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Computer-assisted image-guided orbit surgery

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PURPOSE. *Modern stereotaxy utilizes preoperative computed tomography (CT) and magnetic resonance imaging (MRI) to provide accurate localization information which can be very helpful in orbital surgery. The purpose of this report is to evaluate the usefulness of stereotactic surgery and application of this procedure in the orbit.*
METHODS. *Interventional case series of three patients with orbital tumors. All patients had tumor resection with the utilization of two frameless stereotactic systems: Cygnus™ and Stealth Station™.*
RESULTS. *The applications of image-guided stereotactic surgery proved to be beneficial in three extensive orbital tumors, including optic nerve glioma, recurrent pleomorphic adenoma of lacrimal gland, and secondary orbital meningioma.*
CONCLUSIONS. *The interactive nature of image guidance can be useful in orbital surgery to orient the surgeon to the exact location within the surgical field and to determine the tumor margins. (Eur J Ophthalmol 2006; 16: 446-52)*

KEY WORDS. *Image guidance, Stereotactic surgery, Orbit tumors, Orbit surgery*

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INTRODUCTION

Frameless image-guided surgery, based on the concept of stereotaxis, enables the surgeon to localize specific points within the surgical field by overlapping the three-dimensional surgical area with previously acquired digital images from computerized tomography (CT) and magnetic resonance imaging (MRI) (1-4).

Advances in computer technology during the last decade influenced the makers of stereotactic equipment to further refine the image-guidance systems (5, 6). For example, computer-generated skin surface rendering allows stereotactic space to be referenced to the previously placed landmarks or anatomic landmarks, obviating the need for a frame rigidly fixed to the skull. Thus, most image-guidance equipment has become “frameless” (4, 5). In general, applications of image-guided surgery have been limited to neurologic surgery and to radiosurgery using the Gamma knife or the linear accelerator. Stereotactic radiosurgery by the Gamma knife is also used in the treatment of orbital tumors (7-11).

Recently, however, physicians in other surgical disciplines, including craniofacial surgery, otolaryngology, and ophthalmology, have discovered the advantages of the capability to localize specific points within the surgical field with the assistance of image-guided systems (12). We utilize the computerized image-guided system in orbital surgery in various pathologies including neoplasms, thyroid-associated orbitopathy, and orbital trauma with or without foreign bodies.

The purpose of our report is to underline the potential advantages of computer-assisted image-guided surgery in the region of the orbit and its surrounding structures, including the nasal cavity, paranasal sinuses, globe, optic nerve, chiasm, and the cavernous sinus area. The orbit and its neighboring structures have a complex anatomy because of the presence of many vital tissues within a relatively small space. The computer-assisted image-guided

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approach provides accurate localization in orbital surgery, particularly in posterior orbit. In this article, we summarize the usefulness of this technique in three different orbital tumors.

METHODS

Two frameless stereotactic systems were used for the cases summarized below (Fig. 1). One unit employs magnetic spacial referencing and tracking (the Cygnus PFS System™, Compass International, Rochester, MN, USA); the other employs optical referencing and tracking (StealthStation™, Medtronics, Memphis, TN, USA).

Prior to surgery, all three patients underwent volumetric CT and MRI studies with previously placed fiducial markers. In two patients, fiducial screw markers were placed in the outer table of the skull under local anesthesia in order to optimize accuracy; these implants were supplemented by adhesive markers. The third patient had only adhesive markers. MRI studies were acquired in volumetric SPGR sequences with contrast (1.5 mm cuts) and FLAIR sequences (3 mm, no gap). CT acquisition was volumetric using slice thicknesses ranging from 1 to 3 mm.

At the time of surgery, all patients underwent general endotracheal anesthesia. The head was subsequently immobilized with a three-point fixation head-holder (Mayfield, OMI, Cincinnati, OH). The image-guidance systems were attached and referenced. Calculated accuracy was 1.2 mm ± 0.4. True intraoperative accuracy was excellent in all cases.

