in intraparenchymal, and 1.1% in ventriculostomies have been reported.[14] In coagulation disorders the recommendation is made to correct them before placing the ICP probe.[14 15] The overall rate of fatal haemorrhage in patients with coagulation disorders is 10%.[14 16 17]

According to the manufacturer's specifications, the Camino® ICP monitor has a maximum zero drift during the first 24 hours of 0 ± 2 mm Hg and less than ± 1 mm Hg/day on subsequent days.[4 18] Previous studies stated that they trend to drift towards positive values, and thus overestimate ICP readings.[1 4 5 19–21]

Materials and methods

One hundred and eight consecutive Camino® probes were prospectively implanted at the Departments of Neurosurgery of the Hospital Clínic of Barcelona (88 cases) and Hospital del Río Hortega of Valladolid (20 cases) from January to December 1997, using identical monitoring techniques in both centres. This prospective study was undertaken to analyse the accuracy, complication rate, and drift characteristics of Camino® ICP monitors (Camino Laboratories, San Diego, California, USA).

Coagulopathy was defined by clinically apparent bleeding, or abnormalities in the prothrombin activity, partial thromboplastin time, or platelet count. In the study of complications we defined intracranial bleeding attributable to the monitor as a new area of haemorrhage

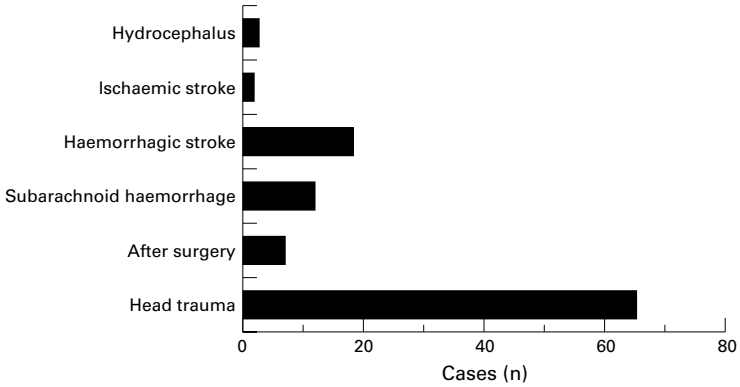

Figure 1 Severe head injury (Glasgow coma scale<9) was the first cause for monitoring with 66 cases, followed by intraparenchymal haemorrhages in 18 cases, and subarachnoid haemorrhages in 13 cases.

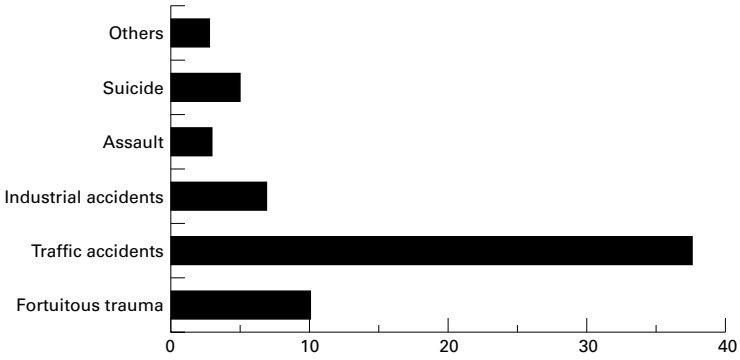

Figure 2 The most frequent cause of head injury was road traffic accidents in 38 cases followed by fortuitous trauma in 10 cases and seven cases of industrial accidents.

adjacent to the probe on CT. To study infection rate 68 probe tips were sent for culture. Meningitis and ventriculitis were defined if CSF samples were positive for pathogens on gram stain, or bacterial growth on culture. Prophylactic intravenous cephalosporins were given during monitoring.

Zero drift was measured by monitoring the pressure signal when the probe was removed and after waiting for 20–30 seconds, allowing the temperature to drop because of the cooling of the tip at room temperature (all the probes were placed at room temperature). The duration of placement of the ICP probe was recorded. Statistical analysis was performed using Student's *t* test and linear regression analysis.

Results

From January to December 1997, 108 consecutive Camino® ICP probes were placed in 101 patients, some in whom more than one device was inserted. Sixty three of them had an intraparenchymal, 28 a subdural, and 17 an intraventricular probe. Sixty per cent were male (65 males and 43 females), and the mean age was 44.8 years (range 2–82 years).

