

Chapter 3

Method

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Abstract

Since 1994 we have followed the principles of current neuroanaesthesia, including measurement of subdural ICP and cerebral perfusion pressure, and the data have been prospectively registered. In the first study of the procedure we described the method of subdural ICP monitoring during anaesthesia and found a fairly good correlation in paired subdural ICP measurements and almost identical pressure waves and levels of ICP.

In this chapter the method for subdural ICP monitoring and the monitoring of other physiological parameters that we utilize are described in detail. The anaesthetic techniques used, both inhaled and intravenous, are discussed. The scale for the surgeons' estimation of dural tension is disclosed, and the comparative studies mentioned in subsequent chapters are briefly described. A short summary of the statistical methods used is added.

Since 1994 we have followed the principles of current neuroanaesthesia, including measurement of subdural ICP and CPP, and the data have been prospectively registered. In the first study of the procedure we described the method of subdural ICP monitoring during anaesthesia, and found a fairly good correlation in paired subdural ICP measurements, and almost identical pressure waves and levels of ICP (Cold et al. 1996). In subsequent publications we described the influence of anaesthetic methods, and methods for evaluation of dural tension and degree of cerebral swelling after opening of dura (Bundgaard and Cold 2000; Petersen et al. 2003). Measurements of CBF and CMRO₂ were described (Bundgaard et al. 1996, 1998). Methods in connection with subdural ICP monitoring during rTp were published by Tankisi et al. (2002). Measurement of transcranial Doppler sonographics was used and described by Rasmussen et al. (2004). In the following the principles of methods used in studies of subdural ICP and cerebral haemodynamics are summarized.

3.1

Neuroradiological Examination in Patients with Cerebral Tumours

From the latest CT or MR scanning the localization of the tumours and mid-line shifts were registered. The maximum tumour area was calculated using the formula for area of an ellipse ($\text{area} = ab\pi$, where a is half the length and b is half the width of the tumour).

3.2

Localization of Aneurysm and Hunt and Hess Gradation

The localization of the aneurysm was classified with preoperative four-vessel angiography. Classification according to the Hunt and Hess scale was done just before induction of anaesthesia.

3.3

Anaesthesia and Monitoring

If premedication was deemed necessary, diazepam 5–10 mg was administered perorally. If preoperative steroid and/or anticonvulsant treatment were instituted they were given together with diazepam. Any other daily medication was given at the discretion of the attending anaesthesiologist.

Monitoring before induction consisted of automated non-invasive blood pressure (NIBP, oscillometric blood pressure), continuous electrocardiogram and pulse oximetry. After induction of anaesthesia end-tidal CO_2 and concentration of inspired and expired anaesthetic gas were monitored continuously (Datex AS3, Helsinki, Finland). Controlled ventilation (fraction of inspired oxygen (FiO_2) 50–60% by oxygen/air) was applied at a PaCO_2 between 30 and 40 mmHg, inspiratory peak pressure < 20 cm H_2O and a respiratory frequency between 10 and 20/min. The level of PaCO_2 was achieved by continuous monitoring of pulmonary ventilation and end-tidal CO_2 , and verified by arterial blood gas analysis. A Foley catheter was placed in the urinary bladder, and rectal temperature was continuously monitored. A radial artery catheter was inserted for continuous blood pressure monitoring and blood sampling. A catheter was introduced into the bulb of the internal jugular vein for pressure monitoring and blood sampling. The location of the catheter was checked by x-ray. Bupivacaine 2.5 mg/ml with epinephrine or lidocaine with epinephrine were used for infiltration of the scalp. Train-of-four stimulation was used to monitor muscular relaxation, which was achieved by a continuous infusion of atracurium.

The anaesthetic procedures included the following.

Group 1: Propofol-Fentanyl

Anaesthesia was induced with propofol 1–3 mg/kg given over 1 min and fentanyl 3–4 µg/kg. Lidocaine 1 mg/kg was administered over 1 min followed by muscular relaxation by atracurium 0.5 mg/kg. Anaesthesia was maintained with infusions of propofol 6–10 mg/kg/h and fentanyl 2–3 µg/kg/h. Just before incision of the scalp doses of propofol 1 mg/kg and/or fentanyl 1–2 µg/kg/h were supplemented, if necessary. The infusion rates of propofol and fentanyl were unchanged during the ICP measurements and during the estimation of dural swelling.

Group 2: Isoflurane-Fentanyl

Anaesthesia was induced with propofol 1–3 mg/kg given over 1 min and fentanyl 2–3 µg/kg. Lidocaine and atracurium were administered as in group 1. Anaesthesia was maintained with isoflurane (maximally 1.5 minimal alveolar concentration (MAC)) and fentanyl 2–3 µg/kg/h. Just before incision of the scalp fentanyl 1–2 µg/kg/h was supplemented, if necessary. The dose of isoflurane and the infusion rate of fentanyl were unchanged during the ICP measurements and during the estimation of dural swelling.

