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Review Article

Navigational systems in rhinology: should we all be using them?

J Doshi, R Youngs

Abstract

The proximity of the paranasal sinuses to important anatomical structures creates the potential for serious complications following endoscopic sinus surgery. Over recent years, navigational systems have been developed and are increasingly being used by some centres.

We summarise the history and principles of navigational sinus surgery, review the medical literature on the topic, and try to assess what role navigational systems should play in modern day rhinology practice.

Key words: Surgery, Computer-Assisted; Paranasal Sinuses

Introduction

Endoscopic sinus surgery is a common rhinological procedure performed in most otolaryngology units in the UK. The proximity of important anatomical structures to the nasal sinuses creates the potential for serious complications, which may in turn generate possible medico-legal action. Computer-aided navigation systems have made rapid advances over recent years and are almost routinely used in some countries, particularly the USA.

The aim of this paper was to summarise the concepts of image-guidance surgery, to review the medical literature on the use of navigation systems in sinus surgery, and to assess what role such systems should play in modern day rhinological practice.

History

Navigational systems were originally developed for use in neurosurgery. They were first used within otolaryngology in the 1980s, when a navigational system for use in rhinology was developed in Germany.[1] Navigational systems have inevitably been refined and updated since their inception, to produce the sophisticated systems which are available today. A thorough account of the history of the origins of navigational systems and their development in sinus surgery can be found in the papers published by Anon[2] and Reardon.[3]

How does it work?

The main principle of image-guidance surgery is to track the location of surgical instruments in relation to the patient's individual anatomical structures. This requires two features fundamental to image-guidance surgery: registration and tracking.

Registration

Registration is the process of linking the patient's pre-operative imaging to that of the patient's actual position in space. This requires the radiological landmarks on the scan to be linked with corresponding physical landmarks on the patient; these landmarks can be anatomical or fiducial.

Anatomical landmarks (e.g. medial canthus, lateral canthus, tragus) can be inaccurate owing to variations in soft tissue anatomy dependent on changes in tissue hydration. Fiducial markers can be bone-anchored, skin-anchored or attached to an external device, such as a headset, worn by the patient.

Bone-anchored fiducial markers provide accurate reference points but are clinically impractical. Skin-anchored fiducial markers have limited use, as any displacement of these markers before the operation requires new pre-operative imaging.

Modern day navigational systems can use fiducial markers that are incorporated into a headset worn by the patient during the pre-operative scan and again at the time of surgery. The headset is designed to fit the patient in only one way; therefore, the software can perform automatic registration on the day of the operation.

Not all navigation systems require a patient to wear a headset during pre-operative imaging. In contour-based registration, the navigational software constructs a virtual three-dimensional model of the

From the Department of Otolaryngology, Gloucestershire Royal Hospital, Gloucester, UK.
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patient's anatomy based on the pre-operative scanning images. At the time of surgery, the actual physical contours of the patient's facial anatomy are scanned into the software (using a laser or light-emitting diodes, which are used to reflect light off the patient's face to an overhead camera). Several hundred discrete points are localised, and the software can match the pre-operative imaging with the actual patient's physical anatomy.

Tracking

There are two types of tracking system available: electromagnetic and optical.

Electromagnetic systems use radiofrequency signals. A patient needs to wear a headset during the pre-operative computed tomography (CT) scan and then wear the same headset again at the time of surgery. The headset emits radiofrequency waves which are detected by receivers in the dedicated endoscopic instruments; the software can then calculate the location of the instruments relative to the patient's pre-operative imaging.

Optical systems can be active or passive, both using infra-red signals. Active systems comprise a patient headset and surgical instruments with light-emitting diodes, which are tracked by an overhead camera. Software then calculates the relative positions of the patient and the surgical instruments. Passive systems comprise an overhead device that emits infra-red light, which is reflected by the surgical instruments and the patient headset and detected by an overhead camera; the software then calculates the relative positions of the instruments and the headset. Table I summarises the advantages and disadvantages of the two types of tracking system.

How accurate are navigational systems?

Commercially available navigational systems use a combination of different tracking and registration protocols. Therefore, comparing accuracy between systems is difficult.[4] However, an accuracy of 2 mm or less is accepted as the minimum standard for rhinological procedures.[1]

Do navigational systems reduce the risk of complications of endoscopic sinus surgery ?

The risk of sinus surgery (endoscopic or computer-aided) naturally depends upon many factors, including variations in anatomy and pathology, the extent of endoscopic dissection, operator experience and intra-operative conditions. Reardon reviewed the reported complications in the medical literature for 'traditional' endoscopic sinus surgery; the risk of a major complication was approximately 1 per cent.[3] This included orbital injury and intracranial complications such as cerebrospinal fluid leak, arterial injury and pneumocephalus.

