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The Cygnus PFS Image-guided System

The Cygnus PFS Image-guided System is manufactured by Compass International, Cascade Business Park, 919 37th Avenue, NW, Rochester, MN 55901 (telephone: 800/933-2143; fax: 507/281-1736). The base price of the system is $88,000, including the control unit, magnetic transmitter and receiver, mounting brackets, cables, pointer and suction tips, host computer system, planning software, and protective portable carrying case.

Background

In 1908, Horsley and Clarke (6) coined the word "stereotaxic," from the Greek words *stereo* ("three-dimensional") and *taxic* ("an arrangement"), to describe their method of mapping the brain in mathematically defined space within a Cartesian frame of reference. The word "stereotactic," incorporating "-tactic" from the Latin word meaning "to touch," was agreed on approximately 65 years later for applications of these methods to human surgery. A number of excellent reviews of the history of stereotaxy have been published (2). All stereotaxy requires a frame of reference to define stereotactic space. In classic frame-based stereotaxy, stereotactic space is defined in relation to an external frame or ring that is rigidly fixed to the cranium of the patient before data acquisition. The foundation for interactive, volumetric, image-guided surgery was established in frame-based stereotaxy by Kelly et al. (3, 7).

Frameless image-guided surgery

In the past few years, advances in frameless stereotactic technology have paralleled the rapid developments in computer technology. In frameless stereotaxy, computer-generated skin surface rendering using anatomic or adhesive fiducial landmarks permits stereotactic space to be referenced to these surface landmarks. The interactive nature of this image guidance allows unlimited targets and volumes to be identified intraoperatively via computer tracking of a sterile pointing device. A number of diverse technologies have been used for intraoperative pointer tracking; these have included ultrasonographic tracking (1, 12, 13), tracking with robotic arms (11, 16) or articulated arms (5, 10), optical tracking of light-emitting diodes (15) or passive markers (4), and magnetic field localization (14). In some methods, the microscope focal point becomes the pointing device while the microscope is tracked on a robotic arm (11) or optically tracked from attached light-emitting diodes or passive markers (4, 15).

The Compass Cygnus PFS System uses tracking of an instrument within a magnetic field to relate stereotactic surgical space to an imaging database. The tracking magnet is compact and can be easily attached to a three-point head-holder. With the exponential increases in laptop computing power, it has become possible to configure a very portable system.

Description of the system

The Compass Cygnus PFS System is a portable frameless stereotactic system. It is housed in a high-impact trunk on wheels (*Fig. 1*). The system operates on a LINUX platform installed in a 300-MHz Dell Latitude laptop computer (my computer contains an older 233-MHz microprocessor) (Dell, Round Rock, TX). A control unit slightly larger than the laptop computer is connected to the computer, as well as to the transmitter and receiver cables (*Fig. 2*). The direct-current magnetic field transmitter is attached, via an adjustable L-bracket, to the outer starburst of a three-point head-holder (such as a Mayfield head-holder; OMI Medical, Cincinnati, OH). The receiver is a small unit that is clipped onto a disposable plastic pointer assembly with a blunt metal probe (*Fig. 3*). A short suction tip can be used instead of the blunt probe. Two receiver cables are supplied with the system, one for nonsterile registration and the other for use with the sterile probe or suction tip in the surgical field. The magnetic field can be placed on standby, to eliminate interference with other equipment (i.e., electroencephalographic equipment for electrocorticography). The company has recently begun to produce longer straight or bayoneted suction tips, with dedicated receiver and cable. Volumetric acquisition of computed tomo-

FIGURE 1. The portable Cygnus PFS Image-guided System, in its carrying case.

FIGURE 2. Laptop computer for preoperative planning and intraoperative navigation, shown atop the Cygnus electromagnetic control unit.

FIGURE 3. Example of the surgical configuration, showing the electromagnetic field source attached to a head-holder via an L-bracket. The hand of the surgeon is holding a probe attached to the electromagnetic receiver. An optional flat-screen monitor can be observed in the background.

graphic (CT) or magnetic resonance imaging scans with a slice thickness of 3 mm or less is recommended. Data imaging can be downloaded via the ethernet or downloaded onto digital audiotape (DAT) using a separate DAT driver. A Zip driver for data backup is also supplied. Planning and intraoperative image guidance can be performed on the Dell laptop computer screen. A separate, high-resolution, flat-screen monitor with a stand is available (as an option) for operating room use.

Pre- and intraoperative configuration

A clear concise operating manual is supplied with the Cygnus system (I admit that I read it for the first time in preparation for this review). Magnetic resonance imaging and CT calibration and installation are performed by the Compass staff at the time of system delivery. Scanning protocols are similar to those used with other frameless stereotactic systems. When data are transferred via DAT tape, a separate tape must be prepared for each patient. Backup tape copies are prepared in the usual manner, in our case from GE scanners (General Electric, Milwaukee, WI). Surgical planning requires only the laptop computer and a DAT tape drive, and I perform surgical planning at home in the evenings. Tape downloading requires only a few minutes for each study. Orientations, top and bottom slices of the volumetric study, and image levels are chosen using screen prompts. Although the mouse pad is otherwise quite convenient, ideal image contrast and brightness levels are occasionally difficult to obtain with it, especially with thin-cut CT images.