In Chapter 11, study 1, and in the study in Chapter 12, isoflurane was administered with nitrous oxide 50–67% and fentanyl.

Group 3: Sevoflurane-Fentanyl

Anaesthesia was induced with propofol 1–3 mg/kg given over 1 min and fentanyl 2–3 µg/kg. Lidocaine and atracurium were administered as in group 1. Anaesthesia was maintained with sevoflurane (maximally 1.5 MAC) and fentanyl 2–3 µg/kg/h. Just before incision of the scalp fentanyl 1–2 µg/kg/h was supplemented, if necessary. The dose of sevoflurane and the infusion rate of fentanyl were unchanged during the ICP measurements and during the estimation of dural swelling.

Group 4: Propofol-Remifentanyl

Anaesthesia was induced using 1–3 mg/kg propofol supplemented with 0.5–1 µg/kg remifentanyl during 1 min followed by 0.1–0.15 mg/kg cisatracurium for muscular relaxation. Anaesthesia was maintained with 0.2–0.5 µg/kg/min remifentanyl and 4–8 mg/kg/h propofol. The infusion rates of propofol and remifentanyl were unchanged during the ICP measurements and during the estimation of dural swelling.

In patients with supratentorial cerebral tumours the effect of anaesthesia on ICP, MABP, CPP and jugular bulb pressure (JBP), and the effect of hyperventilation are indicated in Chapter 10. The same parameters in patients with cerebral aneurysm are indicated in Chapter 19.

3.4

Fluid Administration and Regulation of Blood Pressure

During the first hour of anaesthesia isotonic saline 15 ml/kg was administered, and followed by 2–4 ml/kg/h. If systolic blood pressure decreased > 20 mmHg colloids, in the form of either Haes-Steril 6% (hydroxyethyl starch; Fresenius Kabi, Uppsala, Sweden) or 5% dextran in saline, were administered, if needed, eventually supplemented with ephedrine 5–10 mg intravenously. Packed erythrocytes, albumin or fresh frozen plasma were not given before the ICP measurements.

3.5

Subdural Intracranial Pressure and Cerebral Perfusion Pressure

Subdural ICP was measured during surgery by use of the following method. After removal of the bone flap ICP was measured subdurally by an intravenous needle (22G/0.8 mm), which was connected to a pressure transducer via a polyethylene catheter. The transducer was placed in the same sagittal plane as the dura, and zero point adjustment was performed with the tip of the needle placed at the point of intended insertion of the dura. The needle was introduced through the dura until a continuous recording of ICP with typical cardiac and respiratory waves appeared. After 1 min of stabilization the integrated mean value of subdural pressure was used as an estimate of ICP. The needle was left in situ until the study was finished, and during the measurement no surgical intervention was performed. Simultaneously the integrated value of MABP was recorded via the radial artery catheter. The mid-axillary line was used for zero point adjustment for the arterial blood pressure.

The CPP was calculated as the difference between MABP and ICP. The surgeons were blinded as regards the values of ICP, MABP and JBP. The

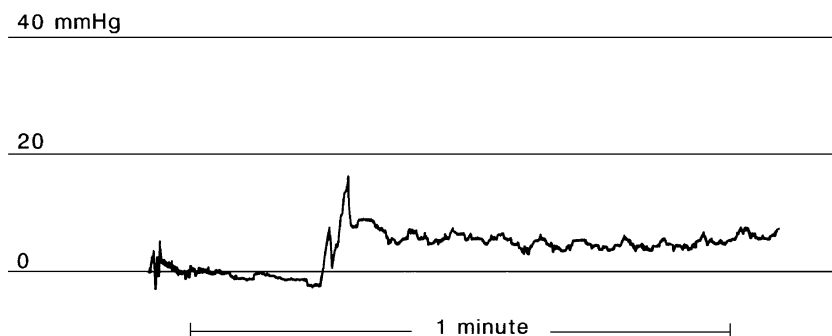


Fig. 3.1 Recording of subdural ICP, with zero-point adjustment, perforation of dura mater and cardiac and respiratory waves

measurement of subdural ICP was normally finished after 1 min. In Figure 3.1 subdural ICP is illustrated with cardiac and respiratory waves.

In Chapter 21 studies of subdural or spinal pressure during spinal surgery are described. In these studies the distance between the skin and the surface of the spinal dura was measured, and the transducer was placed according to this distance.

