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A review of perioperative complications during frameless stereotactic surgery: our institutional experience

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Abstract

Purpose. Frameless stereotactic neurosurgery is increasingly being used for the biopsy of intracranial tumors and the resection of deep-seated lesions where reliance on surface anatomic landmarks can be misleading, as well as in movement disorders, psychiatric disorders, seizure disorders, and chronic refractory pain. Nascent biological approaches, including gene therapy and stem-cell and tissue transplants for movement disorders, also utilize neuronavigational techniques. These procedures are complex and involve understanding of the basic principles and factors affecting neuronavigation. The procedure may appear to be simple, but serious complications may occur.

Methods. The purpose of this study was to review the intraoperative and postoperative complications occurring during frameless stereotaxy at our institution from January 2003 to July 2007.

Results. Seventy-eight patients underwent various neurosurgical procedures under general anesthesia. Intraoperative complications seen were intraoperative brain bulge ($n = 3$), seizures ($n = 3$), failure to extubate ($n = 4$), and fresh neurodeficits ($n = 6$). No hemodynamic disturbances such as hypertension or hypotension or bradycardia or tachycardia requiring active intervention were observed.

Conclusion. Awareness and vigilance can help in the early identification and better management of the above intraoperative complications.

Key words Neuronavigation · Frameless stereotaxy · Intraoperative complications

Introduction

Frame-based stereotaxy provides the neurosurgeon with a safe and effective (diagnostic yield >95%) [1–3] means of biopsy retrieval compared with freehand computed tomographic (CT)-directed burr-hole biopsy [4,5]. However, frame-based systems are point-based, require complex calculations for each target, employ large cumbersome structures, require scanning within the frame, and, for the anesthesiologist, cause difficult airway access. Some frameless stereotactic systems have been shown to have a level of accuracy similar to that of the frame-based methods [6]. Frameless stereotactic biopsy with a neuronavigation system also allows rapid interactive planning of several targets; high-risk structures can be displayed and delineated on the workstation, yielding important information regarding the route of the biopsy needle [7]. The integration of intraoperative ultrasonography and functional imaging modalities; in particular, magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET) with frameless stereotaxy has permitted surgery in the vicinity of eloquent brain areas with minimum morbidity [8]. The spatial accuracy of the modern frameless stereotaxy system is further enhanced by the use of intraoperative MRI that provides real-time images to document the residual lesion and to assess for brain shift during surgery [9,10].

These procedures present a challenge to the anesthesiologist as they are complex and involve understanding of the basic principles and the factors affecting neuronavigation. Maintenance of normocapnia and the judicious use of decongestants and diuretics are essential, as the anesthetic management can affect the effective diagnostic yield of the biopsy. The procedure may appear to be simple, but complications such as seizures, intraoperative brain bulge, and postoperative neurodeficits can occur. Our literature search revealed anesthetic management and intraoperative complications associated with framed stereotaxy [11,12]. However, the same has never been reported for frameless stereotaxy. The purpose of this study was to review our experience of patients undergoing frameless stereotaxy with

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an emphasis on the intraoperative and postoperative complications.

Patients, materials, and methods

After obtaining institutional ethics committee approval, data were collected retrospectively on all patients who had undergone frameless stereotaxic-guided biopsies of intracranial tumors, gene therapy for glioblastoma multiforme, and aspiration of brain abscess (Table 1) at our institute from January 2003 to July 2007. Data were collected about the general demographics, each patient's medical condition, any comorbid condition, the type of neuronavigational procedure, anesthetic management, intraoperative and postoperative complications, and any new postoperative deficit arising after surgery. A standard management protocol had been followed for all patients. All patients were premedicated with glycopyrrolate 0.2 mg intramuscularly, 1 h before surgery. External markers (fiducials) were applied on the scalp, prior to or on the day of surgery. After the placement of the fiducials, MRI scanning was done to visualize brain structures. Patients were then transferred to the operating room with the fiducials in place, where care of the patient was taken over by the anesthesiologist. Patients were placed in the supine position. An intravenous line was established and standard anesthesia monitors (noninvasive blood pressure, electrocardiogram, and pulse oximeter) were attached.