Case reports

Case 1

A 75-year-old man was seen with recurrent intracranial meningioma extending into the left orbit. Three months earlier, a large epidural mass from the region of the left sphenoid wing was excised. The histopathologic diagnosis was atypical meningioma. The orbital lesion was present at the time of initial surgery, but the operation was not extended into the orbit. On admission to our clinic, the patient's vision was 20/30 in the right eye and 20/60 in the left. A firm, irregular mass was palpable in the left superior lateral orbit, causing a 3-mm proptosis and restriction of horizontal and vertical eye movements. The patient complained of diplopia at all gazes but the primary gaze. The left upper eyelid had ptosis. The left pupil revealed a 2+ afferent pupillary defect (APD) but no disc edema or atrophy was detected. Goldmann perimetry revealed a large blind spot and arcuate field defect superiorly in the left eye. The ocular and systemic examinations were otherwise unremarkable.

CT and MRI revealed an infiltrating mass in the left anterior temporal lobe and the meninges; the anterior aspect of the middle fossa extended into the posterio-lateral aspect of the left orbit, creating an anterior displacement of the globe. The tumor extended toward orbital fissures. The lateral rectus muscle was pushed medially; however, there was no visible compression of the mass on the optic nerve. The patient underwent an orbito-fronto-zygomatic craniotomy and superolateral orbitotomy under the computer-assisted image guidance. The orbito-fronto-zygomatic osteotomy was mobilized and the lateral roof of the orbit and the zygomatic process were removed in one piece. The area just under the lacrimal "keyhole" was suspicious of tumor infiltration. The extent of tumor into this area was identified with the help of image guidance. Meningioma was identified in the dura of the middle fossa, the skull base, lateral orbital wall, and extending into the lateral periorbita. Tumor margins of the orbital wall and periorbita were also monitored by image guidance and were confirmed by frozen sections during resection. Although the periorbita was involved, the orbital soft tissues were free of tumor. Three years after surgery, the patient's visual acuity is 20/25+1 in the left eye and he is free of diplopia at all gazes with 1 mm proptosis.

Case 2

A 43-year-old man presented with a recurrent benign mixed lacrimal gland tumor. The initial diagnosis of the tumor was made at the age of 14 when the patient was undergoing a ptosis procedure. The lesion was partially excised and histopathologically diagnosed to be a pleomorphic adenoma (benign mixed tumor). The patient subsequently underwent three other surgical procedures for tumor recurrence.

At the last recurrence, a superior-medial mass was identified which was firm with an irregular surface and which extended into the superior orbit. The patient's best-corrected visual acuities were 20/20 in the right eye and 20/40 – 2 in the left. The left superior eyelid had mechanical ptosis and the extraocular motility was severely limited at all gazes. Pupils were equal, round, and equally reactive to light; color-vision testing was within normal limits.

On the CT and MRI examinations, a large superior orbital mass was identified extending into the roof of the orbit and the frontal sinus. CT showed irregular bony invasion and on MRI, the mass revealed increased intensity in T2-weighted images and presented a rather homogenous appearance (Fig. 2). On several cuts of the coronal CT scans, the tumor was seen to involve the bone with questionable extension into the cranial cavity.

At surgery, the tumor was very difficult to distinguish due to an abundance of scar tissue from prior operations. Image guidance was particularly useful in this context by indicating areas of contrast enhancement or fluid-attenuated inversion recovery (FLAIR) hyperintensity that correlated well with the presence of the tumor within the scar tissue.

On histopathologic examination, the tumor was diagnosed as a recurrent pleomorphic adenoma with focal intraepithelial carcinoma; no invasive malignancy was seen. Three and one-half years after surgery, no recurrent disease is present.

Case 3

A 12-year-old girl was seen in the clinic with a large optic nerve glioma of the right orbit. The child was diagnosed with optic nerve glioma at age 3 and was treated with external beam radiation therapy at age 6. After the radiation treatment, the tumor continued to grow and created a large intraorbital lesion extending into the chiasm (Fig. 3). Hertel's exophthalmometry of the right eye revealed 2-mm proptosis with a 2+ APD. Extraocular motility was full and visual acuity was count fingers at 1 foot in the right eye and 20/20 in the left. The right optic disc was pale with total atrophy. The left optic disc was within normal limits. The MRI study with oblique images revealed that the tumor extended into the nerve posteriorly, approaching the chiasm, with increased tumor size compared to an MRI performed approximately 1 year earlier. At this point, the Goldmann visual field of the left eye was performed and found to be normal and it was decided that the tumor should be excised surgically because of the possibility of extension into the chiasm and the increased risk of visual loss in the good eye.

