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REVIEW

The use of image guided navigational tracking systems for endoscopic sinus surgery and skull base surgery: A review

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Abstract The use of tracking technology and navigation system has revolutionised the field of endoscopic sinus and skull base surgery. The role of the navigation system is to enhance surgeon's knowledge of anatomy and experience and not to replace it. Most common navigation system use is optical or electromagnetic tracking technology. Both tracking technologies have been found to be suitable for the demands of intraoperative navigation. It has improved the precision and accuracy of performing surgery and reduced complication rates. The navigation's accuracy depends on factors such as image modality, tracking technology, and registration technique. It allows the surgeon to have information on bony anatomy, position and size of any lesion, as well as location of critical structures such as the carotid artery and optic nerve. We reviewed the use of optical and electromagnetic tracking systems and their differences in endoscopic sinus and skull base surgery.

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1. Introduction

The emergence of endoscopic sinus surgery (ESS) in the late 1980s and early 1990s has brought about a revolutionary advancement from the open sinus surgery to the now minimally invasive approach to surgery for sinusitis.[1] The goal of ESS is to re-establish physiologically normal sinus drainage pathways by removing or correcting diseased pieces of tissue in key areas of sinus obstruction. With the advent of more high definition endoscopes and the use of fibre-optics, the ability to see within the nasal cavity and the sinus cavity has much improved. Evolution of the pre-operative procedures such as computer tomography to high resolution computer tomography with thinner slices also aid in the selectiveness of the dissection during endoscopic surgery, whereby the healthy tissue is identified and preserved. Open sinus surgery often requires facial incisions with resulting facial scars and a lot of nasal bleed and packing. Recovery is usually faster in ESS with less post-operative pain and bleed.

Although we have come a long way in addressing sinus disease, surgeons are still faced with challenges such as intra operative bleed, trauma to the surrounding structures such as the eye and central nervous system and even complications leading up to death. This is due to the complex anatomy of nasal cavity and the paranasal sinus, anatomical variations in individuals, narrow surgical field, obscured surgical field due to bleeding that limit the exact placement of the instrument especially in unskilled hands (beginners).[1–5]

ESS as well as surgery to various parts of the anterior skull base is challenging due to the variety of vascular and neural structures in a very confined space and with previous surgical procedures, scaring and the destructive nature of some diseases affecting the skull base, surgical landmarks are distorted thus increasing the immediate intraoperative complications and long term post-operative defects.[2] This is where the image guided systems or navigation systems are fast becoming an important tool. Image guided systems or navigation systems are essentially like GPS (global positioning satellite) systems for the anatomy of the head. These navigational systems are used to aid the surgeon in confirming the location of critical structures. The usage of the navigation systems has tremendously improved the outcome of ESS and has decreased the complication rate of the surgery. With the road map to the anatomy of the head, surgical precision is improved, instrumentation is more accurate up to 2 mm or better and there is less collateral damage to the surrounding tissues.[3] However, image guided surgical navigation is not a substitute for sound surgical judgement and operative experience.

To use the navigation system, a computer tomography (CT) scan of the sinuses or the skull base of the patient is performed using a specific navigation protocol (in some cases the CT scan is saved into a DICOM format). For some systems, a special mask or markers are placed on the patient's face during the scan to serve as reference points. The CT scan is then transferred into a disc or USB, which is then uploaded into the image guidance system. During surgery, a detection array or mask or in some cases a headband is placed on the patient's head. The CT scan images loaded into the navigation system are then calibrated to the patient's anatomy using the pre-set reference points, which may be the mask or markers specific anatomic points on the face such at the lateral canthus, the glabella and the columnella.[4–6] The position of the sinus surgery instruments can then be tracked by the navigation system by integrating the information detected from the patient's pre-set reference points and comparing it to the information on the CT scan "map". MRI images may also be used with the new navigational systems and the technique is similar to the setting up of the CT scan images into the navigation system.

