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*S. B. Sobottka*
*G. Schackert*
*A. Steinmetz*

Neurochirurgische Klinik der Technischen Universität Carl Gustav Carus, Dresden

# Suitability and Limitations of Pointer-Based and Microscope-Based Neuronavigational Systems for Surgical Treatment of Intracerebral Tumours – a Comparative Study of 66 Patients

**Key Words**
Neuronavigation · Intracerebral tumours · Computer-guided surgery · Minimally invasive neurosurgery

**Summary**
Frameless neuronavigational systems are a recent novelty for a precise approach to intracerebral tumours in open surgery. In this study 66 patients with a variety of intracranial tumours in various locations underwent surgical resection with neuronavigational guidance. Two different neuronavigational systems – the arm- and pointer-based ISG viewing wand and the miroscope-based MKM system – were compared for four different indications. Neuronavigation was used (a) in multiple tumours, e. g. brain metastases, (b) in solitary cortical or subcortical tumours located in eloquent brain areas, e. g. motor cortex or speech region, (c) in deep-situated brain tumours, including brain stem neoplasms, and (d) in infiltratively growing tumours to define the borders of the lesion. Using taped skin markers (MKM system) and a surface-fit algorithm (viewing wand) for registration, an accuracy of 1 to 2 mm deviation was achieved, which was sufficient for removal of all of the intracranial neoplasms investigated. Both systems proved to be safe and useful surgical tools regardless of the patient`s age, positioning of the patient during surgery or the location of the lesion. When these two systems were compared, the viewing wand was found to be preferable for resection of multiple brain tumours located in distant operative sides and solitary tumours in eloquent brain areas; this was because of the wide range of movement of the pointing device and the possibility of 3D reconstruction of the brain surface. As the MKM system provided the option of stereotactical guidance during the operative procedure, it was found to be superior in approaching small and deep-situated lesions. In certain cases brain shifting due to early drainage of the CSF led to minor underestimation of the real depth. For the precise definement of tumour borders of intraparenchymal neoplasms both system were equally suitable. However, intrusion of brain parenchyma into the resection cavity led to minor overestimation of the real tumour size in certain large intraparenchymal tumours.

**Schlüsselwörter**
Neuronavigation · Intrazerebrale Tumoren · Computer-gestützte Operationstechnik · Minimal invasive Neurochirurgie

**Zusammenfassung**
Rahmenfreie Neuronavigationssysteme stellen eine Neuerung in der offenen operativen Behandlung intrazerebraler Tumoren dar. In dieser Studie wurden 66 Patienten mit verschiedenen intrakraniellen Tumoren in unterschiedlichen Lokalisationen mit Hilfe der Neuronavigation operiert. Hierbei wurden zwei verschiedene Navigationssysteme – ein Arm- und Pointer-basierendes System (ISG Viewing Wand) und ein Mikroskop-basierendes System (MKM) – für vier verschiedene Indikationen miteinander verglichen. Die Neuronavigation wurde verwendet (a) bei multiplen Tumoren, wie z. B. Hirnmetastasen, (b) bei solitären kortikalen oder subkortikalen Prozessen in eloquenten Hirnarealen, wie z. B. Motorkortex oder Sprachregion, (c) bei tiefgelegenen Hirntumoren einschließlich Hirnstammtumoren und (d) bei infiltrativ wachsenden Tumoren zur Bestimmung der Tumorgrenzen. Die Verwendung von Hautklebemarkern (MKM-System) und eines Oberflächen-Anpassungsalgorithmus (Viewing Wand) zur Registrierung war mit einer Genauigkeit von 1 bis 2 mm Abweichung für die operative Entfernung aller intrakraniellen Tumoren ausreichend. Beide Systeme bestätigten sich als sichere und geeignete chirurgische Hilfsmittel unabhängig vom Alter der Patienten, der Lagerung des Patienten unter dem chirurgischen Eingriff und der Lokalisation der Raumforderung. Im Systemvergleich zeigte die Viewing Wand durch einen weiten Bewegungsraum des Pointers und der Möglichkeit einer dreidimensionalen Rekonstruktion der Hirnoberfläche Vorteile in der Entfernung von multiplen, in entfernten Hirnregionen gelegenen Tumoren sowie von solitären Prozessen in eloquenter Lokalisation. Das MKM-System war durch die Bereitstellung einer stereotaktischen Führung während des operativen Eingriffes in der Ansteuerung kleiner tiefgelegener Prozesse zu bevorzugen. Eine frühzeitige Liquordrainage führte zu einem brain shifting mit einer diskreten Unterschätzung der wirklichen Tiefe. Für eine genaue Festlegung der Tumorgrenzen von intraparenchymalen Tumoren waren beide Systeme vergleichbar geeignet. Das Relabieren von Hirngewebe in die Resektionshöhle führte jedoch in einigen Fällen von großen intraparenchymalen Tumoren bei beiden Systemen zu einer geringen Überschätzung der wirklichen Tumorgrenzen.