The patient underwent a craniotomy and superior orbitotomy through the roof of the orbit, and the optic nerve glioma was excised. Both anterior and posterior margins of the tumor were confirmed with image guidance. The anterior margin of the tumor was easy to resect; posteriorly, however, it was extensively adherent to the surrounding tissues within the optic canal that had to be dissected and cauterized following the unroofing of the canal. The image-guided system was particularly useful in determining the posterior extent of the tumor into the chiasm, especially on FLAIR sequences. By importing images from the MRI FLAIR sequence into the image-guidance systems, it was possible to determine the posterior margin of the tumor and to section the nerve just beyond the tumor without undue endangerment of the chiasm. The histopathologic examination of the tumor specimen revealed tumor-free anterior and posterior resection margins.

Four years after surgery, the patient did not show any visual field defect in the left eye or recurrence of the tumor within the chiasm or right orbit.

DISCUSSION

Today's frameless stereotactic surgery primarily relies on spatial information obtained from computer-processed images of CT and MRI. The spatial accuracy with CT is determined largely by the position and the number of detecting sensors and therefore is constant among different studies and different patients. Spatial truthfulness in MRI, however, is dependent on the linearity between the position and the strength of the magnetic field (6). The volumetric acquisition of CT or MRI scans with a slice thickness less than 3 mm is recommended. Data imaging can be downloaded onto digital audiotape or by Ethernet™.

Image guidance requires a frame of reference to define stereotactic space. In the classical frame-based stereotaxy, this space is defined in relation to an external frame that is rigidly fixed to the cranium of the patient before data acquisition. In frameless stereotaxy, on the other hand, computer-generated skin surface rendering, using anatomic or adhesive fiducial landmarks, permits the stereotactic space to be referenced to these superficial reference points. When "frame-like" precision is required, the addition of skull-implanted markers further improves accuracy (1, 13, 14).

The interactive nature of the image guidance allows unlimited target points to be identified intraoperatively via computer tracking of a sterile probe. A number of devices have been used for intraoperative pointer tracking, including robotic arms and optical tracking. The Cygnus-PFS System™ that was used in our surgery tracks a probe within a magnetic field, which relates the stereotactic sur-

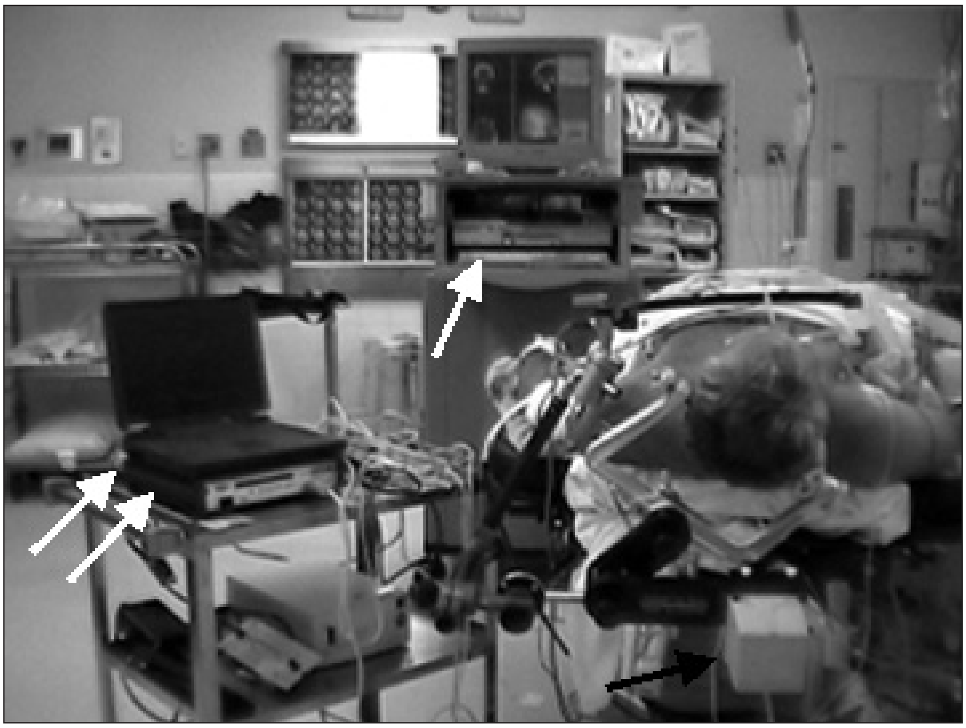

Fig. 1 - *Operating room arrangement showing both Cygnus^{TM} (double white arrows) and StealthStation^{TM} (single white arrow) systems in place to be used in our second case. The Cygnus^{TM} system's electromagnetic field source (single black arrow) is attached to a three-point fixation head holder with an L-bracket. The Cygnus^{TM} electromagnetic control unit and the laptop computer are on the left side of the patient. The StealthStation^{TM} monitor unit is in the background.*

