Original Article

Neuronavigation: Principles, Clinical Applications and Potential Pitfalls

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Localization of brain lesions and prevention of damage to vital structures are important in operation of brain pathologies. Despite development of many techniques including angiography, MRI, sonography ,and frame base stereotaxy , a more accurate localizing technique is still needed (1,2) . A step forward to achieve this goal is to develop a navigation system. In this manuscript, we explained some clinical applications, advantages, and disadvantages of navigation system and tried to have a short glimpse on its future.

Key words: *Neuronavigation, Neurosurgery, Skull Base*

Iran J Psychiatry 2012; 7:97-103

Localization and delineation of extent of lesions are critical for safe maximal resection of brain and spinal cord tumors. Neuronavigation systems have been developed for image-guided neurosurgery to aid in the accurate resection of brain tumors (3,4) . Basic principles of navigated surgery are to see the tip of a pointer in an image space. A relationship between the device space and the image space has to be established[5,6]. This operation is called registration or calibration of the navigation device. Basically, a transformation matrix (T) has to be calculated to map the coordinates of any point between the image and the device spaces. The aim of transformation matrix is to create a linkage between digital image data and anatomical structure , and therefore, to provide increasing 3-D orientation (7). Today's navigation systems provide approximately 2mm accuracy (8) .

Stereoscopic navigation-controlled display of preoperative MRI and intraoperative 3D ultrasound is a new technology for minimally invasive image-guided surgery approaches in planning and guiding neurosurgery. Interactive stereoscopic visualization improves perception and enhances the ability to understand complex 3D anatomy [9,10].In 1947, Spiegel and Wycis performed the first stereotactic thalamotomy in humans, using the commissura posterior or pineal body as an internal individual reference system (11,12). Functional operations with similar frames and techniques were introduced by Talairach in Paris in 1949 (13), by Riechert [14] in Freiburg, Germany in 1952, and by Leksell [3] in Stockholm in 1949 for the treatment of extrapyramidal movement disorders, intractable pain, epilepsy, and psychiatric disorders.

After the development of CT technology by Hounsfield in 1973 (15) and Cormack (16,17) based on mathematical solutions published by the Viennese mathematician Radon in 1917 [18], stereotactic coordinate based calculation was applicable in the whole intracranial space, enlarging the field of indications to biopsies, interstitial brachytherapy, endoscopy, and localization of tumors for open surgery (4,19). Till the end of the 1980s, frame-based stereotaxy was the standard method for accurately localizing small intracranial lesions by introducing catheters into the tumors or for determining the tumor volume in space (20,21,22). Coordinate transformation

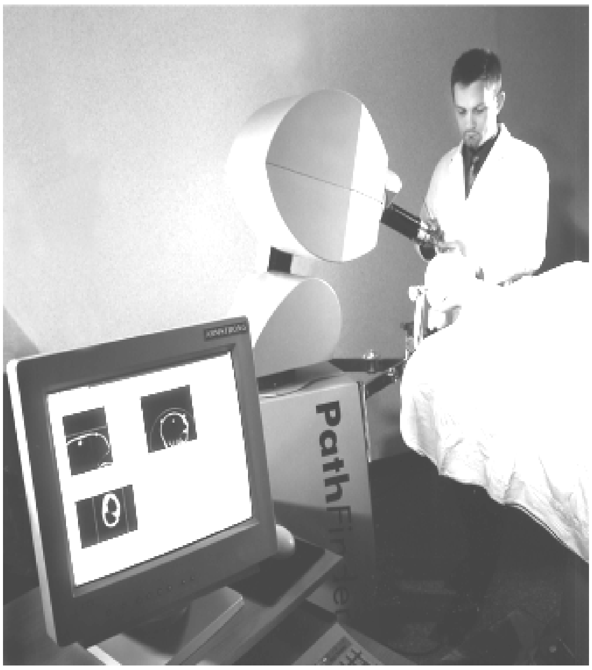

Figure 1. Arm base navigation

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Figure 2. Arm less navigation

of the selected target point between the image and the frame space was established using a localization frame. The idea behind using frameless, interactive, computer-aided surgery in navigation systems is to show in real time the position of the tip of an instrument in the corresponding images, without requiring a stereotactic frame for calculation. In Switzerland in 1988, Reinhardt was working on an armless navigation system which used a pointer emitting ultrasound sources (23,24).

Magnetic sources were also described later by Kato [25], and infrared light-emitting diodes (LEDs) as emitting sources by Zamorano [26]. Additional robotic capabilities were integrated into navigated microscopes by Giorgi (27) and Luber (28).

