Surgical information strategy Desk

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ABSTRACT

Using of the intraoperative imaging in neurosurgery dramatically changed the principles of management of parenchymal brain tumors. Current technical advances permit to localize the neoplasm perfectly, to estimate its volume, and to define relationships with the eloquent brain structures, which provides optimal conditions for complete surgical resection of the lesion without disabling postoperative complications. On this way, preciseness and intraoperative availability of the various medical data seem to be extremely important for attainment of the optimal treatment results. Development of the surgical information strategy desk is directed on the optimization of the distribution of the medical information between the members of the surgical team with a goal to improve intraoperative decision-making process.

1. INTRODUCTION

Medical treatment in the 20th century was mainly based on the feedback-controlled principles. Correspondingly, up to date the decision-making of the doctors is usually based on the personal intuition and previous experience. It can be expected, however, that in the 21st century the practical medicine will transform into a "feedfoward" process with preemptive estimation and management of various risks, which can be attained by integrated analyses of the various medical information.

A wide spectrum of the medical information, such as various preoperative images, data of the intraoperative neuronavigation, parameters of the neurophysiological monitoring, details of the cortical mapping, and main characteristics of the current patient condition, should be visualized and provided for a surgeon at the time of the neurosurgical procedure. Moreover, these data has to be constantly updating, presented in a real-time regime, and widely distributed between the members of the surgical team for incorporation into the treatment process with a goal to predict the risk of possible complications and avoid them. At optimal, various scientific data from the evidence-based reports and different databases, integrated using probability assessment technique, should be also available. Under such conditions, medical treatment will become significantly dependent on the quality of provided information.

2. Importance of information-guided surgery for cerebral gliomas

The decades of neurosurgical experience made clear evidence, that routine surgical technique does not permit aggressive removal of parenchymal brain tumors located in the vicinity to the eloquent brain structures without significant risk of permanent postoperative neurological deterioration. Therefore, up to date many surgeons prefer incomplete resection of gliomas, which has a significant negative impact on the patient survival. Recent progress in the technology of the magnetic resonance imaging (MRI) has resulted in opportunity to acquire intraoperative images, which dramatically changed the principles of surgery for malignant brain tumors.

Information-guided surgery is required in cases of parenchymal brain tumors due to several reasons [1]. First, gliomas, which arise from the cerebral tissue itself, could not be clearly distinguished from the normal brain through the operative microscope. This is especially evident at the periphery of the neoplasm, because of its propensity for infiltrative growth. Second, intraaxial location of these tumors results in frequent involvement of the functionally important cerebral structures, such as speech area, motor cortex, or pyramidal tract, in the pathological process. Precise localization of the eloquent brain areas based only on anatomical data might be difficult, because of individual variability of their location and further migration during tumor growth. It is evident, however, that these structures have to be clearly defined and preserved during removal of the neoplasm for avoidance of the postoperative complications. Third, the effect of brain shift due to evacuation of the cerebrospinal fluid (CSF) or lesion removal accompanies any neurosurgical procedure, and can result in significant mislocalization errors if conventional neuronavigation, based on the preoperative imaging, is used. Therefore, for attainment of the maximal resection of the parenchymal brain tumor without major postoperative complications, using of the information-guided surgery, based on the anatomical data of the intraoperative real-time neuronavigation, and functional data obtained by precise neurophysiological monitoring and cortical mapping, seems to be mandatory.

3. Intelligent operating theater in Tokyo Women`s Medical University

The intelligent operating theater in the Tokyo Women`s Medical University (TWMU) was created for advanced neurosurgical management of various brain lesions, including parenchymal brain tumors [2]. It is located in the room with a size of 5.8 to 4.2 m. densely packed with various surgical devices, which result in relatively narrow effective space compared with the ordinary operating theatres. Therefore, optimal internal organization is extremely important to provide for a surgical team an opportunity to perform a surgery in the comfortable conditions with the most efficient use of the different equipment and tools (Fig.1).

