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Technical solutions for old problems: Parallels in neurosurgery and agricultural science

At first glance neurosurgery and agriculture have not much in common. When looking closer however, some parallels appear: The high heterogeneity of tissues as well as local factors present severe difficulties for neurosurgeons and farmers alike. New technologies, such as navigation and specific sensor systems can nowadays help to precisely adjust treatment and processing of soil and crops to specific local needs. This article summaries some striking parallels in the development of neurosurgical and agricultural techniques and is meant as stimulus to look for solutions beyond the margins of the own discipline.

Keywords
navigation, neurosurgery, precision agriculture

Abstract
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The attempt to compare neurosurgery and agricultural science appears unusual. However at close quarters many parallels can be found – similar problems are addressed by the application of the same technology. Concerning the agricultural sciences the pioneer Albrecht Thaer predicted: The effect of work is considerably enhanced by two strong levers: Division of labour and machines [1]. Other applied sciences, like neurosurgery, have similar problems and seek similar solutions. Therefore the authors suggest that it might be rewarding to take a glance beyond the edge of the own field of research to look for new inspirations.

Historical considerations

Neurosurgery and agriculture are both ancient techniques. While for agriculture this is hardly surprising, the knowledge of neurosurgery was lost for centuries. Nevertheless the oldest evidence of a neurosurgical procedure in Europe, skull of Vasilevka II (Ucrayina), was dated back by the carbon 14 method to about 7300-6220 b.C. [2]. The trepannated skull in **Figure 1 A** was found in Germany, near Merseburg and dates to the early bronze age (about 2000 b.C.). The purpose of such prehistoric surgical procedures yet unknown, but bone growth at the edges of such burr holes suggest, that many bronze age patients survived these procedures. In another skull, which was found in Bölkendorf, about 60 km north east of Berlin, Piek and colleagues could show that a trepannation was probably placed to treat a skull fracture [3].

Agricultural scientists were likewise very enterprising in this period. The single-furrow plough shown in **Figure 1 B** and C was found near Walle in Germany and dates also back to the time about 2000 b.C. It is the oldest piece of this kind. The oaken artefact measures about 3 meter and the plough share is about 60 cm long. The application of such a machine definitely enhanced the efficiency of the farmers labour.

Individualization and spatial variability

The inventors of the plough from Walle might have noticed that different areas on their acres produced different quantities of crops, or that some crops grew better at certain spots. Stafford already mentioned [4] that this knowledge literally dates back to biblical times (compare parable of the sower [5]). Nowadays we are aware that these inhomogeneous yields are the result of local environmental factors like composition of the ground or soil moisture content. In recent years agricultural scientists designed technologies to finally address this ancient challenge.

In the beginning the local enviromental factors have to be identified. Modern imaging technologies can give valuable information even before the soil processing starts. For many years rather rough data as it is for Germany provided by the "Reichsbodenschätzung" from 1934 were all that was available. This survey was based on soil samples taken in a grid of 50 x 50 m. Recently aerial or satellite photography allows the examination of individual fields at different vegetative phases (**Figure 2 A**). By these means further information can be gathered.

For example images taken during droughts provide information concerning water supply and drainage. False colour images inform about crop health (**Figure 2 B**) [6]. Furthermore data like crop yield (**Figure 2 C**), electrical conductivity of the soil (**Figure 2 D**), etc. can be superimposed to these photographs.

Fig. 1

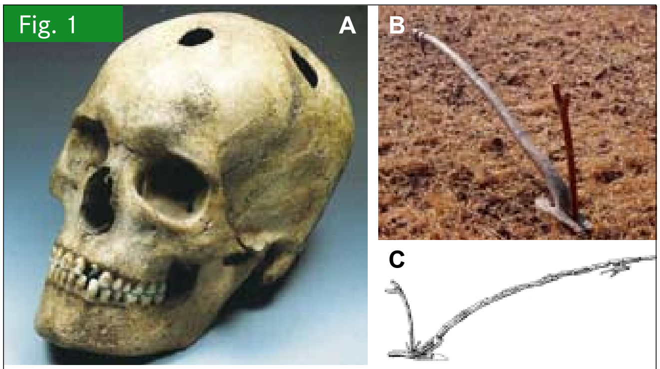

Fig. 1 A: Trepannated skull from the early bronze age (about 2000 AD). Source: Postcard of the State Office for Heritage Management and Archaeology Sachsen-Anhalt
Fig. 1 B, C: Reconstruction of a single frurrow-plough (B) resp. drawing (C) from the early bronze age. Source: Copyright Landesmuseum Hannover