After confirmation of the image series, the program automatically delivers skin surface renderings. In contrast to other systems, four separate surface-rendered images, i.e., two lateral views, one anterior view, and one posterior view, are displayed. There are not many options for editing the rendered images. This presents a problem with CT head-holders, which cannot be edited out of the lateral views where they obstruct anatomic landmarks and, to a lesser degree, fiducial markers. This is not as great a problem for fiducials because precise localization is easy in axial slices. I find the simultaneous presentation of three or four rendered head displays to be very convenient for rapid selection of fiducial landmarks, because there is no need to manipulate or rotate a single rendered head display to locate all fiducials. When a rendered fiducial is selected, the corresponding axial slice is presented on the right half of the screen. Slice selection can then be fine-tuned with "S" (superior) and "I" (inferior) keyboard keys. Fiducial/landmark registration is available only in the plane in which the scan was acquired (usually the axial plane). After image registration of three to eight fiducials or landmarks, the unit is ready for use in the operating theater. The total time required for this presurgical data acquisition and planning is approximately 10 to 20 minutes. Trajectory and volume planning will be supported in future versions, and this planning will inevitably add to the planning time.

On the day of surgery, the laptop computer is placed on top of the control unit and connected to it. The receiver cable is connected to the control unit, as is the cable from the transmitter/magnet. After the head has been immobilized in three-point fixation, the brackets and magnet are attached to the outer starburst of the head-holder.

The system is then ready for patient registration. The receiver, with its pointer, is used for registration. After fiducial registration, the estimated fiducial errors between the patient and the images are displayed in a readout. Fiducials can be deleted or reregistered. A particularly instructive feature is the ability to view the difference in fiducial registration in image space versus estimated real space in parallel axial images (under the heading "Show Registration on Images"). The root mean square error is displayed for acceptance or rejection. Even with reregistrations or corrections, the average registration time can be maintained at 5 minutes. Anatomic accuracy is then visually confirmed while the probe is moved over landmarks on the head and face. The system is placed on pause/standby before disconnection of the nonsterile receiver. After the patient has been prepared and drapes have been placed, the sterile receiver and cable are brought into the field and the cable is connected to the control unit. The Cygnus system is then ready for surgical guidance.

Advantages

The Compass Cygnus PFS System works extremely well. This is not a minor point for a system that is operated using a laptop computer. The Dell laptop computer screen images are quite clear, although obviously not as clear as those of a dedicated monitor. Tracking and image updating are surprisingly fast for a laptop computer. Although recent software upgrades for large workstation-based systems are faster, in my experience frameless systems are used more for confirmation of locations than for rapid updates of dynamic pointer movements.

There are concerns regarding interference with registration or localization accuracy with all systems. Arm-based systems and optical tracking systems have been found to be quite accurate. Sound-based probe tracking systems have become somewhat less popular. In the latter systems, errors can result from the effects of air temperature and humidity on sound conduction. Similarly, it has been stated that metal objects in the operating theater may adversely affect the precision of magnetic field-based systems such as the Compass Cygnus PFS System. I have not found this to be a major problem.

Our group has used the Cygnus PFS System in conjunction with a Mayfield head-holder (OMI Medical) for three-point cranial fixation. We initially observed some errors in fiducial registration on the down side of the head closest to the Mayfield head-holder, and we attributed these errors to interference from the metal. The "Show Registration" feature of the Cygnus system is a very useful tool for assessing sources of registration errors. With careful analysis, it became clear that the decreased precision of these fiducials was attributable more to scalp shifting with gravity (even in firm, relatively immobile areas) than to metallic interference from the head-holder. Other types of metallic equipment frequently used in surgical fields include retractor systems. Although the Cygnus manual advises against the use of metallic retractor systems, we used a Budde halo system (OMI Medical) or Leyla bar system (V. Mueller, Deerfield, IL) on several occasions. Accuracy was not obviously affected in most cases, but retractor system effects on intraoperative precision could not be excluded on a few occasions. We have been using retractors less often with the Cygnus system. We performed electrocorticography on two occasions, without noting any obvious adverse effects on the electroencephalographic tracings or on the Cygnus system precision.