Ninety five patients had a single monitor, five patients had two monitors, all of them replaced due to reoperation, and one patient had three probes, all replaced due to rupture of the optic fibre.

INDICATIONS FOR MONITORING

The indications for monitoring are summarised in fig 1. Severe head injury (Glasgow coma scale<9) accounted for 71.2% of implantations, followed by intraparenchymal haemorrhages in 19.4%, and subarachnoid haemorrhages in 12.9%. The most frequent cause of head injury was road traffic accidents followed by industrial accidents and fortuitous trauma (fig 2).

INFECTION

We performed the bacteriological analysis in 68 probe tips. The rest of the cases were rejected because of difficulties in completing the fixed protocol due to contamination of the probe during removal or loss of the probe. Among these 68 probes, 40 were intraparechimatous, 16 subdural, and 12 intraventricular.

Culture was negative in 83.8% of them (57 cases). A positive culture was found in 13.2% (nine cases) but without clinical signs of infection, and 2.9% of all the cultured monitors had a clinical CNS infection (two cases).

Ventriculitis was the clinical picture of intraventricular monitor infection. One of them was meticillin resistant *S aureus* (MRSA) positive, in a patient with the probe placed for 12 days. The infection was controlled with antibiotic therapy. The second case of ventriculitis had a positive culture to coagulase negative *Staphylococcus*. The patient had the monitor in place for 11 days and died because of an arteriovenous malformation rebleeding not related to CNS infection.

Among the cases of positive culture without infection, 10.7% were seen in subdural devices (3/16), 9.5% in intraparenchymal devices (6/40), and 11.7% in intraventricular monitors (2/12). No significant differences in infection rate among the three modalities of Camino® devices were found.

The pathogens isolated in our patients with ICP monitor related infections were *S epidermidis* in eight cases, *E cloacae* in one case, and one case showed positive cultures to multiple pathogens (*Proteus, Staphylococcus*, and *Enterobacter*). No increase in the infection rate was noticed in patients who had more than one probe implanted.

HAEMORRHAGE

Analysis was performed in 108 probes. Twelve monitors were placed in patients with coagulopathy after the criteria described above (13% of all patients). Two cases out of 13 had an episode of postoperative bleeding (15.3%). One of them had a prothrombin activity less than 60% and had a small bleeding area around the tip of the probe but without clinical relevance. Another patient died because of repeated bleeding from an arteriovenous malformation, not directly due to the insertion of the probe.

Bleeding rate in patients without coagulopathy was 2.1% (2/95). There were radiological findings in all of them but without clinical relevance. Considering all the patients with and without coagulation disorders, the overall bleeding rate was 3.7%.

ZERO DRIFT

Analysis was performed in 56 patients (table 1); we lost some patients due to difficulties in completing the protocol. Among the 56 readings, only six exhibited no zero drift (that is, readings of 0 mm Hg at removal). Readings ranged from -24 to 35 mm Hg.

According to the manufacturer's specifications, we could expect a zero drift of 0±2 mm Hg the first 24 hours, then less than ±1 mm Hg/day, so we determined if our probes drifted more than we should expect (fig 3).[4 18] We discounted from our readings the zero drift expected each day. We found no drifting from the expected values in 34 probes (60.71%) (table 2). Thirteen cases drifted to negative values and nine to positive values (table 3).

Linear regression analysis was performed on the 56 readings to study the relation between the the zero drift (not considering the direction of the drift) and the duration of monitoring. We did not find a correlation between the duration of monitoring and zero drift (p=0.27). Moreover, analysis of the probes in which zero drift was more than predicted by manufacturers, and considering the direction of the drift, showed no relation between the direction of the zero drift and the duration of monitoring.