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Dr. med. Stephan B. Sobottka
Klinik und Poliklinik für Neurochirurgie
Technische Universität Carl Gustav Carus
Fetscherstraße 74
D-01307 Dresden (Germany)

## Introduction

Despite recent advances in non-operative treatment modalities – like stereotactic radiotherapy or interventional neuroradiology – surgery is still the treatment of choice for most intracranial lesions, including intracerebral tumours. Radical extirpation with minimally invasive approaches is the major task in operative treatment. However, functional impairment of the patient must be avoided. In certain deep-situated brain lesions or small subcortical lesions precise localization is most difficult task, which means that there is an increased risk of functional impairment of adjacent brain areas. Since 1986, various neuronavigational devices have been developed as alternatives for stereotactic guidance in open surgery [1–6]. These systems have been used for a great variety of intracerebral lesions and have been demonstrated to be a safe tool when used appropriately [7, 8]. However, further clinical data on the suitable indications and limitations of neuronavigators must be evaluated. In this paper a pointer-based navigational system (ISG viewing wand) and a microscope-based system (MKM Zeiss) are compared and suitable indications for the two systems are defined [9].

**Table 1.** Summary of cases according to pathological findings

| Diagnosis | Totals[1] (viewing wand) | Totals[1] (MKM) |
|---|---|---|
| Low-grade glioma (WHO °I and °II) | 3 | 4 |
| High-grade glioma (WHO °III and °IV) | 8 | 11 |
| Single metastases | 7 | 2 |
| Multiple metastases | 10 | – |
| Arteriovenous malformation | 2 | 1 |
| Aneurysm | – | 1 |
| Cavernous hemangioma | 4 | 2 |
| Germinoma | – | 1 |
| Acoustic neuroma | 2 | 1 |
| Meningioma | 1 | 1 |
| Epidermoid | – | 1 |
| Pituitary adenoma | 1 | – |
| Gangliocytoma | 1 | |
| Colloid cyst | – | 1 |
| Plexus papilloma | – | 1 |
| [1] Total number of patients | 39 | 27 |

## Patients and Methods

66 patients underwent surgery for various intracranial lesions using intraoperative neuronavigational guidance. Neuronavigation was used (a) in multiple tumours, e.g. brain metastases, (b) in solitary cortical or subcortical tumours located in eloquent brain areas, e.g. motor cortex or speech region, (c) in deep-situated brain tumours, including brain stem neoplasms, and (d) in infiltratively growing tumours to define the borders of the lesion. Alternatively, an arm-based, pointer-based (ISG viewing wand) and a microscope-based neuronavigational system (MKM Zeiss) were used.

After the injection of gadolinium, T1-weighted MR images were obtained the day before surgery. The thickness of the axial slices was 1 or 2 mm. The generated 2D images were stored on magnetic tape and transferred to a computer workstation in the operating room. With the aid of created 3D reconstruction and triplanar images, the surgical intervention was planned and the best approach was determined. During the surgical procedure the patient's head was immobilized with a standard Sugita head holder. After system calibration registration was performed by using 6–8 fiducial markers in the MKM system. For the ISG viewing wand 6 anatomical surface landmarks combined with 80–120 random points on the patient's scalp were used with a surface-fit algorithm. Registration accuracy was checked by comparing additional anatomical landmarks or unregistered fiducial markers on the skin surface of the patient with their respective position on the triplanar computer images. For assessing loss of precision during the operative procedure 4–5 intraoperative landmarks were defined by drilling small burr holes in the calvaria around the planned craniotomy. These marks were registered as secondary reference points. Any time the neuronavigational device was used, system accuracy was verified using intraoperative or anatomical landmarks. To estimate brain shifting during surgery ultrasound was used additionally in most of the cases prior to and after resection.