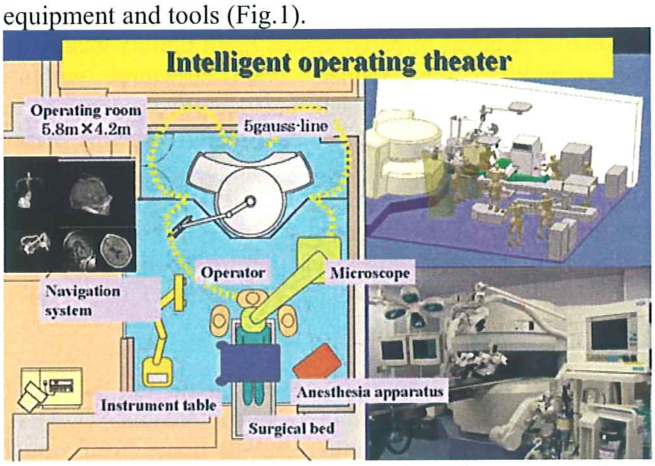

Fig. 1. Internal organization of the intelligent operating theater in TWMU.

3.1 Intraoperative MRI

Intraoperative open MRI scanner (AIRIS II^{TM}, Hitachi Medical Co., Chiba, Japan), which was installed in TWMU in 2000, has a 43 cm gantry gap and a permanent magnet producing vertical magnetic field of 0.3 Tesla. Low magnetic field strength creates narrow 5-gauss line, which permits for the surgeon to use some conventional surgical devices and instruments. It should be specially marked, that this MRI scanner does not require a cooling system, which significantly reduce its operating costs by approximately 10,000 Japanese yen per months.

Newly developed radiofrequency receiver coil (Fig.2) significantly improves the quality of the intraoperative images. This device provides reduction of the distortion artifacts irrespectively on the orientation of the object, which gives an opportunity for optimal positioning of the patient on the operating table. Integration of this coil with modified Komai stereotactic frame permits to perform stereotactically guided surgical procedures under the control of intraoperative MRI [3].

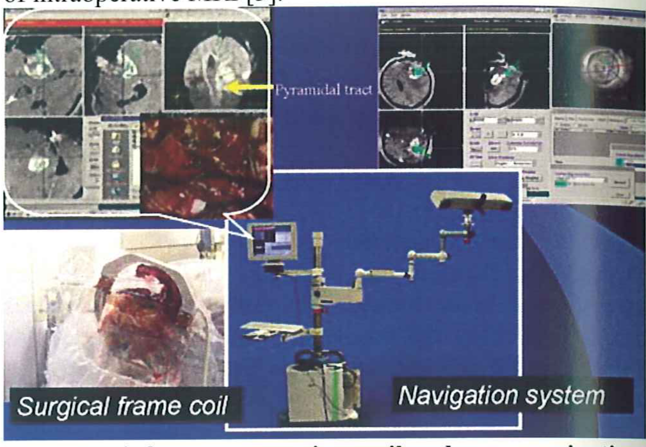

Fig.2. Radiofrequency receiver coil and neuronavigation system.

3.2 Intraoperative “real-time” updated neuronavigation

Real time updated neuronavigation permit to identify exact tumor position and its interrelationships with the surrounding brain structures, which permits to attain complete resection of the neoplasm. Previously developed surgical navigation system (PRS navigator, Toshiba Medical Co. Ltd., Tokyo, Japan) provides optimal clinical results and allows easy and fast updating of the information obtained by the intraoperative MRI. Intraoperative use of volumetric and, especially, diffusion-weighted imaging (DWI) seems to be extremely promising, because it can permit to identify the motor nerve fibers, for example pyramidal tract, and to avoid their damage during tumor removal [4]. The distances between location of the identified functionally-important brain areas, such as speech centers and pyramidal tract, and positioning of the stimulating device identified by the neuronavigation system are automatically measured throughout surgery, basing both on the analysis of the surgical field image and functional information obtained during cortical and subcortical mapping.

