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A COMPARISON BETWEEN THE SPATIAL CONSIDERATIONS OF TECHNOLOGIES IN STANDARD AND HYBRID OPERATING ROOMS

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Abstract

The spatial considerations of operating rooms (ORs) are evolving frequently to keep pace with the scientific development of surgical procedures. The study utilizes a comparative approach to specify the differences between the dimensional and spatial considerations of equipping standard ORs that introduced significant technological improvements and hybrid ORs that integrate developed imaging equipment within the surgical environment. For example, operating tables offer a wide range of tilting angles and a radiolucent surface to pass-through x-rays in the hybrid OR, while the articulating arms of ceiling-mounted booms need enough space to move freely within the OR and suitable load capacity to hold various medical utilities. On the other hand, devices such as anesthesia and heart-lung machines are placed near the patient to provide the required medical support, while imaging equipment in hybrid ORs such as the C-arm require specific spatial

considerations for ergonomic workflows. Ultimately, spatial considerations of hybrid ORs are similar to standard ORs with unique intraoperative imaging technologies.

Keywords

Operating Rooms, Hybrid Operating Rooms, Spatial Requirements, Operating Tables, Surgical Booms, Anesthesia Machines

1. Introduction

This study assumes that there are core differences between standard and hybrid operating rooms on several levels. However, the main function of the two rooms is similar, i.e. to offer seamless and safe surgical procedures with the best outcome for patients. Hybrid ORs offer advanced medical technologies for complex surgical procedures (STERIS, 2018a) that need more advanced equipping than that of the standard ORs and accordingly reshape the spatial considerations of the operating room.

The major objectives of this study are:

- Distinguishing between the major components of each operating room.
- Identifying the spatial requirements of each discussed medical equipment.

For this reason, the research establishes a comparative study through which it describes the spatial considerations of the essential technologies in standard and hybrid ORs. In each of them, it discusses the spatial requirements of fundamental devices such as: operating tables, surgical booms, anesthesia machines, scanning and imaging equipment and other special devices which are necessary for creating ergonomic and developed surgical environments such as back tables.

The study scope only covers the spatial considerations of the major equipment in standard and hybrid ORs, including operating tables, surgical booms, anesthesia machines, back tables, heart-lung machines, and imaging equipment such as C-arm. It does not cover surgical instruments, architectural elements such as doors and windows, mechanical equipment such as air diffusers, or any other medical items or technologies related to the design of ORs.

2. Literature Review

The complex physical environment of operating rooms requires a deep investigation of the spatial requirements of medical equipment, to facilitate the workflow of surgical procedures and

offer an ergonomic workspace for surgeons (Joanna, et al., 2017). The surgical care evolves with the frequent introduction of new medical technologies; that require a parallel evolution of the spatial considerations inside the operating rooms (ORs) (Kaye, Fox, & Urman, 2012, p. 132). For example, hybrid ORs such the one at HYGEIA hospital in Greece offer developed imaging capabilities that require more specific spatial requirements than that for the standard ORs such as the one at St. Mary's Regional Medical Center in United States of America (Nollert & Wich, 2009).

3. Research Issue

There is a radical difference between the medical technologies and equipment of standard and hybrid operating rooms, which require an in-depth investigation of the spatial needs for both of them in order to offer the ergonomic required workflow during surgical procedures.

4. Standard Operating Rooms

The design of a general operating room as shown in figure 1 must have a minimum area and ceiling height of 37 m^2 and 275 cm respectively to allow adequate circulation for the surgical team during the surgical procedures and proper space for fixed and portable equipment (American Institute of Architects, 2007, p. 523; Kaye, Fox, & Urman, 2012, p. 102).