Fig. 2

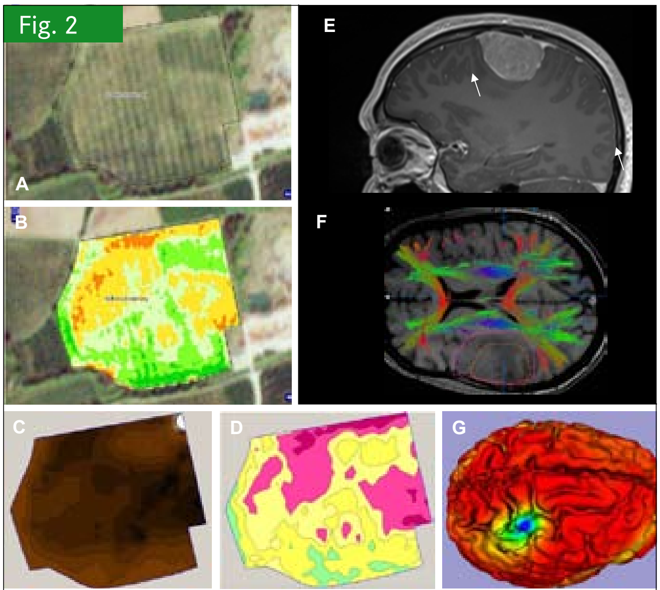

Fig. 2 A: Satellite image of Schweckenberg in southern Lower Saxonie
Fig. 2 B: False color image showing chlorophyll-concentration indicating crop density
Fig. 2 C, D: C and D are images of the same region. C is color-coded for crop yield, while D shows the electrical conductivity of the soil indicating soil water and composition
Fig. 2 E: MRI image of the skull (sagittal plain, T1 weighted with Gadolinium contrast). Directly below the sull a tumor can be seen (meningeoma, arrow)
Fig. 2 F: Fiber tracking (axial plain, DWI weighted MRI). The red/orange outlines show a tumor, however the surrounding fiber tracts (green, blue and red) are not much translocated
Fig. 2 G: Functional surface map of the brain in 3-D. The blue regions are motor areas for the movement of the contralateral thumb. Data was collected by electric stimulation of the cerebral cortex and simultaneous recording of motor potentials in the corresponding muscles

Neurosurgeons likewise face the problem of spatial differences: Structure and function within the human brain are extremely heterogeneously distributed. The bronze age neurosurgeon might have noticed that injuries or procedures in certain regions cause similar deficits, but technical solutions which allow the exact and individual localization of certain functions were only recently developed. Up to date imaging modalities inform the neurosurgeon about the exact location and to a certain degree about the nature of a problem such as a brain tumor. Computer- or Magnet-Resonance tomographs (CT or MRI) allow high resolution imaging of the brain prior to surgical exposure of the cortex (**Figure 2 E**). This is extremely important, as the anatomy might differ significantly among individuals and some pathologies, such as slow growing tumors might even cause certain functions to migrate to other cerebral regions [7]. New techniques, like fiber tracking (**Figure 2 F**) [8], functional MRI, digital subtraction angiography [9], or positron-emission tomography [10] have helped to obtain information that goes beyond simple morphological imaging of the brain, such as location of functional centres, blood supply, etc.

Stereotactic/neuronavigated tumor biopsy – navigated soil sampling

Preoperative imaging like satellite/aerial imaging of the soil does not always provide sufficient information to compose a (treatment-) plan. Histological type and malignancy grade of brain tumors for example can rarely be diagnosed without histopathological examination of the tissue. For this examination it is of course crucial that the sample is taken at exactly the right spot. This regularly requires the application of navigational systems. Frame-based stereotactical operations achieve the highest accuracy. For this procedure the patients head is fixed in a stereotactic frame which provides a coordinate system. The patients head together with the fixed frame is than examined by CT and thus the exact location of the tumor can be located within the frame-based coordinate system. Now the surgeon can calculate the optimal trajectory for puncture of the tumor. The accuracy of this method is < 0.05 cm [11].

