Concept and design engineering: endourology operating room

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Purpose of review
A dedicated operating room with fluoroscopic imaging capability and adequate data connectivity is important to the success of any endourology program. Proper understanding of the recent developments in technology in relation to operating room is necessary before planning an endourology operating room.

Recent findings
An endourology operating room is a fluorocompatible operating room with enough space to accommodate equipment like multiple flat monitors to display video, C-arm with its monitor, ultrasonography machine, laser machine, intracorporeal lithotripsy unit, irrigation pumps and two large trolleys with instruments. This operating room is integrated with devices to continuously record and archive data from endovision and surface cameras, ultrasound and fluoroscopy. Moreover, advances made in data relay systems have created seamless two-way communication between the operating room and electronic medical records, radiological picture archiving and communication system, classroom, auditorium and literally anywhere in the world.

Summary
A dedicated endourology operating room is required for any hospital, which has a significant amount of endourology procedures. A custom-made integrated endourology operating room will facilitate endourology procedures, smoothen the workflow in operating room and improve patient outcomes. Meticulous planning and involving experts in the field are critical for the success of the project.

Keywords
endoscopy, fluoroscopy, operating room, operating room information systems

INTRODUCTION

An integrated modern endourology operating room integrates a fluorocompatible operating room that is modular and ergonomic with state-of-the-art video displays, centralized control of equipment and digital information archiving and transmission. The basic aim of such an operating room is to facilitate and improve the efficiency of technology driven surgical procedures, smoothen workflow and improve patient outcomes. The other advantages are to store and exchange data with hospital information management system (HIMS) and radiological picture archiving and communication system (PACS) of the hospital, connect the surgeon to literally anywhere in the world in real-time so that both teaching and collaboration are seamlessly achieved. There is a need for safety, convenience, and economy in planning of a dedicated endourology operating room complex. Scarcity of publications and guidelines in this regard results in inadequacies that are realized later [1]. This article reviews the recent literature regarding endourology operating room and elaborates the planning necessary for an endourology fluorocompatible operating room to carry out procedures such as percutaneous nephrolithotomy (PCNL) and ureteroscopy (URS).

Planning an endourology operating room

Before the actual planning of the operating room starts, the hospital's requirements and expectations of the concerned stakeholders should be clearly put

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KEY POINTS

- The setting up of an endourology operating room requires prospective planning for at least future 10 years.
- The key components of the operating room are multiple ceiling booms that support equipments, such as lithotripters, light source, endocamera, electrocautery, anesthetic gas connections, and electric plug points.
- Strategic placement of the operating room equipments minimizes procedural time by means of intuitive control and provides shorter changeover times because equipment settings can be freely defined and activated.
- Audio-visual (AV) capture, archival and relay are essential components of a modern day endourology process.

down. The requirements should take into account the growth of the hospital and changes in technology that are expected to happen over the next decade. State-of-the-art design enables hassle-free movement of equipment, the ability of the surgeon to view multiple screens, efficient data archiving, and management of the relay system [2]. In order to create such an efficient operating room it is important to select the construction firm with a good record of work accomplishment. Architect, engineer, equipment planner, construction manager, and key equipment vendors should all be included in the team [3]. It is important to consider the existing workflow and the rooms adjoining the proposed operating room and plan accordingly.

Nowadays, using three-dimensional software, a three-dimensional model of the operating room is designed taking into account the available space, operating room table, equipment like C-arm and supplies for gas, water, air, and electricity. This model allows assessing how the cables and equipment will interact once the operating room is made, so that adjustments can be made in their relative positions and pathways. Those involved in electricity, gas and water piping, ventilation and information systems can use this model to create blueprints for their respective plans. Case studies from similar operating rooms of other disciplines can also give us an overview before planning [4].

GENERAL DESIGN FOR AN ENDOUROLOGY OPERATING ROOM

The main objective of operating room design is to improve the operating room workflow and enhance safety by ensuring good access and clear walkways [5▪▪]. This sets the stage for equipment and equipment planning in the operating room. Devices should be accessible and ergonomic so that they are easy to position and park. Equipment booms and other ceiling-supported equipment are used increasingly in operating rooms because of the advantages they offer [6]. Equipment booms are ceiling-mounted, articulating arms that support equipment, such as lithotripters, light source, endocamera, electrocautery, anesthetic gas connections, and electric plug points. The booms significantly reduce clutter and interconnect equipment by using the space above the false ceiling, thereby enhancing sterile setup and less maintenance as a result of cable breakage. Moreover, this avoids tripping hazards. Booms, however, need a significant amount of structural support that must be coordinated with the lighting, mechanical, and electrical systems above the false ceiling.

