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White Paper

The Multi-Specialty Hybrid Operating Room

Experience and Outlook

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Fig. 1 Control panel of the hybrid operating system. The surgeon controls all elements of the system at the operating table without the need for outside assistance.

The integration of diverse imaging modalities, enabling surgeons to perform a variety of surgical and interventional procedures in a sterile setting, is the core element of hybrid operating rooms [1]. To date, hybrid OR's have been used almost exclusively in the fields of cardiothoracic and vascular surgery, where they are employed for stenting and minimally invasive heart valve implantation, and also in neurosurgery for brain aneurysm repair [2, 3, 4, 5]. There is a definite tendency in all the surgical specialties to make minimally invasive procedures even less invasive. This tendency, and the subsequent increased demands placed on intraoperative visualization, favor the installation of these high-tech operating rooms for other surgical specialties as well [6].

The new Surgery Center built at Ulm University Medical Center turned the vision of a multi-specialty hybrid OR, headed by the Department of Traumatology, into reality. This hybrid operating room comprises a flat panel detector (FD) C-arm integrated into a floor-mounted robotic-arm (Artis zeego, Siemens, Erlangen, Germany). Compared with standard 3D C-arms, this FD C-arm delivers better image quality and a larger region of interest (ROI). In the Ulm hybrid OR the C-arm and the operating table are linked by digital communication. In other words, the C-arm knows exactly the three-dimensional spatial position of the table. This makes it possible to store C-arm positions relative to the table and thereby prevent collisions. In addition, both the C-arm and the table can be moved simultaneously in three-dimensional space. This also permits subsequent automatic homing in on stored positions. And it helps to reduce radiation dose when accessing exact ROI's or alternating between anteroposterior (a.p.) and lateral views, and during advances and retractions in C-arm repositioning. In addition, the surgeon/assistant can fully control the C-arm all by her-/himself with a sterile remote control (Fig. 1). For the first time ever the surgeon has full control at the operating table and does not have to rely on outside assistance.

3D image acquisition (*syngo* DynaCT)

Another feature of vital importance not only in traumatology is the possibility of 3D image acquisition. This imaging modality, so called syngo Dyna computed tomography (CT), rapidly (i.e., in 5 –10 seconds) assembles several hundred individual images into a CT-like 3D data set. And the surgeon can choose between various options. These comprise both high-dose and low-dose programs. Furthermore, the scans can be performed with high or low soft tissue contrast. It is even possible to perform "large volume scans", thus permitting 3D visualization of large ROI's. This is essential in extended instrumentation of the spine and in obese patients. Consequently, it is possible to match the 3D scan program to almost any patient. Image post processing and reconstruction right from the operating table is easy and user friendly. These 3D scans are outstanding because of the excellent image quality and the large imaging volumes (Fig. 2). Depending on the procedure, the surgeon has direct control over the reduction and fixation of the fractures,