Paralleling this, farmers can specify composition of the ground and soil structure by soil sampling, if the information derived from aerial or satellite photography seems insufficient. Like in the neurosurgical OR the exact spot for sampling can be tracked by navigational systems. Since the 1990s the global positioning system (GPS) is available for agricultural purposes [12]. The System can track the position of receivers on the global surface if they are in direct visual axis with at least 3 GPS-satellites. A registration of the system is not required because the position of the satellites does not change relatively to the global surface (geostationary orbits). Alternative systems are the Russian GLONASS [13], which tends to be unreliable because of maintenance problems and the European GNSS (Galileo) [14]. Both systems are however of minor importance for agriculturists. During the 1990s the GPS was still unreliable because moving receivers were frequently covered by trees, building, etc. from sight of some satellites [12] and positioning accuracy was about 5–10 m only. However provider of GPS receivers claim that precision is nowadays at less than 1 m [4]. By GPS-tracking of soil sampling the agriculturist can map

Fig. 3

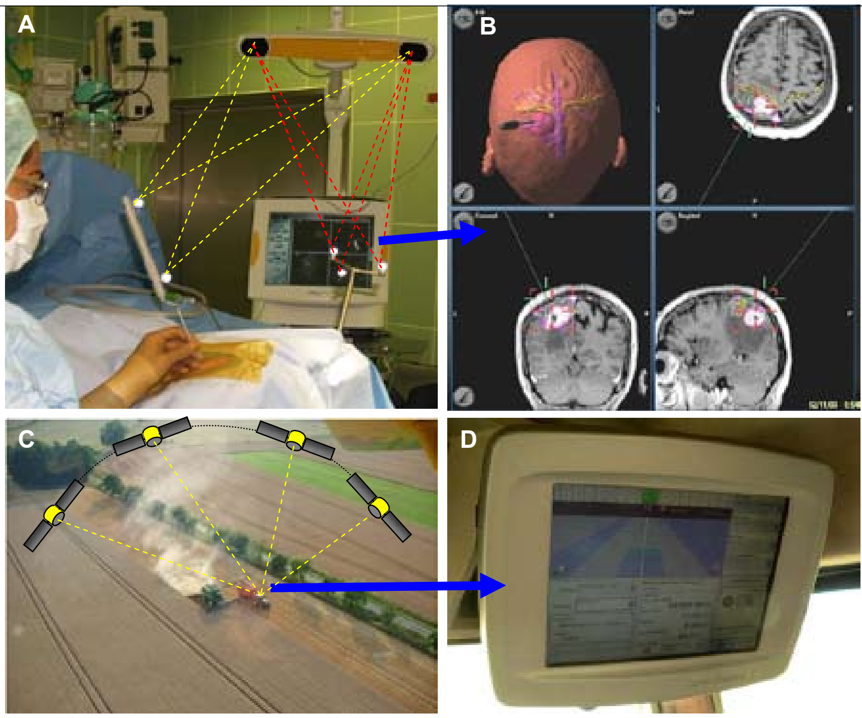

Fig. 3 A: Referencing of a modern frame-less stereotactic system in the operating room. Instruments and reference markers are tracked by a 3-D infrared camera. The yellow lines show the visual axis between camera and instrument, while the red lines show the visual axis to the reference point of the system
Fig. 3 B: A computer calculates the relative position of the instrument to the reference point. By matching of the patient position to a preoperatively acquired MRI-scan the system can show the exact position of the instruments tip on the MRI-images
Fig. 3 C: Likewise a navigation-computer on the tractor communicates with several GPS-satellites (yellow lines). No reference markers are required, as the satellites are on geostationary orbits and do not change their position relatively to the earths surface.
Fig. 3 D: navigational computer on board of the tractor

his fields "individually" with high spatial resolution and thus refined rougher data as for example provided by the German "Reichsbodenschätzung".

