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Computer Assisted Localizer for Planning of Surgery and Intra-Operative Orientation

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Summary

There is discrepancy between the exact representation of anatomical structures and tumours in the CT or MRI scan and the more or less accurate intra-operative localisation methods based mostly upon landmarks of the skull and extracerebral space and visible abnormalities of the cerebral surface.

To overcome these problems of exact intra-operative localisation a Computer Assisted Localizer (CAL) is presented which allows precise intra-operative orientation without these aids.

It consists of a mechanically articulated arm with six degrees of freedom with a high precision digital incremental and an image processor for 3 D data of the head. MRI and/or CT investigation is done pre-operatively with four reference markers fixed on the patient's head. They are visible on the CT or MRI slices and are used as reference points during surgery for adjustment of the device.

The co-ordinates of the digitalizer arm tip are projected into the corresponding axial, sagittal and coronal CT slices so that the system simultaneously presents three orthogonal multiplanar CT reconstructions with a reticule indicating the position of the tip of the arm. As the surgeon directs the arm to the region of interest the corresponding CT slices are displayed on the monitor at a rate of 20 slices/sec determined by the motion of the arm. The accuracy of measurement of the device itself lies within 1 mm.

The accuracy is somewhat reduced however by the thickness of CT or MRI slices (routinely 2 mm slices were taken) and by deviations of the reference markers on the skin surface which amount up to 3 mm.

Intra-operatively the accuracy decreases with CSF and tumour removal. Nevertheless the system has proved to be extremely useful in 50 cases to focus a trepanation and to guide the surgeon to subcortical lesions, invisible from the surface of the brain.

Keywords: Computer assisted neurosurgery; planning of surgery; intra-operative localization; brain tumour.

Introduction

During the last year digital image-generation-systems with a high degree of precision such as CT and NMR have been developed and established in clinical routine.

They have radically improved the diagnostic facilities and pre-operative planning in all surgical fields. However, they offer no more than the possibility of analysing the morphological structures pre-operatively. The surgeon still has the task of reconciling the depicted anatomy with the surgical site. This can cause problems intra-operatively in all cases of tumour-destroyed anatomy and in surgical procedures where the surgeon can due to the location of the tumour not refer to anatomical landmarks.

This scenario is comparable to the situation of aircraft pilots before the introduction of instrument navigation: They had to give up their mission whenever weather conditions worsened to a degree where visual orientation did not permit for secure landing at their destination airfied despite the fact that they had perfect maps. Now, the Computer Assisted Localizer (CAL) introduces instrument navigation into the surgeon's daily practice by providing three-dimensional (3 D) position measurement techniques for the operating theatre. It is the missing link between the representation on CT and MRI and the actual localisation within the skull and brain.

The surgeon's map in this system is a 3 D or multiplanar representation of the skull and the brain generated by a digital image-processing-system and a measuring system capable of determining the instrument's position with respect to the patient's head is the navigation guide.

Two major aims can be achieved by CAL: before starting the operation the surgeon can "move" through the computerized image model of the area in question (either in 3 D technique or simultaneously in three perpendicular planes), thus gaining a three-dimensional impression of the region and its neighbourhood and during the operation he can obtain positional information by simply pointing at an unidentified structure with the tip of an electro-mechanical or optical 3 D coordinate digitalizer and the corresponding sectional views are displayed on the monitor with the position of the pointer optically indicated.

Method

The CAL-system described here was assembled from existing and newly developed hardware at the Faculty of Electrical-Engineering and the Department of E.N.T. and plastic head and neck surgery, Technical University of Aachen[1, 7, 8].

CAL processes digital image information from sources such as CT and MRI (Fig. 1). Images were generated by SIEMENS-computer tomographs SOMATOM Dr. or SOMATOM 2 and SIEMENS MRI MAGNETOM. The usual parameters required in neurosurgery were 50–70 sections, 2 mm slice thickness and 1 mm pixel size. The data were either transmitted by flexible disks or via a fibre optic network, the transportation medium of the Aachen University Hospital's experimental picture archiving and communication system (PACS). The graphical workstation was composed of a standard 68020 VME-Bus computer. A 360 megabyte and an additional 80 megabyte hard disk were used for mass storage.

At this workstation a three-dimensional model of the head is generated.