Table 1 Measurement of zerodrift in 56 fibreoptic pressure probes

Day No	No of zero drift readings	Zero drift (mm Hg)			
		Range	Mean	Median	SD
1	9	−11 to 3	−1.00	−2.00	2.92
2	10	−11 to 20	0.90	−0.50	5.93
3	7	−24 to 15	−0.28	2.00	8.03
4	5	−3 to 35	8.00	4.00	13.86
5	7	−17 to 3	−3.71	−1.00	4.54
6 and 7	6	−18 to 35	1.16	−3.50	11.41
8 and 9	6	−10 to 14	2.16	3.00	2.16
10, 11, and 12	6	−7 to 8	−0.66	−1.00	0.00

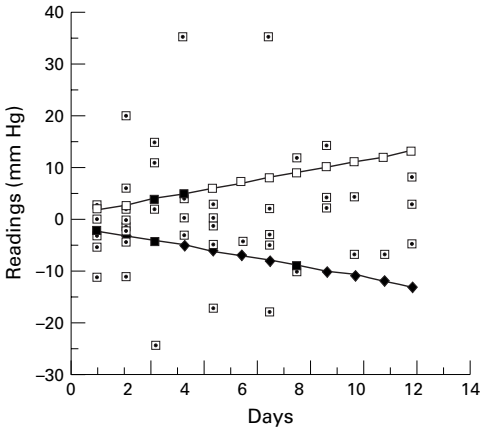

Figure 3 Scatterplot displaying zero drift readings over time. Lines indicate the maximum range of drift predicted by the manufacturer.

Table 2 Measurements obtained in the 34 probes with no more zero drift than predicted by manufacturers

Day No	No of zero drift readings	Zero drift (mm Hg)			
		Range	Mean	Median	SD
1	4	−2 to 2	0.00	0.00	1.63
2	6	−2 to 2	−0.33	−0.50	1.36
3	2	—	2.00	2.00	0.00
4	4	−3 to 4	1.25	2.00	3.40
5	6	−5 to 3	−1.50	−1.00	3.08
6	1	—	−4.00	−4.00	—
7	3	−5 to 2	−2.00	−3.00	3.60
9	2	2 to 4	3.00	3.00	1.41
10	2	−7 to 4	−1.50	−1.50	7.77
11	1	—	−7.00	−7.00	—
12	3	−5 to 8	2.00	3.00	6.55

The overall range and SD were only calculated for days when more than one reading was obtained. On day 3 both readings were 2 mm Hg, in this case range was not applicable.

Table 3 Measurements obtained in the 22 probes with more zero drift than predicted by the manufacturers

Day No	No of zero drift readings	Zero drift (mm Hg)			
		Range	Mean	Median	SD
1	5	−5 to 11	0.60	−3.00	6.54
2	4	−11 to 20	2.75	1.00	13.45
3	5	−24 to 15	−1.20	−4.00	15.38
4	1	—	35.00	35.00	—
5	1	—	−17.00	−17.00	—
7	2	−18 to 35	8.50	8.50	37.47
8	3	−10 to 12	−2.33	−9.00	12.42
9	1	—	14.00	14.00	—

The overall range and SD were only calculated for days when more than one reading was obtained.

Discussion

The aim of this study was to analyse the accuracy and drift characteristics of the Camino® ICP probe in our practice, to compare this with previous reports, and to analyse the complications related to placement of this type of probe.

The average rate of bacterial colonisation described in previous reports was 5% for ventricular probes (range 0–9.5%), 5% for subarachnoid probes (range 0–10%), 4% for subdural probes (range 1–10%), and 14% (range 11.7–16.6%) in parenchimally placed catheter tip fibreoptic devices.[5–7 13 22–25] In our study, a rate of contamination of 13.2% was found, and 2.9% of infections were considered as ventriculitis. Some reports do not show correlation between infection rate and the duration of monitoring during the first 2 weeks.[9 10 13 24] Clark *et al* found an increased risk of infection related to the number of devices placed, thus the first one was about 10.3% and the third one about 80%, although they did not have enough information to draw conclusions.[21] In our study the cases of infection were related to intraventricular Camino® probes placed for more than 10 days, so we recommend removal of the ventricular catheter if monitoring is expected to be longer. The most often isolated pathogen was *S epidermidis* as in previous reports.[8–10] Antibiotic prophylaxis is still controversial, and it needs to be specific against *Staphylococcus*. Because of the low infection rate a cephalosporin should be enough; however, we have no evidence that any antibiotic prophylaxis could be beneficial in long term treatment. All our patients were under antibiotic prophylaxis, and we cannot know the actual incidence of infection. We estimate that severe infections can develop even in patients receiving prophylactic therapy.

