Optimal reverse Trendelenburg position in patients undergoing craniotomy for cerebral tumors

ALP TANKISI, M.D., PH.D., AND GEORG EMIL COLD, M.D., PH.D.

Department of Neuroanesthesia, Aarhus University Hospital, Aarhus, Denmark

Object. To the authors’ knowledge, repeated measurements of intracranial pressure (ICP), cerebral perfusion pressure (CPP), and the degree of dural tension during different positions on the operating table (reverse Trendelenburg position [rTp]) have not been studied in patients undergoing craniotomy.

Methods. In the present study 53 patients with supratentorial cerebral tumors who underwent craniotomy in the supine position were included. Subdural ICP, mean arterial blood pressure (MABP), CPP, and jugular bulb (JB) pressure were recorded, and the degree of dural tension was analyzed while patients were in the neutral operating position and at 5, 10, and 15˚ rTp. The optimal operating position was defined as the one at which subdural ICP was as low as possible, and CPP was greater than or equal to 60 mm Hg or as high as possible.

Subdural ICP, MABP, and JB pressure decreased significantly after each 5˚ change in rTp compared with the preceding position. Dural tension decreased significantly up to 10˚ rTp, but was unchanged at 15˚ rTp. At 5˚ rTp CPP remained unchanged, but it decreased significantly during 10 and 15˚ rTp. The optimal position in the majority of patients was determined to be 15˚ rTp.

Conclusions. Before opening the dura mater for craniotomy, repeated measurements of ICP and CPP, in the neutral position and at 5, 10, and 15˚ rTp, provide valuable information regarding the optimal level of ICP and CPP.

KEY WORDS • craniotomy • intracranial pressure • cerebral swelling • operative position • reverse Trendelenburg position

In a study of patients with intracranial tumors or cerebral aneurysms who underwent intracranial surgery, a decrease in lumbar cerebrospinal pressure averaging 1.8 mm Hg at 30˚ Trendelenburg position was demonstrated, but CPP and MABP did not change significantly. Likewise, studies in patients in a supine or prone position during craniotomy indicate that 10˚ rTp decreases subdural ICP effectively, leaving CPP unchanged.

To our knowledge, a systematic clinical study of the effects of varying degrees of rTp on ICP and CPP during craniotomy in patients in the supine position is not available. In a recent study of 692 patients, cerebral swelling rarely occurred (5% probability) at subdural ICPs less than 5 mm Hg, but at ICPs greater than 13 mm Hg brain swelling occurred with 95% probability. The aims of the present study were to: 1) investigate the effects of the neutral position and 5, 10, and 15˚ rTp on subdural ICP, CPP, MABP, and JB pressure in patients in a supine position who underwent a craniotomy for cerebral tumors; 2) determine the optimal rTp position, defined as the position at which subdural ICP is as low as possible and at which CPP is greater than or equal to 60 mm Hg or as high as possible; and 3) study the effects of ICP on the distribution of optimal position, by evaluating patients in three groups based on the risk of cerebral swelling: low risk (Group I, ICP < 5 mm Hg), intermediate risk (Group II, ICP from 5–13 mm Hg), and high risk (Group III, ICP > 13 mm Hg).

Clinical Material and Methods

Fifty-three consecutive adult patients who underwent elective craniotomy in the supine position for supratentorial cerebral tumors were studied. As a result of previous investigations conducted in our department, we routinely use subdural ICP monitoring and JB catheters, and because of preliminary results of the effects of rTp, we routinely study the effects of rTp in patients undergoing elective craniotomy. The data are collected prospectively and stored in a data bank. Measuring ICP and CPP during rTp are routine procedures as well.