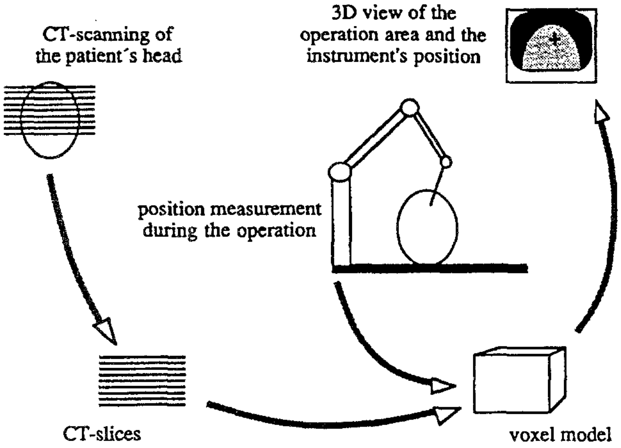

Fig. 1. The individual steps necessary for the set-up of CAL are schematically shown.

This model is shown simultaneously in three standard perpendicular sectional views on the monitor screen. In addition the position of the arm tip and its projection within the skull can be visualized simultaneously.

To correlate the co-ordinate sytem of the created 3 D model with the patient's anatomy, a sufficient number of reference points for adjustment of the device have to be defined. They have to be visible on the CT or the MRI images and must likewise be identifiable during the operation.

Therefore markers visible in CT and/or MRI are attached to the patient's head. They are replaced with colour markings afterwards and are covered sterilely for surgery in cases which make intra-operative reorientation necessary.

At the beginning of the operation orientation of the system has to be carried out. This is achieved within 20 sec by simply tipping at the markings with the tip of the 3 D arm shaped like an angled instrument.

Due to lack of a fixed relationship between the 3 D arm and the head, this orientation has to be repeated after every movement of the skull during the operation. In cases without intra-operative movement orientation before surgical disinfection is sufficient.

The marker's co-ordinates are identified and with the co-ordinates of the corresponding points of the CT images they establish the correlation between the position of the patient's skull and its voxel model.

After the calibration procedure, the position of the tip of the 3 D arm in the operating field and its presentation on the screen are linked optically; that is, the displayed image dynamically moves to the corresspond-ing three perpendicular sectional views of the voxel model.

The experimental accuracy is 0.3 mm[7]. Due to skin slippage, the intra-operative accuracy decreases up to 3 mm after positioning the head with the Mayfield skull-clamp.

Patients

During the last twelve months we have operated on 50 patients with intracranial tumours using CAL. 48 patients with supratentorial tumours were exclusively operated on in supine position and two additional patients with infratentorial tumours were operated on in the sitting position. We used microsurgical techniques in all patients.

There were 31 male and 19 female patients, the average age was 39 years ranging from 3 to 76.

The pathological nature of the lesions are listed in Table 1. 19 patients had small superficial tumours, 11 located in eloquent areas, 5 of them in the precentral region and 8 in non-eloquent regions.

27 patients had deeply seated tumours. 26 were located in elo-

Table 1. *Diagnoses of Lesions Operated on Using CAL*

Pathological nature of lesions	No.
Glioma	25
Metastasis	9
Cavernoma	4
Meningioma	3
Angioma	2
Abscess	2
Arachnoid cyst	2
Neurinoma	2
Plexus Carcinoma	1
Total (no.)	50

Table 2. *Localization of the Lesions Operated on Using CAL*

Location of lesions	No.
Frontal	12
Precentral	12
Temporal	8
Parietal	6
Parieto-occipital	5
Intraventricular	3
Infratentorial	2
Skull-base	2
Total (no.)	50

quent areas, and 7 of them in the precentral region (Table 2). The 4 remaining patients had acoustic neurinomas, a glomus tumour of the jugular foramen, a tumour of the frontal skull base, expanding intracranially, and one patient had a tumour located exclusively in the lateral ventricle. In the latter CAL was used to determine a cerebral defect due the prior surgery used as the approach. The mean diameter of the reported tumours was 2.3 cm (range 1 to 5 cm).

Results

In all (n = 50) patients we used CAL pre-operatively for planning the surgical approach and intra-operatively for localization. In the 19 patients with superficial tumours CAL was mainly used to determine the site of the trepanation, permitting an extremely small, focused trepanation. In the 27 patients with deeply seated tumours CAL was also used to determine the intracerebral location of the tumour.

In patients with supratentorial tumours, operated on in the supine position, repeated orientation procedures showed that accuracy did not change markedly until tumour was resected because the CSF volume released after opening of the subarachnoid space is not sufficient to cause major shifting of cerebral structures if the basal cisterns are not opened.