gical space to the imaging database. The system operates on a LINUX platform installed in a laptop computer. A control unit is hooked up to the laptop computer as well as to the magnetic-field transmitter. The magnetic-field transmitter is attached with an adjustable L-bracket to a three-point head-holder (Fig. 1). The receiver is clipped to a disposable plastic pointer assembly with a blunt metal probe. Two receiver cables are supplied: one for non-sterile calibration and the other for use within the sterile surgical field.

One of the systems we utilized, the StealthStation™, uses optical tracking of light-emitting diodes or passive reflective markers. The system runs on a UNIX platform on a Silicon Graphics workstation. Pointers or surgical instruments can be tracked.

At the time of surgery, the laptop computer of the magnetic system, the receiver cable, and the cable from the transmitter magnet are connected to the control unit; after the patient's head is immobilized in the three-point bracket, the magnet is attached to the head-holder. At this point, the system is ready for patient registration. The receiver with its pointer is used for this purpose. After fiducial registration, the estimated error between the patient and the previously loaded landmarks are displayed in a readout which then is used for calibration. Anatomic accuracy is also confirmed visually while the probe is moved over the landmarks on the head and face, and then the system is placed on standby and the patient is prepped and draped. After this, the sterile receiver probe is brought into the field and the cable is connected to the control unit.

One of the advantages of the Cygnus™ system is its unobtrusiveness at the time of surgery. The magnet is under the drapes and the only parts of the system which are in the field are the receiver cable and the receiver/probe, which can be picked up anytime and placed onto the surgical field, providing immediate observation on the screen. The replacement of the solid probe with a suction probe is also very useful.

The optical system is registered in a similar manner, but requires a reference arc containing light-emitting diodes, which is attached to the head-holder. A second, sterile arc is subsequently attached after sterile draping. The system uses a pair of tracking cameras mounted on a pole in the operating theater.

The advantages of image-guided surgery in the orbit are many. First and foremost, it is very useful to orient the surgeon to the altered anatomy of the orbit when the probe is placed onto certain sites within the deep orbit without direct exposure. This is a particular advantage with small lesions in the posterior orbit. Even with direct exposure, one occasionally finds oneself undecided re-

