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Advanced intraoperative imaging: Gold standard in brain and spine surgery?

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Abstract

There are several unique features of the concept of advanced intraoperative imaging modalities with CT (computed tomography), MRI (magnet resonance imaging) and DSA (digital substraction angiography) inaugurated in one operating tract. For the first time, there is the opportunity to switch from postoperative to intraoperative imaging – when the surgeon can not only check the result of surgery but improve it – but in general, that is, for all specialties, at least theoretically. Intraoperative imaging is a broad term with many technologies already in routine use today, such as image intensifier, ultrasound, fluorescence technologies, and soon. Using intra-operative CT, MRI, and DSA is not indisputable. Does the benefit justify such immense costs, both in building and in maintenance? To evaluate the clinical benefit and possible drawbacks of these technologies and if there's a substantial benefit for the patients. Also, this is a review of literature to evaluate the evidence and clinical impact of advanced intraoperative imaging in neurosurgery. There is one prospective randomized trial showing that intraoperative MRI increases the extent of resection. In spine surgery, there are several randomized trials showing that pedicle screws are inserted more accurately when image guidance is used. However, there is no RCT comparing navigation with intraoperative CT-updated navigation. Several prospective studies are showing that intraoperative DSA is able to identify vascular remnants or vessel occlusions in case of aneurysm-, arteriovenous malformation-and arteriovenous fistula-surgery. A fair comparison of the benefit of these new technologies must take into consideration that other methods of intraoperative imaging or image guidance already exist. Hence, there are some patients in whom the use of the more advanced technologies makes a personal, individual difference that may affect quality of life and survival. We have to differentiate between (1) the best diagnostic procedure and (2) the term "standard of care." Advanced intraoperative imaging is a gold standard in terms of imaging but not a standard of care.

Keywords

intraoperative imaging, intraoperative magnet resonance imaging, intraoperative digital substraction angiography, intraoperative computed tomography

In February 2017, one of the most modern surgical theater complex in the world was inaugurated at the Inselspital in Bern, with much attention by the media. There are several unique features of the concept at the Inselspital that are different from other hospitals, with intraoperative magnetic resonance imaging (MRI), computed tomography (CT), or digital subtraction angiography (DSA). The availability of all three major imaging modalities in three separate rooms—all equipped with high-end neuronavigation which allows all surgical specialties to use it for all tissues and organ systems. For the first time, there is the opportunity to switch from postoperative to intraoperative imaging—when the surgeon can not only check the result of surgery but improve it—but in general, that is, for all specialties, at least theoretically. This is a step into the future. It is not only in science fiction movies but also in technology and health-care think tanks that imaging is in the center of

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surgical theaters of the future, whether with robots or with humans as surgeons.

Intraoperative imaging is a broad term with many technologies already in routine use today, such as image intensifier, ultrasound, fluorescence technologies, and so on. Using intraoperative CT, MRI, and DSA is not indisputable. Does the benefit justify such immense costs, both in building and in maintenance? As neurosurgery is at the forefront of using these technologies for decades, we try to ask and answer some critical questions in this editorial.

What is the clinical benefit of these technologies, and what are the drawbacks?

In principle, they allow to use the best imaging modality—usually the same we use before and after surgery—for checking intraoperatively the result of surgery. Obviously, the time of use makes the difference. During the procedure, the surgeon can check the result and improve it, when necessary. For neurosurgery, the main applications for intraoperative imaging are brain tumors in case of a MRI, spinal instrumentations for a CT and vascular operations for a DSA.

In brain tumors, the modern concept of "maximum safe surgery" follows the observation that the extent of surgery correlates with the overall survival, at least for "gross total" or "near total" resections.[1–8] Today we try to achieve a supramarginal resection in low-grade gliomas and metastasis, and a complete removal of T1-enhancing tumor in glioblastomas, or even a Fluid-attenuated inversion recovery complete surgery, if achievable. In the literature, there is evidence that even in those tumors preoperatively judged as "complete resectable," the surgeons on average only achieve an MRI complete resection in 40–70% of patients.[9] Intraoperative MRI can help to achieve this goal not only in a higher average percentage, but for the individual patient, which should be our goal. However, this increased extent of resection inevitably comes with a higher risk of permanent neurological deficits. Therefore, the term maximum safe surgery requires the second technology of neuromonitoring and mapping with or without awake surgery; and in real-life, it is often the functional boundary that sets the limit of resection.[10] Thus, tools that increase the extent of resection need to be complemented with tools that increase the safety of the patient.[11]

In spine surgery, freehand placement of implants, mainly pedicle screws, results in a higher rate of "suboptimal" positions as compared with image guidance. The latter has limitations if preoperative images are used and the registration of navigation is not perfect. A recent meta-analysis showed that image guidance can reduce the incidence of pedicle breach from 15% to 6%.[12] A further reduction of this problem can be achieved when intraoperative imaging eliminates the inaccuracies of current registration procedures and provides the highest accuracy for navigation.[13] Another important aspect is the radiation exposure for the patient and the surgeon. Freehand placement with the intraoperative use of image intensifier, which is the most often used method today, exposes the surgeon to a higher cumulative dose compared to using intraoperative navigation with or without intraoperative CT with no radiation exposure for the surgeon.[14] However, the patient radiation dose is higher when intraoperative CT is used instead of an image intensifier. The development of surgical procedures is also influenced by the cause of complication. Inaccurate positioned pedicle screws are a directly surgeon-related complication, potentially harming the patient by a screw tip position outside the bone and, although rare, causing severe vascular or nerve injuries. We postulate, that from a conceptual point of view, this complication of pedicle screw placement may be completely avoidable, if the screw is placed entirely inside the bone of the pedicle and vertebral body. We also hypothesize, that the neurosurgical and orthopedic community would highly welcome such a technique, because it would eliminate a complication that is considered surgeon related as opposed to infection, implant failure, or adjacent-level degeneration.

