Cerebral tumor resection assisted by electromagnetic tracking frameless stereotactic system

RESUMO

Introdução: Tecnologia eletromagnética usada como sistema de localização em Neurocirurgia é relativamente nova e menos comum que a correspondente e menos comum forma óptica, sendo poucas as companhias que as manufaturam. O principal objetivo é descrever a tecnologia usada (Compass Cygnus), suas vantagens e desvantagens em ressecções de tumores cerebrais, quando incorporadas em um programa de neuro-oncologia. Mótodos: Utilizamos o sistema estereotáti-co Compass Cygnuss-PFS, que realiza localização eletromagnética (EMFSS); analisamos a tecnologia usada no sistema e descrevemos a realização do procedimento, suas vantagens e desvantagens. Ainda, relatamos nossa experiência inicial na ressecção de tumores com esta tecnologia, no período de agosto de 2008 a janeiro de 2009, no programa de neurooncologia do hospital de Diagnóstico de El Salvador. Resultados: O EMFSS opera com a utilização de tecnologia Flock of Birds (FOB). Vinte pacientes foram operados com esta técnica, sendo 18 portadores de tumores primários ou secundários: sua precisão foi considerada adequada em 16 casos (88.8%), quando comparada a estruturas não deformáveis e não móveis (base do crânio, foice e tenda). Ultrasom transoperatorário foi utilizado em dois casos. Em dois casos o EMFSS foi considerado inadequado, devido à deformação ou desvio cerebral e a um novo registro foi necessário durante a cirurgia. A localização dos tumores foi em área não eloqüente, em área próxima e em córtex eloqüente. A ressecção tumoral volumétrica foi de 87% (40-100%). Cinco pacientes tiveram complicações (27.7%), sendo quatro delas transitórias e com resolução em trinta dias e um deles com piora neurológica definitiva. A taxa de mortalidade operatória (30 dias) foi zero. O escote de Karnofski na internação, na alta e no controle em 30 dias foi 80 (60-90), 80 (60-90) e 84 (60-100) respectivamente. Conclusões: Localização eletromagnética é um sistema confiável quando sua acurácia é testada contra estruturas não-móveis e pelo ultrasom: é compacta, e sua direção e sua grande vantagem é permitir um planejamento adequado da cirurgia, bem como orientação espacial em tumores profundos, onde o ultrasom é inefetivo. Sua grande limitação é a incapacidade de fazer correção de registros de pontos anatómicos, bem como fusão ou transição de imagens.

INTRODUCTION

Frameless Stereotactic Systems (FSS) have demonstrated their utility in Neurosurgery.\(^6\)\(^4\)\(^1\)\(^8\) In Neuro-oncology FSS is useful as it delivers three dimensional (3D) information of the magnitude and precise localization of the lesions, giving automatic feedback of 3D orientation at all times of tumor relations with regards to normal brain tissue. FSS has demonstrated to be useful in low grade glioma tumor resection\(^1\)\(^4\). Low grade tumors in comparison to their high grade counterparts are more difficult to be visualized and be distinguished with the “naked eye” or even when tumor resection is assisted by intraoperative ultrasound\(^9\) and probably represents one of the most useful clinical applications of FSS.

FSS is also known as image guided surgery systems (IGS). As its name implies, it uses preoperative computed tomography (CT) or magnetic resonance imaging (MRI) and displays them in the operating room (OR) using a method known as sequential synchronization, which means a continuous tracking of a tool in space and a continuous transition and visualization of the preoperative images in accordance with the spatial orientation of the tool that is being tracked. There are two main technologies being used in clinical practice, the most widely used is optical tracking (infrared) and the other one is electromagnetic tracking\(^1\)\(^2\).

This article describes the technology and the normal “flow” of a procedure done by electromagnetic FSS (EMFSS). It also analyses the results obtained in tumor resection surgery, and it describes the practical advantages and disadvantages of the system.

