IV. Image-guided Surgery

Neurosurgical Tools and Techniques — Modern Image-guided Surgery

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Abstract

Cushing and other great neurosurgeons made their mental preparations for surgical procedures through extensive, beautiful drawings. Three-dimensional visualization was in those days supported through interpretation of pneumoencephalograms with displacements of structures indicating where a space-occupying process might be located. Today this visualization necessary for each neurosurgeon is partly lost in the teaching process due to axial magnetic resonance imaging and computed tomography scans and of minimal invasive techniques. Microsurgical navigation on the brain surface is like sailing along a coastline. Navigating in the brain is like sailing in fog and tools for navigation must be developed accordingly. The robotic microscope Surgiscope enables the surgeon to have at the same time a microscope, a pointing devise and a bidirectional tool for automatic maneuverability in the brain. A neurosurgeon may be distracted and thereby perform less adequate. Computer technology and virtual reality models enhances possibilities for rehearsal of difficult operations and of controlling the surgical performance. Computer technology is thus a supporter of future neurosurgeons and a part of quality control. Future education must be linked to this fact.

"Residents do not have an extensive library of mental images from which to draw to initialize the visualization process. The use of computers or robotic assisted designs is a way to overcome this."

(Steven Giannotta, 1995)

For the majority of todays neurosurgeons, image-guided surgery, neuronavigation, and robotics are crazy, new unnecessary techniques. When Jules Verne wrote his book: “A Journey to the Moon” nobody believed him, however today his ideas have come true and man have walked the moon. Thirty years ago all aircrafts were taken down for landing by pilots alone, today all are grounded by instrumentation controlled by the pilots and ground personnel and nobody would disagree with the benefits of security and reliability of this concept.6)

In older days many neurosurgeons were artists. Upcoming neurosurgeons should consult the works of Cushing, Dandy, and Scarff and enjoy how they presented their ideas of surgical techniques.3) They illustrated their mental preparation through artistic drawings of the operative procedures. The image guidance of neurosurgery has thus always existed.4)

We agree that an artist or an architect must possess visualization in three-dimensional (3-D) viewing. The neurosurgeons were taught to approach the 3-D space e.g. the brain in which the space-occupying lesions occurs using pneumoencephalograms, ventriculograms, or angiograms, all demonstrating dislocations of normal structures e.g. ventricles indicating where the tumor had to be. Large craniotomies lead the surgeon — after careful palpation — to puncture the brain lesion with probes. This palpation gave the surgeon additional information via another sensation and in the surgeons brain a fusion between the sensation and the picture of the brain surface was the result. However in order to create a true and precise 3-D space, stereotactic frame based surgery for precise targeting was introduced in the late 1940s.6,8)

Unfortunately all modern imaging has been introduced in an axial two-dimensional (2-D) fashion, which have left out the normal orientation we have for example at the operation table. Since the introduction of computed tomography (CT) and later magnetic resonance (MR) imaging scanning, the majority of 3-D teaching thus left neurosurgery.8)

Why? — because we are bombarded with “perfect-ed” axial slices demonstrating the tumor. Our personal simulation of our visual sensory input is a hypothesis of reality and the simulation equals experience.9) We do not visualize raw data but a simulation of these. Of course it is of no relevance for us to
know how the simulation is carried out in details, so the brain help us to forget the details and focus on the result — the simulation. This concept was also the driving force behind the development of Apple computers in contrast to PCs that were developed alone by and for engineers. I as a surgeon do not care how filing is carried on the computer, I just want to push the one button that tells me — in my language — that filing is now being done. So despite that all tumors are now visualized beautifully in many image modalities, emphasize is put on the tumor itself and not on the dislocation of normal structures and thereby the true 3-D space visualization. Therefore, when ventriculography and palpation were abandoned, 3-D visualization left to a major degree neurosurgery. 

Dissection in the edematous tissue around a small tumor is like driving our car in heavy fog. So what we have achieved in more precise imaging has been lost in loss of 3-D visualization and training. We must bear in mind that the microsurgery we all have adapted is concerned with operations mainly on the surface or the ventricles of the brain. Here we have localizing points such as bony spurs, sphenoid ridge, arteries, and veins. Microsurgery is thus like navigating along a coastline in usually clear weather whereas we in the parenchyma are lost in the fog of the brain.

