Operating Room Informatics: An Approach to Managing and Utilizing Patients' Surgical Data

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Abstract

Background: Operating rooms (ORs), containing a variety of tools and equipment, have become more complex. Yet, most OR information systems operate in an isolated fashion with little or no attention to data management and utilization. This study proposes a new approach to the design of an integrated OR informatics approach offering automated storage and management of data before, during, and after an operation; medical segmentation and tracking of patient surgical case data using a well- structured database design for future retrieval and utilization of the data; an OR educational medical library and support for surgeons and medical teams to better control OR instruments.

Methods: This study discusses the special requirements and challenges of ORs and medical education and proposes a design, strategies, and techniques to address these concerns.

Results: A comprehensive OR informatics system can be developed, which when combined with a database of patient cases provides medical students with the data and skills they need to succeed.

Conclusions: We propose a modern approach and design that facilitates better data management and utilization through the integration of different information systems, devices and e-learning systems.

Key words: Medical education; e-learning; integration; learning management systems; online education; medical informatics; operating room informatics

Introduction

With the growth in the production of medical devices and the rapid technology advancement in medicine, operating rooms (ORs) have become more complicated and require more staff to control the tools and equipments. There are several OR information systems currently in development or employed in ORs, mostly in an

isolated fashion due to the absence of appropriate integration. It is, therefore, necessary to address the integration concern and to develop strategies for improving surgical/interventional workflows and data storage and utilization.

An OR automation system is a combination of hardware and software designed to control multiple OR devices via a common interface. OR systems range from the relatively basic to advanced designs capable of storing and exchanging images and videos with other systems, which can be controlled by a single person via a simple interface, e.g., touch-screen or voice commands. This allows surgeons and medical teams to focus on the patient and procedures rather than diffused dealing with complicated and unstructured tools and devices. In addition, it offers light control to adjust suitable illumination for the operation, OR-table control to adjust the position of the operating table as needed, and the ability to archive and store captured video and images. Furthermore, the new design of an OR guarantees more free space for medical staff, efficiency in design and shortened housekeeping time, no cables or scattered equipment, and real-time collaboration.[1,2]

In the last two decades, minimally invasive surgery (MIS) has seen a great and solid rise in popularity resulting in the advancement and evolution of advanced video and robotics technologies to replace the old open surgical methods.[3] MIS procedures offer the ability to record procedures either fully or partially on tape, multimedia or special storage servers.

Patient medical records (MRs) are an essential element in hospital care. Each record contains vital patient medical information such as allergies, previous medication, medication history, discharge reports, radiology images, and other demographic and medical information, but has little or no detailed information (images, videos, data) on surgeries and procedures the patient has undergone.[4]

Medical education and training approaches vary from the traditional with basic exposure to multi dimensional and interactive approaches including real cases contained in the MRs. In addition, the MRs are important for medical educational and training activities. They can be used as medical cases on several educational levels including undergraduate, graduate, postgraduate, and continuing medical education (CME). Such medical cases are taught to medical students/doctors as case studies or as part of the course/degree program.[5] Furthermore, research activities have been fully or partially reliant on data stored in MRs for ages. Retrospective studies and case studies, in addition to several kinds of research methodologies, are mainly conducted totally or partially based on data stored in medical records.

In addition, the continuous and rapid advancement in information technology and communications has led to the evolution of e-learning environments. E-learning systems are educational systems that utilize information and communication technologies resources such as the Internet, networks, and multimedia applications to enhance the learning process. In an e-learning environment, the learner is the focus instead of the material itself. Such an environment allows learners to study at their own pace according to their capabilities, to communicate with colleagues and teachers through discussion groups and video conferencing, and to conduct self-assessment through online evaluations. E-learning environments provide learners with the flexibility of studying regardless of their location or time zone.[5,6] Medical and

surgical education is currently searching for new and innovative training tools that match the sophistication of the new operating methods. In addition, the "To Err is Human" report published by the Institute of Medicine in the United States and the "Bristol Case" in the U.K. suggested that better training and objective assessment would be key strategies in attaining the goal of reducing medical errors. Several studies and reports have discussed and evaluated virtual reality training in operating rooms since Satava first proposed training surgical skills in a virtual reality (VR) environment in the early 1990s.[3,7,8]

Because of the great importance of e-learning in modern education, and its role in improving students' performance[9], the King Saud University Hospitals (KSUHs) have begun to implement a modern e-learning system containing state-of-the-art e-learning components.[5,10]

In medical education, enabling students to practice medicine, by laying a hand on live cases and taking part in the examination, procedure and diagnosis processes, is essential and of great importance to supply them with the necessary skills and experience to treat their future patients. Traditionally, this was done by organizing student rounds, where small groups of students observed and examined cases, and discussed patients' conditions with their instructors, and by attending educational surgeries and operating room activities. This traditional approach suffers from the following disadvantages.