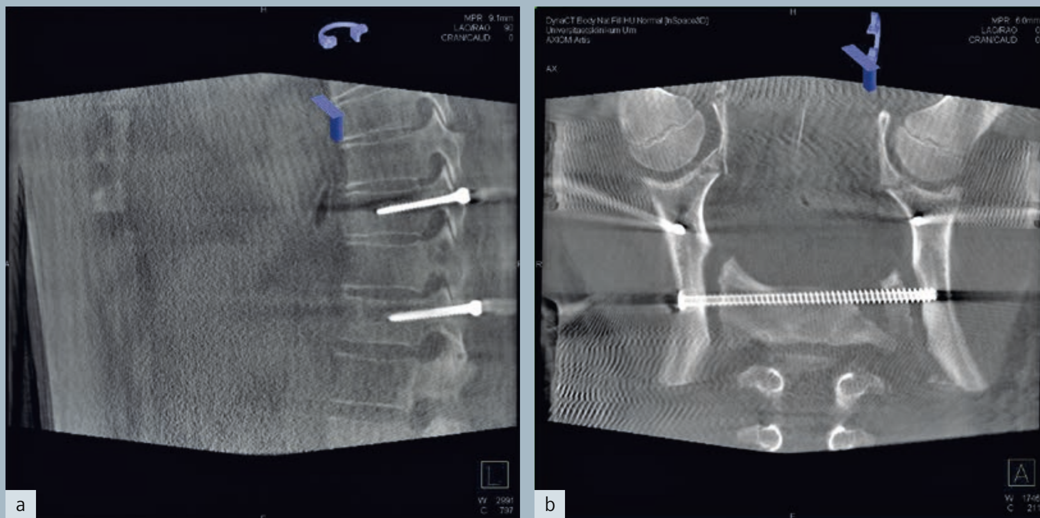

Fig. 2 The large ROI permits visualization of the full surgical field (a, b). Since the full pelvis is depicted in one image, the navigated implantation of the screw stabilizing both sacroiliac (SI) joints requires just one 3D scan (b).

including the option of prompt intraoperative correction without having to resort to complicated re-operation.
By avoiding both the need for reoperation in cases of implant malposition and the cost of postoperative CT studies, the hybrid OR also offers attractive economic benefits.

Integrated Navigation System

The setting of the Ulm hybrid OR combines the robotic-arm mounted 3D flat panel detector imaging system with a navigation system (BrainLab Curve, BrainLab, Munich, Germany). The 3D images generated during the procedure are automatically transmitted to the navigation system. This closes the gap between the best possible imaging and maximum intraoperative accuracy. The joint development effort in this setting has made it possible, for the first time, that the robotic-arm based 3D imaging can interact with the navigation system.

A multi-specialty concept was conceived in order to ensure economic feasibility and high volume utilization of the hybrid OR. Sole use by the Department of Traumatology does not appear to be a viable economic proposition at present because the German DRG system does not reimburse such a complex system. Despite the fact that to date floor-mounted FD C-arms had only been used in angiography and cardiac surgery, a deliberate decision was made in favor of this system, since this type of C-arm offers maximum flexibility and effectiveness. This was quintessential for multi-specialty use of the hybrid OR. Hygiene requirements (laminar flow) ruled out a ceiling-mounted system. And a track-mounted system simply was not practical.
In our Surgery Center the hybrid OR is used two days a week each by the Department of Cardiac and Vascular Surgery and the Department of Traumatology respectively, while the Department of Neurosurgery operates there one day per week. (Fig. 3). This schedule is not set in stone but handled flexibly by the various departments; the core issue is interdepartmental communication and interaction. This increases the utilization, effectiveness, and economic viability of the hybrid OR, thereby ensuring maximum usage in routine operation.

As part of this concept it might be worthwhile to consider creating a radiologic technologist staff position solely for the hybrid OR. However, in our case we deliberately did not pursue this, since we believe that the C-arm should be controlled by the surgeon and/or one of the assistants and not by anyone else. The key issue here is the fact that it is impossible to train all personnel in the use of this system; in addition, each department using the hybrid OR has its own specific intraoperative setup, which clearly differs, e.g., between vascular surgery and navigated applications. The hybrid OR will only function effectively if each department can deploy a “core team” extensively trained in the intricacies of the system as well as the peripheral equipment (navigation system, microscope). In our University Surgery Center the OR nursing staff work a wide variety of shifts, and therefore it is impossible to assign permanent OR teams. Consequently, a well trained team of surgeons becomes a matter of necessity.