3.6

Catheterization of the Internal Jugular Vein and Blood Gas Analyses

A jugular bulb catheter was inserted percutaneously at the level of the cricoid. In order to avoid puncture of the carotid artery, catheterization was performed with the head in neutral position (Sulek et al. 1996) and with the patient positioned in 5–10° rTp. This position dilates the jugular vein (Clenaghan et al. 2005). The catheter was introduced 12–14 cm in the cranial direction. Correct cranial position was verified by ascertaining an increase in jugular pressure following neck compression and by unrestrained blood withdrawal. In some cases a lateral x-ray of the neck was exposed to verify correct position of the catheter. The catheter was connected to a transducer and placed in the same sagittal plane as the transducer connected to the needle for subdural ICP measurement.

Blood was withdrawn simultaneously from the arterial and jugular catheters for measurement of PaO_2 , PaCO_2 , pH, glucose lactate, Na^+ , K^+ and Ca^{++} (ABL 555 and ABL 700; Radiometer, Copenhagen, Denmark). AVDO_2 was calculated as the difference between arterial and jugular venous oxygen content. Furthermore, the arteriovenous difference of PaCO_2 (AVD-CO_2), pH (AVD-pH), lactate ($\text{AVD-lactate (mmol/L)}$), Na^+ ($\text{AVD-Na}^+ \text{ (mmol/L)}$), K^+ ($\text{AVD-K}^+ \text{ (mmol/L)}$) and Ca^{++} ($\text{AVD-Ca}^{++} \text{ (mmol/L)}$) were calculated.

3.7

Measurement of Cerebral Blood Flow and Cerebral Metabolic Rate of Oxygen

Two angular detectors were placed on each side of the head. As tracer, ^{133}Xe (3–4 mCi i.v.) was used. CBF was measured over a period of 10 min as initial slope index using 10-min clearance curves with a Novo Cerebrograph 10. Correction for rest activity and recirculation was performed. The average of the two CBFs was used. CMRO_2 was calculated according to the formula $\text{CMRO}_2 = \text{CBF} \times \text{AVDO}_2$. CBF is measured in Chapter 11, study 1 (indomethacin), Chapter 12 (dihydroergotamine) and Chapter 9 (sevoflurane). In the study of dihydroergotamine (Chapter 12) the CVR was calculated using the formula $\text{CPP} = \text{CBF} \times \text{CVR}$.

3.8

Measurement of Flow Velocity

Transcranial Doppler ultrasonography was used in study 2 in Chapter 11 (indomethacin). In this study middle cerebral artery flow velocity was measured bilaterally. The artery was identified at a depth varying between 45 and 55 mm. The flow velocity was monitored beat-to-beat using a 2-MHz pulsed Doppler probe (TC 2000S; EME Überlingen, Germany). Transcranial Doppler frequency spectra, converted into flow velocity (cm/s), were calculated automatically over 4–5 consecutive cardiac cycles. The mean middle cerebral artery blood flow velocity was recorded and, because flow velocity fluctuates with respiration, the value during end-expiration was used.

3.9

Effect of Hyperventilation and Indomethacin

After the initial ICP measurement the pulmonary ventilation was increased by 30% for 10 min. The measurements were repeated 11 min after the first measurements. CO_2 reactivity was calculated as % change $\text{AVDO}_2 / \Delta \text{PaCO}_2$ mmHg (Chapter 10) or % change $\text{AVDO}_2 / \Delta \text{PaCO}_2$ kPa (Chapter 13).

In some comparable studies the effect of indomethacin and hyperventilation was analysed by comparing the changes in ICP or changes in AVDO_2 .

3.10

Estimation of Dural Tension and Cerebral Swelling

Before subdural ICP measurement the surgeon made a tactile evaluation of the dural tension. The neurosurgeons were blinded as regards choice of anaesthesia and the ICP value obtained. The tensions were categorized as follows: (1) very slack, (2) normal, (3) increased tension and (4) pronounced increased tension.

The degree of brain swelling during hyperventilation was evaluated by the neurosurgeon after opening of dura. Swelling was estimated as: (1) no swelling, (2) moderate swelling of the brain and (3) pronounced swelling of the brain.