Two patients with infratentorial tumours were operated on in the sitting position. In both the accuracy decreased significantly after opening the subarachnoid space due to releasing of CSF, making CAL useless.

To obtain good accuracy, recalibration was carried out more than once in 35 patients because of insufficient accuracy after the first procedures. This could be controlled by comparing the actual position of the tip of the arm pointed onto the different skin-markers with its virtual position visualized by a reticule on the screen. This was partly due to uncontrolled movements of the mechanical arm and partly to additional movement of the skin during calibration procedure. During surgery it was quite often necessary to change the position of the patient's head by moving the operating table. In this case the CAL device allows recalibration to the new position within minutes.

The average diameter of the bone flap in patients with supratentorial lesions was 3.6 cm (range 2.0 – 5.0 cm). In all cases the trepanation was located in front of the tumour or the pre-operatively chosen sulcus. The surgical approach in these patients was always the safest one, using sulci identified by CAL (Fig. 2), thereby allowing a small trepanation and accordingly a small skin incision because no orientation was necessary on the surface of the brain.

In the 22 patients with deeply seated gliomas the cortex even at the bottom of the sulcus appeared normal. In these cases CAL allowed us to identify the projection of the tumour onto the cortex and thereby

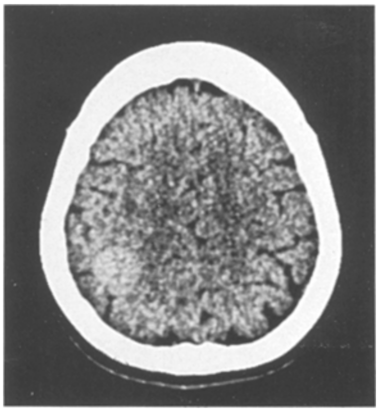

Fig. 2. In this 35 year old woman, CAL allows us to identify intra-operatively the sulci adjacent to the tumour and to use one of them as the surgical approach

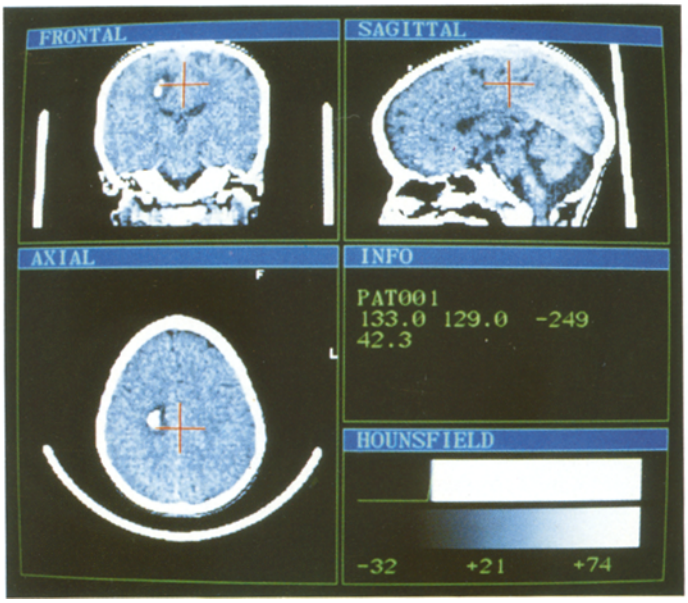

Fig. 3

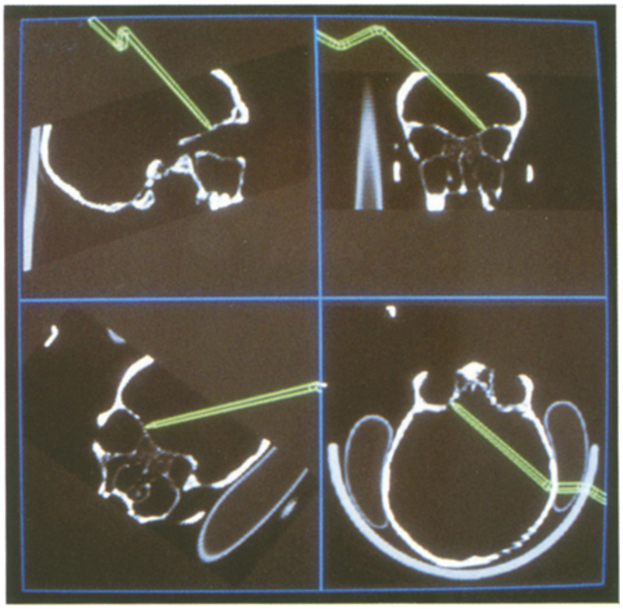

Fig. 4

Fig. 3. 7 year old boy with a subcortically situated astrocytoma II in cingular gyrus operated on using an interhemispheric approach. The cortex looked normal and the location of the tumour could be pin-pointed by using CAL

Fig. 4. Display of the trajectory of the arm

to reach the tumour by the shortest and safest route as shown on Fig. 3.