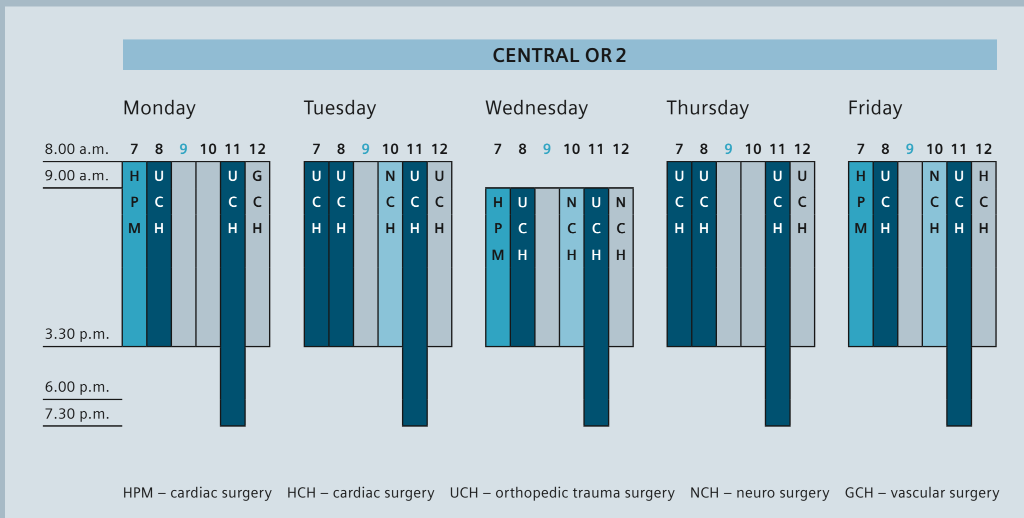

Fig. 3 Central OR suite schedule at Ulm University Surgery Center. **Number 12 is the hybrid OR**. Mondays: Vascular Surgery (GCH), Tuesdays and Thursdays: Orthopedic Trauma Surgery (UCH), Wednesdays: Neurosurgery (NCH) and Fridays: Cardiac Surgery (HPM)

Applications and Experience

In our department the hybrid OR is mainly used for spinal and pelvic surgery. Compared with standard C-arms the most important benefits are improved image quality and larger ROI's. This is especially useful in cervical and thoracic spine procedures where the standard C-arm quickly reaches its limits. Combined with navigation this ensures a high degree of accuracy and safety when placing screws in the intricate anatomy of the neck.

Radiology based pedicle screw placement in extended spinal instrumentation requires multiple repositioning of the standard C-arm. With the large volume visualized by robotic-arm three-dimensional FD imaging this repositioning is no longer needed since it usually is possible to depict the entire surgical field with just one fluoroscopic image ("landscape/portrait mode") (Fig. 2a). In most cases a single 3D scan at the end of the operation will suffice for intraoperative assessment of the implant position.

Quite often motor vehicle accidents and falls from great height will involve injuries to the sacrum, SI joints, and acetabulum. In pelvic fracture management the FD C-arm offers the crucial advantage that the 2D image covers the a.p. view of the full pelvis, while the 3D scan corresponds with a CT study, also of the full pelvis. Today, in fractures with no or only minor dislocation minimally invasive screw fixation is the procedure of choice [7]. At our center navigated surgery has been used routinely in these cases for years [8]. In the past, unfortunately, the intraoperative 3D scans acquired during this type of surgery suffered from poor image quality and small ROI's. With robotic-arm three-dimensional FD imaging it is now possible to visualize the full pelvis in three dimensions and outstanding image quality with just a single 3D scan. Navigated screw placement improves safety and allows a better view both during planning and implantation. Due to the size of the data set it is also possible to stabilize both SI joints with one screw or insert screws into both acetabuli (Fig. 2b).

Loading the intraoperative 3D scans into the navigation system makes it possible to fuse different imaging modalities. The fusion of preoperative magnetic resonance imaging (MRI) studies with the intraoperative 3D scan is particularly helpful in orthopedic tumor surgery, since quite often the naked eye can't delimit the resection margins with certainty. This way, screw positions and resection margins can be defined before the procedure. They may be visualized by the navigation system based on instrument and chisel references, thereby helping to resect the tumor in its entirety while protecting vital structures (Fig. 4, [9, 10]).