3.3. Chemical neuronavigation

In cases of malignant gliomas, which total resection is difficult because of unclear boundary between the neoplasm and normal brain, using of chemical neuronavigation with 5-aminolevulenic acid-HCl (5-ALA) can be helpful. This substance accumulates exclusively in the tumor tissue and can be clearly detected under the ultraviolet light as luminescent area.

3.4. Presentation and distribution of the medical information

For distribution of the information five liquid crystal displays (LCD) are installed in the operating theater (Fig.3). Different MR images (T_1, T_2, DWI, MRA, fMRI, 3D), views of the surgical field via the microscope and/or endoscope, data from the neuronavigation, neurophysiological monitoring, and awake surgery support systems, can be shown simultaneously or consequently. The operating room is monitored with 16 charged coupled device cameras, and these pictures can be also projected on in-room LCD, if necessary. Such system allows an optimal sharing of the available medical data between the members of the surgical team.

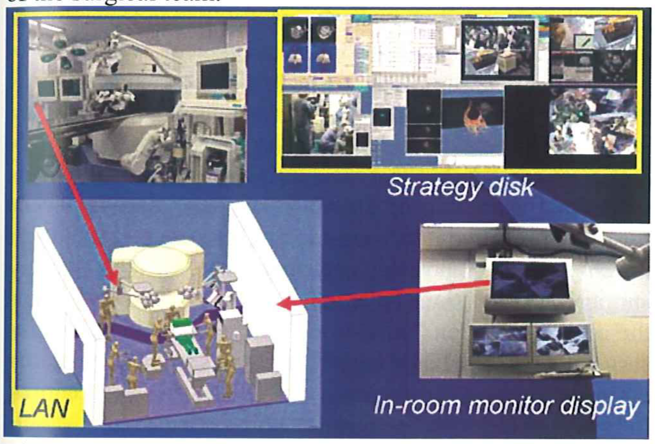

Fig. 3. **Location of LCD in the intelligent operating theater and surgical information strategy desk.**

Fig.4.IEMAS system

Intraoperative examination monitor for awake surgery (IEMAS) system is the most important information-sharing device in the intelligent operating theater (Fig.4). It provides for a surgeon, anesthesiologist, and other members of the surgical team the wide spectrum of data about condition of the patient, nuances of the surgical procedure, and details of the neurophysiological monitoring. The whole set of both anatomical and functional information, such as view of the patient mimic and face movements during answering on the test questions, type of examination task, position of the surgical instruments on the navigation display, parameters of the bispectral index (BIS) monitor, and general surgical field view through the operating microscope and/or microscope, is presented compactly in one monitor with several displays, which provide an optimal conditions to perform fast integrated real-time analysis of the multiple data, nearly without interruption of the surgical manipulations.

4.Clinical experience and results

The first case with the use of intraoperative MRI was done in TWMU on March 13, 2000 and up to date 423 neurosurgical procedures were accomplished in the intelligent operating theater. These included, mainly, resection of gliomas, as well as other tumors (pituitary adenomas, craniopharingeomas, meningiomas), and non-neoplastic intracranial lesions (cavernous angiomas and arteriovenous malformations). In overall, neuronavigation system was used in 337 cases. Since recently intraoperative DWI was used for navigation during resection of gliomas located in or in the nearest vicinity to the pyramidal tract. Chemical neuronavigation and awake craniotomy were performed routinely, whenever indications existed.

Development of a system directed on the advanced neurosurgical management of gliomas significantly increased their resection rate, which average value constituted in our series 93%, whereas median residual tumor volume was 0.17 mL. In 46% of cases total tumor removal was attained, which is significantly better compared to 12%, marked in the last edition of the Brain Tumor Registry of Japan [5]. Moreover, increasing surgical experience resulted in gradual improvement of our surgical results and in cases, which were operated on after complete establishment of the treatment algorithm and improvement of the image quality the mean residual tumor volume was just 0.025 mL [6]. Optimal surgical results were reflected in an improved 5-year survival rate, which constituted in our series 88%, 80%, 7%, and 44%, for grade II, III, IV, and III-IV gliomas, respectively. The same rates, marked by the Brain Tumor Registry of Japan, are 69%, 25%, 7%, 18%, correspondingly.