Subdural ICP measurement is a research device for "control of production" during craniotomy. Measurements of subdural ICP and JB pressure are additional procedures, and therefore may be associated with complications or lengthening of operations, and are not part of the standard of care. Thus, this study was classified as a control of production, and in accordance with the local ethics committee, informed consent was not necessary. Insertion of a catheter into the radial artery is a routine neurosurgical procedure in our
department. As a result of data from a recent study indicating that subdural ICP during propofol–fentanyl anesthesia is lower compared with isoflurane–fentanyl or sevoflurane–fentanyl anesthesia, propofol–fentanyl anesthesia was used as the standard in the present study.\textsuperscript{21}

\textbf{Tumor Data}

Localization of the tumors was determined using computed tomography or magnetic resonance images. The maximum cross-sectional area of the tumors (in cm\textsuperscript{2}) and the extent of the midline shift (in mm) were determined. Histopathological diagnoses were obtained.

\textbf{General Anesthesia and Monitoring}

All patients were placed in a state of anesthesia using propofol–fentanyl after oral premedication (5–15 mg diazepam). After patients arrived at the operating room, they were routinely monitored by continuous electrocardiography, pulse oximetry, and automatic noninvasive blood pressure monitoring. After induction of anesthesia, end-tidal CO\textsubscript{2}, rectal temperature, left radial arterial catheter invasive blood pressure, and right JB pressure were monitored using an anesthesia monitor (Datex AS/3, Soma Technology, Inc.). Anesthesia was induced with propofol (1.5–2.5 mg/kg) and fentanyl (2–4 µg/kg). Cisatracurium (0.2 mg/kg) was used for tracheal intubation. The patients were monitored using train-of-four stimulation. For maintenance of anesthesia, propofol (8–12 mg/kg/hr) and fentanyl (1.5–2.5 µg/kg/hr) were used.

After endotracheal oral intubation, patients were moderately hyperventilated using a ventilator with an O\textsubscript{2}–air mixture. We attempted to achieve levels of PaCO\textsubscript{2}, and PaO\textsubscript{2}, at 4.0 to 4.5 kPa and greater than 13 kPa, respectively.

Normal saline (15 ml/kg) and 6% hydroxyethyl starch (500 ml) were infused intravenously over the 1st hour after induction of anesthesia. For maintenance, 2 to 4 ml/kg/hr normal saline was used. Hypotension was treated with 5 to 10 mg ephedrine intravenously. Before surgery, 0.25% bupivacaine (5–10 ml) was used for infiltration analgesia in the scalp.

\textbf{Measurement of Subdural ICP, MABP, CPP, and JB Pressure}

Subdural ICP was measured using a previously described technique.\textsuperscript{4} A 22-gauge needle (Venflon, 0.8 mm) connected to a pressure transducer via a water-filled polyethylene catheter was used. The transducer was placed on the same horizontal plane as the craniotomy opening, and a zero-point adjustment was performed with the tip of the needle positioned at the site of the subsequent dural perforation. The needle was advanced through the dura mater until typical cardiac and respiratory waves were observed. The integrated mean value of subdural pressure was used as an estimate of subdural ICP. An arterial line was inserted in the right or left radial artery. A jugular catheter was inserted percutaneously at the level of the cricoid. The catheter was introduced 12 to 14 cm into the JB. Ascertaining the correct position of the catheter was determined by identifying an increase in jugular pressure after application of high neck compression and verifying unrestrained withdrawal of blood through the catheter.

The arterial and jugular pressure transducers were placed on the same horizontal plane as the ICP transducer to eliminate the influence of a hydrostatic pressure difference during tilting of the operating table. Cerebral perfusion pressure was calculated as the difference between MABP and ICP. After reference measurements of ICP, CPP, MABP, and JB pressure in patients in the neutral position, the operating table was adjusted to 5˚ rTp (whole-body trunk tilting without flexion at the hips), and all pressure transducers were readjusted to the same horizontal level of dural perfusion. The measurement procedure was repeated after readjustment of the table to 10 and 15˚ rTp. In accordance with data from a recent study in which MABP, ICP, CPP, and JB pressure were stable within 1 minute after tilting to 10˚ rTp and remained stable for the following 10 minutes,\textsuperscript{5} the pressure measurements in this study were performed 1 minute after a change in position.