In this child (Fig. 3) the cortex of the cingulate gyrus which contains a grade II astrocytoma looked normal. The location of the subcortically seated tumour could be accomplished with CAL. Only one patient with a tumour located in the motor cortex had a worsened deficit postoperatively which did not improve.

None of the other 11 patients with tumours located in this area had worsened or had new deficits postoperatively. In the remaining patients having tumours in functionally important areas no additional deficit occurred after surgery.

Two patients with glioblastomas who had external postoperative X-ray therapy had local infections 4 weeks and 2 weeks respectively after surgery. Both were treated by wound revision, bone flap removal and specific antibiotics.

Discussion

In 1987 Watanabe[13] first wrote a paper about intra-operative application of a system similar to ours. Since that time, many authors[3, 4, 6, 8, 9, 10, 11, 12] working in the same field presented different devices to achieve computerized intra-operative localization.

The advantages of the system presented here are high accuracy, the combination of an image processing unit and a positioning device permitting planning of surgery and also intra-operative localization. CAL is not an active robot like the device presented by Drake[3] but is hand-guided. Prior to surgery the computer allows a dynamic study on the region of interest, the surgeon being able to "walk through" the area. The simultaneous presentation of the axial, coronal and sagittal plans on the screen gives a pseudo three-dimensional impression. The surgeon can study the different possible surgical approaches and the tumour's relationship to neighbouring structures which could also be used intra-operatively as landmarks.

The new software used in CAL (Fig. 4) during the last four months permits the display of a three-dimensional representation of the head and to show the trajectory of the arm. This is similar to the system developed by Guthrie[4]. The neuro-navigator presented by Kosugi and Watanabe[6, 13, 14] has not got this ability. It refers only to one plane and the commercially available image processing units cannot be combined with an intra-operative localizer.

The experimental accuracy of the mechanical and electronical parts of the device is less then 1 mm[7]. During surgery the accuracy decreases approximately to

3 mm for skin, bone and cerebral tissue before release of CSF or resection of the tumour. This loss of accuracy is due to the shift of the skin when positioning the head with the Mayfield-skull clamp.

Nevertheless the accuracy of 3 mm has proved to be sufficient in all reported cases for focusing the trepanation, identifying sulci and bony structures. For that reason we do not use screws as markers fixed preoperatively in the bone[5].

Considering the system's aim to localize which is essentially useful at the first step of surgery before important CSF release or large tumour resection takes place, the decrease of accuracy was not a major problem. It becomes more important when operating upon patients in the sitting position because of the massive release of CSF occuring in this position causing a remarkable shift of cerebral structures. The accuracy is not influenced by any other parameter in contrast to the systems of Reinhardt[11] and Roberts[12] using ultrasound sources as references which are no longer reliable when air motion or acoustic interferences appear.

More recently Kato[5] developed a new device using magnetic fields offering good experimental accuracy. But intra-operatively magnetic metals in the neighbourhood can create interferences decreasing the accuracy. The major advantage of his systems is the absence of a mechanical arm.

In the near future we will report about our first clinical experience with a newly developed armless localizer using infrared light sources as references. Concerning CAL, we plan a fixed relatioships between head/operating table and digitalized arm as realized by Watanabe[13, 14] in order to avoid repetitive calibration procedures after each movement of the head or table. The very low operative morbidity (1/50), especially in patients with tumours located in the precentral region illustrates the safety gain achieved by the combination of microsurgery and CAL which both help to prevent damage to cerebral tissue. There was no morbidity related to CAL itself.

In conclusion, the here presented CAL allows safe surgery by precise pre-operative planning and reliable intra-operative localization with sufficient accuracy obtained without any invasive procedure. It can be considered as good complementary tool to intra-operative ultra-sound. In the future, the simultaneous use of CAL and intra-operative ultrasound probes will further increase the safety of microsurgical and stereotactic operations.

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