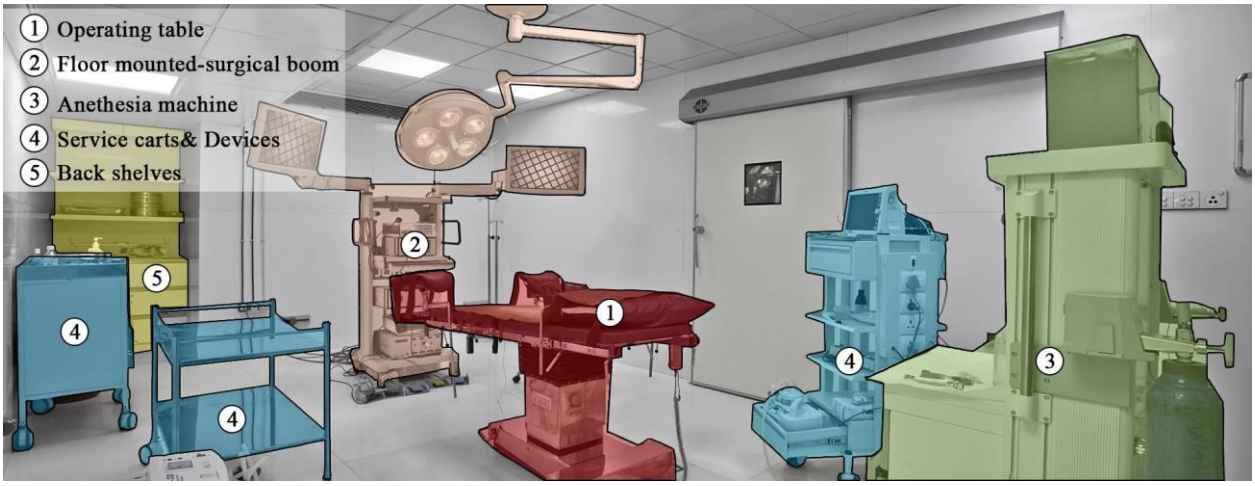

Figure 1: *Components of Standard Operating Rooms. Adapted from: (Wikimedia Commons, 2013)*

4.1 Operating Tables

The operating table is a central and major component in the OR where patients lie down in different positions during surgery (Shaikh, 2019, p. 7). It is a flexible and adjustable bed with

breakpoints at the head, waist, and knee and removable sections suitable for different types of surgical procedures (Association of Surgical Technologists, 2017, p. 78).

The general-purpose operating table is controlled electrically and consists mainly of pads, movable head section, central body section, lower extremity section, kidney elevation bar, side rails, control box, pedestal, and base with casters. Extensions, headrests, and other accessories may be added to the table for different surgical purposes (Phillips & Hornacky, 2020, p. 494).

Operating tables have a metal top that measures 201 to 225 cm in length and 51 to 61 cm in width, rest on an electric or hydraulic pedestal, and covered with 8 cm thick self-adhering pads (Ibid.). Some models have a height range between 59.5 and 89.5 cm and a working load of 225 kilograms (kg) (Merivaara, n.d.); however, all models have a wide base that prevents inclination under uneven weight distribution (Association of Surgical Technologists, 2017, p. 79).

According to the type and model of the operating table, the adjustment ranges vary according to patient positing; which accordingly influence the spatial considerations around the table. For example, the head section tilts with a range of ± 45º, lower extremity section with a range of -90º to +20º, and the body-head i.e., back section with a range of -40º to +70º. While the whole table can have a ± 20º lateral tilt, 220º flex angle, or 110º reflex angle (Merivaara, n.d.).

4.2 Surgical Booms

The surgical boom is a centralized ceiling-mounted device inside the OR. It has several articulating arms that host shelves and various utilities such as outlets for medical gases and electrical power, surgical lights, display monitors, or any other medical devices (Association of Surgical Technologists, 2017, pp. 77, 78). Surgical booms promote flexibility, provide ease of accessibility, and improve organization and visibility inside the OR (Flint, et al., 2008, p. 167).