The degree of tilting was adjusted using a spirit level (Waterpas) 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 optimal position was defined as the position at which subdural ICP was as low as possible, and CPP was greater than or equal to 60 mm Hg or as high as possible. After the measurements, the subdural needle was withdrawn and the surgical procedure was continued at the position preferred by both the surgeon and anesthesiologist.

In a recent study, the risk of cerebral swelling after opening of the dura depended on the subdural ICP.\textsuperscript{21} Therefore, the distribution of optimal positions was divided into three groups of patients at the neutral position. Group I consisted of 15 patients with ICP less than 5 mm Hg, Group II was composed of 29 patients with ICP from 5 to 13 mm Hg, and Group III contained nine patients with ICP greater than 13 mm Hg.

\textbf{Dural Tension and Cerebral Swelling}

After removal of the bone flap and exposure of the dura, dural tension was estimated by the neurosurgeon as slack, normal tension, increased tension, or pronounced increased tension in the neutral position. Estimations of dural tension were repeated consecutively during 5, 10, and 15˚ rTp. The degree of cerebral swelling after dural incision was evaluated 1 minute after opening of the dura and graduated as brain below the level of the dura, no swelling, moderate swelling, or pronounced swelling of the brain.

\textbf{Statistical Analysis}

All ICP, CPP, MABP, and JB pressure data were found to be normally distributed. The results are presented as the mean ± SD. Comparisons between the neutral position and measurements at 5, 10, and 15˚ rTp were performed using analysis of variance for repeated measures. Comparisons between the groups were performed using an independent t-test. The chi-square test was used for comparisons of demographic data, dural tension, and distributions of optimal positions. A probability value of less than 0.05 was considered statistically significant.

\textbf{Results}

Demographic, PaCO\textsubscript{2}, PaO\textsubscript{2}, rectal temperature, histopa-
thological findings, and neuroradiology data obtained in the 53 patients in the study are summarized in Table 1. No significant differences were observed between the respective groups in any of these data categories.

**Effects of rTp on ICP, MABP, and CPP**

Subdural ICP, MABP, and JB pressure decreased significantly after each 5˚ change in position compared with the preceding position (p < 0.05). In contrast, CPP remained unchanged at 5˚ rTp, but decreased significantly at 10 and 15˚ rTp compared with the neutral position (p < 0.05; Table 2). At the neutral position, nine patients were at a high risk of cerebral swelling (ICP > 13 mm Hg) compared with one patient at 15˚ rTp. The number of patients with low cerebral swelling risk (ICP < 5 mm Hg) increased from 15 to 39 at 10˚ rTp, and from 39 to 42 when position changed from 10 to 15˚ rTp (Table 3).

**Optimal Position**

The optimal position was defined as the position at which subdural ICP was as low as possible and CPP was greater than or equal to 60 mm Hg or as high as possible. Including all 53 patients, the optimal position was the neutral position in five patients (9.4%), at 5˚ rTp in five (9.4%), at 10˚ rTp in 10 (18.9%), and at 15˚ rTp in 33 (62.3%) (Table 4). In contrast, the lowest ICP was found in one patient (2%) in the neutral position, in two (4%) at 5˚ rTp, in 10 (19%) at 10˚ rTp, and in 40 (75%) at 15˚ rTp. No significant intergroup differences regarding the distribution of optimal position were found between patients in Groups I, II, and III, representing low (5%), intermediate, and high (95%) risk of cerebral swelling, respectively.

In the majority of patients, the position at which the dura was opened differed from the optimal position, either because the levels of ICP and CPP and the degree of dural tension were found to be acceptable by the neurosurgeon, or because surgical access was difficult or impossible due to excessive tilting of the operating table.