3.11

Measurement of Intracranial Pressure During Tilting of the Operating Table

The arterial and jugular pressure (JP) transducers were placed on the same horizontal plane as the ICP transducer to eliminate the influence of hydro-

static pressure difference during tilting of the operating table. CPP was calculated as the difference between MABP and subdural ICP. After reference measurements of ICP, MABP and JP in neutral position, the operating table was tilted 5° head-down (5° rTp), with whole-body trunk tilting without flexion of the hips. In this position all pressure transducers were readjusted to the same horizontal level of the dural perforation. The degree of tilting was adjusted using a spirit level fixed to the operating table. A laser pointer fixed to the transducer table was used to place the transducers in the same horizontal plane as the subdural needle. The measurement procedure was repeated after readjustment of the table to 10° and 15° rTp. In accordance with previous investigations performed in our clinic, in which MABP, ICP, CPP and JBP were stable within 1 min after tilting to 10° rTp, the pressure measurements were performed 1 min after a change in position. The effect of rTp on ICP, MABP, CPP and JBP are summarized in Chapter 15.

3.12

Comparative Studies of Intracranial Pressure-Reducing Methods

Data from patients with supratentorial tumours were extracted from our database for the period 1997–2006. The following criteria were used as inclusion in the study: The neurosurgeon estimated that the dura tension was increased and/or ICP exceeded 10 mm Hg at the initial measurement. The following ICP-reducing techniques were used.

3.12.1

Hyperventilation

The minute ventilation of the ventilator was increased by 20–50% for 5 min. In order to keep the peak respiratory pressure below 20 cmH₂O, the respiratory rate was eventually increased. Before and 5 min after the increase in minute ventilation subdural ICP and MABP were recorded, and arterial gas tensions were monitored. Thirty patients were included.

3.12.2

Ten Degrees Reverse Trendelenburg Position

After reference measurements of ICP, CPP and MABP in neutral position, the table was adjusted to 10° rTp (whole body trunk tilting without flexion at the hips) and all pressure transducers were re-adjusted to the same level of dural perforation. As a result of a recent study, indicating stable CPP and ICP within 1 min after tilting to 10° rTp, the measurements were performed 1 min after change in position. Sixteen patients were included.

3.12.3

Mannitol Treatment

Over about 5 min, 0.5–1.0 g/kg mannitol was administered intravenously. ICP and CPP were recorded before and 5 min after conclusion of mannitol infusion. Nineteen patients were included.

3.12.4

Indomethacin

Indomethacin 0.5 mg/kg was administered i.v. as a bolus dose. ICP and CPP were recorded for 5 min, and arterial gas analysis was performed before and 5 min after indomethacin. Fifteen patients were included.

3.12.5

Surgical Decompression

Surgical decompression was performed either by drainage via a ventricular catheter inserted during the operation ($n=3$) or by evacuation of fluid from cystic tumours ($n=10$). ICP and CPP were recorded before and after decompression, and the volume of fluid from drainage was recorded. Thirteen patients were included.

3.13

Studies of the Effect of Central Analgetics in Patients with Cerebral Tumours

During propofol-fentanyl anaesthesia patients subjected to craniotomy for supratentorial cerebral tumours were subjected to a bolus dose of alfentanil in the following doses: 10, 20 and 30 $\mu\text{g/kg}$ alfentanil followed by an infusion of 10, 20 and 30 $\mu\text{g/kg/h}$. ICP and CPP were measured continuously before and after administration (Chapter 13). In the same chapter the effects of i.v. fentanyl bolus dose, and remifentanyl bolus dose were investigated.

3.14

Studies of Propofol Bolus Dose

In Chapter 14 the effect of an i.v. bolus dose of propofol was studied during propofol-fentanyl and during propofol-remifentanyl anaesthesia.

3.15

Patients Subjected to Controlled Studies

After informed consent and before premedication, a sealed numbered envelope indicating anaesthetic procedure or test drug/placebo was opened.

3.16

Statistical Analysis

In intra- and intergroup studies the statistical analyses were as follows: Data within groups were tested for normal distribution. The normality test and equal variance test were applied and one-way ANOVA was used for analysis if these tests were passed. The Tukey test was used for pair-wise multiple comparison procedures. The Kruskal-Wallis one-way analysis of variance on ranks and multiple comparisons versus control groups (Dunn's method) were used for statistical analysis when the normality test or equal variance showed that the data were not normally distributed. These data included subdural ICP, MABP and $AVDO_2$. Bonferroni's test was applied for statistical analysis. In other studies where only two groups were compared the *t*-test was used if the normality test was passed; if not Mann-Whitney's test was used for intergroup differences and Wilcoxon's test for intragroup changes. The chi-square test was used for statistical analysis of demographic data, localization, size and histopathological diagnosis of the tumours, preoperative steroid administration and position of the head. Difference in tension of dura and the degree of cerebral swelling were tested by the chi-square test in 2×4 or 2×3 tables. For correlation studies Pearson's product moment correlation and linear regression were performed. Means and standard deviation (SD) were calculated in some studies and median and range in others, according to the distribution of the data. $P < 0.05$ was considered statistically significant.

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