**Navigation today:** Now what has happened recently? CT scans provides us with stacks of 2-D images that can create a 3-D coordinate system where pixel size of CT images defines the anteroposterior and lateral coordinates whereas the Z coordinate is calculated by the computer. In modern systems the Z coordinate is thus accurately determined by the scanner table and gantry position measurements and true 3-D coordinates can be defined of any pixel in the image set. Reconstructing images in multi-planar reformatting and segmentation selecting specific structures makes it possible to produce 3-D pictures by so-called 3-D rendering. 

**Fig. 1** Surgiscope planning of target and trajectory for removal of small fusiform aneurysm.
dustrial type 3-D digitizers in a transformational stereotaxis. Today we use five to six registrations points to obtain the highest possible precision until surface matching systems will be commercially available.

Transparent cross registration of multiple coordinate systems can then be done and in this way the computer defines a Cartesian coordinate system for the surgical workspace with and without a patient and for the image workspace. Cross registration is carried out defining common pivot points translated into each coordinate system. These systems are rotated together and are scaled to the same dimensions. Now a pointer or navigation tool can localize target objects in both workspaces.4)

The until now most common devices have been a robotic “arm.” The active robotic arm moves a pointer to a defined position in space. Six different joints or degrees of freedom is allowed and the arm can hold retractors, electrodes, or drills. Instead of a troublesome active arm, a passive articulated arm hold by the surgeon and used as a pointing device was introduced by Watanabe et al.18) This arm and pointing technique was made commercially available with the ISG Wieving Wand (Elekta, Stockholm, Sweden).16)

Further Bucholz and Smith3) and Maciunas11) introduced functional three linear light emitting diodes on a surgical instrument. Linear CCD videocameras converts a point from the LED into a line and with the three cameras an algorithm is used to describe the exact tracking of the LED. The surgical workspace is defined by similar — usually three — LEDs attached to the Mayfield head holder. Connected to a microscope, this system was developed in e.g., the Easy-Guide (Philips Medical System, Best, the Netherlands) and the Viewscope (Elekta) systems. Lately robotically controlled microscope systems e.g. MKM (Zeiss, Oberkochen, Germany) and DeeMed/Surgiscope/Leica (Elekta) can coregister with different imaging studies and actively drive the microscopes focal point (resembling the pointer) into the planned target. Bidirectional correspondence exist in these systems and the actual coordinate point of the focal point is demonstrated online on the computer screen. An example of tracking and planning approach to a fusiform aneurysm on a middle cerebral artery branch to the central region is shown in Fig. 1 taken from the Surgiscope concept which we have utilized since February 1996.

Today we can add endoscopes to the system and they can be positioned by the robot exactly in a preset point by a preset trajectory.2)

The Surgiscope features several levels of function. It functions as a microscope, as a simple pointing device for localization of craniotomies and it serves as a viewscope for navigation. The automatic robotic features enables the surgeon to learn to accept that automatisms that will be part of our lives in the operation room in the future.5,8)

Using modern instrumentation e.g. the Surgiscope the following procedures are encountered. Images are imported from the Radiology Department via Dicom network to a computer workstation. Here the neurosurgeon can use all imaging modalities by fusing techniques, manipulate results in all degrees, visualize in different planes and angles, and make 3-D models of the target and the head. Eloquent areas can be introduced from the images and thus prevent the neurosurgeon from entering them in the planning procedure (Fig. 1). We have recently developed an algorithm whereby the tips of our floating catheters used for embolization of arteriovenous malformations (AVMs) can be determined in space using a frame and be translocated into our MR imaging used for planning. Hereby we can identify specific vessels within the AVM and find them with our robotic microscope.

As the patient is fixed on the operation table, the patient, the workstation with images, and — in the Surgiscope concept — the microscope are linked with the operation space, and safe navigation can begin.