**Intracranial Pressure and Cerebral Swelling**

Cerebral swelling was not evaluated in two patients in whom a stereotactic biopsy procedure was performed. In 26 patients (49%) with ICP less than 5 mm Hg during dural incision, no cerebral swelling occurred. Cerebral swelling was observed in seven (35%) of 20 patients with subdural ICP between 5 and 13 mm Hg and in four (80%) of five patients with subdural ICP greater than 13 mm Hg (Fig. 1).

**Relationship Between Dural Tension and Subdural ICP**

At the neutral position, 23 patients had increased dural tension. The number of patients with increased dural tension decreased to 17 at 5˚ rTp, to 10 at 10˚ rTp, and to nine at 15˚ rTp. The dural tension decreased significantly at 5 and 10˚ rTp compared with the neutral position. The change in dural tension from 10 to 15˚ rTp was not significant.

**Discussion**

Head elevation is a standard treatment procedure for patients with intracranial hypertension.5,7,19,28,29 The effect of 30 to 45˚ head elevation on decreasing ICP is well documented, but a decrease in CPP can occur. In several studies, however, large interindividual responses to head elevation were found with regard to changes in ICP and CPP.6,7,19,20,28 Consequently, a 15 to 30˚ head elevation is advocated.6,7,19,20,28 Our results in this study are in agreement with these previous findings. In the present study, a decrease in ICP with increasing rTp from the neutral position to 15˚ was discovered. Cerebral perfusion pressure remained stable at 5˚ rTp but decreased successively with 10 and 15˚ rTp.

With the criteria used in the present study for optimal positioning, large interindividual differences were found regarding ICP and CPP levels, because of the progressive decrease in MABP and consequently CPP. Although 15˚ rTp was found to be the optimal position in the majority of patients for ICP and CPP, in the majority of patients the position at which the dura was opened differed from the optimal position—most often because the levels of ICP and CPP and the degree of dural tension were found to be acceptable by the neurosurgeon—and consequently surgery was continued at 5 or 10˚ rTp.

In a recent study we observed that cerebral swelling after opening of the dura rarely occurred at subdural ICPs less than 5 mm Hg (5% probability), whereas swelling occurred with 95% probability at ICPs greater than 13 mm Hg.23 Accordingly, in the present study no cerebral swelling was observed in patients with ICPs less than 5 mm Hg, and cerebral swelling occurred in four of five patients with ICPs greater than 13 mm Hg. The importance of the threshold of ICP less than 5 mm Hg is supported by the observation that rTp is an effective method for decreasing ICP and preventing cerebral swelling.5,25,31

In a clinical study of patients with normal neurological function, cerebral autoregulation was not affected during propofol–fentanyl anesthesia,20 and in patients in whom anesthesia was induced with propofol until isoelectric electroencephalographic activity suppression, cerebral autoreg-
There are no studies of cerebral autoregulation during propofol–fentanyl anesthesia in patients with cerebral tumors, however, and in the present study cerebral autoregulation was not investigated. In patients with head injury and intact cerebral autoregulation, a reduction in CPP within the autoregulatory range induces cerebral vasodilation and increases CBV and ICP. In contrast, a decrease in CPP is accompanied by a decrease in ICP in patients with abolished cerebral autoregulation, or in patients in whom CPP is below the lower point of cerebral autoregulation. In the present study, the decrease in CPP was minimal, averaging 1.7 ± 3.8 and 3.7 ± 4.7 mm Hg at 10 and 15˚ rTp, respectively, and no significant relationship was found between the change in ICP and the change in CPP. In these findings, it is assumed that the change in CPP had only a minimal effect on the change in ICP, and that the decrease in CPP was not clinically significant and did not activate the cerebral autoregulation and consequently influence the change in ICP.