Length of the arms ranges from 120 to 60 cm (Stryker, 2014, p. 88); they host several items such as lights, shelves, display monitors, intravenous (IV) poles, and other organizational items such as drawers. Most surgical lights are fluorescent with intensity ranging from 27,000 to 127,000 lux that distributed evenly throughout the room. Shelves are used for holding equipment such as electrosurgical units (ESUs) (Phillips & Hornacky, 2020, p. 182; STERIS, 2018b).

Installation and spatial considerations of surgical booms such as load capacity, number of articulating arms, and range of motion play a crucial role in their performance (Flint, et al., 2008, p. 167). The design team must confirm that the surgical boom weight does not reach the maximum load capacity of the OR's ceiling. They must weight each equipment individually to confirm that

load does not exceed 34 kg on each shelf, and they must distribute the weights equally among the whole system and individual shelves (Stryker, 2014, pp. 97, 99).

Surgical booms are designed to provide flexible and optimized configurations depending on the surgical procedure requirements (STERIS, 2018b); however, their range of motion and number of equipment they hold must be studied to provide a proper layout (Flint, et al., 2008, p. 163). They must be placed in a suitable location away from the OR door, while the articulating arms must not interfere with the movement of the surgical team or the lighting units. Computer-aided simulations can enhance the decision-making of booms' placement and movement during the early design process to achieve better results (Kaye, Fox, & Urman, 2012, p. 102).

4.3 Anesthesia Machine

Anesthesia machines are used to prepare a precise mixture of medical gases with variable compositions to be delivered to a breathing system. These gases are supplied through cylinders or medical gas piping systems under high pressure. It mainly provides oxygen (O_2) for patient ventilation and precisely mixes anesthetic gases (Baheti & Laheri, 2018, p. 33; Gurudatt, 2013).

Anesthesia machines are composed of flow meters to regulate the concentration of gases and their flow rate, vaporizers to deliver inhalable anesthetic agents, a reservoir bag to deliver positive-pressure ventilation, a ventilator to deliver ventilation automatically, and other inner systems and circuits for regulating medical gases. They also have displays to monitor blood pressure, heart rate, respiratory rate, and anesthetic rates (Rose & McLarney, 2014, pp. 4-8).

The location of anesthesia machines may be near the patient's side or feet inside the OR (Phillips & Hornacky, 2020, p. 852). There are several design alternatives of the anesthesia machine, however, they all target the same purposes (Rose & McLarney, 2014, p. 3) and seek an ergonomic anesthesia workflow (Dräger, n.d.).

Each model requires specific space requirements according to its type and composition. The height of anesthesia machines ranges from 132 to 150 cm, length from 62 to 115 cm, and width from 59 to 90 cm. While their weight ranges from 116 to 165 kg (Ibid.). The OR bed must provide enough space for the anesthesia machine and allow the anesthesia provider who sits alongside it to access the patient's head and neck easily (Phillips & Hornacky, 2020, p. 852).

4.4 Other Equipment in Standard Operating Rooms

The complex environment of the operating room requires other components and devices that are necessary for improving the entire workflow. These components might be sterile such as back

tables, mayo stands, or ring stands, which used to hold the required intraoperative sterile instruments, or non-sterile such as linen hampers, sharp containers, suction systems, and kick buckets which used for waste disposal (Association of Surgical Technologists, 2017, pp. 78-80). The average dimensions of the back tables are 116 × 61 × 86.5 cm (MedWurx, n.d.).

The heart-lung machine or cardiopulmonary bypass (CPB) machine is an important device in modern cardiac surgeries. It takes over the function of the heart and lungs to maintain the circulation of blood and oxygen inside the patient's body. It is mainly composed of pumps, catheters, and pressure sensors (Khandpur, 2020, pp. 766-771). It has wide configurations that determine its size, for example, the dimensions of the 5-pump console are 103.6 × 60 × 148.5 cm (Maquet, n.d.), thus, its location must not interfere with the circulation of the surgical team and allow proper space for the percussionist to run it (Whitlock, 2020).