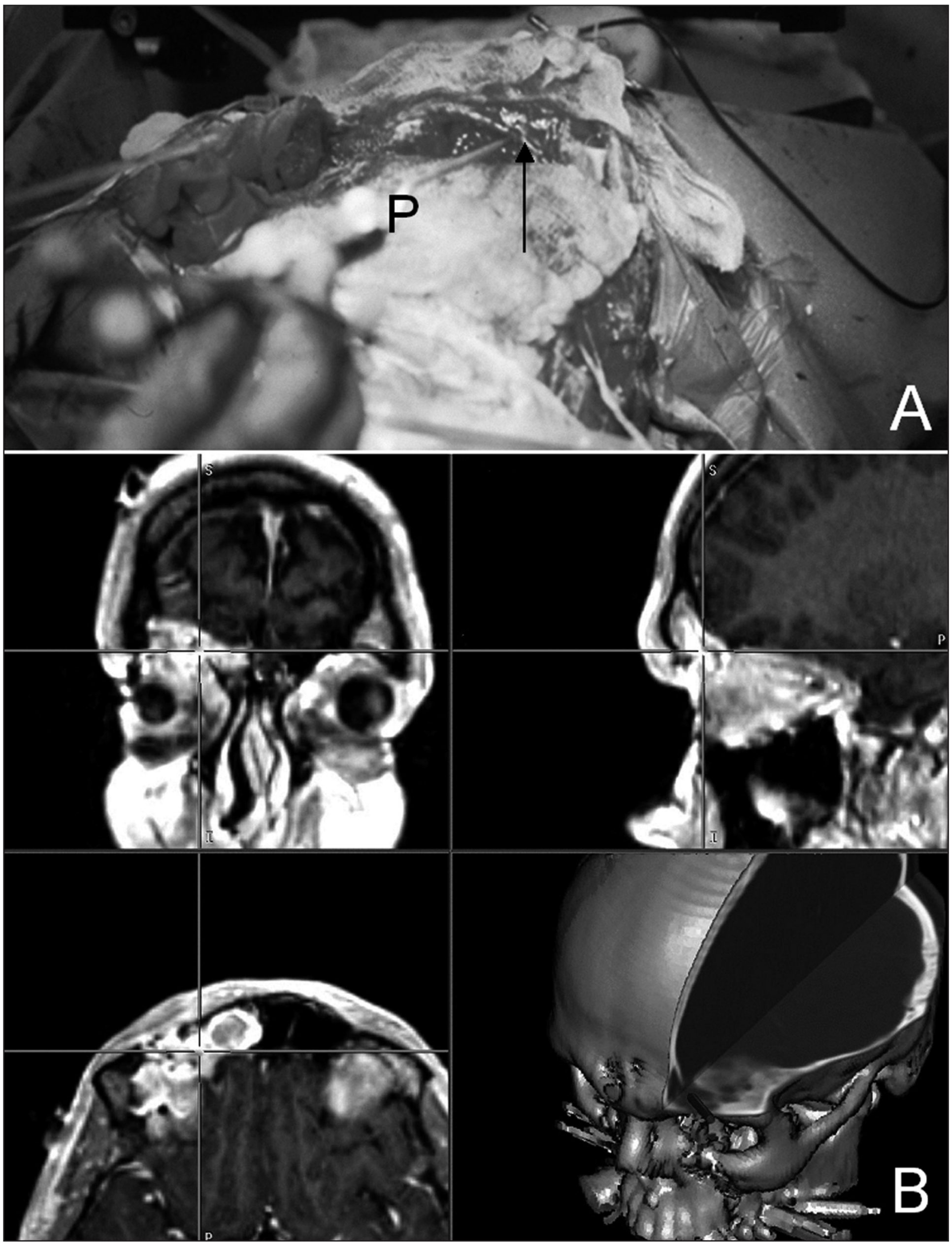

Fig. 2 - *The probe (P) of the StealthStation™ system is positioned onto the superior margin of the frontal sinus (arrow). (***A***) Magnetic resonance images depicting Gd-DPTA-enhanced area of the recurrent pleomorphic adenoma with cross hair marker at the superior margin of the tumor (***B***).*

garding distorted anatomy in congenital anomalies and trauma (e.g., tracking a fistula). The image-guidance probe is also useful to orient the surgeon to the extent of the infiltrating tumors and to decide on tumor-free margins to excise, as in our operations. A further advantage of the system in tumor surgery is the superimposition of CT and MR images during the operation because MR offers greater soft tissue detail but CT gives better bone delineation.

Another application of the image-guidance system for the orbital surgeon is to obtain biopsy material from posterior orbital lesions and apical tumors (15,16). Berger and Char recently reported the usefulness of interactive image guidance to localize and biopsy three orbital apex tumors: two meningiomas and one osteoblastoma (15). The authors underlined that the methodology was very accurate to find the lesion within 1 mm of its actual location in the three-dimensional space. The guidance probes reach the orbital apex without difficulty and can be guided to any lesion with extreme accuracy. With a filter-type catching device at the other end of a stereotactic suction, sufficient histologic/cytologic material can be obtained. With the