2. Differences between the optical and electromagnetic tracking systems

There are two main types of navigation systems available in the market today. They are the infrared (optical) systems and the electromagnetic systems. Both systems perform the same functions. However, the technology used to provide the information to the surgeon is very different. In all cases, there will be a device attached to the patient known as the head mask or head frame.[7]

The optical system or the infrared system, as its name suggests, uses infrared sensors in combination with light-emitting structures or light reflectors that are fixed to the patient's head (via a headband strap or sticker) and fixed to a handheld probe (Fig. 1). Both the headband and instrument must be detected or "seen" by the system's camera, or computer in order to track where the surgeon's instrument is within the sinuses.[8]

As for the electromagnetic systems, these systems use electromagnetic fields that use reference points on a device attached to the patient's head (a plastic mask with metallic beads or headband) and a wired instrument that the surgeon uses within the nose and sinuses (Fig. 2).

Unlike the optical systems, the electromagnetic systems do not have to be "seen" by the computer meaning that it does not matter if other devices or equipment in the operation theatre are placed in between the computer and the patient. However, too much metal within the electromagnetic field can cause inaccuracies. The comparison between both navigational systems is listed in Table 1.

Figure 1 Optical image guided navigational tracking system.

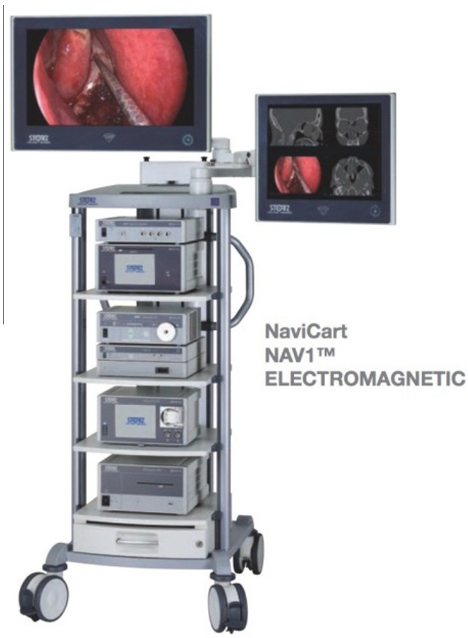

Figure 2 Electromagnetic image guided navigational tracking system.

3. The advantages and disadvantages of optical and electromagnetic tracking systems

Both optical and electromagnetic navigation systems allow the possibility to explore the paranasal sinuses and the skull base completely. It helps in the clearing of small cells in narrow spaces.[9] Accuracy is the main stay of the navigation system as the surgeon will be able to accurately localise the lesions.[10] In patients that have sphenoid sinus with septations and altered anatomy, it will guide surgeons to approach the ethmoid and frontal regions safely and accurately identify the landmarks that have been distorted by disease.

The safety of the patients also improves with the improved accuracy and precision in identifying the landmarks even up to 2 mm or better. Furthermore, the navigation system simplifies complex procedures. The surgeon is able to reach the brain and skull base without much neurovascular damage to the surrounding brain tissue that usually happens with the old fashion method of open surgery where the brain cerebellum or in some cases the frontal gyrus is retracted for access. Most of all, postoperative morbidity and mortality is reduced by decreasing the extent of neurovascular compromise or damage caused by surgery.

With the sagittal reconstruction and the three dimensional imaging capacity of the navigation system, the surgeon is more reassured and confident in his skills as there is better understanding of complex anatomy and improved learning curve for residents.[11]

On the other hand, setting up and using the navigation requires additional training and experience on both parts of the surgeon and the operation theatre staff. Also, the setting up of the system takes up precious time. Registering the probe and equipment requires at least 15 min of the operative time. Furthermore, navigation system uses preloaded images which are done preoperatively, and not the current scan. To improve accuracy for the navigation system, there had been suggestions for an ongoing CT while operating. However, this exposes the patient and also the operating staff to additional radiation.