- Due to space limitations and convenience in clinics or operating rooms, only a small number of students can study each case, which means that students can only be involved in a limited number of cases during their training. This also applies to the limited number of surgeries and procedures students can observe.

- Students are limited in their ability to examine patient history and radiology images. Traditional learning enables them to examine only a small subset of patient data and images, which in turn limits the skills and experience gained by the students.

The benefits of face-to-face learning include direct and immediate response communication and easy motivation. On the other hand, disadvantages include time and place constraints, lack of student focus, the fact that the majority of the control rests with the instructor, and more expense in the delivery.[6] To overcome the disadvantages of traditional teaching activities, KSUHs designed and implemented a new approach in which traditional teaching is supported by technological tools to enhance the experience gained by medical students and trainees. The system should be used to assist and support the current systems and to provide students with tools to better manage their learning activities and tasks, and assist them in gaining knowledge and improving their skills.

The KSUHs include the College of Medicine, College of Dental Medicine, King Khaled University Hospital (KKUH), King Abdulaziz University Hospital (KAUH), and King Fahd Cardiology Center (KFCC). There are over two thousand students enrolled in these colleges, which employ more than four hundred staff. The technical

infrastructure in the KSUHs comprises a 100 Mbps intranet connecting the campus colleges and the KKUH, and a 32 Mbps microwave link connecting the KAUH campus. The main functions of the KSUHs are education, research, and providing medical services to the public. The University academic environment encourages students to carry out research, and to provide them with the necessary tools and skills through skill labs, anatomy and physiology software packages, and other applications and activities.

This study discusses the design and approach adopted by the KSUHs to:

- implement medical segmentation, tracking and retrieval of patients' surgical case data and images with a well structured database design for future retrieval and utilization of the data;
- create an OR educational medical library to be utilized in both educational and research activities;
- provide automated storage and management of data flow before, during and after an operation, and provide support for surgeons and medical teams to better control OR tools and instruments.

System Design

The first step in the system design involved building an initial model that takes into consideration the general OR, medical, and educational requirements. This model should be dynamic enough to be able to overcome challenges that may appear in the future. Figure 1 depicts the model used to define the different components of the system.

Design considerations

The following considerations were incorporated into the system design.

Data and system considerations

The design focused on the best approach to store patient data, images, and videos generated before (pre-operation), during (intra-operation), and after operations (post-operation) for future medical consultation and to build up a complete medical case history from diagnosis to discharge. Data stored during operations comprises mainly videos and images from laparoscopic devices, hamlet cameras, and radiology and ultrasound films. The system design allows the recording and forwarding of images and/or videos to other displays and/or classrooms locally or remotely. The KSUHs have five operating rooms equipped with up to six cameras in each, as well as laparoscopic devices, and hamlet cameras. Videos from these cameras are recorded on

a SAN storage device; tracking and segmentation of recordings are designed to be introduced to recorded materials by voice commands or via touch screen commands. These commands allow the separation of different segments of the operation phases for searching and retrieval purposes. In addition, commands can be added to tag certain landmarks or events during the operation. Pre-operation data includes the diagnosis, radiology films and lab results, in addition to the patient's demographic data. Post-operation data includes medical notes, the discharge report, radiological films, and other examinations. Content of this enormous magnitude recorded during the operation is expensive in terms of both cost and effort, and requires several systems and servers with vast storage capacities and sufficient computational capabilities to keep it safe and secure with the required performance level.

Space limitation

The proposed design considers the restricted space in the OR and available areas for medical staff movement. The resulting design offers more free space for medical staff, efficiency in terms of reduced housekeeping time, no cables or scattered equipment, and real-time collaboration.

Medical considerations

The design allows the surgeon to consult in real-time with remotely located colleagues, conduct a video conference, and route the operation from various imaging devices to other output screens. The proposed approach allows the surgeon and medical team to focus on the patient and procedure rather than dealing with complicated and unstructured tools and devices. It further offers lighting control to provide a suitable mixture for the operation and control of the OR table to adjust its position as needed.

