CASE REPORT

Practical Applications of Image-Guided Navigation during Anterior Craniofacial Resection

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Abstract—Intraoperative image-guided navigation allows the surgeon to identify anatomic landmarks obscured by overlying normal tissue, neoplasms, infection, or previous surgery. This case presentation illustrates some of the practical applications of the ISG image-guided navigation system during anterior cranial base surgery. The advantages and the pitfalls of the ISG system are discussed. (*Skull Base Surgery*, 5(1):51–55, 1995)

Recent advances in intraoperative image-guided navigation allow the surgeon to identify anatomic landmarks obscured by neoplasm, infection, previous surgery, or overlying normal tissue.^{1–7} The ISG Viewing Wand system (ISG Technologies, Inc., Toronto) uses a probe attached to a position-sensing articulated arm. The position-sensing arm and probe allow intraoperative navigation through a surgical field matched to a computerized three-dimensional reconstruction obtained from the digitized data of a preoperative axial computed tomography (CT) scan or magnetic resonance imaging (MRI).² The surgical field (ie, head and face of the patient) is registered to the computerized reconstruction (virtual image) by matching coordinates that correspond to surface anatomic landmarks such as the nasion, medial and lateral canthi, and supraorbital and infraorbital notches, or to fiducial markers placed at the time of imaging.

The following case report illustrates some of the practical applications of the ISG system during anterior craniofacial resection.

CASE REPORT

A 27-year-old white female complained of left cheek pain and left nasal obstruction of 4 weeks duration. The patient developed lateral displacement and proptosis of the left eye 2 weeks prior to presentation. Physical examination revealed a mass in the left nasal cavity. The visual acuity was 20/20 (corrected).

Axial and coronal CT scans with contrast enhancement revealed a mass occupying the upper three quarters of the left nasal cavity and displacing the nasal septum toward the right nasal cavity. The tumor extended laterally into the medial aspect of the orbit, displacing the orbital contents laterally, and into the maxillary infundibulum and nasofrontal recess, causing obstruction of the maxillary and frontal sinuses. Computed tomography scan images, however, did not clearly differentiate tumor from inflamed mucosa within the left paranasal sinuses. Posteriorly, the tumor involved the vault of the nasal cavity as far

back as the planum sphenoidale. The sphenoid sinus, although obstructed, was not invaded by the tumor. The medial aspect of the fovea ethmoidalis was eroded, but no tumor was identified in the anterior cranial fossa.

Magnetic resonance imaging corroborated the CT findings and provided better delineation of the interface of tumor with obstructed secretions in the frontal maxillary sinuses. The MRI revealed involvement of the dura over the area of the fovea ethmoidalis.

Histological analysis of punch biopsies, including hematoxylin and eosin, as well as immunoperoxidase stains, identified the tumor as an embryonal rhabdomyosarcoma. Because of our previous experience with the ISG system, we anticipated that intraoperative navigation would be most helpful in identifying the optic foramen and canal, as the tumor involved the posterior ethmoid cells around the optic canal, and we were planning a subperiosteal dissection. The "wand" could also delineate the boundaries of the frontal sinus, thereby guiding the frontal sinusotomy approach, as well as the posterior boundary of the tumor at the planum sphenoidale (ie, posterior intracranial osteotomy).

The digitized CT scan was performed with administration of intravenous contrast. Three-millimeter-thick contiguous axial slices were acquired. The data was transferred to the Allegro (ISG Technologies) work station for three-dimensional reformatting.

Computed tomography density thresholds were used to generate skin surface and bone tridimensional (3-D) "objects." Region of interest tracing was used to produce 3-D objects representing tumor, optic nerves, and ethmoid/frontal/sphenoid sinuses. The reformatted data was transferred to the Viewing Wand system in the operating room. On the Viewing Wand system, the 3-D objects can be displayed as opaque surface 3-D images. Sections of each 3-D object could be cut away to show deeper areas of interest. The bidimensional (2-D) axial image data set was also transferred so that triplanar (sagittal, coronal, and axial planes) reformatting could be performed during the surgical procedure.

Intraoperatively, the patient was placed in a supine position with her head supported by a horseshoe Mayfield head holder (Codman, Johnson and Johnson, Boston). Surface coordinates within the surgical field were registered to match the computer data set (primary registration). The adequacy of the registration was confirmed by touching identifiable landmarks or "markers" with the position-sensing probe.

Once primary registration was achieved, the surface incisions were made with particular care taken not to move the head and thus lose the integrity of the primary registration. Secondary points were then identified on the skull and facial skeleton. These were marked with cautery and their positions entered into the computer as secondary registration points. Secondary registration can then be done by placing the probe on the various secondary registration points and indicating the appropriate position coordinates on the computer.

This secondary registration reestablishes the position of the anatomy to the computer data and is done if the head is moved during the procedure. Secondary registration points are required as the original points of primary registration are moved during elevation of the scalp and cheek flaps. At least five reproducible bone coordinates were used in the secondary registration to insure accurate reregistration.