General anesthesia was induced with fentanyl 2 $\mu g \cdot kg^{-1}$ and thiopentone 4–5 $mg \cdot kg^{-1}$ and rocuronium 1 $mg \cdot kg^{-1}$ to facilitate tracheal intubation. Anesthesia was maintained with isoflurane (minimum alveolar concentration [MAC], 0.8–1.2) in a mixture of oxygen and nitrous oxide (1 :2), with vecuronium (0.02 $mg \cdot kg^{-1}$) and fentanyl (1 $\mu g \cdot kg^{-1}$). Mechanical ventilation was started to maintain end-tidal carbon dioxide between 35 and 40 mmHg. Hemodynamic parameters such as heart rate and mean blood pressure were maintained near baseline values for the individual patient. Normal saline 0.9% was used to replace and maintain fluid deficits. Diuretics and mannitol were not given. Serial arterial blood gas analysis is usually not required for these procedures and was obtained only if deemed necessary.

Table 1. Indications for surgery

Tumors	*n*
Frontal SOL	15
Parietal SOL	7
Temporal SOL	3
Basal ganglia SOL	6
CNS lymphoma	5
Thalamic SOL	22
Pontine cavernoma	4
Corpus callosum glioma	3
Insular glioma	3
GBM (gene therapy)	2
Tectal glioma	1
IIIrd ventricular tumor	1
Brain abscess	3
Tuberculoma	1
CNS metastasis	2

SOL, space-occupying lesion; CNS, central nervous system; GBM, glioblastoma multiforme; *n*, number of patients

The neuronavigation system employed was the Stealth system (Stealthstation Treon System; Medtronic, Louisville, CO, USA). The procedure for frameless stereotaxy consisted of image acquisition in the MRI suite, and transfer of data to the navigation system on an optical disc. After induction and the positioning of the patient in a Mayfields head clamp, the position of the fiducials was confirmed (registration) by the neurosurgeon, using infrared light-emitting diodes (IRLEDs). Registration allowed the alignment of the preoperative image dataset with the real-time anatomy of the surgical space in the operating theater. Point-based registration was used, which involved selecting corresponding points in different images and on the patient. The points selected on the patient were the artificial applied markers—fiducials. The coordinates of each set of points were defined, and then a geometric transformation was calculated between them. After registration, and preparing and draping of the patient, entry point selection was done using a hand-held pointer. A burr hole was done as planned. Distance to target was calculated and the trajectory defined. Depth stop was positioned on the biopsy needle and biopsy specimens were retrieved. A stationary arm was used to steady the biopsy needle during the procedure. At the end of the procedure anesthesia was discontinued and neuromuscular blockade was reversed with neostigmine 0.05 $mg \cdot kg^{-1}$ and glycopyrrolate 0.01 $mg \cdot kg^{-1}$. All patients were shifted to the intensive care unit (ICU) for further management and supportive care.

Results

Seventy-eight consecutive patients who underwent frameless stereotaxy were reviewed. Demographic data and the various indications for stereotactic procedures are tabulated in Tables 1 and 2. Table 3 summarizes the intraoperative and postoperative events. As these procedures are not associated with large fluid shifts and blood loss, normal saline 0.9% was used to replace and maintain intraoperative fluid deficits. Approximately 2 to 3 l of the maintenance fluid was used in these patients. Wide fluctuations in arterial blood pressure in the form of hypotension or hypertension or heart rate variations such as bradycardia or tachycardia requiring active

Table 2. Patient demographic characteristics and intraoperative surgery time

Age (years)	34.4 ± 14.3
Sex (M:F)	50:28
Weight (kg)	57.9 ± 20.1
Duration of surgery (min)[a]	248.5 ± 59.9
ASA I/II	70
ASA III/IV	8

ASA, American Society of Anesthesiologists grade

[a] Mean ± SD

Table 3. Intraoperative and postoperative complications

Complications	*n*
Bronchospasm	1
Intraoperative brain bulge	3
Seizures	3
Failure to extubate	4
Fresh neurodeficits	6
Miscellaneous	
Difficult intubation	1
Allergic rash after phenytoin administration	1
Deep venous thrombosis	1
Pneumonia	1
Pseudomeningocele	1
Negative biopsy	1

n, number of patients

intervention were not observed in our series of patients. Ten patients (12.8%) suffered complications during these procedures; the complications were mostly surgical. Some of the patients suffered more than one complication. The common complications observed in these patients are summarized below.