## Results

In this series 66 patients were operated on for various intracranial lesions with the aid of neuronavigation (table 1). In 94% of the cases a mean deviation within 1 to 2 mm was achieved for both navigation systems after initial registration (registration accuracy) using taped skin markers (MKM system) or a surface registration algorithm (viewing wand). In three of the cases the mean deviation was above 2 mm and could not be improved despite repeated registrations. However, in these cases deviation was found to be below 4 mm, allowing restricted usage of the system during surgery. Systematic error analysis revealed that an inaccuracy was most likely caused by temporary displacement of fiducial markers. In two cases the computer system went down during surgery and registration data had to be reestablished. In one case neuronavigation could not be used because of displacement of the patient's head before intraoperative landmarks were established, resulting in an inaccuracy of more than 5 mm mean deviation. In all other cases movement of the patient's head could be corrected by re-registration using the intraoperative landmarks.

Neuronavigation was used in 7 pediatric and 59 adult patients with a total number of 85 intracranial lesions at various operative sides (table 2). Both navigational systems proved to be suitable tools for intraoperative guidance regardless of the patient`s age, positioning of the patient during surgery, or the location of lesion. In Table 3 the main indications for use of neuronavigation are summarized for all patients investigated. Neuronavigation was stated to be helpful in 97% of cases in respect to these indications. In none of the cases was neuronavigation harmful to the patient. The postoperative course of all patients was uneventful. Neurological worsening due to intraoperative navigation did not occur in any patient.

Comparing both navigational systems, the viewing wand allowed the position of the patient's head to be changed during the operation without requiring reregistration. The MKM system, however, demonstrated a restricted range of movement and did not allow large position changes of the patient's head. 20 patients were operated on for multiple neoplasms ranging from 2 to 5 lesions per patient. 10 of the patients were operated on for multiple lesions located in distant brain regions using the pointer-based navigation system. All

**Table 2.** Summary of cases according to location

| Operative site | Totals[1] (viewing wand) | Totals[1] (MKM) |
|---|---|---|
| Intraparenchymal supratentorial | 13 | 18 |
| Intraparenchymal infratentorial | 4 | 3 |
| Convexity (cortical/subcortical) | 24 | 3 |
| Falcine/parasagittal | 9 | 2 |
| Intraventricular/periventricular | – | 3 |
| Cranial base | 4 | 2 |
| [1] Total number of lesions | 54 | 31 |

**Table 3.** Summary of cases according to main indication for neuronavigation

| Indication | Totals[1] (viewing wand) | Totals[1] (MKM) |
|---|---|---|
| 1. Multiple tumours (multiple, minimally invasive approaches) | 10 | 2 |
| 2. Solitary cortical or subcortical lesions in eloquent brain areas | 11 | 2 |
| 3. Precise approach to deep-situated lesions | 8 | 11 |
| 4. Identification of tumour borders adjacent to important brain structures | 10 | 12 |
| [1] Total number of patients | 39 | 27 |

tumours were precisely localized and resected using multiple minimal craniotomies and cortical incisions usually performed in one operation. The MKM system was only used in 2 patients with multiple, neighbouring, deep-situated lesions. All patients with multiple neoplasms had an uneventful postoperative course without neurological worsening and were usually discharged after being hospitalized for 8 days.

When approaching cortical or subcortical lesions adjacent to important brain regions (e.g. precentral gyrus or angular region), the possibility of 3D image reconstruction of the brain surface provided by the viewing wand software was most helpful. Preoperative definition of straight or curved approaches, including assessment of entry and target points, as provided by the MKM system, was advantageous for approaching deep-situated, small, intraparenchymal lesions. The preoperatively defined approach could be easily followed by using the navigational route continuously displayed in the MKM operating microscope. In certain cases inaccuracies occurring during surgery were related to brain shifting. For instance, early drainage of CSF or cyst fluid typically led to minor overestimation of the real depth. Accordingly, the real target point was found to be slightly deeper, as expected from navigation in these cases.

For defining the resection borders of poorly demarcated intraparenchymal tumours, both systems were suitable with some restrictions. In large tumours the extent of tumour removal was frequently underestimated because of collapse of the lateral resection walls into the resection cavity. However, neuronavigation was still found to be reliable in identifying important brain regions prior to tumour resection and in defining a safe tumour approach. In certain patients the amount of brain shifting could be estimated by observing the relative position of shifted and fixed intraoperative anatomical landmarks (brain surface, fissures, vessels, bone structures, etc.) during the surgical procedure. Intraoperative ultrasound was additionally used for detecting inaccuracies due to brain shifting. The feature of continuous display of the tumour contours and the planned navigation route in the MKM operating microscope was superior to the pointing device, which required interruption of the surgical procedure.