The patient underwent an anterior craniofacial resection and medial maxillectomy through lateral rhinotomy and bicoronal scalp incisions. A medial subperiosteal dissection was performed (ie, resecting periorbital en bloc with the tumor) with preservation of all other intraorbital structures. During this dissection the usual bony landmarks, such as the ethmoidal neurovascular foramina and frontoethmoid suture, are not visible. The wand was of great assistance in recognizing these landmarks and the optic foramen, complementing the surgeon's assessment of the anatomy, and thus added a safety factor during the orbital osteotomies.

The frontal sinusotomy was designed using a standard 6-foot Caldwell view template and the wand. Although both methods yielded similar results, the ISG wand was more accurate in identifying the boundaries of the superior and lateral recesses of the frontal sinus (Fig. 1). The wand was used again to mark the posterior and lateral extensions of the tumor and to corroborate the position of the optic canals, therefore guiding the intracranial osteotomies (Fig. 2). The tumor was removed en bloc with the medial maxillectomy and involved anterior cranial base. The adequacy of the resection was assessed by frozen-section analysis.

The floor of the anterior cranial fossa was reconstructed with a pericranial flap. The resected dura was replaced with cadaver dura using a watertight closure. The periorbital was reconstructed using a free pericranial graft, and the medial orbital wall was reconstructed with titanium mesh. The anterior wall of the frontal sinus was replaced and fixated with titanium microplates. The scalp and lateral rhinotomy incisions were closed using a multiple layer technique. The postoperative period was uneventful, and the patient was discharged to home 6 days after surgery.

DISCUSSION

The ISG Viewing Wand is an intraoperative navigational device that links a position-sensing articulated arm and probe to a computerized image display. The computer correlates the anatomy of the patient to the CT- or MRI-reformatted data, providing "navigation" throughout the procedure.

The computer first correlates the patient's anatomy by obtaining surface coordinates (primary registration). If the patient's head is fixed (rigid system), as with Mayfield pins, the primary registration will be accurate throughout the procedure. A secondary registration is taken for veri-

Figure 1. A: Frontal sinus “mapping” as delineated by the “magic wand” (ISG) and Caldwell radiogram template (Temp). B: Transfrontal sinus craniotomy following the template markings. Notice the bony overhang (arrows) demonstrated with a Cottle elevator. The mapping obtained with the magic wand was more accurate than the template mapping.

fication, and to restore the frame of reference once the surface landmarks have been disturbed or the patient’s head moved. Secondary registration is crucial to navigate in a nonrigid (plastic) field. The secondary registration may be performed using internal (bony) landmarks, which is more practical and accurate for most skull base cases. Secondary coordinates on bone may be marked by screws or drill holes. It is essential that the accuracy of the registration is confirmed throughout the procedure because any movement of the head will downgrade the accuracy of the system.

The computer monitor displays a 3-D reconstruction, as well as 2-D images in the sagittal, coronal, and axial planes. The virtual probe of the 3-D reconstruction and cross hairs of the 2-D images effectively move in real time as the tip of the probe is moved over the surgical field, enabling the surgeon to identify anatomic landmarks that have been obscured by tumor, infection, trauma, or pre-

vious surgery. It also enables the surgeon to correlate the surface anatomy with deeper anatomic structures or pathology. This may assist in the design of the surgical approach. The 3-D images can be interactively rotated and can provide translucent and “cut-away” images of the surface structures (soft tissue and bone) to explore the feasibility and adequacy of the exposure provided by different surgical approaches or to increase the understanding of the anatomy (Fig. 3).

The Viewing Wand provides reasonable accuracy and involves no intraoperative radiation.¹⁻⁷ The system is designed to assist but not to substitute for the surgeon’s anatomic expertise. It involves investment of minimal time (3 to 5 minutes) to register the primary and secondary coordinates, and adds one more piece of equipment to what may be a crowded operating room. The articulated arm is somewhat bulky and occupies some of the space around the surgical field, but it is light and easy to use, and

Figure 2. A: Intraoperative photograph of the ISG probe (arrow-head) over the planum sphenoidale at the level of the rostrum of the sphenoid sinus, demonstrating the posterior extent of the tumor. B: Computer display: cross hairs (2-D images) and virtual probe (3-D image) showing the position of the tip of the probe over the planum sphenoidale.

Figure 3. Translucent image demonstrating optic canal (arrow-heads), optic chiasm (open arrow), and tumor (solid arrow). This image can be manipulated intraoperatively to explore or highlight the anatomic areas of interest.

has a wide range of movement. The cost to the patient is unknown because the equipment is still in the initial stages of clinical marketing; nevertheless, the benefit of computer-assisted navigation will certainly justify the additional cost in selected cases. Further advances such as a flexible or “free” probe and a tracking device that may follow the intraoperative movements of the head, without the need for fixation of the head or use of an articulated arm, will enhance the use of this system.

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