Bronchospasm

Bronchospasm developed in a patient with recurrent glioblastoma multiforme receiving radiotherapy and scheduled for burr-hole catheter placement and gene therapy. The bronchospasm was treated with steroids and bronchodilators. This complication could be attributed to a lighter plane of anesthesia or incomplete muscle paralysis during tracheal intubation, as the patient did not have a past history of respiratory illness.

Intraoperative brain bulge

"Tight brain" occurred in three patients, diagnosed with thalamic glioma ($n = 2$) and basal ganglia mass ($n = 1$). Administration of mannitol and hyperventilation did not help, and the dura could not be closed. A postoperative scan revealed a biopsy-site hematoma in all three patients. Surgical evacuation was immediately carried out.

Seizures after tracheal extubation

Three patients developed seizures after tracheal extubation. The patients were operated for thalamic glioma, basal ganglia mass, and a frontal glioma. Computed tomography revealed pneumocephalus in all three patients. All three patients were tracheally intubated and managed conservatively in the ICU. Gradual absorption of air improved the condition of these patients.

Failure to extubate

Tracheal extubation was not possible in four patients. Two patients with thalamic glioma and intraoperative brain bulge were drowsy, with CT revealing biopsy-site hematoma. Two patients, one with a pontine cavernous angioma and one with a tectal glioma, were electively ventilated. All patients were successfully weaned off the ventilator in due course in their ICU stay.

Postoperative neurodeficits

Fresh-onset neurodeficits developed in six patients, in the form of hemiparesis and facial and vagal nerve palsy. Computed tomography revealed a biopsy-site hematoma in three patients and pneumocephalus in the remaining three.

Miscellaneous complications

The miscellaneous complications were: difficult intubation; allergic rash after phenytoin administration; deep venous thrombosis and pneumonia during hospital stay; nonretrieval of tumor tissue (surgical procedure had to be repeated); and pseudomeningocele.

Most of the complications reported were directly or indirectly surgical, except for bronchospasm, difficult intubation, pneumonia, and allergy to phenytoin administration, which may be attributed to anesthesia. However, we feel that these complications were unrelated to the surgical technique, and managing these complications was based on conventional guidelines.

Discussion

Anesthesia for neuronavigation represents a challenge because of the complex neurocircuitry in the central nervous system and the comorbidities suffered by patients. The perioperative circumstances impose a knowledge requirement concerning the technical details associated with these procedures. The use of neuronavigational techniques involves an understanding of the factors that lead to brain shift and efforts on the part of anesthesiologist to minimize these changes. The goal of the neuroanesthesiologist is to maintain normal brain bulk and facilitate the surgical procedure with the minimal use of decongestive therapy. In contrast to routine neurosurgical practice, where a slack brain is desired, brain shift due to slack brain may lead to loss of reliability of the navigational system. This may result in missing the anatomical target, or, still worse, injury to a vital area. Normocapnia and normotension, with the judicious use of diuretics and mannitol, is practiced at most neurosurgical centers.

In our patients, all stereotactic procedures for intracranial tumors were performed by frameless stereotaxy using the StealthStation. Surgical navigation was carried out under general anesthesia in both children and adults. Postoperative clinical evaluation, histopathological examinations, and imaging studies confirmed the success of the surgical procedure. However, in one patient with a third ventricular tumor, the anatomical target was missed and the surgical procedure had to be repeated (the nondiagnosis rate in our study was thus 1.3%). The exact cause was difficult to ascertain, as it could have been due to fiducial localization error, target registration error, or brain displacement.