5. Development of the surgical information strategy desk

It is evident, that all information provided intraoperatively for a surgeon, should be not only precise and proved, but have to be presented in a most compact, comfortable and friendly way. Surgical information strategy desk was developed for attainment of this purpose and directed on the optimization of the distribution of the medical information between the members of the surgical team, and improvement of the intraoperative decision-making process. Seven LCD of this system permit the surgeon to see integrated information about situation in the surgical field, data of chemical neuronavigation, intraoperative MRI images etc (Fig.5). All data are provided in a real time regime and their visualization can be easily changed or combined in a different way just by a click of the network switch. Moreover, the system gives an opportunity to transfer the information into the distant areas (at present up to 200 m.), since urgent consulting service with the experts or another specialists, located outside operating theater, can be provided, if necessary.

Another goal of the surgical information strategy desk is providing for a surgical team optimal solutions in a permanently changing surgical situation basing on the real-time integrative analysis of the anatomical or functional intraoperative information, as well as various scientific data. Everyday surgical experience can be progressively incorporated and collected in this system and integrated with the recent technological and scientific information considering diagnosis and treatment for possible use during further medical practice. Using of the multicomponent engineering technologies (such as sensing, modeling-stimulation, medical treatment supporting) permits preoperative stimulation of the surgical procedures and significantly improves the ability of a surgeon to create an optimal treatment strategy. Thereafter, at the time of surgery, this system can provide real-time information whether actual surgical procedure is well correspond to the preliminary developed surgical strategy or not.

Fig. 5. Organization of the surgical information strategy desk.

6. Future Trends

Using of the modern neurophysiological monitoring, awake craniotomy, and intraoperative MRI during the last decade showed their great efficacy for neurosurgical management of various intracranial lesions and revolutionarily changed the principles of surgery for parenchymal brain tumors. Nevertheless, several nuances and potentials for further technical improvements are existed. For example, presence of distortion artifacts, especially if MRI scanners of high magnetic field strength are used, and effect of brain shift due to evacuation of CSF or tumor removal can result in significant mislocalization errors. Even if the gap between the estimated and real target positions is small, it might be of critical importance if the lesion is located within or in the nearest vicinity to the eloquent brain areas. Therefore, development of a computer-based system for constant intraoperative estimation and correction of the mislocalization errors may be of great importance.

It can be expected, that in future the dependence of the neurosurgical management on the permanent availability of all necessary information in the real-time regime will be increasing. This means, that just installation of the surgical records and surgical video into the databases will not be sufficient enough, but that the automatic analysis system for immediate extraction of the very particular data important for intraoperative decision-making process should be developed. The possible consequences of the various surgical manipulations have to be analyzed immediately and the optimal solution "what to do" in permanently changing surgical situation should be offered for a surgeon, which can dramatically improve the safety of the surgical procedures. In a case of any intraoperative trouble such a system should immediately provide several management options, which have to be based both on the previous experience and data from the scientific sources. At optimal, such a system have to have an ability to predict possible risks and inform the surgeon about their probability, which will result in elimination of the possible complication before its actual appearance just by looking on the display screen. It is evident, that such kind of the intraoperative information may have any value only if it will be provided in a real-time regime, because only in such a way it can definitely affect the outcome. For such a purpose, even the fastest possible evaluation of the treatment situation will not be sufficient enough. Therefore, such a system should be probably based on the constructing of the virtual surgical reality with the simulation of the different surgical decisions through input of various surgical events, their real-time analysis, prediction of further possible steps, evaluation of their risks, and providing of the optimal management plan as a road map, which can facilitate achievement of the treatment goals in each individual case. Development of the target controlled management system, directed on the elimination of the possible informational gap between the virtual and actual surgical situation may be also necessary. Certainly, such a system could not be "stable", but should be "progressively developing" through constant input of the newest information from scientific, medical, surgical, and outcome databases. Finally, such a system should not be used only during surgery, but have to serve for the purposes of education and training.

7. ACKNOWLEDGMENT

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