In this study, one of the criteria of optimal position was defined as CPP greater than or equal to 60 mm Hg. This threshold of 60 mm Hg is based on the concept that the lower level of cerebral autoregulation is between 50 and 80 mm Hg,13,16,29 with an average of 60 mm Hg. In a recent study of patients with severe head injury, a CPP less than 60 mm Hg worsened outcome.10 In the same group of patients, a decrease in CPP below 60 mm Hg decreased brain oxygen tension, whereas an increase in CPP above 60 mm Hg did not influence brain oxygen tension.12 Furthermore, in ischemic cerebrovascular disease, unchanged cerebral blood flow at a CPP greater than 60 mm Hg has been documented.23 Studies in healthy volunteers, however, have indicated that the lower level of cerebral autoregulation is a MABP of 85 mm Hg in normotensive patients26,27 and approximately 113 mm Hg in hypertensive patients.23 A threshold of CPP based on preoperative blood pressure level could be justified but was not used in the present study, partly because no patients had arterial hypertension or were undergoing treatment with antihypertensive drugs, and partly because preoperative blood pressure measurement, both before and after premedication, was found to be an inaccurate estimate of the blood pressure because anxiety was not controlled.

One mechanism by which ICP decreases during rTp is through a decrease in CBV caused by augmented venous outflow from the intracranial compartment. In the present study a significant decrease in JB pressure as well as ICP was found. This finding is in accordance with data from previous studies of patients in the supine position25 and in patients in the prone position with cerebral tumors.31 The decrease in JB pressure is also in accordance with the findings of Lovell et al.,35 who found a decrease in CBV in patients in the elevated head position compared with patients in the neutral position.

In the intensive management of neurosurgical patients, a decrease in ICP and no change in CPP at the 30˚ head elevated position has been documented.6,7,20 This finding is in accordance with data from studies performed in patients with cerebral tumors subjected to 10˚ rTp.25,26 Even during a 10-minute observation period, ICP and CPP were stable after a change in position from neutral to 10˚ rTp. In contrast, a significant decrease in CPP (1.7 ± 3.8 mm Hg) was observed in the present study when the neutral position was compared with 10˚ rTp. The perioperative fluid management and anesthetic management were identical. Although the differences in CPP seem to be of minor importance, our previous statement that CPP is unchanged during 10˚ rTp must be adjusted. Although 10 and 15˚ rTp were tolerated by the majority of patients, unpredictable changes in both ICP and CPP may occur when rTp is applied. Careful adjustment of rTp with successive 5˚ increases in the angle of the operating table is therefore advocated.
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Fig. 1. Scatterplot showing the relationship between subdural ICP and cerebral swelling during dural incision. Swelling Degree 1 indicates patients in whom the brain is below the level of the dura, Degree 2 indicates no cerebral swelling, Degree 3 indicates moderate swelling, and Degree 4 indicates pronounced swelling of the brain. Reference lines at 5 and 13 mm Hg indicate the risk of cerebral swelling of 5 and 95%, respectively, in accordance with data from a recent study of patients with cerebral tumors by Rasmussen, Bundgaard, and Cold.

Conclusions

Repeated measurements of ICP and CPP, at the neutral position and at 5 and 10° rTp, can be obtained within a few minutes, and a decision concerning optimal patient position before opening the dura can be drawn immediately after these measurements. The results of this study suggest that 5° rTp reduces ICP without affecting CPP, and therefore 5° rTp can be used without limits provided that intravenous fluid therapy is optimized. In the majority of patients, 15° rTp was optimal with regard to the ICP and CPP levels as defined in this study. Compared with 5° rTp, both 10 and 15° rTp decreased ICP further, but CPP decreased as well. Thus, 10 and 15° rTp should be used with caution, and we advocate that both ICP and CPP should be monitored when these patient positions are considered. Although we did not observe any cases of air embolism in our patients, we note the risk of air embolism because of negative JB pressure values during 10 and 15° rTp.

References


Address reprint requests to: Alp Tankisi, M.D., Ph.D., Department of Neuroanesthesia, Nørrebrogade 44, Bygning 10, 7. Etage, Aarhus University Hospital, 8000 Aarhus C, Denmark. email: alpta@as.aaa.dk.