Monetary costs would also be substantial as the navigation system is costly. As the navigation system depends on a computer, any crash in the computer system, or computer virus infection renders the system useless. The system also takes

Table 1 Comparison between electromagnetic and optical navigational systems.

Electromagnetic	Optical
Pro • Automatic CT/MRI fusion • Intraoperative distance control • Electromagnetic field generator can be integrated into operative table, and is detachable • Able to move patient's head freely for repositioning without recalibration • Electromagnetic headset sensor is detachable and can be easily sterilised • All-in-one equipment in operation theatre, whole navigation system in one trolley (takes up less space in OT) • No need of line of sight • Tracking not affected by titanium • Automatic instrument check upon registration • Other instruments can be autoclaved	*Pro* • Automatic CT/MRI fusion • Intraoperative distance control • Real time display of instrument • Integration of endoscopic video image • Wireless/cordless probe available • No alteration in operation theatre set-up (no change in operation table hear rest) • Frameless, no rigid fixation to operative table • Active and passive tracking system – free hand probe sensed by passive system
Cons • Interference with other metal instruments such as towel clips • Interference with cardiac pacemakers and cochlear implants • Cables are attached to electromagnetic tracking sensors	*Cons* • Headset with reference frame is bulky and occasionally interferes with accessibility due to triangular shape and size • Needs line of sight with the cameras and the infrared diodes and sensors • Difficulty to change from endoscope to microscope if the equipment interferes with line of sight

up electricity and if there is a power shortage, the system would be culled as the life support systems take precedence.[2]

In the hands of a trainee or an inexperienced surgeon over-enthusiastic dissection would cause damage to the surrounding structures. Damage to the cribriform plate and CSF leak may result from excessive dissection to the nasal turbinates and the ethmoids. The vidian nerve and the anterior genu of the carotids would also be affected in an excessive dissection of the medial pterygoid plates.[2]

Nevertheless, in the hands of a skilled surgeon and with fully trained surgical staff the navigation system would be a great tool. It would save time, increase productivity and most of all decrease the rate of post-operative morbidity and mortality. Hence, navigation system can never replace the surgeon's knowledge of anatomy and experience, but serves to enhance it.

4. Indications and contraindications of optical and electromagnetic tracking systems

Both tracking systems offer the advantage over the conventional methods particularly in the paediatric age group. In children, the nasal cavity and the paranasal continues to grow and change throughout their development to adulthood.[12] As pneumatisation occurs the landmarks would change and proper anatomy is mostly guess work. Congenital anomalies, benign and malignant neoplasms, infections and traumatic injuries especially in children are an indication for using the IGS due to the disaster in anomalies of the anatomy in children and obscure surgical landmarks.

According to Keshcner et al.[9] the navigation system not only confirms the sella, which may be clinically obvious, but also points out precisely the clinically relevant structures such as the cavernous sinus, the carotid arteries and also the superior and inferior limits of the sella lesion. Progress of the resection or excision of the benign skull lesions can be monitored. The surgeon would also be able to monitor the proximity of the resection to critical structures and notice the thinning or erosion of the skull base, osteomas and inverted papillomas encroaching to the base of skull.

The navigation system maps the way from endoscopic access to the anterior base of skull in cases of encephalocoeles or in cases with CSF leak, helps in the precise delineation of the area of leak. If the patient had previous surgery or ESS, the usage of the IGS helps define the limit of the bony defect so that landmarks can be identified and surgical reconstruction can commence. In short, the indications of IGS usage are revision surgery with or without distorted anatomy of the base of skull, paranasal sinus and the nasal cavity, defects in the base of skull, benign and malignant neoplasms such as juvenile nasopharyngeal angiofibroma and sinonasal tumours.[13]

As for the contraindications of the usage of IGS, in the optical based system, there must be direct line of sight visualisation of the camera and the infra-red diodes. And as to the electromagnetic based system, patients with electronic devices such as cochlear implants and pacemakers are relative contraindications, as with the advancement of technology these devices have been improved. Patients with electronic devices attached to the brain and nervous system are also contraindicated in the electromagnetic system. Usage of cell phones and pagers while the electromagnetic system is in use can also interfere with the electromagnetic field in the system.[14]