Clinical applications

The aim of image-guided neurosurgery is to accurately project computed tomography (CT) or magnetic resonance imaging (MRI) data into the operative field for defining anatomical landmarks, pathological structures and tumor margins. To achieve this goal, different image-guided and computer-assisted, so-called "neuronavigation" systems have been developed to provide precise spatial information to neurosurgeons(29). The main clinical utilities in modern neurosurgery are: localization of small intracranial lesions, skull-base surgery, intra cerebral biopsies, intracranial endoscopy, functional neurosurgery and spinal navigation(30). Localization of small intracranial tumors is currently the most frequent application of navigated technology in neurosurgery for adults and children (31,32).

Safe navigating of the critical anatomy is of prime importance in skull base surgeries. This is particularly the case for endoscopic skull base surgery (ESBS) where the surgeons work within millimeters of neurovascular structures (7,33).

Navigation can help accurate localization of important anatomic structures such as the carotid artery or cranial nerves, particularly if they are deep in the tumor, as in medial peritoneal wing meningioma or transsphenoidal pituitary surgery [34,35]. Navigation can also help make approaches through the petrosal bone safer, sparing structures of the inner ear. In orofacial approaches to the C2 vertebra [36], and in tumor recurrences at the skull base with a changed anatomic situation, navigation can help the neurosurgeon to operate accurately. Ear, nose, and throat surgeons also use navigation as an aid for nasal, Para nasal, and otologic interventions. (37,38,39)

Endoscopic procedures are mostly performed by the freehand technique. However, navigation can also be incredibly useful in endoscopy and help the surgeon to make more precise planned trajectories; for instance, in cases of narrow access through the foramen of Monro into the third ventricle to prevent damage to the fornix either the navigation is performed with the pointer to mark the burr hole and decide the trajectory, or the endoscope itself is used as a pointer navigation system (40,41). Inside the third ventricle, Muacevic used navigation in ventriculostomies passes through the narrow passage of the foramen of Monro (42). Schr_der and Gaab (43) also used navigation in aqueductoplasty to choose the best approach to the aqueduct. Furthermore, navigation could provide information about the structures behind the surface of the ventricle wall which is visible by the endoscope.Therefore,, the best place can be selected for removal of the specimens or defining the perforation point (44).

Above the third ventricle, fenestration of a cavum vergae can be supported by stereotactic methods to plan an approach ,sparing eloquent cortical areas. In addition, in cases of very large cysts around the lateral ventricles, the perforation into the lateral ventricle can be dangerous if the membrane is thick and not translucent. Orientation inside the cyst is difficult if anatomic landmarks are missing. In these cases, the point of perforation into the lateral ventricle can be defined by navigation. The endoscopic image itself can be further digitized and mapped into the image space of

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the navigation system. The spatial resolution allows performance of distance measurements and, theoretically, also coagulation in the presence of bleeding (45). Zamorano used endoscopic navigation in over 150 tumor cases including biopsies, colloid cyst removals, and tumor extirpations (46).There is also a report on using navigation in pseudo tumor cerebri. In such cases, ventriculoperitoneal shunts were used instead of lumboperitoneal shunts, and favorable outcomes were reported [47,48]. Moreover, endoscopic navigation has been used for decompression of Superior Orbital Fissure Fracture. (49) Functional neurosurgery, intracranial neurosurgical interventions in the deep brain structures regarding pain, extrapyramidal movement disorders, and particularly epilepsy are the classic indications for applying the frame-based technique. Navigation can also be successfully used in epilepsy surgery for localization and introduction of subdural strip and grid electrodes or for implanting deep-brain electrodes in the hippocampus . Equally interesting is the navigated orientation during ablative surgery in cases of epilepsy, such as with hippocampectomy, to more accurately localize the resection size (50,51,52,53,54).

Laborde reported the drainage of abscesses guided by navigation (55). It is also possible to use these catheters for local antibiotic therapy. Rohde introduced a catheter by navigation into intracranial bleedings for evacuation and lysis therapy (56). Other authors used the navigated placement of catheters in connection with interstitial radiation therapy (57).

The magnetic-force-based Computed Assisted Neurosurgery System has been used for epilepsy stress, particularly in eloquent areas such as the central region in some pathologies such as low grade gliomas . After opening the Dura, we will not be able to see superficial visible pathology. In such situations, we can find the right sulcus by using navigation device. Thus, another important function of surgical navigation is providing guidance to sub cortical tumors (67,68,69). By improved CT/MR imaging, a more precise anatomic localization is possible, and navigation techniques help to make atraumatic openings and approaches (70).

Intra-operative brain deformation (brain shift) limits the accuracy of image-guided neuro-surgery systems (71). Ultrasound imaging as a simple, fast and being real time has become an alternative to MR imaging which is an expensive system for brain shift calculation (9,72). The main challenges due to speckle noise and artifacts in US images, is to perform an accurate and fast registration of US images with pre-operative MR images.(73) There are some ideas that suggest an efficient point based registration method called Coherent Point Drift (CPD) , which is implemented and compared to the conventional ICP method . Fusion technique can also be used in this system .It may help lower the cost by allowing previously acquired non stereotactic images such as MRI to be fused to a low-cost stereotactic scan such as CT without contrast surgery to localize targets accurately in the operative field (58).