METHODS

Information regarding the technology that EMFSS (Cygnus-PFS) uses was obtained upon our request from the company (Compass International, Rochester MN. USA). Information from the archives of the Neuro-oncology Program of the Instituto de Neurociencias del Hospital de Diagnóstico of El Salvador was reviewed from August 2008 to January 2009. Twenty patients had been operated on by the main author using this system, two patients harbored vascular intracranial pathology (1 arteriovenous malformation and 1 cavernoma) and were excluded from this series. The remaining 18 harbored a cerebral tumor either primary or secondary and were included in this series. All cases of intraparenchymal tumors were assisted by intraoperative ultrasound (TITAN™ Sonosite Inc. Bothell, WA. USA), which also served to validate the precision of tumor localization by EMFSS (Fig. 1). Most intraaxial supratentorial tumors were operated on using awake craniotomy technique: cortical mapping, described elsewhere, was used when deemed necessary\(^1\).

Figure 1. A. Preop axial T1-Gadolineum (GAD) MRI showing a left frontal intraaxial tumor. B and C. Coronal and sagital (respectively) intraoperative ultrasonographic images showing tumor extension and its mass effect over the left ventricle, red lines delimitate tumor borders. D. Intraoperative IGS shows the deepest seated component of the lesion. E. Resection cavity. F and G. Coronal and sagital (respectively) intraoperative ultrasonographic images showing the resection cavity (red arrows) and tumor borders (red lines). H Postoperative Axial T1-GAD MRI showing tumor resection.

EMFSS TECHNOLOGY

The Regulus Navigator (RN) inside the Cygnus-PFS utilizes a commercially available 144 hertz (Hz) pulsed direct current (DC), Flock of Birds® (FOB) equipment, manufactured by Ascension Technology Corporation; Burlington, MS USA, that generates the electromagnetic field through a digitizer source or transmitter that emits continuous signals into a cubic area that detects the digitizer or receiver in the hand piece (Fig. 2). The transmitter by ways of FOB is capable of making between 20 and 144 measurements per second of the emissions that vary continuously, by degrees of movements and distance generated by the receiver that is localized in the instrument’s grip; this is known as sequential synchronization. The measurements and therefore localization of instruments can be registered and visualized in the personal computer (PC) screen when both instruments (transmitter and receiver) are less than a meter away from each other.

The receiver can be adapted with different instruments used in the OR (Fig. 2), the receiver holds the information by which the transmitter can pinpoint its location in the X,Y,Z axis. By selecting the instrument (pointer, biopsy needles, suckers, etc.) additional information is delivered to the transmitter that regard the length and angle of the particular piece that is being used.
Detailed Procedure

Regular skin markers for IGS are used, usually 5 and 7 are placed in areas where the skin is less mobile. After the skin markers have been placed, an MRI is performed using the Magnetom Avanto, Siemens, Erlanger, Germany or a CT is taken at a gantry angle of 0° (image slicing between 1mm and 3mm without any spacing in between them, and a 256x256 field of view format). We normally use contrast (Gadoversetamide 0.5%, OptiMark, Mallinckrodt, USA) in T1 sequences for high grade gliomas or tumors with contrast enhancement and T2 or FLAIR for low grade gliomas. Once the image has been acquired, it is recorded in a Compact Disk (CD) in digital imaging and communications in medicine (DICOM) format.

The information on the CD is loaded to the Cygnuss-PFS computer, so image registration (IR) and patient registration (PR) can take place in the OR. In order for PR to take place, the head is fixed in a three-point fixation clamp and the transmitter placed as close as possible to the patient’s head and as parallel to the floor as possible. (Fig. 2)

Afterwards, the surgical field (patients head) is correlated to the image data through homology and matching of the reference points that are given by the skin markers in the patients scalp. In the process of IR, the center of the skin markers are selected from the image data and in PR the tip of the instrument is placed as close as possible to the patient’s head and as parallel to the floor as possible. (Fig. 2)

and a number less than 1.5 mm is acceptable (Fig. 3). Once this is done, the precision of the registration is verified again over the patient’s anatomy or skin markers. Incision can then be planned in order to make a “tailored” craniotomy and target anatomical points of interest such as cerebral sulci that are the corridors we use to approach the deep lesion (Fig. 4). Once the system is in sterile mode, we use a secondary sterile receiver so that surgery can proceed.