As it seemed intuitive to avoid mannitol, to minimize brain displacement, we did not use mannitol. Roberts et al. [13] showed that the use of mannitol was not associated with significant brain displacement. They showed that gravity played a dominant role in the settling of the brain due to unintentional cerebrospinal fluid (CSF) drainage.

In our study, intraoperative brain bulge was observed in three patients; this could be attributed to the nature of the pathology or a biopsy-site hematoma. Avoidance or late administration of mannitol after fiducial registration may have contributed to intracerebral hematoma formation. The presence of papilloedema, preoperative neurodeficits, the amount of perilesional edema, and a midline shift in preoperative imaging studies may predict intraoperative brain bulge. Surprisingly, in the current literature, brain bulge has never been reported in stereotactic surgery.

Seizures were not an infrequent complication in the early postoperative period in our study. The trachea had to be reintubated in three patients, after they developed tonic clonic seizures. Pneumocephalus as a possible cause of seizures was seen in all three patients on the postoperative imaging studies. In a similar study by Venkatraghavan et al. [11], using framed stereotaxy with a Leksell head frame, neurological complications were seen in 13 patients—seizures (n = 8), decreased level of consciousness (n = 4), and neurological deficit (n = 1); and respiratory complications were seen in 4 patients (airway obstruction in 2 and respiratory distress in 2). In our study, neurological complications were seen in 9 patients (seizures in 3 and fresh-onset neurodeficits in 6 patients) and respiratory complications (failure to extubate, n = 4; pneumonia, n = 1; bronchospasm, n = 1) in 6 patients. The difference between the two studies may be due to the different patient populations. In the study by Venkatraghavan et al. [11], patients underwent surgery for movement disorders, psychiatric problems, chronic pain, seizures, and multiple sclerosis. In our patients, intracranial tumor was the main pathology, which is possibly associated with more neurological complications. Also, their patients were operated under monitored anesthesia care; our patients received general endotracheal anesthesia. In a study by Stokes et al. [12], anesthesia-related events were reported in children undergoing stereotactic surgery.

In our study, failure to extubate after surgery was seen in patients with an intraoperative brain bulge ($n = 2$) due to biopsy-site hematoma and tumors involving the vital areas pons and tectum (n = 2). Repeated passage of probes and endoscopes may initiate a process of reactive brain edema near the site of lesion resection. This may cause pathological increases in intracranial pressure, and postoperative coma. If a patient fails to awaken to the point of eye-opening on command in 15–20 min, it is imperative to rule out serious brain swelling, or a postoperative hematoma, or pneumocephalus by a CT scan [14].

Six of our 78 patients (7.7 %) developed a fresh-onset neurodeficit. Bernstein et al. [15] reported an incidence of 4.6 % in their series during CT-guided stereotactic biopsy. Fresh-onset neurodeficit occurs as a result of an increase in intracranial pressure, which may be more common with malignant lesions associated with neovascularization, such as malignant glioma and lymphoma. Lesions in eloquent areas may be more likely to undergo neurological deterioration, as neurons and white matter tracts in the dominant frontal or temporal lobe may decrease in function due to increased perilesional edema following needle biopsy. In patients with intracranial hypertension, the small burr hole used in neuronavigational procedures does not allow enough space for the brain to accommodate as compared to open craniotomy.

Neuronavigational procedures require a high degree of precision and complete immobility of the patient during the registration of the real-time anatomy with the preoperative image dataset in the neuronavigational system. Complete immobility is conveniently achieved with general endotracheal anesthesia and muscle paralysis, and so in our study general anesthesia was chosen over local anesthesia. This could be considered a limitation of the study, as anesthetics are known to influence cerebral hemodynamics. However, by keeping anesthetic concentrations at an acceptable MAC value, maintaining normocarbia, providing adequate fluid replacement, and avoiding mannitol and diuretics, we tried to overcome the influence of general anesthesia on these sophisticated navigational procedures.

In summary, frameless stereotactic neurosurgical procedures may be a seemingly simple and innocuous procedure for the anesthesiologist, but on reviewing our experience, we found that intraoperative and postoperative adverse events did occur. An understanding of these complications may be beneficial for the optimal management of patients undergoing these procedures.

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