Room size

The recommended size of a general operating room is 55 m^2. Because endourology procedures need more staff and multiple large pieces of equipment, such as the C-arm, laser, ultrasound machine and the workstation, the recommended size would be 60 to 70 m^2 [7]. Additional space for an adjacent sterilization room and data control room is also mandatory.

Ceiling

The finished ceiling height of the operating room should be 10.0 feet (3.05 meters) above the floor and another 2 feet in the plenum above [8]. Ceiling must be smooth and washable. Gypsum board with a washable, nonreflective finish in a light to medium tone is recommended [9]. The over-ceiling plan is an important feature. This space includes the following: cables for various equipment booms, such as anesthetic gases, compressed air, vacuum, electrical wires; heating, ventilation, and air conditioning (HVAC) ducts; and data relay wires in various hanging arms.

Floor

As endourology operating room is a 'wet' operating room, there should be a central drain outlet from the floor underneath the operating room table. The floor should have a slight slope from all the walls converging at the water drain outlet. The surface of flooring must be slip resistant, strong, and impervious with minimum joints, for example, mosaic

with copper plates for antistatic effect or jointless conductive tiles – terrazzo or linoleum [9].

Walls

Operating room wall must be planned to accommodate cables of electricity and data, pipes supplying gas, air and water, and ventilation equipment. The radiation protection of the suite necessitates 2 mm thick lead lining in all directions. Lining with laminated polyester or smooth paint provides a seamless wall. Light colored (off white, light blue, or green) washable paint will be ideal for walls. There should be a provision for a radiograph illuminator, wall-mounted camera, plasma screen, and drawers for endoscopic disposables recessed into the wall. The wall should also meet standards for fire and sound insulation.

Main door

The main door to the operating room has to be of adequate width (1.2–1.75 m) [10] to facilitate smooth patient trolley, laser, C-arm unit, and ultrasonography machine entry and exit. Sliding doors are preferred so that no air currents are generated. The doors should be rebated such that there is at least 15 mm overlap in the lead contained within each door.

Electricity and grounding

The following criteria are ideal with respect to electricity in the operating room. First, use of line isolation monitor (an alarm device that continuously monitors the integrity of a power system) or ground fault circuit interrupter (is a simpler device that will trip and shut off all power in that circuit when there is leakage of current to ground) is desirable. Second, install appropriate power line as per the local specification. Third, suspended ceiling outlets should have locking plugs to avoid accidental disconnection. Fourth, insulation around ceiling electrical power sources should withstand frequent bending. Fifth, operating room electrical networks need to be connected to the emergency generators with automatic two-way changeover facility.

All electrical equipment in the operating room needs proper grounding. It should be common for all equipment and should come from a main source (like uninterrupted power supply). Grounding offers protection from macro shock (typically more than 10 mA). The grounding of the operating room, control room, auditorium, or wherever transmission is going to be relayed should be at one single place. If every place has its own grounding, then the picture quality of the transmission becomes unclear and shaky. Many times this fact is neglected or not realized, resulting in much trouble later on.

Lighting

In general, two different light sources are needed in an operating room: the surgical (operating) lights used for open procedures and the ambient lighting for interventional procedures. Particular attention should be paid to the possibility to dim the lights. This is frequently needed during fluoroscopy or endoscopy. The key topics for planning the surgical light system include:

(1) Central location above the operating room table (impossible with ceiling mounted C-arm systems).
(2) Usually two or three light heads for optimal illumination of surgical field
(3) Suspension accommodating unrestricted, independent movement and stable positioning of light heads
(4) Modular system with options for extension, e.g. video monitor and/or camera [5▪▪].

Light-emitting diode (LED) lights are currently preferred. In the operating area, the over headlight should be shadow-less and give 40 000–125 000 lux of light (should not exceed 160 000 lux), as in a general operating room. LED light has the advantages of lower heat generation, adjustable light characteristics, a life span of 25 000–40 000 hours, and failing by gradually fading in brightness.