The surgeon can now point to entry site, visualize on the images, and control that craniotomy site is correctly placed. Either with a pointer or with the microscopes focal point, entry point for burrholes are found. Trajectory for different parts of the tumor is used in the same fashion and followed on real time display on the workstation. Control through identification of fix-points (known structures) is used for safety control. All operations are carried out following a log book or a checklist, something we otherwise never use routinely. In this fashion the neurosurgeons are controlled and helped by computers just as the captain of an aircraft.

We have to remember that a surgeon may be fatigued, may be distracted, may not have rehearsed his operation perfectly enough. In Denmark a study showed that the older surgeons performed worse than the junior resident in shunt procedures? Why? Possibly because they were more negligent, thought this shunt procedure was “an easy, boring, routine procedure.” However for the patient, the operation is not a routine procedure but incorporates the same demands for skills and surgical planning as any major procedure. It is not correct nor acceptable if I do not find it necessary to concentrate on the shunt procedures and function as if it was a giant basilar tip aneurysm I dealt with. In airspace it is never
being accepted that standard procedures need less attention than the complicated ones.

Among the weak points of the neurosurgeon are therefore that his handling is influenced by personal function e.g. awareness, tremor, fatigue, and distraction — and the mental status and function cannot be controlled or checked except through the outcome of the patients.\(^{12}\)

In contrast the weak points of the robot is certainly its lack of spontaneous ideas, high costs, and some pure technical clumsiness.\(^4\) But surgeons may be clumsy too and handle instruments in an inadequate fashion! An example is the tremor we all have. Today we can reduce the human tremor by the robot by adapting sensory inputs translated via neurophysiological recordings.\(^4,13\) This implies that in the future we can implement these observations in the robot so that it can feel e.g. touch and slipforce.\(^17\)

"Is it really necessary? I do fine!, I never had a problem!, I always find the target!" — are examples of the overestimation surgeons have in their important selfesteem. However our own studies indicates that a planned craniotomy will be more than 2 cm away from the planned target if navigation techniques is not used. Missing of a subcortical tumor is easy e.g. if a trajectory is made 15 degrees wrong a tumor 5 cm deep will be missed by 1.5 cm.\(^6\)

When an aircraft is launched or taken down, it is mainly run by computers with the help and control of man. This means safety and repetition of standards e.g. less errors and landing procedures can be used even with a sight of 0 meters. When we as neurosurgeons operate in the brain, the patient is solely in the hands of the surgeon. No instrumentation controls or aids. The result will prove errors, errors e.g. deaths, hemiplegia, visual loss, errors that cannot be changed. How this can be accepted by our society is for the author incomprehensible relating to the concept of quality control that is so prominent today.

The problem of education is important in this context. "A fool with a tool, is still a fool," as Lars Leksell said many years ago.

A society demands safety and documentation of procedures. The level of quality in performing is like in the Olympic Games a fact but from have gold medalist among our neurosurgeons, we must today be happy to pass to the quarterfinals. We need consistency in our approaches and we need interference when on a wrong track or in a wrong training sequence. Planning systems and robotics facilitate us with this. The neurosurgeon can import images of the patient and perform the operation on the computer e.g. rehearse! — just as professional athletes do. Import of "test operations" made by senior neurosurgeons including possibility of mistakes just like in the popular computer games can be introduced as part of the training. The virtual reality teaching brain is within reach. Thus we can very fast import skills into the hands and minds of the younger neurosurgeons and wind up with the loss of working hours in the hospital.\(^7\)

Internet and World Wide Web have changed communication today.\(^1,7\) Telementoring e.g. education on a distance, will be introduced world wide, giving poorer countries and countries with sparse population a better chance of having well functioning physicians covering their whole area. Teleproctoring e.g. guidance on a distance facilitates this. Help from all parts of the globe is today possible through communication systems. Simple textbooks will no longer be the basis of learning, hands-on-training, and computer training, rehearsal will be the main task.

Computer technology is of course pure bogus, but it results in possibilities of control, better performance, and better teaching in an international network and will thus be a "standard" in the coming years.\(^11\)

The surgeon is however still the key figure of "the team." The initiative to this development was introduced in 1986 by Kelly\(^10\) and his visionary imaginations seems to be fulfilled — perhaps sooner than he thought.

**References**

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