5. Hybrid Operating Rooms

The hybrid OR shown in figure 2 is defined as a surgical theatre where endovascular and neurovascular treatments are combined with advanced imaging and interventional technologies in the same space (Iihara, et al., 2013), which includes the operating table, anesthesia machine (Tsagakis, et al., 2013), surgical booms (Nollert & Wich, 2009), and C-arms (Yang, et al., 2016).

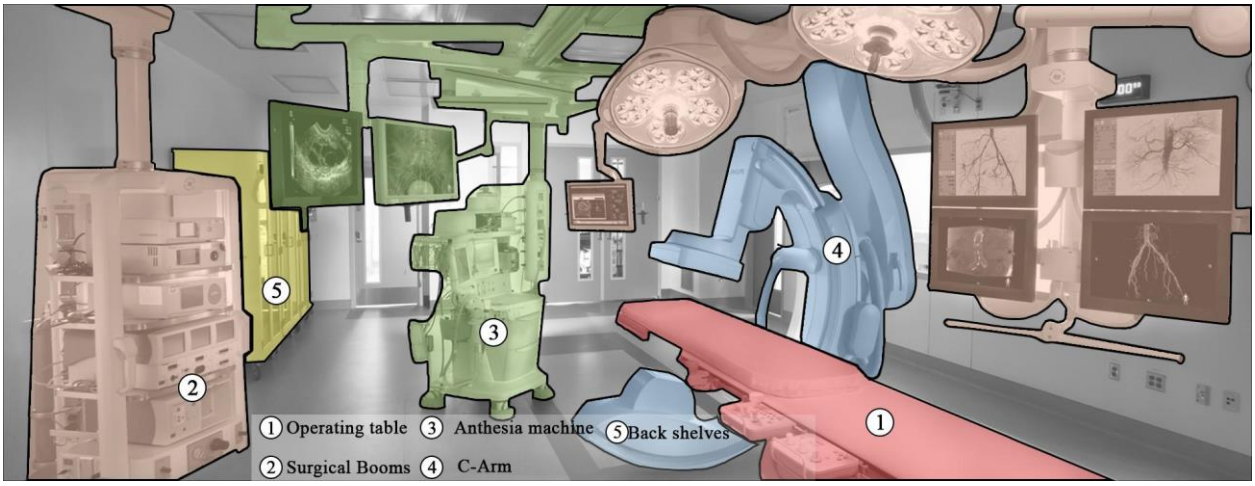

Figure 2: *Components of Hybrid Operating Rooms. Adapted from: (Tru-D, n.d.)*

5.1 Operating Tables

Due to the variety of surgical procedures performed in the hybrid ORs, the spatial needs of the operating table must meet the requirements of all surgical interventions (Nollert & Wich, 2009). It must be a breakable tabletop made mainly from carbon fibers (Yang, et al., 2016) with a

radiolucent surface to permit the pass-through of x-rays during radiographic imaging (Association of Surgical Technologists, 2017, p. 79), linked digitally to a flat panel detector, and connected to a motorized robotic arm (Richter, Gebhard, Dehner, & Scola, 2016).

It must be centered in a diagonal position inside the OR with seven degrees of freedom to allow the angiographic imaging of all the human body and the ability of tilting during the surgical procedures (Tsagakis, et al., 2013). Inflatable cushions might be used to adjust patient positioning if no breakable table is available. In some countries, floating tables are required in hybrid ORs to facilitate the circulation of the surgical team (Nollert & Wich, 2009).

The operating table in hybrid ORs must integrate, in terms of dimensions and directions of rotation, with the movement of other devices, especially the C-arm during imaging. The minimum height of the imaging and surgery table in the hybrid OR is 57.5 cm, while its maximum height is 95 cm. The length ranges from 200.5 to 263.5 cm and the width starts from 50 to 60 cm. Lateral tilting angles are between 20º and 30º, while tilting angles range from 0º to 90º/0º to 105º for leg up/down and 80º to 90º/30º to 60º for back up/down (Meditek, n.d.).