Educational considerations

This design facilitates conducting remote educational sessions utilizing the video conferencing feature in the design. Instead of having students crowded in the OR to learn and gain skills, OR videos, audio, images, and data can be simultaneously routed to various auditoriums and classrooms with commentary by the medical team and interaction with the audience. Furthermore, cases can be stored either fully or partially on the video-on-demand servers and can then be accessed by students/trainees in their own spare time. The approach focuses on designing an OR educational medical library to be utilized in both educational and research activities. This would give students and trainees better access to operations and procedures. Crowding together in the OR with the medical team normally does not provide the majority of students with a good opportunity to follow and observe the details of the procedure, besides the other risks associated with such a practice for both students and patients. In addition, students need to have access to the system from anywhere on the

campus as well as from outside the campus through the Internet. Access control methods were incorporated to prevent unauthorized access, as well as ensuring that the infrastructure needed is powerful enough to allow students to access the system reliably and easily.

General considerations

For such a system to be successful, certain general features must be included; that is, flexibility to adapt the features, capabilities, and goals of the design; ease of use, which means that medical team members and students/trainees can focus on the procedures themselves and learners can focus on the material itself, rather than on how to use the system[11]; interactivity, whereby learners can interact with each other and with their teachers and the surgeons through video conferencing and/or discussion boards; and a solid infrastructure to support the system and provide the learners with easy and fast access to the system.[11,12] The system must utilize the most advanced and most recent technologies to provide optimal performance. The system must also be scalable to accommodate any increase in the numbers of students or staff. It must be expandable, so that new features can be added to further improve the functionality of the system. The system should have a web-based interface to allow students to access it using Internet browsers without considering the location of the student.

The proposed model design satisfies the medical, technical, and educational requirements for the approach. It contains the necessary servers and infrastructure to carry the bandwidth and storage consuming videos, audios, images, and other data. It is expandable and scalable, adheres to international standards, and can accommodate new components. It interacts with different hospital systems, picture archiving and communications systems (PACS), classroom systems, e-learning systems, and lecture broadcasting. Figure 2 illustrates the system design and the components.

Discussion and Conclusion

The growth in medical device production and utilization, and rapid technology advancement in medicine, has meant that medical environments and operation rooms in particular, have become more complicated, requiring more trained and qualified staff to control the myriad of tools and equipment. In addition, the advances in information technology and e-learning have prompted medical education institutes to utilize these technologies to enrich the learning environment and to provide students with tools and systems to enhance their learning experience. It is believed that integrating and utilizing hospital information systems and patient data with an e-learning system in educational hospitals is expected to provide better medical training and educational outcomes.[6]

A well-designed e-learning environment can motivate students to become more engaged with the educational material and more content, thereby becoming more active participants (13). E-learning or interactive learning shifts the focus from a passive, teacher-centered model to one that is active and learner centered, offering a

stronger learning stimulus. Interactivity helps to maintain the learner's interest and provides a means for individual practice and reinforcement. Evidence suggests that e-learning is more efficient than the traditional learning approach because learners are reported to gain knowledge, skills, and attitudes faster. This efficiency is likely to translate into improved motivation and performance.[5,13,14]

Interaction plays an important role in medical education. It enhances the students' capabilities and allows them to get involved in the medical process, as a way of building skills and gaining experience. This interaction is best applied through a blended learning approach, where traditional educational methods are supported and augmented by e-learning tools and resources. The results of previous studies indicate that students and instructors have a better perception of online, electronic, and blended learning than fully electronic and distance learning. The OR informatics approach discussed in this paper is an important component of the blended learning approach, providing students with an effective, integrated learning environment with the highest possible quality and accessibility. Blended learning is an approach that combines both e-learning technologies with traditional instructor-based learning, where, for example, a lecture or demonstration is supplemented by electronic tools.[8,13,15]

Previous studies in both medical and nonmedical settings have consistently demonstrated that students are satisfied with e-learning.[6,12-15] In addition, learners' satisfaction rates increase with e-learning compared with traditional learning, mainly due to the perceived ease of use, better access and navigation, interactivity, and user-friendly interface design.[11] In accordance with previous studies and reports, students themselves do not see e-learning as a replacement for traditional instructor-based training, but as a means of complementing it, forming part of a blended-learning strategy.[5,12]

The proposed design introduces a high level of interactivity further enhancing learning and training capabilities. It is a student-centered model that uses both traditional and e-learning systems integrated with hospital systems, patients' data and real cases to provide students with interactivity and participation in real life cases and procedures. Furthermore, it offers students the flexibility they need to learn at their own pace and according to their needs, while at the same time solving the problem of lack of space in operating rooms and practical classes.[5]

This paper discussed a modern approach designed and adopted by the KSUHs that satisfies the specific requirements of medical education through the integration of different hospital information systems and e-learning systems in the OR environment. This blended learning approach is indeed required for the success of e-learning in medical environments and helps overcome some of the challenges in medical education.