Haemorrhage depends on the compartment where the Camino® probe is placed, and if the patient has any kind of coagulation disorder.[14 15] Other authors agree that the coagulation disorder must be corrected before

placing the probe, and if this is not possible, another less invasive type of device such as an epidural probe should be used.[26] Haemorrhage rate in patients with coagulopathy who undergo placement of epidural devices is 3.8%. Intraparenchymal probes are associated with a 20% rate of subdural haemorrhage and 22% of intraparenchymal haemorrhage.[14] The 2.1% rate of bleeding related to Camino® probe implantation found in our study seems to be similar to that reported in the literature. In all cases the haemorrhage was only a radiological finding without clinical relevance. In patients with coagulopathy a 15.3% incidence of radiological bleeding was seen. Due to this high frequency, although it was not clinically important, we do not recommend the use of Camino® ICP probes in those patients.

Fibreoptic devices need to be calibrated before insertion, but it is not recommended to re-zero them after implantation, which is their major disadvantage. Ventriculostomy catheters need to be calibrated every 8 hours because they have a mean drift of 5 mm Hg every 8 hours and a maximum of 11 mm Hg, and we had had an hydrostatic error of 1.86 mm Hg for each 2.54 cm above or below the anatomical zero.[1–3] Fibreoptic devices have a mean daily drift of 0.6–2 mm Hg so that a a significant cumulative error in ICP after 3–4 days of monitoring can be recorded.[1 19] Some authors stated that their tendency is to drift towards positive values, so when the results of monitoring are wrong, these errors tend to overestimate ICP.[4 5 19–21] On the other hand, Bavetta *et al* in their study found a median value for zero drift of −3 mm Hg. Such a clear negative bias in zero drift had not previously been noted.[27]

An increase in temperature produced a positive drift as high as 0.27 mm Hg/°C, therefore the displayed value of ICP is as much as 4–5 mm Hg higher than the true ICP if calibrated at room temperature.[20 21] In our study we did not find a correlation between the duration of monitoring and zero drift (p=0.27). Contrary to previous studies that showed a tendency to drift towards positive values in this type of ICP device, thus overestimating ICP values, we did not find a relation between the direction of the zero drift and the duration of monitoring when we analysed the 22 probes that drifted more than that predicted by the manufacturers. Futhermore, although 60.71% of our probes seemed to perform according to the manufacturer's specifications, we cannot ignore the cumulative error in ICP records as days go by, with the subsequent therapeutic implications. The aforementioned and the inability of this device to be re-zeroed "in vivo", under sterile conditions, lead us to recommend changing the catheter if a long monitoring is expected.

Conclusions

We conclude that contamination of ICP fibreoptic devices is frequent, but clinically significant infections are rare. In our practice, intraventricular probes have an increased risk of infection with clinical significance. *Staphylococcus epidermidis* is the most frequent isolated pathogen. We do not have enough data to ascertain the efficacy of prophylactic antibiotics towards colonisation of this type of device.

Although we did not find any case of death related to haemorrhage directly due to probe placement, the haemorrhage rate was higher when patients had coagulation disorders. We strongly recommend that coagulopathy should be treated before placing the probe, and if this is not possible it is advisable to use other types of less invasive ICP device such as an epidural probe.

In our study, 60.71% of the probes seemed to perform according to the predictions by the manufacturers, but the remaining 39.28% drifted to positive or negative values. We did not find a correlation between the duration of monitoring and the zero drift (not considering the direction of the drift). Although others report that Camino® ICP monitors usually tend to overestimate ICP values with time, in our study the direction of the drift was independent of the duration of monitoring.

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HISTORICAL NOTE

The circle of Willis (1621–75)

It is easily forgotten that in the century of Shakespeare and Marlowe there was no scientific or rational physiology as we now understand these disciplines. The era was of magic and witchcraft; insubstantial notions of the *spiritus animalis* were rife, and irrational speculation abounded. The genius of Thomas Willis (1621–75) took medicine several stages forward. Willis showed that the cerebral cortex covered many subcortical centres that join the two hemispheres. The cortical grey matter, he thought was responsible for animal spirits, the white matter distributed the spirits to the body, governing movement and sensation. Willis, like Descartes, still believed that man had an immaterial, reasoning soul. Bodily activity was governed by a corporeal soul, in two parts:

> "...the animal Spirits flowing from the Medullary substance into the nerves, are as it were rays diffused from the light itself, and the other Spirits everywhere abounding in the Fibres . . . perform the acts both of the sensitive and locomotive Faculty" (Willis, 1681, p126).