5.2 Surgical Booms

Surgical booms or equipment management booms are a service unit used inside the hybrid ORs, which also called ceiling supply unit and equipment columns (STERIS, n.d.). Surgical booms in the hybrid ORs consist of a straight drop unit with single or double arms that overhang from the ceiling and mounted on a host with two or more instrument carriage components that are connected the housing device. A central control unit which controls and direct instrument mechanism, the service unit which includes shelves and gas outlets, and the display unit are all attached to the central host to keep the space organized and preserve cables and devices off the floor (Beger, 2002).

Equipment management booms host a number of motorized arms with specific spatial considerations. For instance, the load capacity and cargo lift's load capacity should not exceed 180 kg and 280 kg respectively (Getinge, 2019). The boom placement is recommended to be central to allow equipment positioning anywhere within a range of 518 cm (Stryker, 2014), proper installation, a suitable number of hosted arms, adequate range of motion, and appropriate vertical travel. Ceiling lighting devices for hybrid ORs are mostly fluorescent according to ORs' standards, however, other types of light source bulbs may be used (Flint, et al., 2008).

5.3 Anesthesia Machine

Anesthesia machine or anesthesia unit is the device that pumps a continuous flow of initial respiratory and anesthetic gases (Yentis, Hirsch, & Ip, 2013, pp. 6, 7). The anesthesia unit in hybrid ORs is distinguished from the anesthesia machines in the standard ORs in that it has the ability to integrate with other devices, especially the C-arm. This unit consists of two major parts: the anesthesia machines/vents and the anesthesia booms. The machine and the boom have the ability to be used in any patient position according to the type of the surgical procedure, and the ability to be kept away when they are not in use (Keckler Medical, n.d.).

During surgical procedures, the surgical team needs free access from all areas around the patient, the reason why using the ceiling railing system for the anesthesia booms is ideal. It runs the whole width of the room, and about two-thirds of the length to allow the system to be parked all away from the table when it is not used (Schröfel, Bakker, & Boomen, 2010). Anesthesia machines have several connected elements, such as gas outlets, data connections, video signal inputs/outputs, and monitors. Anesthesia machine carts have a height of 135.8 cm, while their width depends on the number of vaporizers and ranges between 75 and 93 cm, however, its depth remains constant at 83 cm, and boom length between 30.5 and 122 cm (Philips, 2013).

5.4 Imaging Equipment in Hybrid Operating Rooms

Hybrid ORs represent an integrated combination between standard ORs and imagining departments. They vary according to the existing scanning equipment and must comply with the standard ORs requirements to ease the flexible use of the room. There are different types of 2D imaging equipment installed in the hybrid ORs, including angiography equipment, magnetic resonance imaging (MRI), and Computed tomography (CT) (Fearon, 2018). Engineers apply two systems of equipment installation: Mono and Biplane systems, according to the type of the surgical procedure performed (Nollert & Wich, 2009).

The monoplane system is defined as the multi-axial robotic angiography system able to rotate with eight axes, which provide images from different directions to generate images similar to the CT scan, but with more flexibility and without using biplane. It is a suitable system for vascular, cardiac, and orthopedic surgical procedures (Nollert & Wich, 2009). On the other hand, the biplane system consists of two robotic arms; one is floor-mounted while the other is ceiling-mounted, which is capable of capturing 3D images from two points at the same time. Biplane systems offer the surgical team better visibility while scanning (Fearon, 2018); however, they add more complexity to

the workplace (Nollert & Wich, 2009) as the motion of the C-arm causes a great amount of radiation (Richter, Gebhard, Dehner, & Scola, 2016). This radiation is comparable to a conventional multi-slice CT radiation, while staff can move out of the operating room during scanning procedure as it lasts only for 10 seconds (Nollert & Wich, 2009).