Operating room table

The operating room should have a mobile, modular operating table with electronically controlled hydraulic drive, battery, and mains operation. It should have a stable base construction, rotatable top, and large twin disk casters for easy travel and maneuvering. The entire tabletop should be without crossbars for it to be compatible with fluoroscopy. A trapezoidal shaped cutout at the foot of the tabletop facilitating access to the patient's perineum is desirable. The other features required for an endourology table are: carbon fiber tabletop to allow for as large as possible viewing window of the kidney with no obstruction [about $25'' \times 20''$ (0.64×0.51 meters) metal-free imaging area for unobstructed fluoro imaging of the entire urinary tract]; the ability to connect split leg spreader bars and gas spring stirrups; the ability to connect arm boards; adequate clearance for the C-arm; at least a 500 lb weight limit; and safety to operate in a 'wet' environment

[11]. Provision for kidney bridge elevation is helpful if open exploration is needed. There should be multilayered radiolucent foam padding for patient comfort and safety.

Flat screens and monitors

The surgeons, the assistant, the anesthesiologist, nurse, and operating room technicians, should all have views of all major imaging and monitoring sources. Therefore, the display of all these sources should be available in all four quadrants of an integrated room. About four to six ceiling-mounted flat screens will be required. Proper planning is required regarding the movement of these flat screens in accordance with the other power booms and operating room lights.

IMAGING EQUIPMENT

The imaging requirements are a C-arm and ultrasonography machine.

C-arm

A mobile C-arm unit is necessary for a urology-dedicated operating room. It should have a high quality image for quick and precise diagnosis and monitor brightness. The image intensifier should have Digital Imaging and Communications in Medicine imaging capabilities, last image hold memory, image processing, text graphics, and other functions. Image display should be on a high-resolution TFT monitor. The data output from the C-arm may also be connected to one of the hanging screen monitors to ease the vision to the operating surgeon.

The combination of a ceiling-mounted radiograph system (Artis Zee Ceiling, Siemens Medical Solutions, Erlangen, Germany) and a new urological intervention table now allows cross-sectional imaging and three-dimensional reconstruction to be performed in the endourological operation room (Urological Dyna-CT) [12▪]. Ex-vivo study has shown that three-dimensional reconstruction of the urinary tract are possible and provide fast and excellent urological imaging using this system. The Uro Dyna-CT can be used for all interventional endourological procedures using the common armamentarium and instruments without significant limitation of image quality, except PCNL working sheath and the rigid URS [13▪]. Modern C-arm systems will be equipped with a flat panel detector that has a higher contrast resolution and less image distortion at edges than current image intensifiers.

Ultrasonography

The advantages of ultrasound-guided renal access are avoidance of radiation, avoiding adjacent and visceral injury and, most importantly, intrarenal vascular injury. Ultrasonography offers the shortest and straight access to the collecting system with minimal morbidity. Ultrasound-guided access is of particular importance in the pediatric population and in special situations in which the procedure is performed with the patient in the supine position. The available ultrasound probes (3.5/5 Hz) come with a puncture attachment and, on scanning, the puncture pathway is represented by a dotted line on the scanner screen, which facilitates exact placement of the needle [14].

Gao *et al.* [15▪] has presented their 8 years experience with x-radiation free endourology operating room during that they had successfully completed 3000 percutaneous nephrolithotomies, 2000 ureteroscopies, and 800 flexible ureteroscopy procedures with complication rates comparable to other institutes using fluoroscopy. The disadvantages of fluoroscopy like radiation to patient and staff, crowding in operating room and need for heavy protective apron could be avoided. The advantages that are lost are a road map, better appreciation of position and guidance for access and dilatation for PCNL. These can be overcome by using ultrasound during PCNL and flexible ureteroscope in case of tortuous ureters in ureteroscopy. Totally ultrasound-guided PCNL has been shown to have stone-free rates and complications comparable to fluoroscopy-guided PCNL [16,17].

STERILIZATION

Endoscopic equipment cleaning room should be planned adjacent to the main endourology operating room. The design of this facility should take into account the requirements for adequate water inflow pressure in the taps, temperature, and drainage; ventilation; plumbing; and power supply. Automated endoscope reprocessors (AERs) providing high-level disinfection for endoscopic instruments are desirable [18]. However, there should also be a provision for manual rinsing and cleaning. Plasma or ozone as the sterilant, are useful for rapid sterilization in between many procedures in a day (e.g., Sterrad NX, Advanced Sterilization Products, Johnson and Johnson, USA).