It can also be used in the treatment of Parkinson's disease (59). Furthermore, use of neuronavigation and electrophysiology in surgery of subcortically located lesions in the sensorimotor strip have been reported [60]. There are some peculiarities about the anatomy navigation in spinal surgery. The spinal cord is much more flexible, and therefore dependent on the position of the patient. Skin markers are thus not applicable. Registration must be performed after preparation of the vertebrae on their characteristic anatomic landmarks either with a paired-point technique or in combination with surface matching .The dynamic reference frame is fixed on a spinous process inside the operating field to register any displacement close to the working space . The main clinical indication for computer-aided navigation in spinal surgery is the transpedicular insertion of screws in the thoracolumbar region (61,62,63,64).

Advantages and disadvantages

There are some concerns about navigation systems including time consuming calculation and registration, restriction of space and view inside the operating field ,and so on .Nevertheless, there are many advantages that can be helpful in the process of operation (65,66).

An error in the white matter by the navigation device even in the range of 3 mm or 4 mm is still lower than when relying only on neurosurgical knowledge . The neurosurgeon is able to calculate the localization and approach a small lesion accurately, therefore feeling more confident. The corticotomy is associated with less .Incorporation of diffusion tensor imaging (DTI) and fiber tracking into the image data set also helps the precision of the system and prevents damage to the eloquent areas . Visualization of certain low-grade tumors may be enhanced by fusing color-encoded fluid-attenuated inversion recovery (FLAIR) images with high-resolution volume MRI. PET, cerebral blood volume or MRS maps may be fused with a stereotactic study to identify the optimal point for brain biopsy (1).

Navigation system also reduces the length of surgery, lowers the incidence of wound infections, and shortens length of hospital stay (74).

In addition, it reduces the risk for neurological morbidity by allowing the surgeon to determine the relationships of the lesion and surgical approach to nearby critical brain structures .Moreover, visualization of critical surface or draining veins may be facilitated using these systems. Accurate, safe intracranial access for the purpose of biopsy by a variety of techniques can be provided by surgical navigation systems(75,76).

One of the shortcomings of this system is Brain Shift and Local Tissue Deformation. This can be minimized

Methods

As a simple, fast, and being real time, ultrasound

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imaging is an alternative to MR imaging which is considered an expensive system for brain shift calculation. The main challenges to speckle noise and artifacts in US images is to perform an accurate and fast registration of US images with pre-operative MR images(9).

It is important to ensure that the DRF (dynamic reference frame) is securely affixed, so its relationship to the head cannot be disturbed after the registration procedure. Brain shift is generally straight down toward the center of the earth. Therefore, by orienting the patient's head in a position where a vertical surgical trajectory is possible, the surgeon will only need to compensate for brain shift in one direction (i.e., the brain and tumor are lower than expected) rather than for a complex three-dimensional slide that may occur when operating from a different direction. Diuretics usage should be minimized; and compensating for volume loss by limiting or reversing hyperventilation may be a useful strategy (77).

When only part of the resection involves critical brain, the surgeon should work on that area first while the shift is minimal. En bloc removal of tumors should be performed as much as possible[78]. Surgeons should avoid puncturing any cystic components or entering the ventricles until all critical areas of the tumor boundary have been surgically defined .Placing large cotton balls in the resection cavity can usually expand the cavity to the preoperative dimensions(79).

Future

It is difficult to provide any prognosis for the development and role of navigated surgery in the future, as the computer technology is changing so rapidly. Manwaring reported a magnetic emitting source fixed directly to the patient’s skull, producing a nonlinear magnetic field through the brain. Flexible catheters with a magnetic tip could be introduced along these nonlinear magnetic trajectories to the target point. Navigational instruments are presently undergoing a process of evolution with many types developing due to different technical realizations (80).

A presumable future of navigation seems to depend on microsurgical robots. There are some ideas about combining these two innovations to solve the most important shortcoming of neuronavigation : brain shift. This important can be achieved by injecting microsurgical robots through the vessels and synchronizing registration while observing the brain through various aspects from different points. By this root, signals can be transferred to a central computer out of the body. By integrating this information, a 3D map of different points of the brain and its pathologies can be formed. Simultaneously, these robots can play some therapeutic roles. (81,82,83)

Conclusion

Navigation system has some limitations in clinical applications and is expensive. Nevertheless, it can be useful for the surgeons and patients. Most reports indicate that these devices are cost-effective, and may reduce surgical morbidity, and enhance outcome.

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