Reardon then compared complication rates in two patient groups: those undergoing traditional endoscopic sinus surgery and those undergoing computer-aided sinus surgery (400 patients in each group). There were fewer complications in the computer-aided group; however, this was not statistically significant. Multiple, retrospective patient series from other centres have also reported lower complication rates using computer-aided surgery;[5–7] however, this difference has been found to be statistically significant in only one paper.[8]

When should navigational systems be used?

The American Academy of Otolaryngology-Head and Neck Surgery published guidance on the topic in 2002.[9] They conceded that it was impossible to produce level one evidence in order to demonstrate the superiority of image- guidance surgery, and that such guidance should be used at the discretion of the operating surgeon. However, they felt that there was sufficient consensus of expert opinion and published evidence for the technology to be of particular use in specific situations (Table II).

Does the surgery take longer?

Naturally, there is a learning curve with the introduction of any new surgical technique, with the mean duration of the procedure decreasing with increasing experience. The average duration of an endoscopic sinus procedure has been shown to be approximately 15 minutes longer when using a navigational system, once the surgeon is experienced with the equipment.[3,5,10] However, there is no consensus on how many cases need be performed before a surgeon is deemed 'experienced' with a navigational system. A learning curve has been demonstrated up to the 180th case, and major complications have been

TABLE I

COMPARISON OF TRACKING SYSTEMS

Electromagnetic	Optical
Headset required during pre-operative imaging & operation	No headset required during pre-operative imaging, only during surgery
Radiofrequency signals used	Infra-red signals used
Potential of interference from large metallic objects (operating table may need damping with additional mattress)	During operation, line of sight needed between overhead camera, patient and instruments

TABLE II

EXAMPLES OF SITUATION IN WHICH IMAGE-GUIDANCE SURGERY MAY BE OF USE[9]

Revision sinus surgery
Distorted sinus anatomy (of development, post-operative or traumatic origin)
Extensive sino-nasal polyposis
Pathology involving frontal, posterior ethmoid & sphenoid sinuses
Disease abutting the skull base, orbit, optic nerve or carotid artery
CSF rhinorrhoea or conditions in which there is a skull base defect
Benign & malignant sino-nasal neoplasms

CSF = cerebrospinal fluid

reported by surgeons who have performed more than 300 operations.[11]

How much does it cost?

There are a number of commercially available systems. The cost can be divided into initial purchase cost and maintenance. Some companies have a 'pay as you go' rental system, which has the advantages of reducing the initial financial outlay and also protecting the institution from the cost of upgrading equipment as hardware and software technology advances. Purchase costs range from GB £40 000 to £100 000, depending upon the system specification.

What does the future hold?

Real time imaging to take into account intra-operative changes in anatomy has been investigated. Recently, portable CT systems have become available, allowing intra-operative images to be used to update navigational systems during the course of a surgical procedure. There are obvious practical and financial disadvantages in using intra-operative CT imaging, in addition to the multiple radiation doses given to the patient; furthermore, a study showed no significant difference in accuracy.[12]

A magnetic resonance imaging (MRI) scan may sometimes be the pre-operative modality of choice, for example, in navigation-assisted pituitary surgery. Intra-operative MRI has been investigated; however, this shares similar practical and financial drawbacks to intra-operative CT. In addition, there is a potential for problematic image acquisition, due to interference with metallic objects in the operating room.[13]

- **Endoscopic sinus surgery is a commonly performed procedure**
- **Proximity of the sinuses to important anatomical structures creates the potential for serious complications**
- **Navigational systems are increasingly being used in rhinological practice**
- **The authors summarise the history and principles of navigational sinus surgery**
- **The authors review the medical literature on navigational sinus surgery and try to assess what role it should play in modern day rhinology practice**

Software is available which fuses MRI, CT and positron emission tomography data. This technology allows the surgeon to view each of the three image types in turn, or to view a fusion image created from all three modalities, depending on which view is most appropriate for that part of the operation.[14] Virtual imaging of the internal carotid arteries has been developed using contrast CT angiography, which may be of value for endoscopic approaches to the sphenoid sinus.[15]

Fully automated and surgeon-controlled robotic systems have been used on cadaver heads to perform sinus surgery; this technology is still in its infancy and is under development.[16]

Conclusions

Navigational systems are constantly being updated and refined. Their potential use within rhinology is expanding as technology improves. A navigational system is no substitute for a detailed knowledge of the anatomy of the paranasal sinuses; however, it can be a useful adjunct, valuable in specific cases. Access to this technology in hospitals is naturally limited due to costs. This raises the possibility of concentration of complex cases within tertiary referral centres, where navigational systems combined with surgical expertise can be utilised in order to achieve optimum outcomes in challenging sinus cases. The field of surgical navigation is under constant development. The challenge for companies marketing this technology is to produce systems within the economic reach of otolaryngology departments, in an era in which control of costs is often an overriding objective in the healthcare community.

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Address for correspondence:
Mr Jayesh Doshi,
ENT Department,
Gloucestershire Royal Hospital,
Great Western Road,
Gloucester GL1 3NN, UK.

Fax: 08454 226432
E-mail: jayeshdoshi@hotmail.com

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