There are several challenges facing the deployment of the OR informatics approach. Some of these are technical, while others are related to the skills of the doctors, users, and students. Before research on building the system could begin, it was necessary to measure the users' information technology skills to assess their readiness for the new system. Students were given a questionnaire with a number of questions including whether they owned a computer, and how they used computers in general.[15] The

results of this questionnaire showed that although the students had reasonable general computer skills, they lacked the capability of using these skills in medical education and research. This confirmed that students required proper training to utilize the system in the best way, and The College of Medicine was urged to add courses in medical informatics for the students. When the skills of the staff/doctors were examined, it was observed that many of them also lacked the necessary skills to use these systems in the best way.[16] The above challenges had to be considered before implementing a new system.

The integration of e-learning into existing medical curricula should be the result of a well-devised plan. In medical education, an OR informatics approach is even of greater importance because of its role in overcoming problems such as the lack of space in operating rooms and critical areas allowing the students to attend procedures and surgeries without endangering the patients' safety and security.

The proposed OR informatics design where all hospital systems are integrated in a smart technological environment, supports and augments traditional education by providing instructors/consultants with easy to use tools enabling them to concentrate on delivering high quality education/training. At the same time students can obtain a complete picture of every case they study, increasing the quality of their education and allowing them to participate fully with the diagnosis and examination procedures.

The integration of e-learning into all levels of medical education including CME should promote a shift toward interactive learning in medical education[16], where educators no longer serve solely as distributors of content, but act more as facilitators of learning and assessors of competency. With the advancement in information and communication technologies, the future offers the promise of high-fidelity, high-speed simulations and personalized instruction using both adaptive and collaborative learning.[14]

Furthermore, the e-learning process and methods should be evaluated with respect to outcomes and efficiency. The evaluation of e-learning should include a peer-review process and an assessment of outcomes such as learner satisfaction, content, usability, and demonstration of learning. In addition, faculty skills in creating and delivering e-learning materials and content may differ from those needed for traditional teaching, which should be commensurate with effort. Moreover, faculty rewards for scholarly activity must be encouraged and recognized.

Sharing content with different institutions in the country, and throughout the world is an additional dimension for blended learning, electronic content and e-learning systems.[18] This, in turn, should improve the quality of learning in medical institutions. The expandability feature of the blended approach and e-learning system enables the addition of new tools or features that may appear to take advantage of the latest developments in e-learning technology. It is believed that the integration of an e-learning system with traditional classroom teaching is a uniquely applicable approach.[17] The model discussed in this paper is a student-centered blended model that uses both traditional and e-learning systems to provide students with the flexibility they need to learn at their own pace and according to their needs, while at the same time solving problems including lack of space in operating rooms, clinics,

and practical classes. The model introduces a high level of interactivity, further enhancing learning capabilities.

Future studies should be planed and conducted to evaluate the utilizations of health informatics tools in operation rooms. Furthermore safety for both patients and students should be evaluated with new informatics solutions.

Acknowledgment

The Authors extend their appreciation to the Deanship of Scientific Research at KSU for funding the work through the research group project No RGP-VPP-058.

Conflict of Interest: None declared.

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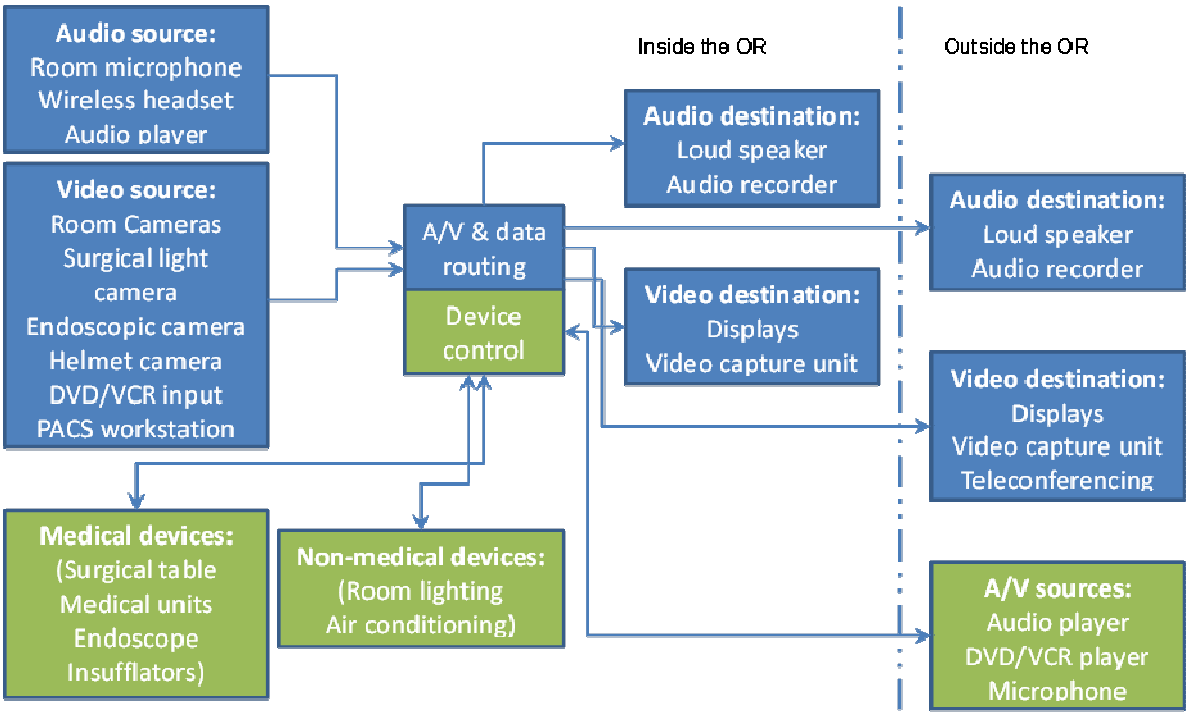