However, the hybrid OR isn't reserved solely for spinal and pelvic operations but is also used for tumor surgery. The hybrid OR has also proved its worth in the single-session management of polytrauma patients with injuries involving different parts of the body. In these cases the angiography modality of the system is of vital importance in stenting and in managing major bleeding. Intraoperative 3D scanning and navigation may be particularly helpful in complex isolated fractures of the major joints.

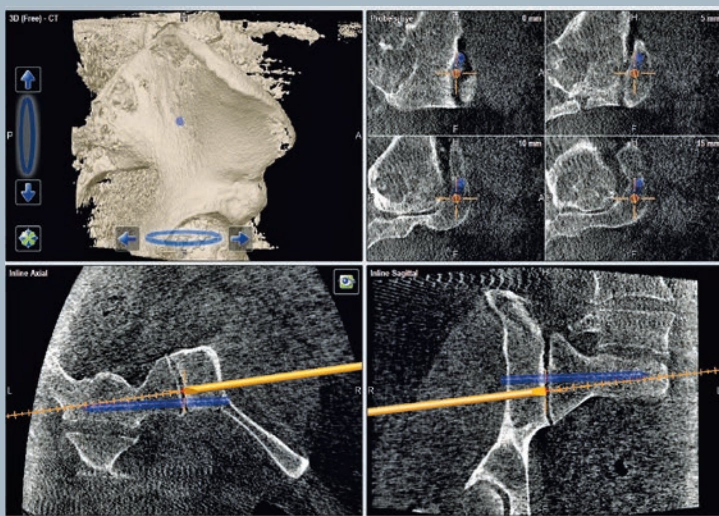

Fig. 4 The images are transmitted automatically to the navigation system once the intraoperative 3D scan has been completed. Precise resection is made possible by fusion with the preoperative MRI data set and the planning markings. Sacroiliac screw placement can be performed during the same step (blue).

Outlook

The hybrid OR concept is steadily gaining ground. At present the different specialties worldwide demonstrate a marked interest in this concept. New guidelines in the UK have limited endovascular infrarenal aortic procedures to hybrid OR's [11]. This demonstrates that the installation of a hybrid OR will become a matter of necessity for major surgery centers. When it comes to economic feasibility, multi-specialty usage appears to be an outstanding solution. Hybrid OR's offer the surgeon the option to fuse preoperative planning with intraoperative imaging and navigation "on the fly" – in other words, the surgeon controls the entire information flow and can process the data directly. This setting offers the ideal platform for integrating additional imaging modalities, thereby further improving surgical outcome. For instance, previously defined resection margins can be checked, without additional radiation doses, by "wireless" intraoperative ultrasonography. In addition, integrated transesophageal echocardiography (TEE) could help in accurate minimally invasive heart valve implantation. Ultrasound re-referencing of a navigation image also appears to be feasible. Furthermore, fusion of MRI, ultrasound, and CT studies could become reality within the next few years. The future may see the emergence of certain subspecializations in hybrid OR usage. One such possibility could be a "head & neck setting" where such different specialties as neurosurgery, ENT, and oral and maxillofacial surgery run the hybrid OR together and share their experience.

In unstable fractures the instruments used in the OR are a constant source of inaccuracy in implant placement. Particularly when placing screws in fractures of the upper cervical spine the instruments should exert as little pressure as possible. In these cases integrated retention systems might be useful.

Conclusion

Combining a robotic-arm mounted FD C-arm with the operating table and a navigation system makes the hybrid OR the ideal environment for minimally invasive surgery and the management of complex injuries. We regard the multi-specialty utilization of the hybrid OR as the cost effective concept of the future because several departments would share the high initial costs and ensure a high degree of OR utilization. The future of hybrid ORs lies in the fusion of additional imaging modalities and integration of assistive retention devices.

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