Application of navigational systems for surgical procedures and soil processing

The significance of navigation is not restricted to sampling. Besides the frame-based stereotaxy frame-less stereotaxy has been developed in recent years. This technique provides orientation during more complex procedures. The most common system is based on an infrared stereo-camera which follows movements during the operation by tracking special infrared markers. At the beginning of surgery the exact position of the head relatively to some infrared markers (a so called reference star) is registered. Instruments applied during surgery are likewise equipped with infrared markers and their movement relatively to the reference star is tracked by the stereo-camera. The resulting technical accuracy is <0.5 cm (**Figure 3 A**) [15]. A computer superimposes preoperative imaging studies (CT or MRI, etc.) with the information obtained by the camera and can thus show the exact position of the instruments on the MR- or CT images [16, 17]. This helps the surgeons orientation and results in a higher safety and accuracy during tumor resection and other procedures. The surgeon can also use the navigation computer prior to surgery to prepare a work plan. Specific structures, such as tumor, blood vessels, fiber tracts, etc. are marked in specific colours or trajectories for the surgical approach are drawn. The navigation software than displays this treatment plan during surgery (**Figure 3 B**).

Analogically with this agriculturalists use navigational systems not only for soil sampling but for the processing as well. Modern tractors are equipped with GPS receivers and an autopilot can steer the vehicle according to the GPS-coordinates (**Figure 3 C, D**). Integration of GPS-data, satellite images, and the results of navigation tracked soil sampling allows the farmer to compose a plan for optimal distribution of herbicides, fertilizer, water, seeds, etc. Modern spreaders furthermore allow GPS-mediated spatial regulation of the quantities spread our [18]. Nevertheless for achieving this precision the agriculturalist has, like the neurosurgeon, to spend considerable time in front of his computer, developing an work plan for soil processing.

Sensors for spectral analysis of cerebral tissue or vegetation

Alternatively to sampling and histopahtological examination – which is of course time consuming – specific sensor-systems can be applied in some cases. This allows collection of further data without time loss. Already in the 1950s, long before the introduction of neuronavigation, operating microscopes were applied for better intraoperative discrimination of different tissues etc. [19]. The introduction of intraoperative fluorescence markers, like 5-amino levulinic acid (5-ALA), brought a further improvement for the intraoperative identification of tumor tissue. Several hours prior to surgery the patient drinks a 5-ALA solution. 5-ALA is than metabolized to protoporphyrin IX, a fluorescent intermediate of the haem-biosynthesis, within the tumor cells [20, 21]. Under UV-light excitation the tumor tissue shows bright red fluorescence, while the adjacent brain tissue shows only mild blueish fluorescence (**Figure 4 A, B**). Other spectral sensors are subject of ongoing neurosurgical research [22-24].

Here again parallels can be found in agricului science. Besides the identification of crop health and nutrition availability by assessment of spectral satellite images (**Figure 4 C, D**) [6], ground-based sensors are investigated. Already in 1998 Stafford and Bolam for example introduced a tractor mounted radiometric sensor system [25], of which the Hydro-Precise cooperation presently offers a commercially available version [4].

Electrophysiological monitoring and measurement of the electrical conductivity of the soil

The most reliable method for detecting functional centres in the brain is direct electrical stimulation. After surgical exposure of the cerebral cortex the surgeon can directly stimulate areas of interest electrically. The electrical activity in the effector-organ (for example the muscles in the right hand) is recorded simultaneously. If in our example the concerned cerebral region is responsible for the movement of right hand the concerned muscles will show electrical activity [26, 27]. This kind of test can be repeated for all areas of interest (**Figure 2 G**).

Once more similar techniques are applied in agricultural science. Several studies could show that the electrical conductivity of the soil is an important predictor for composition of the ground and soil moisture content (**Figure 2 C**) [28, 29]. Like in neurosurgery direct measurements using electrodes that are introduced in the soil or contact-free electrodes can be applied. For both kinds of measurement the equipment is nowadays commercially available.