5. Pre-operative evaluations and requirements

Thorough history taking and complete general examination together with otorhinolaryngological and neurological assessment should be done. Evaluation of the cardio and pulmonary parameters are also important.[15] The patient should be prepared for surgery and informed consent should be taken. During the preoperative consultation, the surgeon should explain about the uses of the navigation system and the benefits of using the system, however the system is a tool and does not replace surgical experience.[2,5,9]

Proper review of the radiological studies of either CT or MRI or both should be done prior to the operation. These imaging studies are performed to help define bony anatomy of the paranasal sinuses, the pneumatisation of the sinuses, anatomical orientation of the sphenoid sinus to surrounding structures such as the carotid arteries, optic nerve, cavernous sinus, sellar and pre-sellar areas. Most systems require reprocessing of the radiological images into a proper format compatible with the navigation systems' computer, for example CT DICOM (2 mm or 1 mm) cuts. These images later would be uploaded into the navigation system via USB (universal-serial-bus) or via a compact disc or even via the hospital network.

In the operating room, the surgery is best done under general anaesthesia. The anaesthetist would induce the patient for general anaesthesia and intubation with the endotracheal tube is done with a throat pack inserted, to prevent leaks and aspiration. In some centres, the laryngeal mask would sometimes be used instead of the endotracheal tube. The choice of anaesthetic drug such as TIVA (total intravenous anaesthesia), or gases such as sevoflurane or desflurane for maintenance is also widely used. It is important to maintain optimal blood pressure and vital signs during the operation to prevent excessive bleed intraoperatively.

Patient is placed supine on the operating table and most surgeons would prefer a reverse Trendelenburg to minimise intraoperative bleed. The head strap is then placed unto the patient's head. The patient is cleaned and draped and the sterilised transmitter (reference pointer) either optical or electromagnetic is then attached to the head strap. Thus, ensuring sterility. Patient's head is freely positioned so that it can be easily moved or adjusted during the surgery.

Registration of the tracking probe is an important step. The position of the instrument in the surgical field is correlated with the CT images of the patient. The probe or tracker is registered to show the position when compared to the images on the CT of the patient. A set of cross hairs or pointer, or mouse arrow moves across the CT images according to the movement of the tracker. The navigation system monitor will show the axial, sagittal and coronal cuts of the CT in regard to the targeted anatomy, thus displaying the anatomy properly. There will also be a quadrant on the monitor screen for the endoscopic view as well.[16]

Usually, there will be 3 anatomical markers that are set by selecting the bony prominences that are beneath the skin. In the optical system the root of the nose, and the right and left lateral canthi over the eyebrows, form a "T". As for the electromagnetic system a triangle will be formed with the two lateral canthi and the base of the philtrum as the reference point. To set up and register the probe in the electromagnetic field or the field of vision of the navigation system, the reference points selected have to be touched by the pointer. A confirmatory tone will be emitted when the points touched are confirmed by the anatomic location. However registration method varies from system to system.[4]

The accuracy is later then confirmed and tested by testing the known landmarks and correlating their position with the CT images. And these data are saved and used to monitor the accuracy of the navigation system device, either the probe or the sucker or instruments registered to use with the navigation system. Thus, the role of the navigation system is essential in localising obscure structures that were an anatomical variant or structures that were destroyed either by the disease or previous surgery.

6. Conclusions

The use of image guided navigation system has proved valuable in enhancing and complementing the knowledge and skill of surgeons. It is useful in complex and difficult surgeries in guiding towards the right place for removal of diseased tissues and avoids complications and damage to the surrounding tissues. The limiting factor to its use is the cost as not many hospitals may be able to afford it and it may add on to the already high treatment cost of patients. However, with the increasing medicolegal cases being recorded, its use may perhaps be mandatory in the near future.

Conflict of interest

All authors declared no conflict of interest.

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