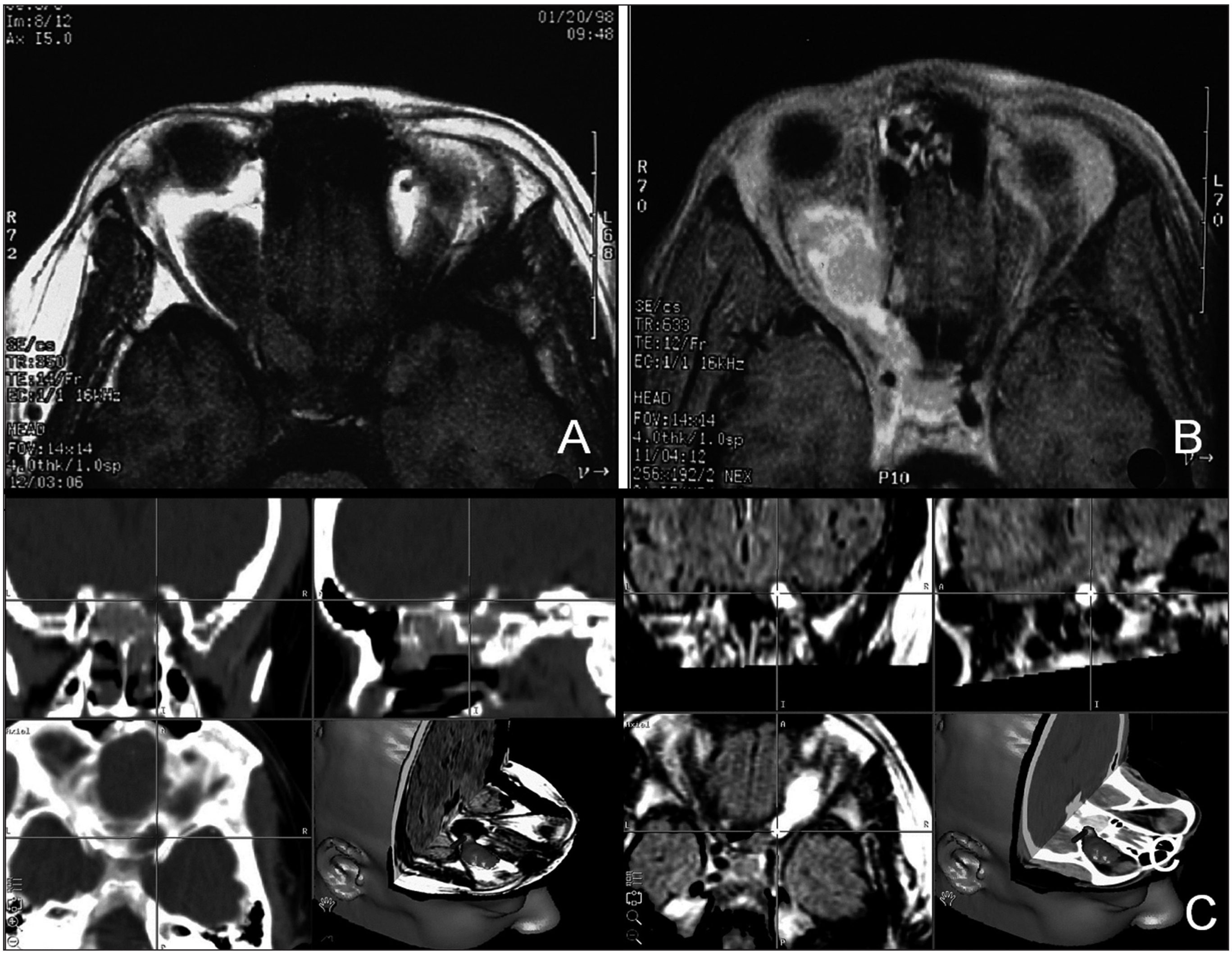

Fig. 3 - *The T1- and T2-weighted images (***A, B***) of axial magnetic resonance images depicting the large optic nerve glioma extending into the optic canal and chiasm. The image-display mode shows triplanar slices, volumetric rendering, and cross hair markers onto the junction of the tumor and normal chiasm (***C***).*

availability of Cytospin™, and/or frozen section capability, the material can be evaluated within 15 to 20 minutes during surgery. This technique can save a considerable amount of time compared to orbitotomy and is far less invasive. This capability is particularly very useful for posteriorly located small lesions. Although Cygnus™ has a biopsy kit, we are in the process of developing one that will obtain better-preserved tissue material. Another beneficial application of the image-guided system is to locate and remove posteriorly located orbital foreign bodies (12).

Equipment price range for image guidance systems is from $100,000 to 400,000 USD but hospitals that are well equipped enough for orbital surgery also have stereotactic equipment for neurosurgical cases; these systems can be adapted and used without extra cost. Added time during surgery is usually less than 30 minutes; however, additional time and expense are needed to obtain volumetrically acquired CT and/or MRI preoperatively. The preparation of the head does not require shaving or any other special procedure but there is usually a need for rigid fixation of the head at surgery with a three pin head-holder. The fixation points hurt minimally after the surgery and need to be treated with antibiotic ointment for a few days.