In comparison to intraoperative ultrasound, both neuronavigation systems offer good MRI picture quality, allowing identification of small anatomical structures like cranial nerves, vessels or brain nuclei. Neuronavigation can be used from the beginning of the surgical procedure, whereas ultrasound is restricted to use after craniotomy.

The following two case reports illustrate the clinical utility of pointer and microscope-based navigational systems for interactive image-guided surgery.

*Case 1.* During the course of 5–6 weeks a 66-year-old white male developed a sensorimotor deficit of the right hand, a homonymous hemianopia of the right visual fields, sensory aphasia and impaired short-term memory, resulting in disorientation. MR imaging demonstrated two intracerebral masses with ring-shaped enhancement of the contrast medium. The first one was located in the left temporooccipital region near the brain surface and the second one deep in the temporomedial area; it was poorly delimited and close to the basal ganglia, mesencephalon and hippocampal region. The aim of surgery was to acquire a histological diagnosis and achieve the most radical removal possible of both tumours. Because of the eloquent brain areas surrounding both tumours, the lesions were approached and surgically removed using the MKM navigation system (fig. 1). Postoperatively, the patient showed good recovery with improved general condition and without additional neurological deficit. The impaired short-term memory and visual deficits were unchanged postoperatively. The sensorimotor deficit of the right hand improved under physiotherapy. Histology revealed a glioblastoma multiforme. Two weeks after surgery the patient was discharged with moderate short-term memory loss being his only complaint. Postoperative radiotherapy was initiated.

*Case 2.* A 23-year-old male presented with repeated Jacksonian fits of the left mouth region after having received surgery for an undifferentiated, highly malignant carcinoma growing in the nasal cavity and infiltrating the left orbita, the paranasal sinus, and the frontal base of the skull 6 months before. MR imaging study revealed five intracranial dural metastases (fig. 2). Because of the good general condition of the patient and the fact that there was no further evidence of systemic tumour dissimination, surgical excision of all five intracranial metastases was planned using the pointer-based viewing wand equipment with 3D reconstruction of the skin, brain and tumour surface (fig. 3). For planning the skull-opening site the tip of the pointer was passed along the scalp in the region of the five tumours. By changing the site and angle of the pointer and observing its graphic presentation on the reconstructed

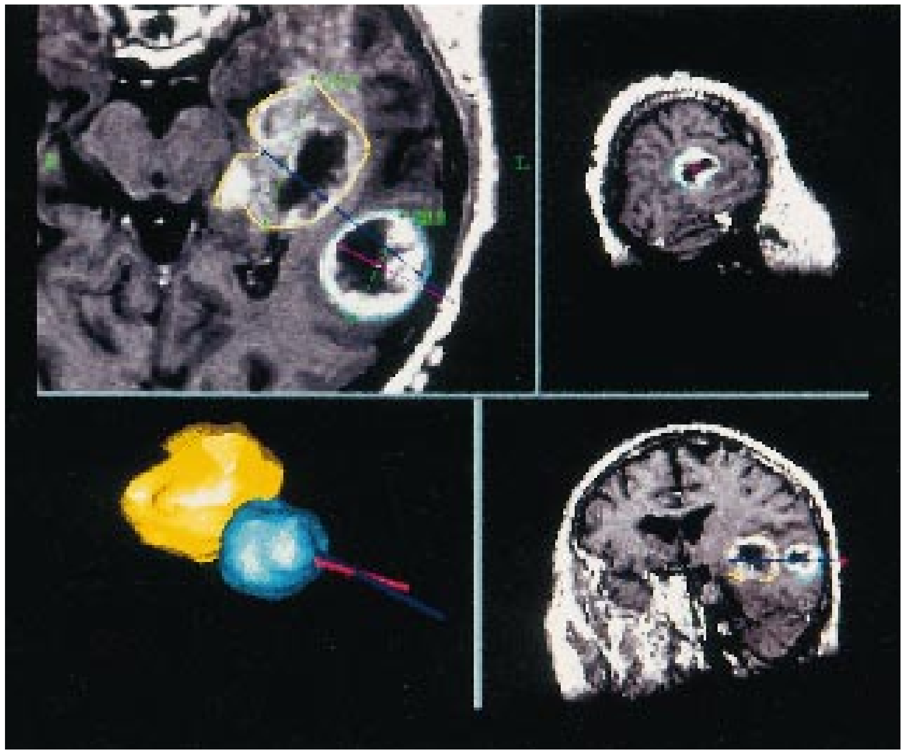

**Fig. 1.** Planning the surgical excision of two intracerebral tumours in the left temporooccipital and deep temporomedial area using the microscope-based MKM system. Left/top: Definition of tumour contours (superficial lesion – turquoise, deep lesion – yellow contour, diameter of lesions – green numbers) and of two straight appoaches to both lesions (red and blue lines). Right/top: Perpendicular view for approaching the superficial lesion, demonstrating the brain-surface architecture (red approach). Left/bottom: 3D reconstruction of the tumour surface, including red and blue approach lines. Right/bottom: Trajectory view for approaching the deep temporomedial lesion through the resection cavity of the superficial one, using the blue approach line for navigational guidance.