The placement of imaging equipment inside the hybrid OR acquires great attention and considers many aspects. Some equipment systems are floor-based, while others are ceiling railing system based (Fearon, 2018). The C-arm connects to a flat detector with 30.5 × 35.5 cm with the ability to be parked in the corner of the room (Iihara, et al., 2013). The design team must consider four main zones for imagining purposes and radiation effects: sterile zone, circulation pathway, movable equipment zone, and anesthesia zone (Fearon, 2018). The maximum extension of C-arm is 259 cm from the back cover to the tip of tube housing with an 86 cm base width. While the dimensions of the monitor cart are 68.5 × 68.5 × 162.5 cm (Plimpton, 2019).

Facility Guideline Institute (FGI) requires the hybrid OR to meet the requirements of the net floor area of the standard OR, clear heights, and the room imaging equipment storage needs. Hybrid ORs must meet the minimum area requirements of standard ORs, the factor of considering the four zones, and the clear area needed by the imaging equipment (Fearon, 2018).

6. Conclusion

The effect of equipment technology used in standard and hybrid ORs is shown clearly on the spatial planning of spaces, due to the difference of spatial needs of these devices and the type of the surgical procedures performed in each room. This study opens new horizons for future multidisciplinary research that blends architectural design and ergonomics with medical and surgical fields. Future research is encouraged to conduct sophisticated studies that select specific types of surgical procedures such as orthopedic and open-heart surgeries and investigate their spatial requirements for equipment and medical technologies, which enhance the overall surgical workflow and improve patients' outcomes. On one hand, standard ORs contain some elements similar to hybrid ORs. On the other hand, hybrid ORs specialize in some device technologies, along with their differences in the spatial requirements and dimensions due to their integration with other devices and systems to provide adequate space for the medical team and provide the essential flexibility for use as shown in Table 1.

Table 1: *Spatial Considerations for Standard and Hybrid ORs*

<table>
<tr><td></td><td colspan="4">Spatial considerations for installed equipment</td></tr>
<tr><td></td><td colspan="2">Standard ORs</td><td colspan="2">Hybrid ORs</td></tr>
<tr><td rowspan="3">Operating table</td><td>L=120:60 cm</td><td>W=51:56 cm</td><td>L=200:263 cm</td><td>W=50:60 cm</td></tr>
<tr><td colspan="2">H=59.5:89.5 cm</td><td colspan="2">* It must be a motorized floating table</td></tr>
<tr><td colspan="2">* Adjustment ranges vary according to patient positing</td><td colspan="2">* Centered in a diagonal position with degrees of freedom</td></tr>
<tr><td rowspan="3">Surgical boom</td><td>L=120:60 cm</td><td></td><td colspan="2">Radius within 518 cm</td></tr>
<tr><td colspan="2">*Placed away from OR door</td><td colspan="2">*Placed anywhere depending on tools</td></tr>
<tr><td colspan="2">*Range of motion differs due to numb of arms</td><td colspan="2">*Preferred to be central to allow a supplies and range of motion</td></tr>
<tr><td rowspan="3">Anesthesia machines</td><td rowspan="3">L=62:115 cm</td><td rowspan="3">W=59:90 cm</td><td colspan="2">Boom Width= whole OR width</td></tr>
<tr><td colspan="2">Boom Length=2/3 of OR length</td></tr>
<tr><td>Cart W=75:93 cm</td><td>Cart L=83 cm</td></tr>
<tr><td>Back tables</td><td>L=116cm</td><td>W=61cm</td><td colspan="2"></td></tr>
<tr><td rowspan="4">C-arm & imaging equipment</td><td colspan="2" rowspan="4"></td><td colspan="2">Maximum extension=259 cm</td></tr>
<tr><td colspan="2">Monitor cart =68.5 × 68.5 × 162.5 cm</td></tr>
<tr><td colspan="2">Flat detector = 30.5 × 35.5 cm</td></tr>
<tr><td colspan="2">*Divide area into 4 zones</td></tr>
<tr><td colspan="5">*Essential spatial considerations for each element
L = Length H = Height W = Width</td></tr>
</table>

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