![Figure 2](image2.png)

**Figure 2.** A. Our operation room setup where the electromagnetic transmitter (red arrow in A and B) is placed as near as possible to the patient head. B. Company’s system setup and its theoretical electromagnetic field (3cu.ft +1meter, electromagnetic field). It shows one of the various options of instruments that are accepted by the receiver (blue arrow). C. Pointer, bayonet and biopsy needles can be tracked once have been joined to the receiver (with permission by Cygnuss-PFS, Compass International, Rochester MN. USA).

![Figure 3](image3.png)

**Figure 3.** Root Mean Square (RMS) error of image-patient coregistration. The points with the bigger error can be eliminated, in order to lower the RMS error. Less than 1.5mm is acceptable, according to manufacturer’s standards.

![Figure 4](image4.png)

**Figure 4.** A. Coronal T1-GAD MRI shows a cystic lesion on the left frontoparietal region: the sulci chosen as surgical corridor to approach the lesion (red circle). B and C. Coronal and sagittal views of functional MRI shows right hand activation and its relation to the lesion. D Coronal vision of IGS localizes the sulci and motor strip (hand), red circle shows the sulci. E. Craniotomy design showing the hand activation area (M) and the red circle showing the sulci. F. View of the brain, H=hand (motor strip) S=sulci. G. Intraoperative ultrasonographic image shows the lesion underneath, red circle shows the sulci. H. Coronal vision of IGS at the isocenter of the lesion. I. Postoperative CT shows collapse of the lesion.
Patients, tumor characteristics and technology used during surgery are in table 1.

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TABLE 1. Patients operated of brain tumors using MFSS.

* KPS= Karnofsky Performance Score
† Eloquence modified by Sawaya et al. 1= Non eloquent 2= Near eloquent area 3= Eloquent area
‡ Astrocitoma Grade II (WHO)
§ GBM= Glioblastoma Multiforme. ¶ Pilocityc Astrocitoma

RESULTS

The average time for image and patient registration was 20 min. (10 – 30 min). Two patients (11.1%) required recalibration during surgery due to significant changes in the operative table after registration process and clear precision errors. Adequate precision (reliable) for surgery of the system’s tracking capabilities was confirmed by targeting rigid intracranial structures (falx, cranium base, etc) or ultrasound confirmation of tumor borders in 16 patients. In two patients (11.1%) the precision was deemed not reliable, do to brain deformation/shift that occurred during the case.

Tumor localization based on eloquence area was: 5 (27.7%) in non eloquent, 8 (44.4%) near eloquent, 5 (27.7%) in eloquent cortex. Ten patients (55.5%) where operated on with awake craniotomy and the others under general anesthesia.
Overall tumor resection was 88.5% (40-100%) in the 17 patients (94.4%) where resection was the goal. In one patient (3.6%), a biopsy of a sellar lesion was the objective. Of these patients, 17 (94.4%) were controlled by means of MRI volumetric measurements 48 hours after surgery and one patient by means of CT without volumetric measurement.

Mean preoperative Karnofsky Physiological Score (KPS) was 80 (100-60), KPS at discharge and at one month follow up was 80 (60-90), 80 (60-100) respectively. Five patients (27.7%) had complications: 4 of them were transient in nature and had resolved at 30 day follow-up, 3 had neurological worsening and 1 had acute renal failure. One patient (5.5%) had a deep thalamic infarct and a persistent left hemiparesis 2/5. Mean time of hospital stay was 3.2 (1-5) days; the 30 day mortality rate was zero.

Only one patient (5.5%) had died at the end of the present study, mean survival was 6 months and 4 days, histological diagnosis was glioblastoma multiforme (GBM).

**DISCUSSION**

Although EM technology dates back almost to a decade ago, it has been less widely used than its optical counterpart in IGS, its precision has already been compared to its optical counterpart. Macott et al. compared both systems in 70 patients and found the RMS to be 1.4+/-.06 mm using the electromagnetic system and to be 1.4+/-.08 mm using the optical tracking system. Description of the implementations IGS are recent in Latin America and those that are operational are mainly optical systems. Rather than detailing the millimetric accuracy as it had already been done, this article was intended to analyze the functional and practical aspects of electromagnetic tracking systems and how it was incorporated in our oncology program.