The disadvantages of this type of surgery should also be mentioned. First of all, there are inherent limitations of frameless stereotaxy. The reliability of the fiducial scalp markers and anatomic landmarks can be a source of error in all frameless systems. The desirable level of precision for frameless stereotaxy in the orbit is approximately 1 mm. In the magnetic system, magnetic field interference could add a potential source of error. The optical system is much larger and can be cumbersome, both in the operating room and in the field. Better accuracy is clearly obtained with skull-implanted markers with both systems. This accuracy can be further improved by the placement of the marker around the orbit. Other disadvantages are prolonged intraoperative and preoperative times and additional cost to purchase the equipment and to obtain preoperative imaging procedures. In our hands, the preoperative preparation time averages 40 minutes.

In conclusion, although the experience with image-guidance systems is limited in orbital surgery, it offers certain unique advantages as described in our report. As in any other surgical technique, as its applications expand, more advantages and disadvantages will surface.

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REFERENCES

1. Mascott CR, Karcioglu ZA. Computer image guidance and skull base strategies. In: Karcioglu ZA, ed. Orbital Tumors: Diagnosis and Treatment. New York: Springer-Verlag Publishers; 2005: 391-7.
2. Kelly PJ, Goerss SJ, Kall BA. Evolution of contemporary instrumentation for computer assisted stereotactic surgery. Surg Neurol 1988; 30: 204-15.
3. Leksell L, Leksell D, Schwebel J. Stereotaxis and nuclear magnetic resonance. J Neurol Neurosurg Psychiatry 1985; 48: 14-8.
4. Barnett H, Kormos DW, Steiner CT, Weisenberger J. Intraoperative localization using an armless, frameless stereotactic wand. J Neurosurg 1993; 78: 510-4.
5. Gildenberg PL, Tasker RR, eds. Textbook of Stereotactic and Functional Neurosurgery. New York: McGraw Hill; 1998.
6. Gumprecht HK, Widenka DC, Lumenta CB. BrainLab Vector Vision Neuronavigation system: technology and clinical experience in 131 cases. Neurosurgery 1999; 44: 97-105.
7. Walch C, Stammberger H, Unger F, Anderhuber W. A new therapy concept in esthesioneuroblastoma. Laryngorhinootologie 2000; 79: 743-8.
8. Thompson TP, Lunsford LD, Flickinger JC. Radiosurgery for hemangiomas of the cavernous sinus and orbit: technical case report. Neurosurgery 2000; 47: 778-83.
9. Schultes G, Karcher H, Gaggl A, Santler G. Computer assisted tumour resection of the skull base: case report. J Craniomaxillofac Surg 2001; 29: 326-31.
10. Papalkar D, Francis IC, Stoodley M, et l. Cavernous haemangioma in the orbital apx: stereotactic- guided transcranial cryoextraction. Clin Experiment Ophthalmol 2005; 33: 421-3.
11. Selva D, Chen C, Wormald PI. Frontoethomoidal osteoma a stereotactic-assisted sino-orbital approach. Ophthal Plast Reconstr Surg 2003; 19: 237-8.
12. Klapan I, Barbir A, Simicic R, et al. Dynamic 3D computer-assisted reconstruction of a metallic retrobulbar foreign body for diagnostic and surgical purposes. Orbit 2001; 20: 35-49.
13. Wang MY, Maurer C R Jr, Fitzpatrick JM, Maciunas RJ. An automatic technique for finding and localizing externally attached markers in CT and MR volume images of the head. Trans Biomed Eng 1996; 43: 627-37.
14. Maurer CR, Fitzpatric JM, Wang MY. Registration of head volume images using implantable fiducial markers. Trans Med Imaging 1997; 16: 447-62.
15. Berger M, Char DH. Interactive image guidance for surgical localization of orbital atypical tumors. Orbit 2002; 21: 199-203.
16. Novak Z, Nadvornik LP, Chrastina J. Stereotaxic biopsy of orbital tumors Cesk Slov Oftalmol 1997; 53: 220-2.