The vital soul was the "flame" in the blood, and the sensitive soul was the animal spirit diffused through the brain. His experiments showed that if the blood was prevented from reaching the brain then "nerve function ceased because vital spirits could not reach the ventricles for conversion into the essential animal spirits,"—an early notion of cerebral ischaemia.

He began to employ scientific methods. With Ralph Bathurst, Richard Lower, Thomas Millington, and Sir Christopher Wren, Willis studied neuroanatomy, and comparative and experimental pathology. They all contributed to his *Cerebri Anatome*. He injected dyes to demonstrate the main blood vessels, thus providing new and superior anatomical demonstrations.

The circle of Willis

Amongst his clinical highlights was a man who died of a mesenteric tumour, who in life had no neurological symptoms. He published a case report in *Cerebri Anatome* in 1664[2 3]:

> " . . .When his skull was opened we noted amongst the usual intracranial findings, the right carotid artery, in its intracranial part, bony or even hard, its lumen being almost totally occluded; so that the influx of the blood being denied by this route, it seemed remarkable that this person had not died previously of an apoplexy: which indeed he was so far from, that he enjoyed to the last moments of his life, the free exercise of his mental and bodily functions. For indeed, nature had provided a sufficient remedy against the risk of apoplexy in the vertebral artery of the same side in which the carotid was wanting, since the size of this vessel was enlarged, becoming thrice that of the contralateral vessel..."

This case shows that Willis was fully aware of both the anatomy and the physiological importance of the circle. Thus he founded his understanding of the vascular circle at the base of the brain[4]. And, more importantly, he was able to relate the anatomy to the clinical effects of vascular disease.

> " . . .We have already shewn, that these Vessels are variously and very much ingrafted or inoculated among themselves, not only the Arteries with the Veins, but what is more rare and singular, Arteries with Arteries; to wit, the Carotidick Arteries of one side, in many, are united with the Carotides of the other side; besides the Vertebrals of either side among themselves, and are also inoculated into the posterior branches of the Carotides before united. The joynings together of the Carotides, in most living Creatures, are made about the Basis of the Skull under the Dura Mater..."[5]

Willis was not the first to demonstrate the anatomy of the circle. Gabrielle Fallopio (1523–62), Guilio Casserio in 1627, and Johann Vesling from Padua gave descriptions or illustrations of the circle, and Johann Jakob Wepfer has priority for the description but not the illustration of the Circle in his book on apoplexy[6] of 1658. Willis, however, published the first complete description, illustration, and understanding of the function of the circle. The illustration was probably the work of Wren.

Born on 27 January 1621 at Great Bedwin in Wiltshire, Willis qualified BM Oxford in 1646. He took a house opposite Merton college. Willis married the sister of John Fell, a local priest, and was active in the Church of England. He became Sedleian Professor of Natural Philosophy in 1660 and in the same year was made Doctor of Medicine. He was one of the early Fellows of the Royal Society and was elected honorary Fellow of the College of Physicians in 1664. He moved to St Martin's Lane in 1666 and was immediately successful:

> "so infinitely resorted to for his practice, that never any physician before went before him, or got more money yearly than he" (Wood, *Athenae Oxon*. ii,402).[7]

James II consulted him about the health of his children born with ulcers, "originating in the amours of their father". Willis's opinions ("mala stamina vitae") were too candid, and he was not consulted again He was widely held to be pious and,

> "a man of no carriage, little discourse, complaisance, or society . . .yet for his deep insight, happy researches in natural and experimental philosophy, anatomy, and chemistry . . .pure elegancy, delightful unaffected neatness of Latin style, none scarce have equalled . . ." (Wood).

His contemporaries neglected his extensive writings. They are well described by Hughes[3], Isler,[1] and in Munk's roll.[7] He died at St Martin's lane and was buried in Westminster Abbey.

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