As technology is more widely available, simpler neurosurgical image guided resources became accessible. IGS costs are becoming more affordable, as processors inside convectional computers became more powerful. The combination of different IGS and surgical techniques has allowed us to perform complex tumor surgery and to obtain accurate results with regards to tumor resection and morbidity-mortality rates in a small country like El Salvador.

The main advantages we have found using the EMFSS are two: one, we have been able to design and perform smaller and more precise craniotomies than can even be intended to localize small structures such as sulci: this has been particularly useful for awake procedures as smaller craniotomies are faster, less cumbersome and more comfortable for the surgical team and the patient. When cortical mapping has been necessary, we do not consider that a bigger exposure and a more extensive mapping is absolutely necessary; in other words, to our standards these systems have allowed us to perform craniotomies that match tumor size and that eventually will be smaller than the lesion being removed as it has been demonstrated in cranium base endonеurosurgery procedures where IGS is also important. Size of craniotomy is not necessarily the main issue, lowering patient morbidity, hospitalization time, and costs while optimizing tumor resection. The second most important contribution that EMFSS has brought to our program is in microscopic tumor resection of deep seated lesions where ultrasound is no longer practical or safe in the surgical field.

The main technical advantages of electromagnetic technology versus its optical counterparts is that it does not require a “line-of-sight” between the camera and the instrument being tracked: this setup usually requires a more cumbersome surgeon, personnel and instrument position, so all or most spheres that provide the tracking ability come into sight. EMFSS by nature does not require any form of “line-of-sight”, and it is recommended that electromagnetic systems should not be positioned near metallic structures such as Mayo stand, as its tracking abilities may be impaired. We did not have this problem yet and nothing has been modified in our original operation room setup.

Set up time for this system is not lengthy (<20 minutes) and is particularly simple as it is based on a regular laptop Linux® operational system. The Cygnuss-PFS is highly movable and compact.

Some of the big limitations of the current system is that if recalibration is needed due to obvious error in precision and it has to be carried out with anatomical landmarks during surgery, it is extremely complex: in two cases we have not been able to do it, we had to stop surgery, undrape the skin markers and to recalibrate. Another limitation is that it cannot provide “picture-in-picture” imaging display or even a fast transition between MRI or CT sequences during operation. Image fusion is quite limited, and this can be a short coming in cranium base endoscopic procedures where CT and MRI images are important when proceeding from the bony work to the intracerebral surgery, or if T1GAD/T2 sequences are needed to pursue areas of hyper-intensity demonstrated in T2 in high grade glioma surgery.

We complement all intra-axial tumor resections with intraoperative ultrasound (more than 80 patients have been operated by our group with the aid of ultrasound). To us ultrasound is extremely useful as it provides real-time information and is unaffected by brain deformation/shift which has always been the limitations of conventional IGS technology, and MFSS is not an exception. It was not our intention to compare ultrasound to EMFSS, as both systems are synergistic in neuro-oncology surgery. To us, EMFSS is particularly useful in precise craniotomy design and intraoperative orientation in deep-seated lesions. We utilize ultrasound’s main strength of “real time” information to corroborate that the tumor borders have not changed with regards to EMFSS. Due to brain deformation or brain shift, this combination of technology has been recognized and integrated into one instrument by some groups. If brain deformation/shift has ensued, we rely mainly on ultrasound and clinical experience.
This series is small and its great downfall might be that it does not objectively measure the precision of the system, but is fair to mention that it was not our objective. Our goal was mainly to analyze the pros and cons of this technology and to report how it was incorporated into our program. Although the number of patients in this article is small, the results that have been obtained with regards to tumor resection and overall complications have been acceptable. The tumor resection number is high due to a mixture of non infiltrative benign tumors with infiltrative high grade tumors; our overall high-grade tumor resection is 77%, which is less when compared to other larger series7 that have an 87% overall tumor resection, but our neuro-oncology program is young and our expertise is growing up. It is too soon to statistically validate the overall impact in survival and how this technology will affect the treatment of our patients, but greater tumor resection is well known to augment overall survival in glioma patients7,14.

DISCLOSURE

Information regarding Cygnus-PFS and FOB was provided by Compass International. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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