Figure 1: Model used to define the different components of the system

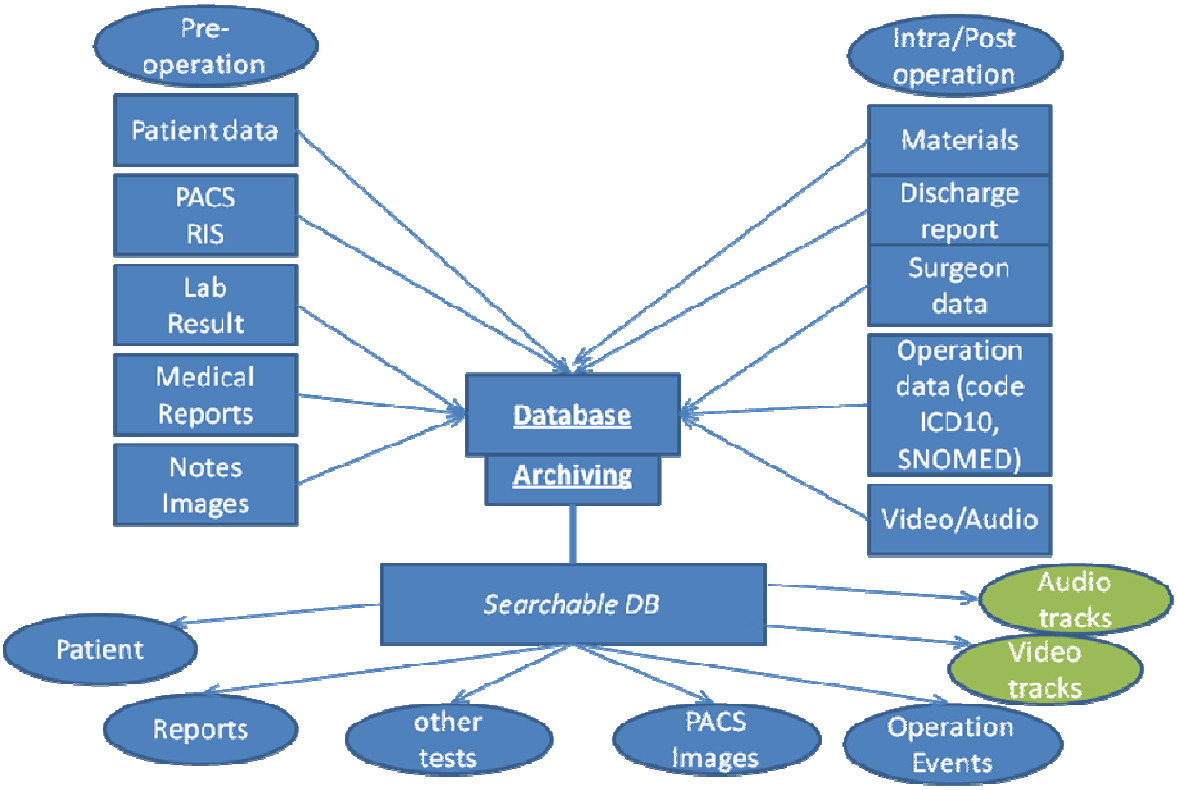

Figure 2: System design with main components