3D images of the skull and brain surface, the appropriate site for craniotomies were selected for all tumours. All five tumours were removed in one operation, using appropriate small craniotomies. Postoperatively, the patient showed an excellent recovery without neurological deficits, and two days after surgery he was back to his normal state of health without any complaints.

## Discussion

Neuronavigation has been reported to be a useful tool for resection of a great variety of intracranial lesions [7, 8]. As it offers certain advantages such as being a frameless procedure and providing online feedback of the intraoperative position on preoperative imaging studies, it has the potential to replace stereotactical guidance in open surgery today. In our clinical study both pointer-based and microscope-based systems demonstrated high accuracy for a wide range of different surgical procedures using taped skin markers and a surface-fit algorithm for registration. Accuracy with a mean deviation of less than 2 mm was sufficient for all operations performed regardless of the patient's age, positioning of the patient during surgery, or location of the lesion. Accordingly, cranial screws or stereotactic ring systems can be avoided for the majority of operative procedures, as also demonstrated by other authors [7, 8]. Since no invasive procedures are required preoperatively, neuronavigation is suitable for pediatric patients as well. As no neurological worsening related to the navigational devices was observed in any of the cases, both systems were demonstrated to be safe surgical tools when handled carefully. However, technical problems and brain shifting may occur during surgery, and its use should be restricted to experienced surgeons. Four main indications for intraoperative use of neuronavigation have been defined in this study: (a) multiple tumours, e.g. brain metastases, (b) solitary cortical or subcortical tumours in eloquent brain areas, (c) deep-situated, and (d) infiltratively growing tumours.

As revealed by recent clinical studies, the prognosis of patients suffering from multiple intracerebral metastases can be improved by surgical excision if all lesions are accessible [10, 11]. Accordingly, surgery may be considered as an alternative to radiosurgery in certain patients. Several factors, including the general condition of the patient, systemic tumour spread, and the origin of the primary tumour, are known to have an impact on prognosis. In our study 10 patients were treated for multiple metastases with the aid of neuronavigational guidance. Up to 5 metastases per patient were resected in one operation, using separate minimally invasive approaches. The postoperative course was uneventful in all patients, and time of hospitalization was no longer than for patients with comparable solitary lesions. Accordingly, the prognosis of certain patients with multiple intracerebral metastases can be improved by computer-guided surgery, and this must be evaluated in further clinical studies.

Neuronavigation facilitates the achievement of minimally invasive approaches by precise planning of the craniotomy and cortical incision and thus putting less strain on the patient. For surgical treatment of cortical or subcortical lesions adjacent to important brain areas (motor cortex or speech region) minimal brain exposure can be achieved, reducing the risk of postoperative morbidity. 3D reconstruction of the brain surface