The greatest advantage of the Cygnus system, however, is its unobtrusiveness at the time of surgery. This advantage cannot be overemphasized. The magnet is attached to the headpiece and is under the drapes. The only parts of the system that are in the field are the receiver cable, receiver, and probe. The probe can be picked up any time and placed in the surgical field. Observation on the screen is immediate; there is no foot pedal to activate. Replacement of the probe with a suction probe is extremely useful, because suction is one of the most universally used tools in neurosurgery. With the suction probe, online observation of the suction tip in imaging studies is possible for the surgeon, assistant, and nursing and anesthesia staff. The suction probe is quite short, and the longer version now available is a welcome addition. Using a suction probe in this way would be awkward and impractical with an arm-based system. Optical tracking systems can track probes, bipolar forceps, and many other instruments, but a clear line of sight must be maintained between the tracking cameras and the instruments to be tracked. This is difficult to achieve consistently in most operating room environments. There is no line-of-sight interference with the Cygnus system.

Disadvantages

There are many caveats with respect to frameless stereotaxy itself. The reliability of fiducial scalp markers and anatomic landmarks can be a source of error in all frameless systems. These reliability problems are not specific to the Cygnus system. The desirable level of precision for frameless stereotaxy is approximately 3 mm. The standard of 1-mm precision observed in frame-based, CT scanning-guided stereotaxy (8) is not achieved, because of slight movements of the scalp, magnetic resonance imaging distortions, and many other factors (9). Intracranial volume shifts are also universally recognized sources of error in stereotaxy.

With respect to the sources of error encountered in frameless stereotaxy, one of the greatest disadvantages of the Cygnus system is that there are always concerns regarding the possibility of interference with the magnetic field. On the basis of our experience, such interference probably does not occur, but magnetic field interference could be an additional potential source of error. When using the Cygnus system, we have hesitated to use self-retaining retractor systems, to minimize this possible source of error. The availability of a nonmagnetic retractor system would greatly alleviate anxieties regarding magnetic field interference.

Another current disadvantage is the rather rudimentary nature of the Cygnus system surgical planning. It is sufficient for most applications, but trajectory or volume-based planning can sometimes be useful. This will apparently soon be incorporated. I miss the options for multimodality image fusion, which I have recently been using extensively (higher-power laptop computers may be necessary to implement these features).

More flexibility in surface rendering would be desirable. The lack of on-screen detail in surface renderings on the laptop computer, with image registration limited to one orientation, is not reassuring for surface landmark registration without fiducials. Surface scalp renderings are probably better observed with the dedicated flat-screen monitor, which I did not review. There are no registration problems when adhesive fiducials are used. I also miss the lack of cortical surface renderings, as I would with the many other systems that have not yet incorporated this feature.

Suggestions

In addition to the continuing software updates, the following hardware features would be highly desirable. 1) A small stand to house the Cygnus system in the operating theater. The system fits neatly onto most "prep" stands but, unless the system is frequently moved from hospital to hospital, repacking it into its carrying case for storage is slightly impractical. 2) An optional smaller soft carrying case. The Cygnus system is indeed very portable, but its well-padded, large, suitcase-like, carrying case is more cumbersome than necessary if a surgeon intends to frequently transport the system from hospital to hospital. A soft backpack-size case would be sufficient for daily transport needs. 3) A simple, nonmagnetic, sterilizable clamp and bar to accommodate self-retaining retractor arms. The inclusion of these pieces with the system would alleviate some of the concerns regarding retractor systems and magnetic interference. 4) A disposable probe consisting of a stylet to accommodate a ventricular catheter. The simplicity of the installation and use of the Cygnus PFS System make it an obvious choice for image guidance of catheter placement, without unnecessary complication of the procedure.

Conclusion

The Cygnus PFS Image-guided System is an accurate, user-friendly, cost-effective tool for frameless stereotaxy. It can be rapidly installed, is particularly unobtrusive during surgery, and requires little space in the operating room. Its ease of operation is based on the use of a magnetic field to reference stereotactic space. There are concerns that metal objects may decrease stereotactic precision by interfering with the magnetic field, but I have not found this to be a major problem in 1 year of systematic use. With some minor software and hardware additions, the Cygnus PFS System would be outstanding. In addition to the Cygnus PFS System, I have extensive experience with the following frameless systems: the ISG Wand (ISG Technologies, Toronto, Ontario, Canada), the Radionics OAS (Radionics, Burlington, MA), and the StealthStation (Sofamor Danek Group, Memphis, TN).

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COMMENTS

Mascott evaluated a new, portable, image-guided system, after a 1-year experience. The system provides the advantage of portability, which may be of particular importance to surgeons who perform operations at different hospitals and may be constrained by hospitals that cannot afford new, image-guided, surgical platforms. Because the system is based on a personal computer, one would not expect the image quality or image-handling ability to be as advanced as with a workstation. Do we require all of the image projections and tools provided by a workstation? Perhaps. Most surgeons I know use only a standard array of axial, sagittal, and coronal images during surgery and do not often take advantage of three-dimensional renderings or other available views. As Mascott notes, improved software should become available as laptop computer memory and speed are increased. At a cost below that of other image-guided navigation systems, the Cygnus PFS System should be of interest to many. Whether this platform will satisfy the ever-increasing image guidance requirements of surgeons remains to be determined.

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