For neurovascular diseases, endovascular treatment is now given for 40–70% of aneurysms, and neurosurgeons have less procedures with a higher rate of complex anatomy and higher claims to perfection. Although the development and introduction of infrared light–based indocyanine green videoangiography has reduced the need for intraoperative angiography,[15,16] there are many cases of aneurysms and arteriovenous malformations where better results can be achieved when using intraoperative DSA with its ability to reliably show the branches and anatomy of hidden structures.

Is there solid evidence?

There is one prospective randomized trial showing that intraoperative MRI increases the extent of resection.[17] Progression-free survival was prolonged, but improved overall survival could not be demonstrated. The scarcity of randomized controlled trials (RCTs) is also a sign that most institutions equipped with intraoperative MRI take the surrogate outcome of complete resection or extent of resection and believe in the concept of maximum safe surgery.

In spine surgery, there are several randomized trials showing that pedicle screws are inserted more accurately when image guidance is used. However, there is no RCT comparing navigation with intraoperative CT-updated navigation. Compared to MRI, the suboptimal surgical results or even neurological sequelae are surgeon-related issues, and techniques to eliminate them will be embraced with a high likelihood, even when there are no randomized trials.

Several prospective studies are showing that intraoperative DSA is able to identify vascular remnants or vessel occlusions in case of aneurysm-, arteriovenous malformation- and arteriovenous fistula-surgery in between 5% and 20%, influencing the surgical procedure in about two-thirds of all cases.[18,19] In Arteriovenous malformation surgery, unidentified remnants will likely bleed after surgery, occluded vessels will lead to infarction, and aneurysm remnants will need further observation or even treatment. Because of the impact of these clinical facts, randomized trials are unlikely to be ever performed.

How many patients will benefit from these technologies?

A fair comparison of the benefit of these new technologies must take into consideration that other methods of intraoperative imaging or image guidance already exist. They cover many clinical needs, but they are not considered the gold standard when it comes to preoperative or postoperative imaging. Hence, there are some patients in whom the use of the more advanced technologies makes a personal, individual difference that may affect quality of life and survival. Our personal experience is that about 5% of patients with glioblastoma, 50% of patients with lower grade gliomas, 10% of patients with a cerebral metastasis, 20% of spinal instrumentations, 50% of AVMs, and 5% of intracranial aneurysms benefit from intraoperative high-quality imaging with MRI, CT, or DSA.

What is the trade-off?

All these technologies are expensive and there is no reimbursement with the current Diagnosis Related Groups (DRG) system. Economically, they are never paying off and they are an investment into the patient's outcome rather than the hospitals budget. Financing these technologies may be improved when economical concepts are taken into account. Although the surgeon's first choice, the economically worst scenario would be the availability of an MRI only for a single specialty, built into the operating theater, without being used for other nonsurgical patients. The same holds true for DSA, that is, hybrid rooms that are only used by surgeons. We need to share these expensive tools with other specialties, in separate rooms, with a 2-room solution, with the MRI to allow an interdisciplinary use and a hospital-wide concept of intra- rather than postoperative imaging and procedure modification.

Time of the procedure—not necessarily the time of surgery—will increase at least with intraoperative use of DSA and MRI. There will be less cases per day in a surgical room and more human resources needed, as well as procedures and standards of safety, especially with the MRI. In intraoperative CT, radiation exposure to the patient increases compared to using image intensifier. Due to the positioning of the patients' head and body during operation, intraoperative DSA will not always have the same image quality compared to a biplanar procedure in the angio suite. The so-called hybrid procedures, where the neurosurgeon and the neuroradiologist are operating on the same patient in one session, are potentially more likely of both a thromboembolic complication and a bleeding complication.

How many sites do we need?

Given the economic issue, there should be a limited number of sites, with separate reimbursement and more centralized specialized cases. This would also increase the site experience with these technologies. However, the need is higher than what it seems to be at the first glance and a concentration of these devices in only a few sites would also include limiting the treatment of quite a few neurosurgical diseases that are not considered to require highly specialized procedures. Thus, most likely it remains an issue of the institution and strategy whether or not to invest in these technologies.

Is this the gold standard?

This question is difficult to be answered. There is already the controversy about the intraoperative use of DSA in aneurysm surgery that can be taken as an example to answer this question. We have to differentiate between (1) the best diagnostic procedure and (2) the term "standard of care." In aneurysm surgery, the many publications about the benefits of using DSA have led to the conclusion that DSA is the gold standard for assessing the clipping result intraoperatively. However, because it is time-consuming, requires resources, and may have complications, DSA is not widely used. Thus, it is a gold standard in terms of imaging but not a standard of care. The same holds true for all imaging procedures that give surgically relevant information not given by other methods. However, as with DSA, they may not be a standard of care, but when available, they are the gold standard of imaging. As already mentioned, the term gold standard cannot be applied to an imaging method per se but for a specific diagnostic question. For example, the patency of small perforating vessels can better be assessed with Indocyanine green (ICG) angiography, and the completeness of resection of glioblastoma better with 5-aminolevulinic acid (5-ALA), so they are the gold standard for these diagnostic questions. DSA, MRI and CT may be the gold standard for others.

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