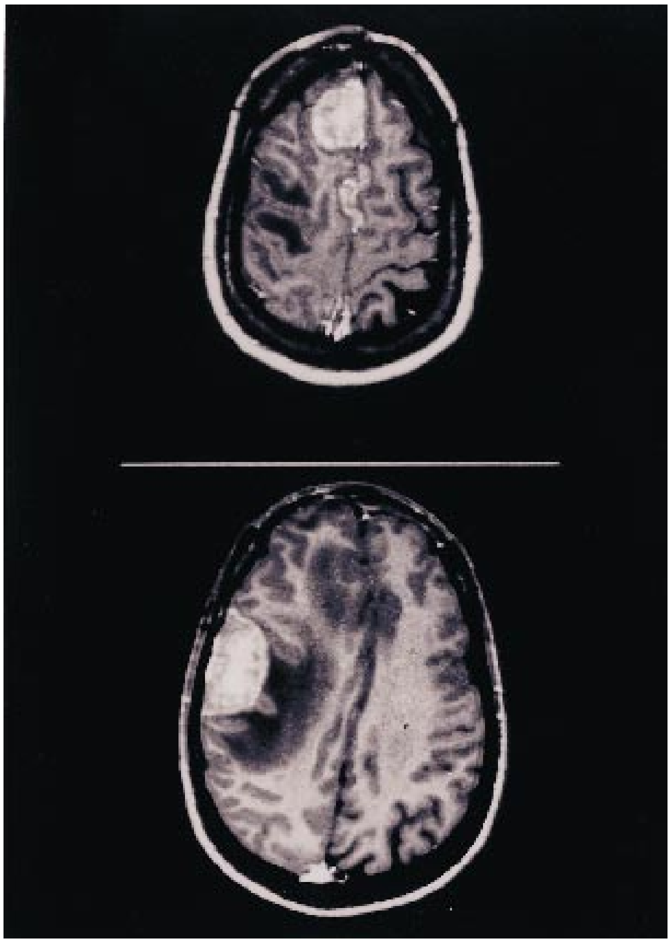

**Fig. 2.** Axial MR images demonstrating five intracerebral tumours. Top: One tumour located in right precoronal parasagittal area (20 mm in diameter), two tumours located in the left and one in the right postcoronal parasagittal area (less than 10 mm in diameter). Bottom: Tumour located in the right frontotemporal area (35 mm in diameter).

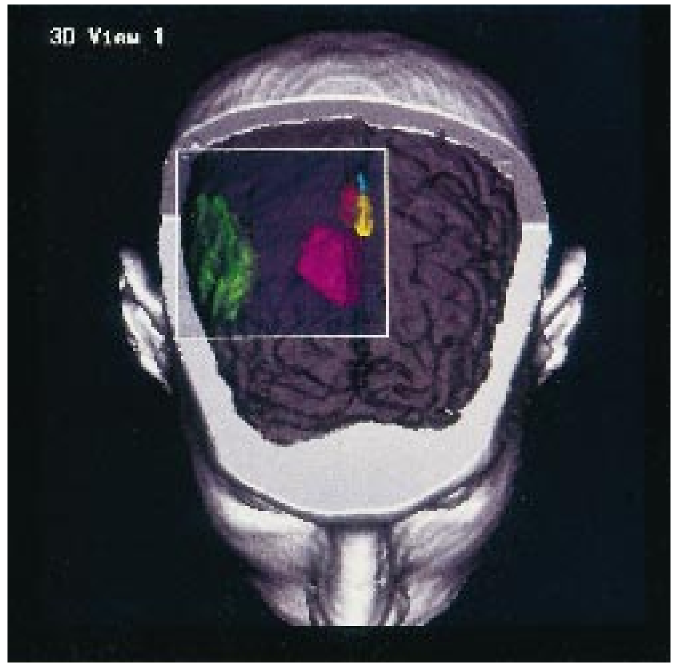


**Fig. 3.** 3D reconstruction of skin, brain and tumour surfaces for planning the surgical excision of five intracranial metastases (accentuated by different colours) using the pointer-based viewing wand system.

allows intraoperative identification of important anatomical gyri. In comparison, intraoperative ultrasound cannot be used prior to craniotomy, and its field of view is restricted by the craniotomy size.

Both pointer- and microscope-based navigational systems could be used as alternatives for the great majority of cases. However, when the two systems were compared, certain advantages and limitations became apparent. The viewing wand offers a wide range of movement of the pointer device, facilitating the approach to multiple lesions located in distant brain regions. Because it provides the option of excellent 3D reconstruction of the brain surface, it may be preferred for resection of cortical or subcortical lesions in eloquent brain areas as well. As it has the option of intraoperative stereotactic guidance, the MKM system is advantageous for removal of deep-situated small lesions, especially in patients where a precise straight or curved approach adjacent to important anatomical structures is essential for avoiding postoperative deficits. In certain cases inaccuracies occurring during surgery were related to brain shifting. In this respect early drainage of CSF may lead to minor overestimation of the real depth.

Both navigational systems demonstrated inaccuracies in defining the exact borders during tumour resection in certain large intraparenchymal tumours. Brain shifting into the resection cavity most likely accounts for these inaccuracies, which leads to overestimation of the real tumour size. This fact may result in extensive resection, increasing the risk of neurological worsening in certain brain areas. Intraoperative imaging studies may overcome this limitation by providing the option of an update of the neuronavigational data during the surgical procedure. Despite showing some restrictions and pitfalls, computer-assisted neuronavigation is a suitable and safe tool for surgical removal of intracerebral neoplasms, as it facilitates minimally invasive approaches and reduces the risk of postoperative morbidity for the patient.

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