Therapy control – spatial registration of crop history

In the neurosurgical setting the control of results after surgical procedures is of considerable importance. Not only young neurosurgeons profit from constant critical monitoring of outcomes to improve their performance. Adverse events and critical incidents can be diagnosed at an early stage and complications might be avoided or treated in time. Besides clinical examinations early postoperative imaging studies like CT or MRI are very important for this purpose. Likewise up to date harvesters allow spatially-resolved registration of crop yield (**Figure 2 D**). Paralleling the therapy control in neurosurgery this data can be used to improve soil processing. The crop yield itself is the best indicator for combined effect of all environmental factors [30]. By constant monitoring of the crop yield the effects of varied parameters such as amount of fertilizer, selection of crops, etc. can be optimized.

Conclusions

One main problem of the technical development described above is the growing expenditure of material and time [4]. The expected result must match the input in terms of patient benefit and environmental impact. And of course inputs must be justified from the economical point of view, as economical considerations does not only effect agriculture, but also play a growing role in healthcare. However the technical development of the last 20 years does leave no doubt that navigational systems and individualized treatment concepts eg. Spatially “individualized” precision agriculture will dominate in the end.

A further, probably larger problem presents the growing amount of data that has to be processed by farmes and neurosurgeons. A growing part of the working time will be consumed by data assessment and drawing up of work plans. Here intelligent systems for pre-processing and integrated presentation of data are on demand in order to keep the complexity at a manageable level. Outsourcing of specific tasks like data-analysis to specialist is a possible solution. This would signify that the consequent application of machinery (the second part of the above cited thesis of the pioneer in agricultural science Albrecht Thaer) would lead to the implementation of the first part (division of labour).

However, future will see a growing accuracy of navigational systems and specific sensors in both agricultural science and neurosurgery. Logical endpoints of this development for neurosurgeons are spatial resolutions that allow identification and discrimination of individual cells. Tumors and most other pathologies do not occur in smaller compounds. For agriculturists the identification of individual plants might present such a logical endpoint. This spatial resolution will probably not be reached by application of navigational systems alone, but will require the additional integration of other techniques like optical or spectral sensors [31, 32].

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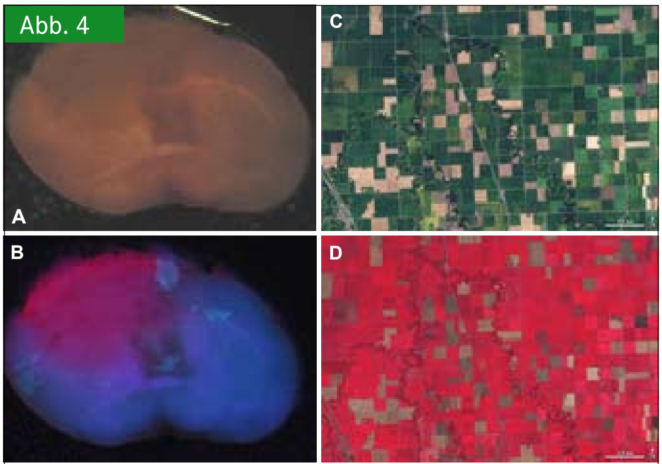

Fig. 4 A: Coronal section of a mouse brain with experimental glioma in the left hemisphere. Under white-light illumination it is difficult to discriminate the exact outline of the tumor
Fig. 4 B: B shows the same section under UV-light excitation. Before harvesting of the tumor bearing mouse-brain the animal has been treated with 5-aminolaevolinic acid which is metabolized within the tumor to fluorescent protoporphyrine IX. Now the brighly red fluorescent tumor can easily be differentiated from the surrounding brain tissue
Fig. 4 C: Satellite image of an area in northwest Minnesota at the Buffalo River: Green fields show growing crops, brown areas are already harvested fields. Source: NASA Earth Observatory, Jesse Allen (Landsat data, contribiuted by the United States Geological Survey)
Fig. 4 D: An infrared image (Landsat 5 TM) reveals further information: Red indicates crop health, yellow shows infested crop, black indicates flooding, etc. Source: NASA Earth Observatory, Jesse Allen (Landsat data, contribiuted by the United States Geological Survey)

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