OPERATING ROOM CONFIGURATION FOR ENDOUROLOGIC PROCEDURES

Strategic placement of the operating room equipment minimizes procedural time by means of

intuitive control and provides shorter changeover times because equipment settings can be freely defined and activated. In an integrated operating room, all medical instruments for an endoscopic intervention can be operated by means of user-independent voice control or a touch screen at a central console in the sterile or support area. The anesthesia workstation should have a dedicated boom to supply gases so that it can be moved along with the anesthesia cart when the side of procedure is changed. It should change the location on the cephalad end of the patient as per the side of the procedure. There should be a minimum of three hanging display screen monitors supported by the boom to be placed on the front end of the surgeon. The display on the screen should include fluoroscopic image, endovision image, ultrasonographic image, and HIMS or PACS image.

The prefabricated modular operating room offers the advantage of speedy construction combined with design, future expansion, and development in surgical technique, whereas simultaneously providing a structure of the highest quality and standards. The standard package includes an operating table, operating lights, endoscopy equipment, and a range of monitors that surround the patient [19]. Currently, two endourology-dedicated modular operating rooms are available from Karl-Storz, Tuttlingen, Germany, and Richard Wolf, Knittlingen, Germany; they can be installed on demand by the respective technical teams.

DATA ARCHIVING

Audio-visual capture, archival and relay are essential components of a modern day endourology process. Customized operating room software can be designed for individual needs [16]. Audio-visual data capture is done via endovision camera, surface camera, fluoroscopy unit and ultrasonography machine. Three-chip systems provide better overall image quality than one-chip systems. The use of high-definition cameras and monitors during minimally invasive procedures can provide the surgeon and operating team with more than twice the resolution of standard definition systems. If a high-definition camera is selected, it is imperative to invest in computer hardware and software capable of editing and outputting high-definition video. Signal from endocamera processing unit can be inputted directly into an operating room panel on the workstation. There are many options for providing good quality video capture in viewing endourologic procedures on the body surface [20]. At least three surface cameras should be present in the operating room for video capturing. The central camera may be mounted on a surgical light or can be kept separate on a hanging boom. The second should be wall mounted at a height near the ceiling, which will give an overview of the full operating room. This camera can be zoomed in or out by remote control as needed. The third camera should be on one of the TFT screens for videoconferencing.

In the modern operating room, there should be an electronic workstation located in one corner. The cable input enters the operating room panel wherein the composite audio-visual signal is converted to S-video signal. The S-video output can be transmitted to any of the hanging display monitors (TFT screens) in front of the surgeon. The workstation also has a video processor with digital video output. The video archiving subsystem consists of a hard disk or network recorder and software. High-definition video is, thus, captured and recorded on digital versatile disc (DVD) for archiving and future editing [21]. The operating room panel is also connected via two-way circuit to the HIMS. The necessary information, including the history, examination, radiographs, computed tomography images can be relayed to the monitor in front of the surgeon during the operation. At the same time, the operating room details can also be fed to the HIMS for data archiving. The workstation has three integrated services digital network line connections.

If live transmission is frequently done, for conference workshops or teaching, install facilities for data relay during construction of the operating room. A small control room near the operating room is helpful for a data relay system. The control room receives cable connections from all of the data capturing components. This control room has the capability to route audio, video, and data to and from the operating room. Information is not only distributed within the operating room but also to remote locations, such as image archiving systems, classroom, and auditorium.

CONCLUSION

An integrated modern endourology operating room is an essential part of a urology center. It facilitates advanced endourology procedures, improves workflow, reduces patient turnover time and ultimately improves patient outcomes. Archiving operative data and establishing communication networks and decision support facilitate training and helps in intraoperative decision-making. Moreover, these facilities help in publishing data and organizing live operative workshops easily. Although general recommendations have been given in this review, the individual project team is of utmost importance

in customizing the operating room according to local needs and facilities.

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Conflicts of interest

There are no conflicts of interest.

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- ■ of special interest
- ■■ of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 186).

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This chapter has in depth details regarding the planning, design of a state-of-the-art hybrid operating room. Although it deals mainly with a cardiac hybrid operating room, there are many similarities to an endourology operating room. Many hospitals are currently developing hybrid operating rooms that will be shared between various specialties like cardiology, cardiothoracic surgery, neurosurgery, urology, orthopedics, and radiology. Thus, this chapter provides the knowledge required to develop an operating room that can be shared by multiple specialties.

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